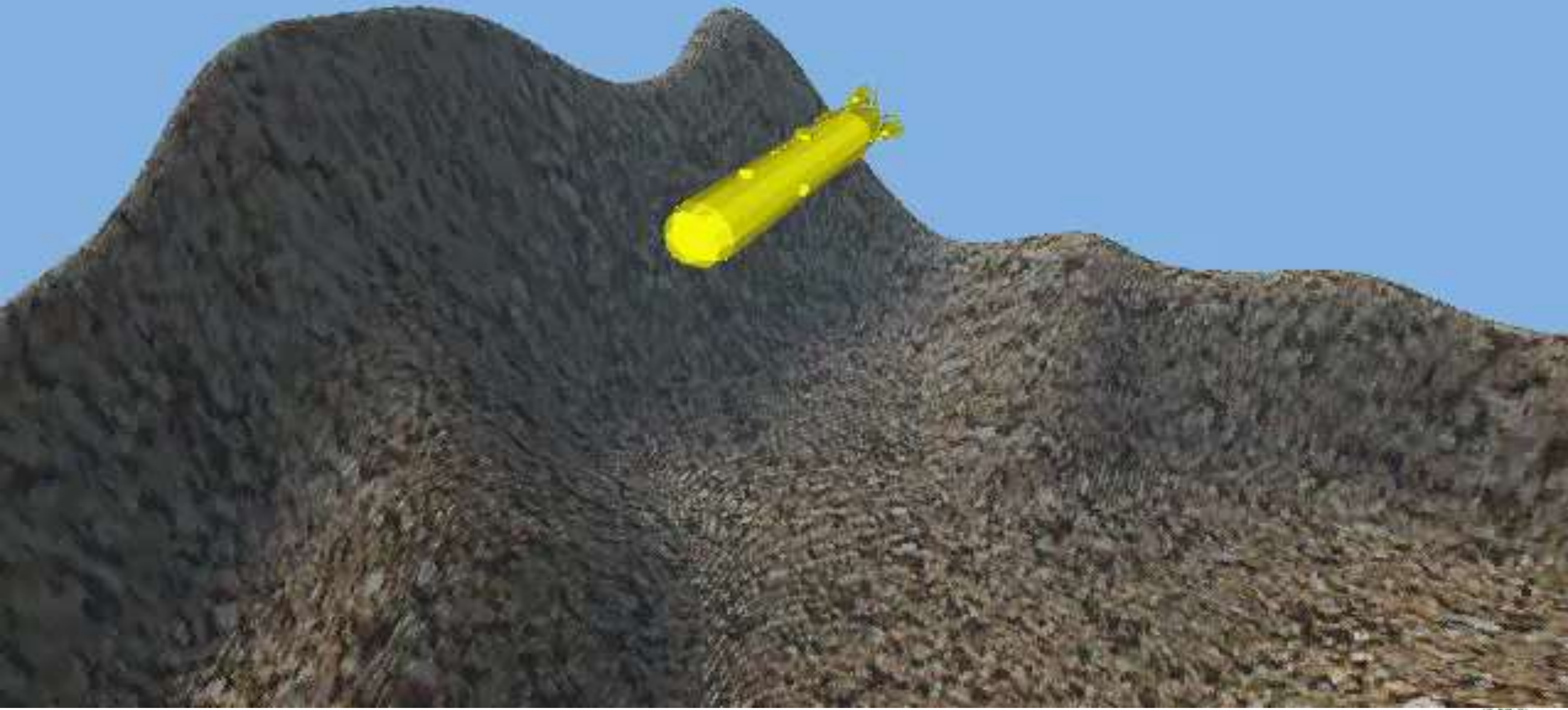
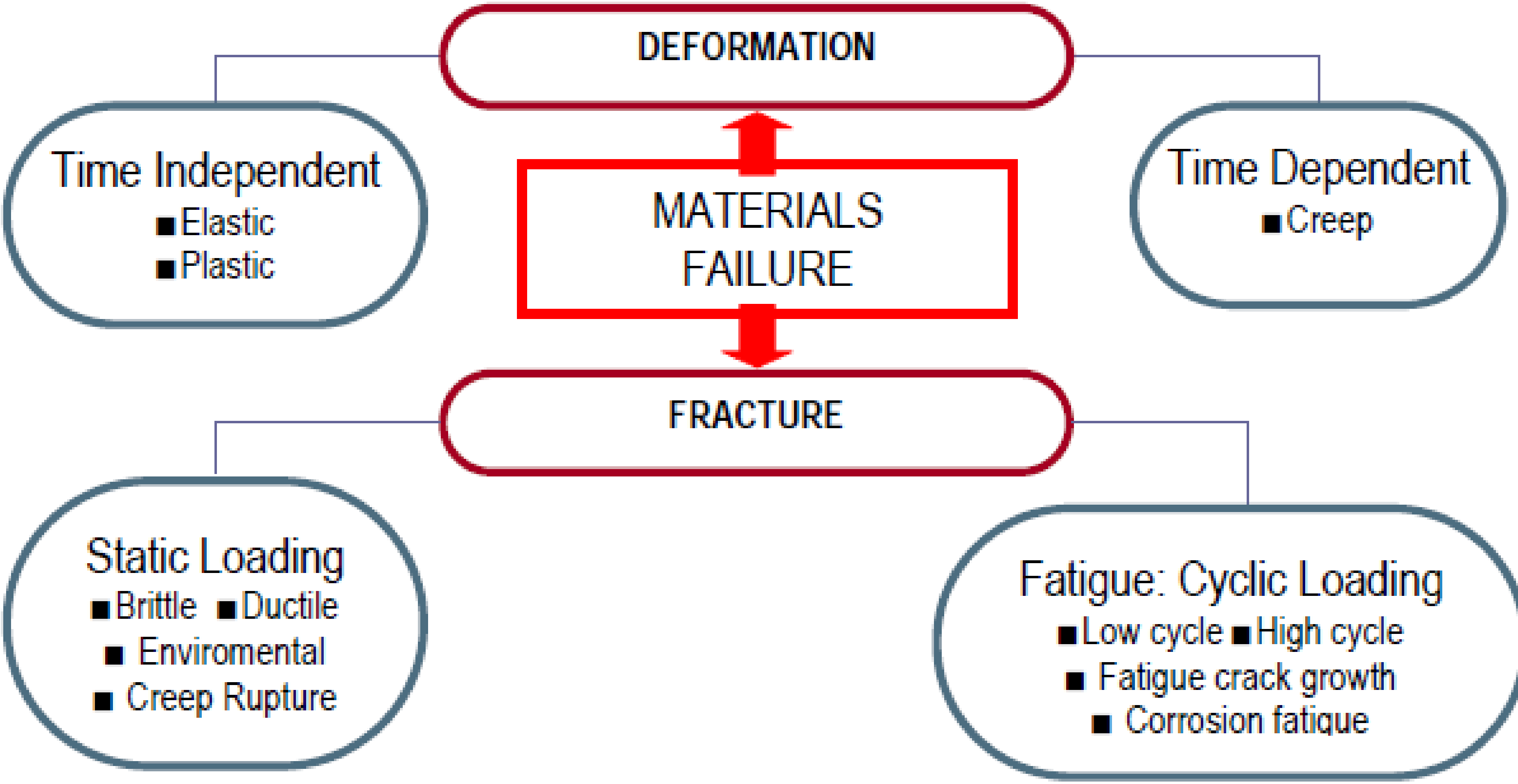
Limits of NDT



RUSSIAN – GERMAN HIGH-TECHNOLOGY COOPERATION

MATERIAL CHARACTERIZATION



Basic Types of Material Failure

PIPE FAILURE

Thermal Ageing

J. Jansky: 12. Int. SMIRT Conf. !993

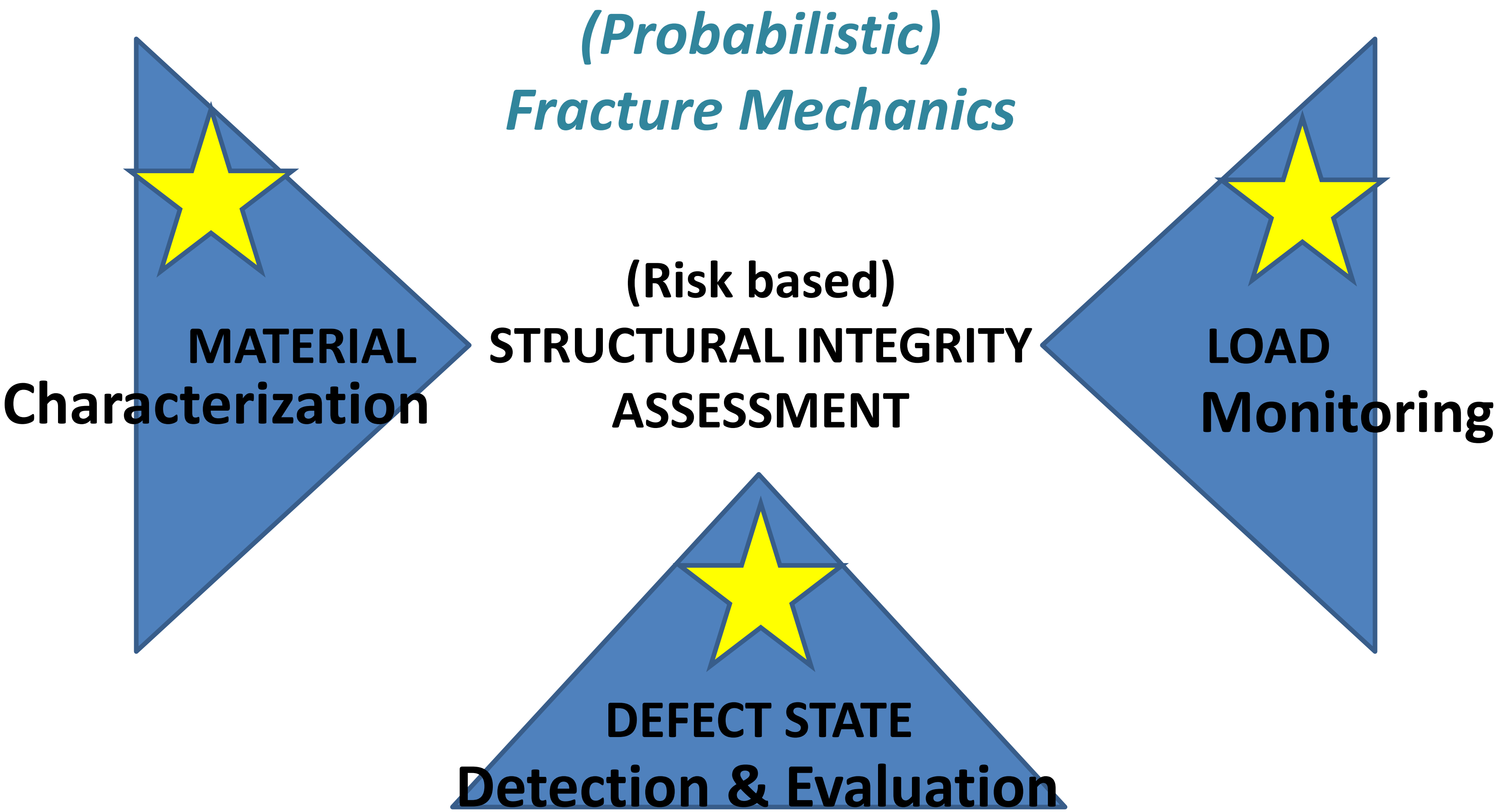
STIFFNESS & STRENGTH

Important aspects of structures are stiffness and strength.

Stiffness is the resistance against reversible deformation Strength, the resistance against irreversible deformation.

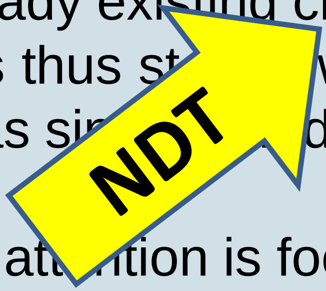
Requirements on stiffness may vary over a wide range. Strength is always required to be high, because this deformation may lead to loss of functionality and eventual global failure.

Limits of NDT



Fracture Mechanics

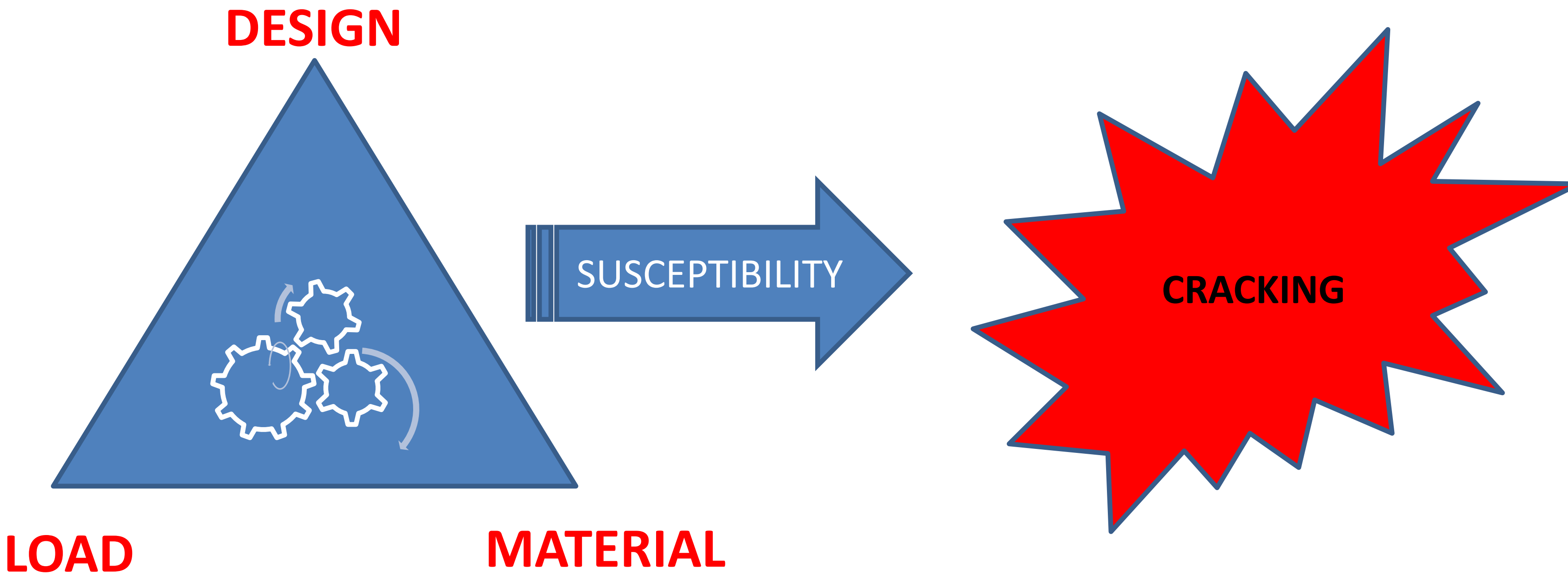
Griffith was the first to recognize that attention must be focused to imperfections like already existing cracks.
Fracture Mechanics is thus st with the experimental studies by Griffith in 1921 and has si developed in various directions.



In fracture mechanics att ition is focused on a single crack.
Theoretical concepts and experimental techniques have been and are being developed, which allow answers to questions like:

- ***Will a crack grow under the given load ?***
- ***When a crack grows, what is its speed and direction ?***
- ***Will crack growth stop ?***
- ***What is the residual strength of a construction (part) as a function of the (initial) crack length and the load ?***
- ***What is the proper inspection frequency?***
- ***When must the part be repaired or replaced ?***

Flaw Detection & Evaluation



CRACK INITIATION
“INCUBATION TIME”

CRACK NUCLEATION

Geometry	Material	Load
Local Stress Concentration	Local Susceptibility	Local Attack

CRACK GROWTH RATE

CRACKING MODES

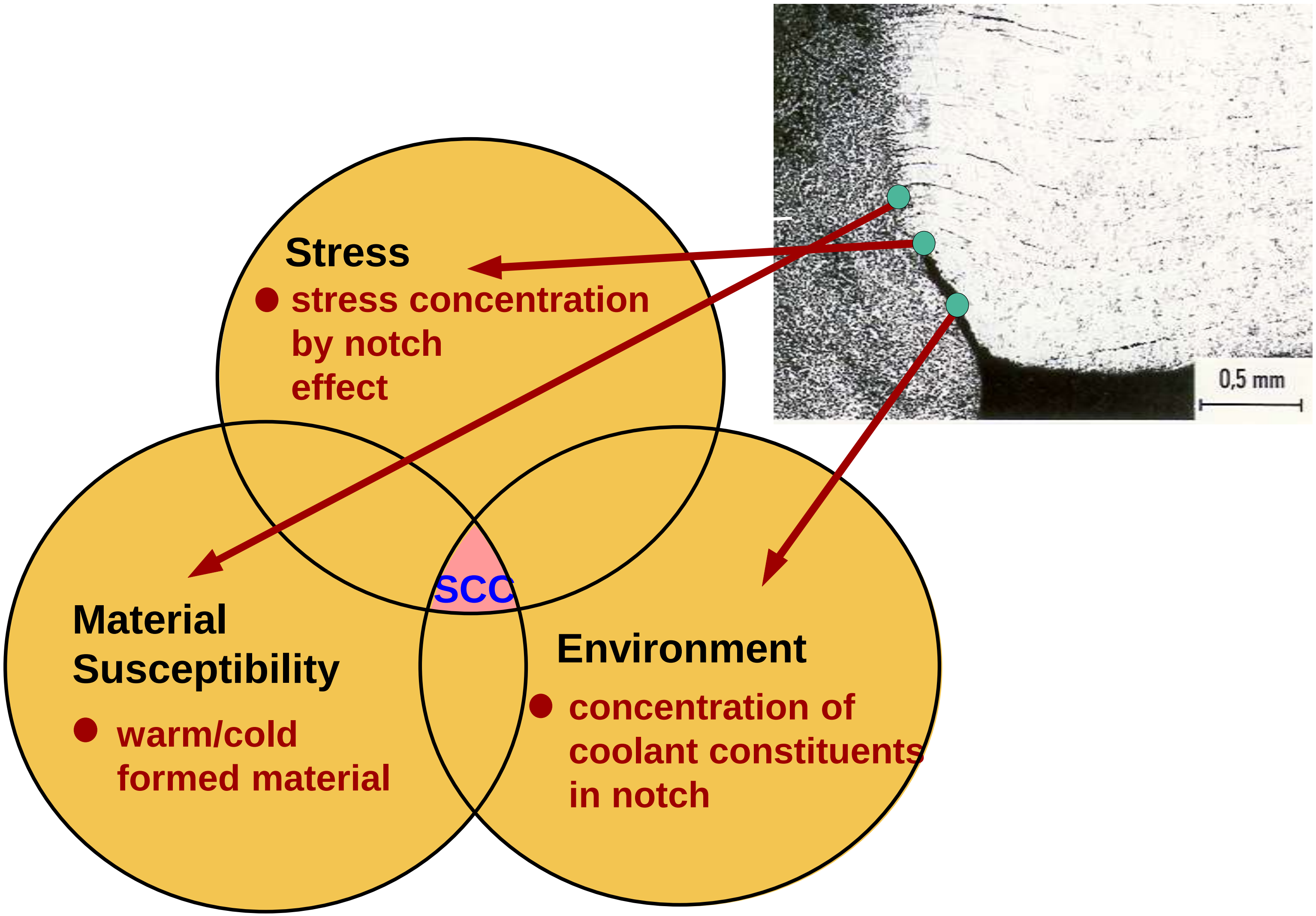
- Shear fracture
- Cleavage fracture
- Fatigue fracture

CRACK CORROSION

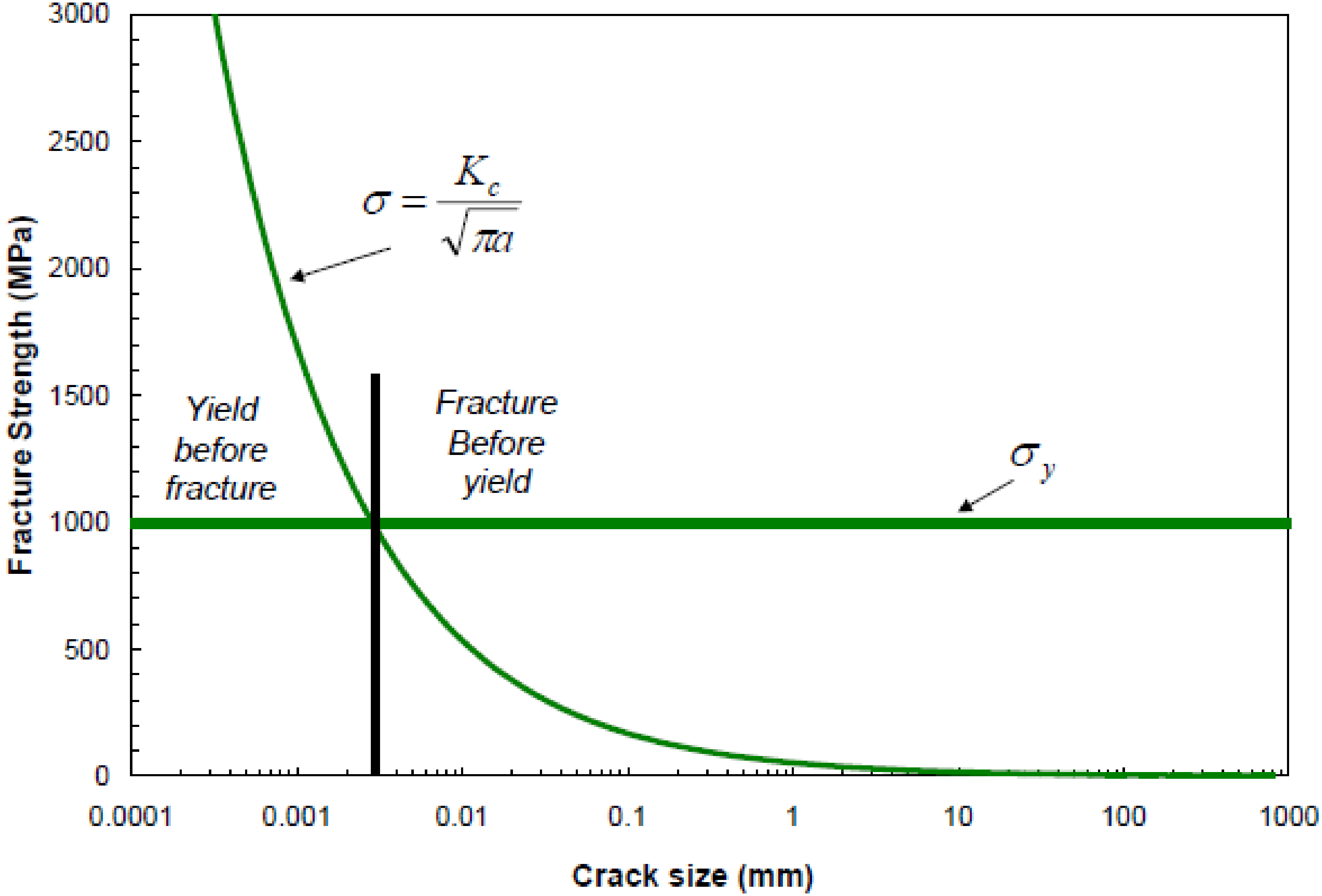
- Trans-crystalline
- Inter-crystalline

CASE STUDIES ARE NECESSARY IN VIEW OF THE PROBLEM DIMENSION
EVEN FOR THE SAME CASE:
INCUBATION TIME & CRACK GROWTH RATES VARY SIGNIFICANTLY (PWSCC)

Cracking in Austenitic Stainless Steel Piping
Importance of Root Formation during Welding Process



YIELD or FRACTURE



Shearing

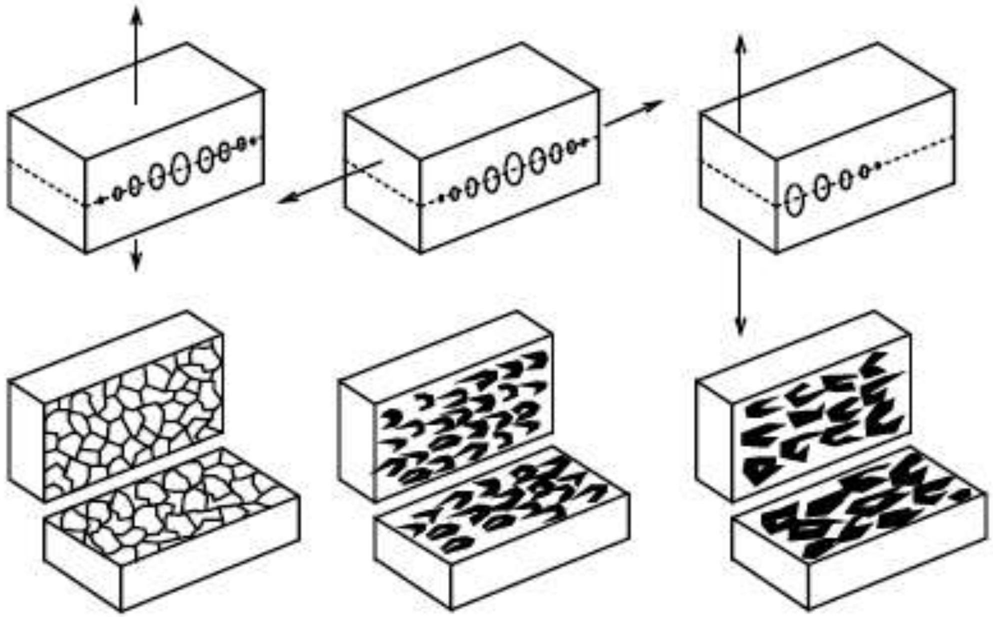
When a crystalline material is loaded,
dislocations will start to move through the lattice
Due to local shear stresses.
The number of dislocations will increase.
Because the internal structure is changed irreversibly,
the macroscopic deformation is permanent (plastic).

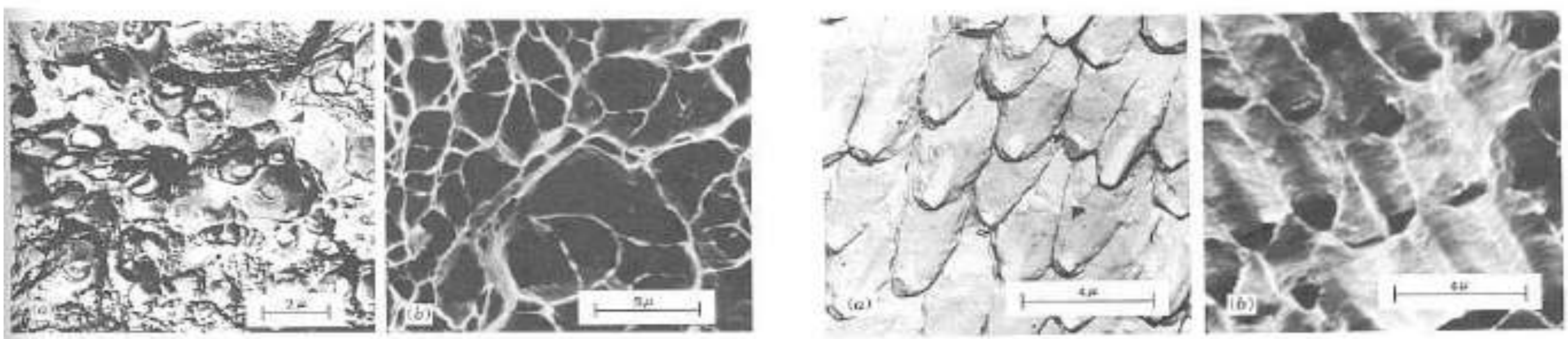
The dislocations will coalesce at grain boundaries
and accumulate to make a void.
These voids will grow and one or more of them
will transfer in a macroscopic crack.

One or more cracks may then grow and lead to failure.

Plastic deformation is essential,
so this mechanism will generally
be observed in FCC crystals,
which have many closed-packed planes.

Dislocation Movement and Coalescence into Grain Boundary Voids Resulting in Dimples in the Crack Surface





TEM SEM TEM SEM

Flaw Detection & Evaluation

- The crack will grow if:

$$EG_c = \sigma^2 \pi a$$

or

$$\sqrt{EG_c} = \sigma \sqrt{\pi a}$$

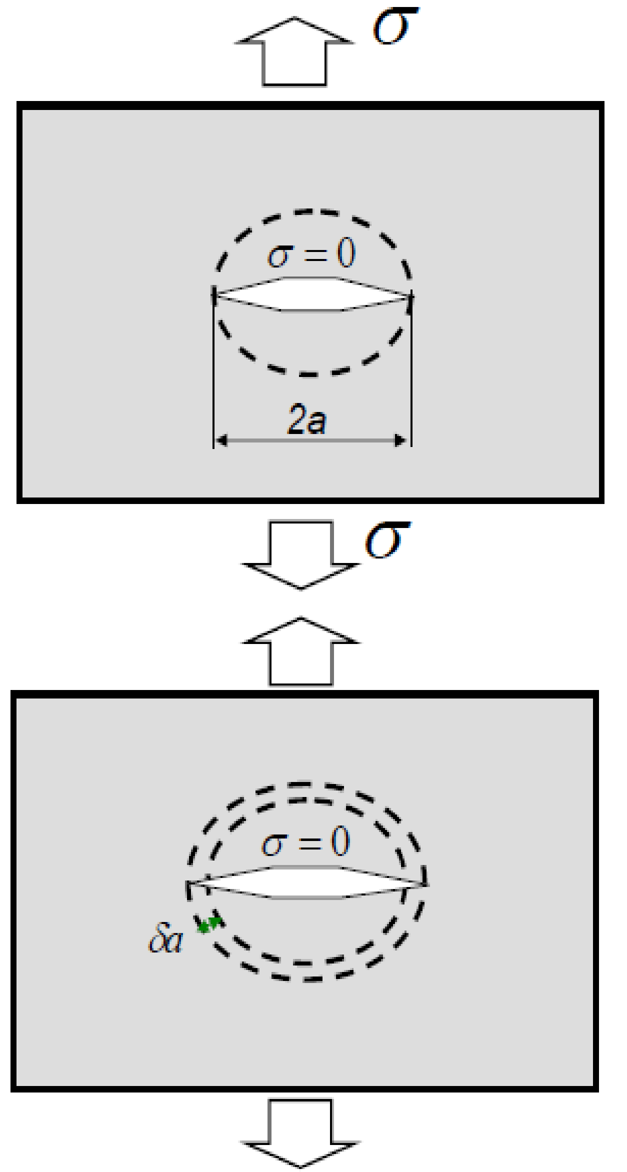
G_c : Toughness $[J/m^2]$

$K = \sigma\sqrt{\pi a}$: stress intensity factor $[N/m^{3/2}]$

$K_c = \sqrt{EG_c}$: critical stress intensity factor

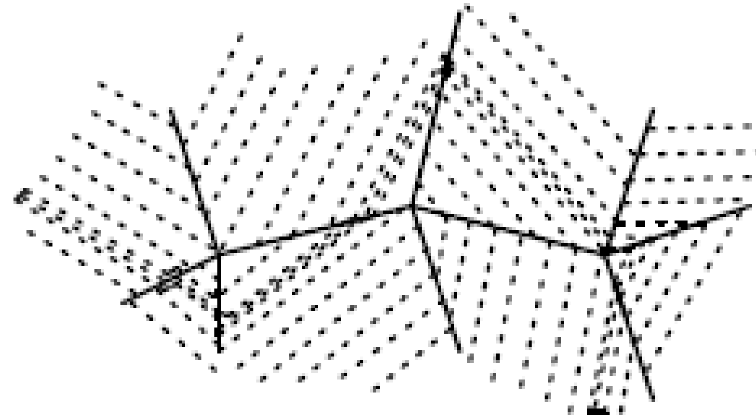
or fracture toughness $[N/m^{3/2}$ or $Pa\sqrt{m}]$

Griffith Criterion : $K = K_c$



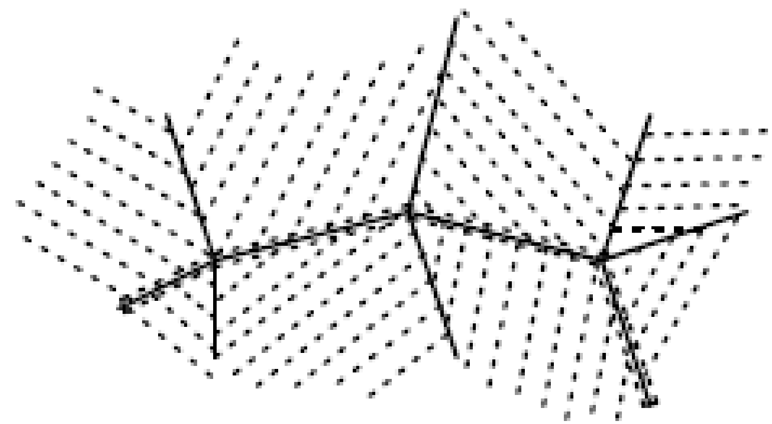
Cleavage Fracture

When plastic deformation at the crack tip is prohibited,
the crack can travel through grains by splitting atom bonds in lattice planes.



Cleavage fracture prevails in materials
with little or no closed-packed planes
having BCC crystal structure.
It will also be observed
when plastic deformation is prohibited
due to low temperature or high strain rate.
A three-dimensional stress state may also result in this mechanism.

Inter-granular cleavage will be found in material
with weak or damaged grain boundaries.
The latter can be caused by
hydrogen or high temperature.

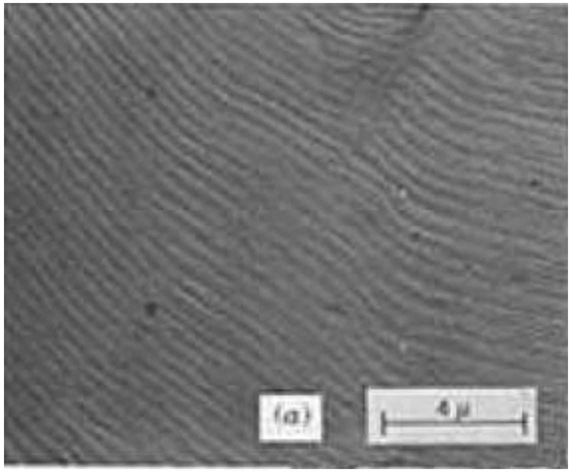


The crack surface has a 'shiny' appearance.
The discontinuity of the lattice orientations
in neighboring grains will lead to so-called cleavage steps

Fatigue

When a crack is subjected to cyclic loading, the crack tip will travel a very short distance in each loading cycle, provided that the stress is high enough, but not too high to cause sudden global fracture. The crack surface shows a ’clam shell’ structure .

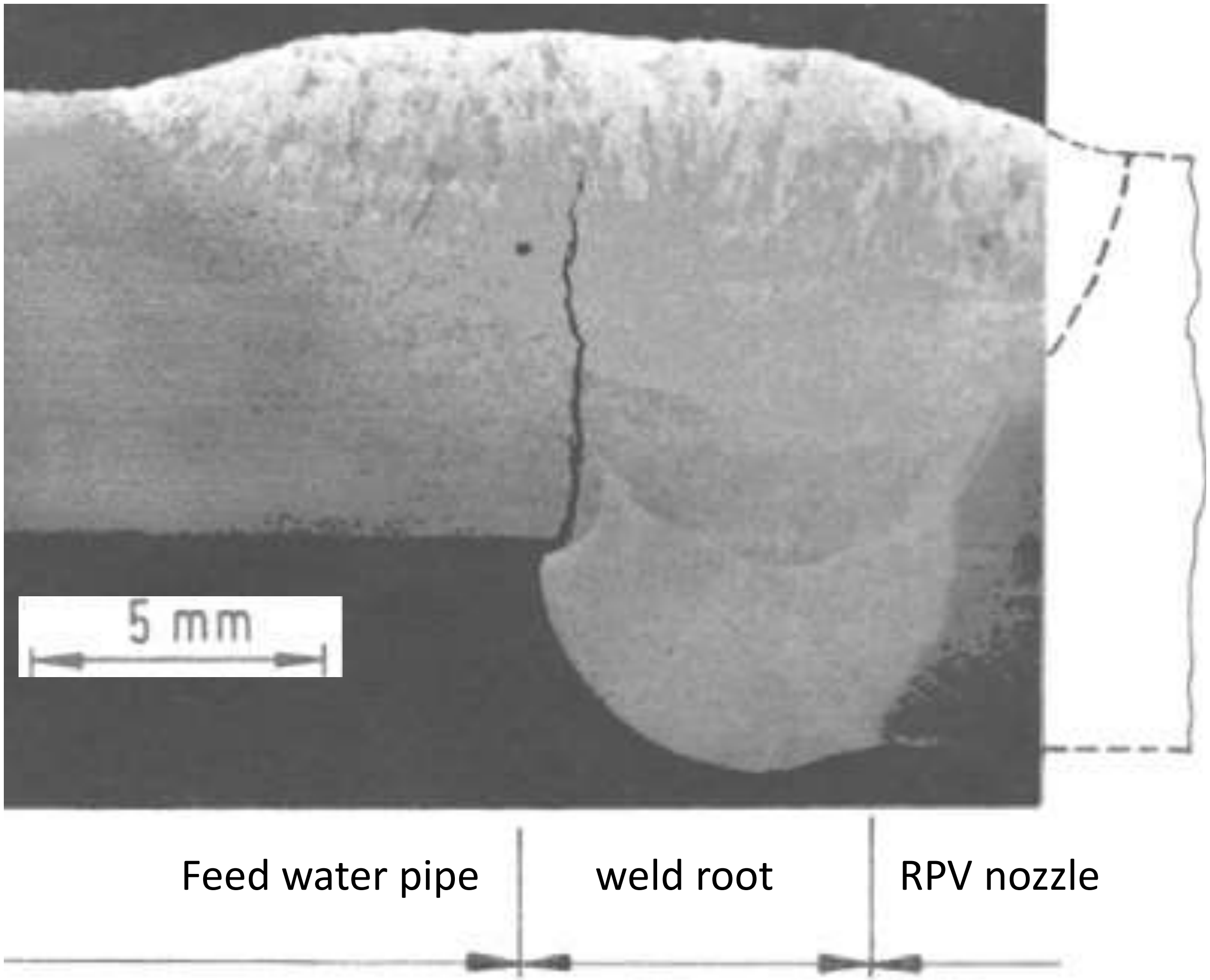
Under a microscope ’striations’ can be seen, which mark the locations of the crack tip After each individual loading cycle.



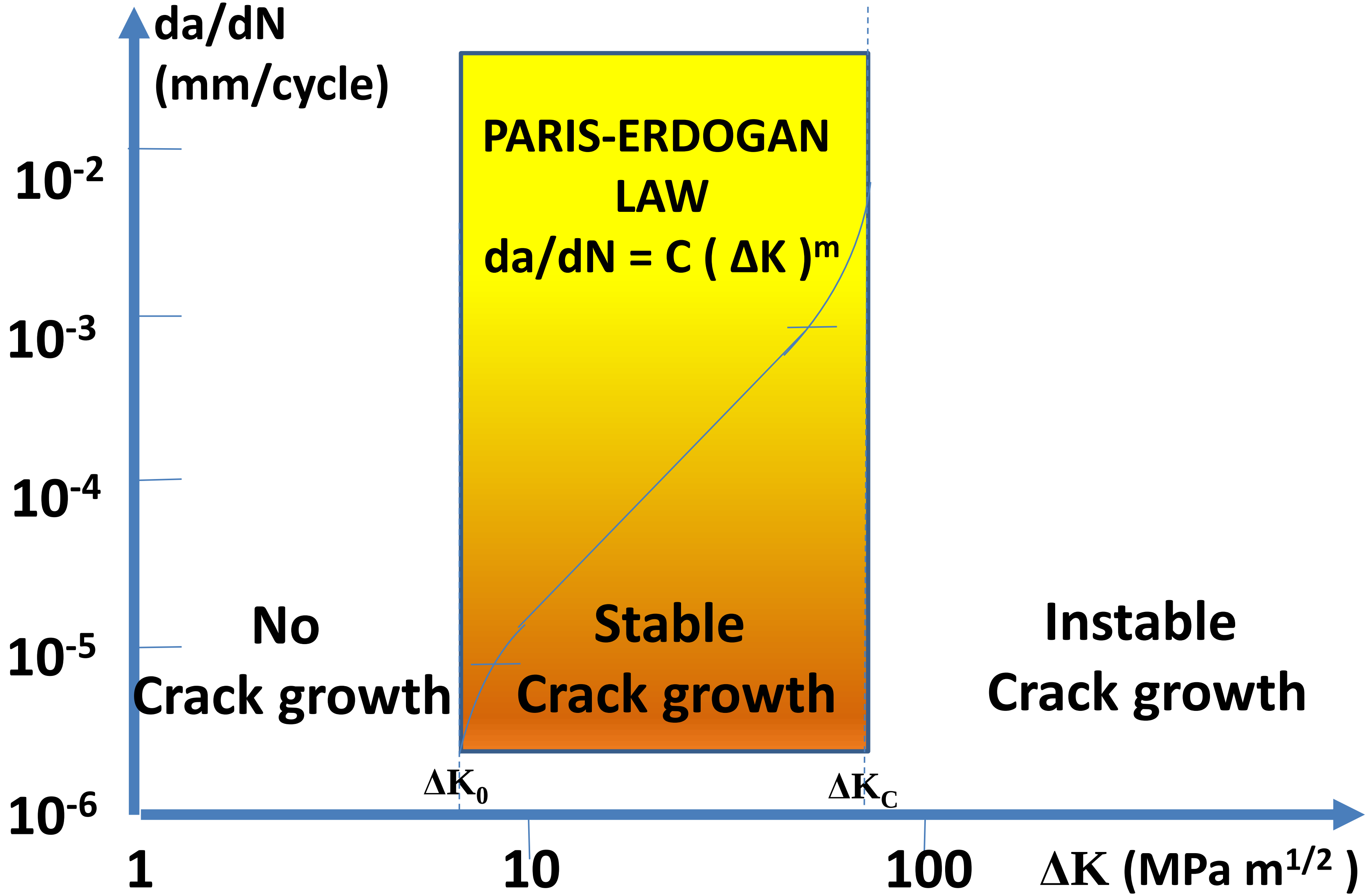
Because crack propagation is very small In each individual load cycle, a large number of cycles is needed before total failure occurs. The number of cycles to failure N_f is strongly related to the stress amplitude **$\Delta\sigma = 1/2\ (\sigma_{max} - \sigma_{min})$** and the average stress **$\sigma_m = 1/2\ (\sigma_{max} + \sigma_{min})$**

Characteristics of Fatigue in Metal Alloys

- Dislocation Movements
- Persistant Slip Bands
- Short Cracks
- (Fatigue Cracks)

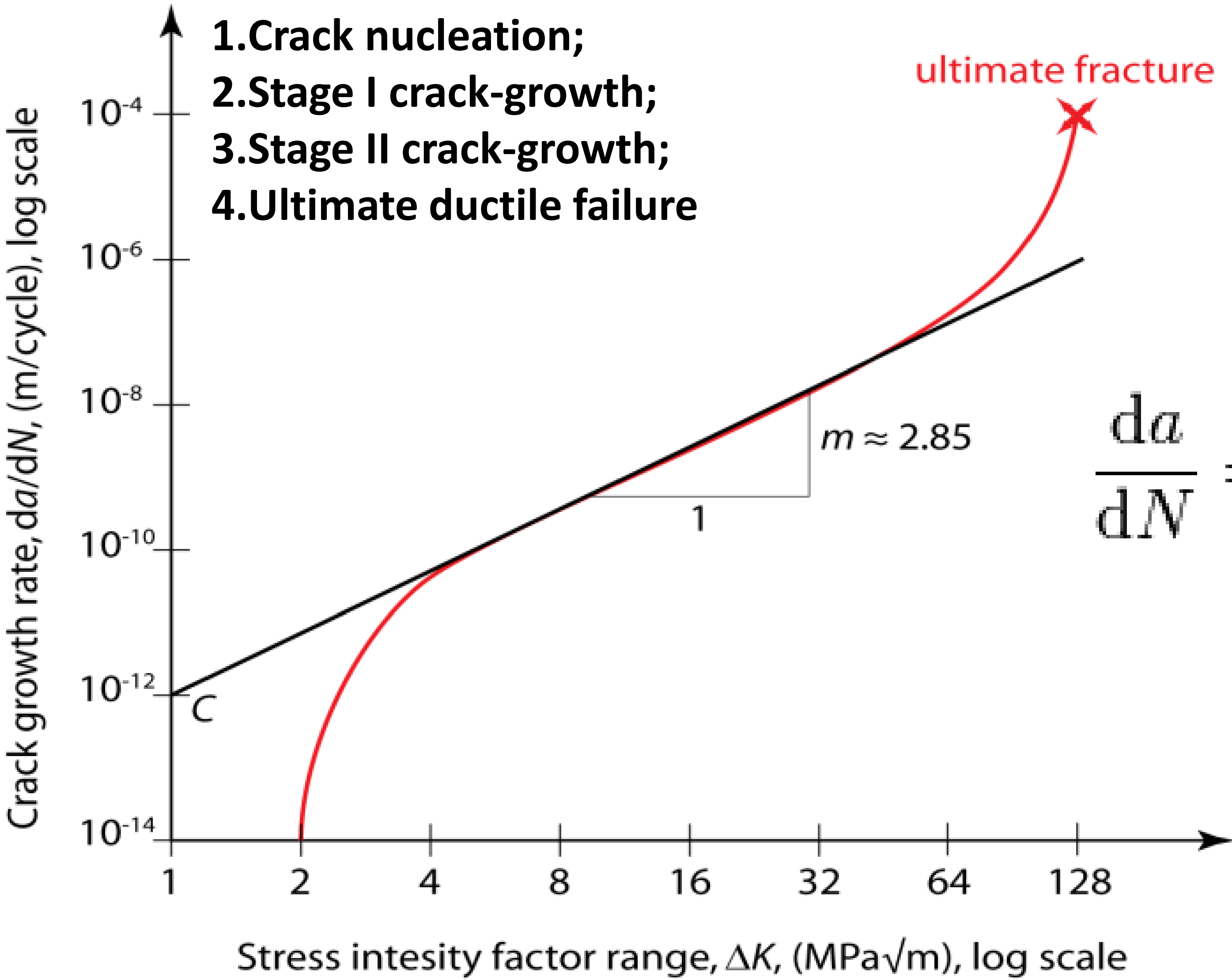


Fatigue Crack


da/dN
(mm/cycle)
10-2
10-3
10-4
10-5
10-6
PARIS-ERDOGAN
LAW
da/dN = C (ΔK)m
No
Crack growth
Stable
Crack growth
Instable
Crack growth
ΔK0
ΔKC
1
10
100
ΔK (MPa m1/2)

Fatigue Crack Growth to Fracture

1.Crack nucleation;
2.Stage I crack-growth;
3.Stage II crack-growth;
4.Ultimate ductile failure



$$\frac{da}{dN} = C(\Delta K)^m$$

FLAW MINIMIZATION

BY DESIGN AND QUALITY
WE MINIMIZE FLAWS
WITH THE OBJECTIVE OF DEFECT FREE STRUCTURES AND MATERIALS

?NO CRACKS?

THERE ARE CRACKS
THEY SHOULD NOT GROW
(to become critical)

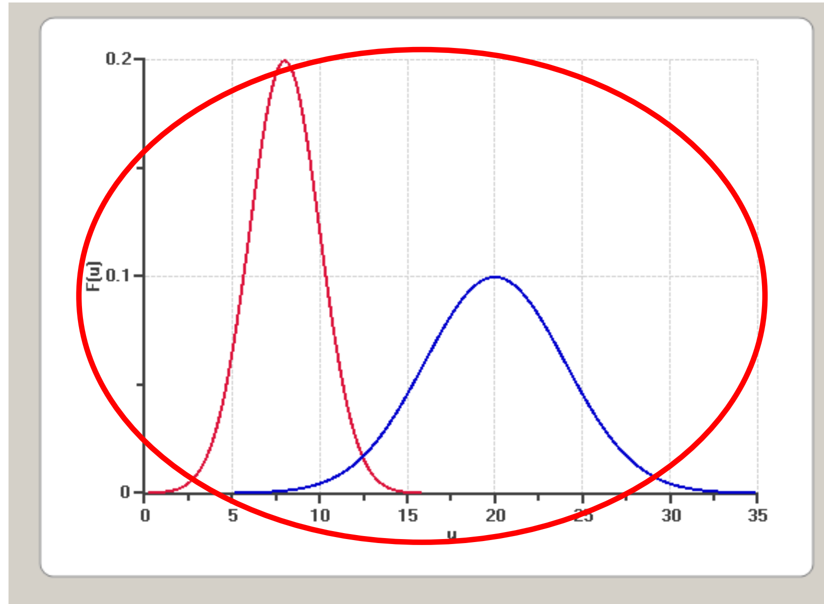
Probabilistic Fracture Mechanic Approach

Sizing errors

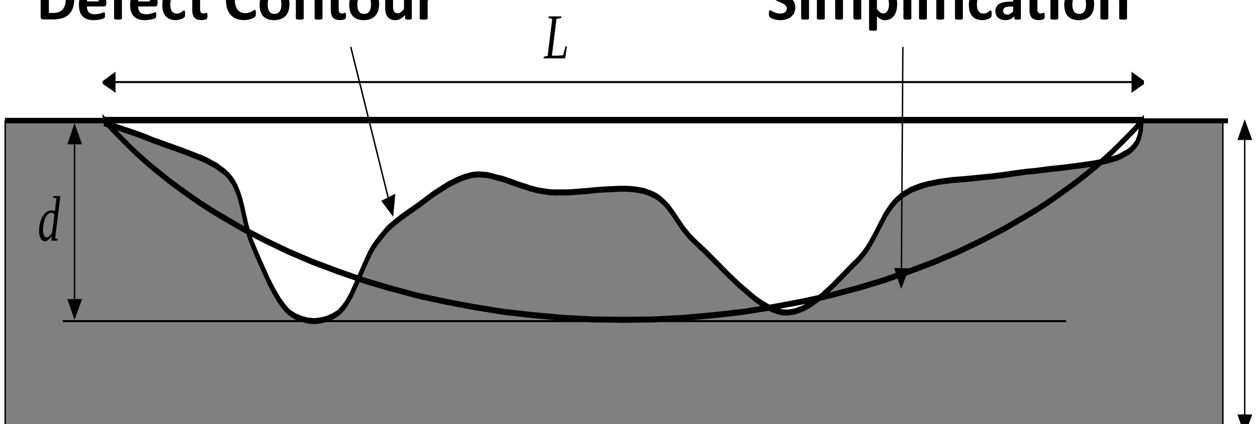
&

scattering of material values

are represented by distributions

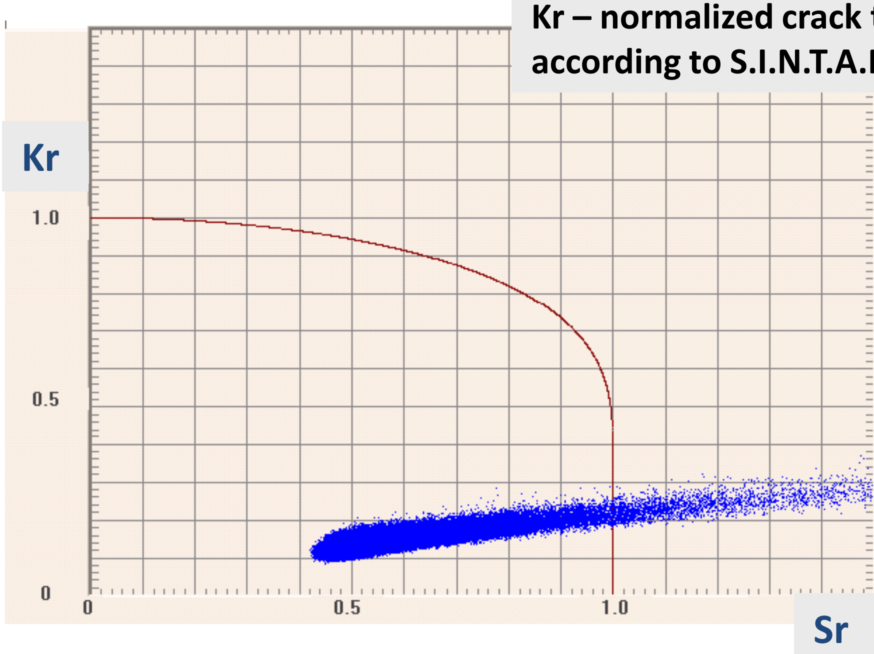


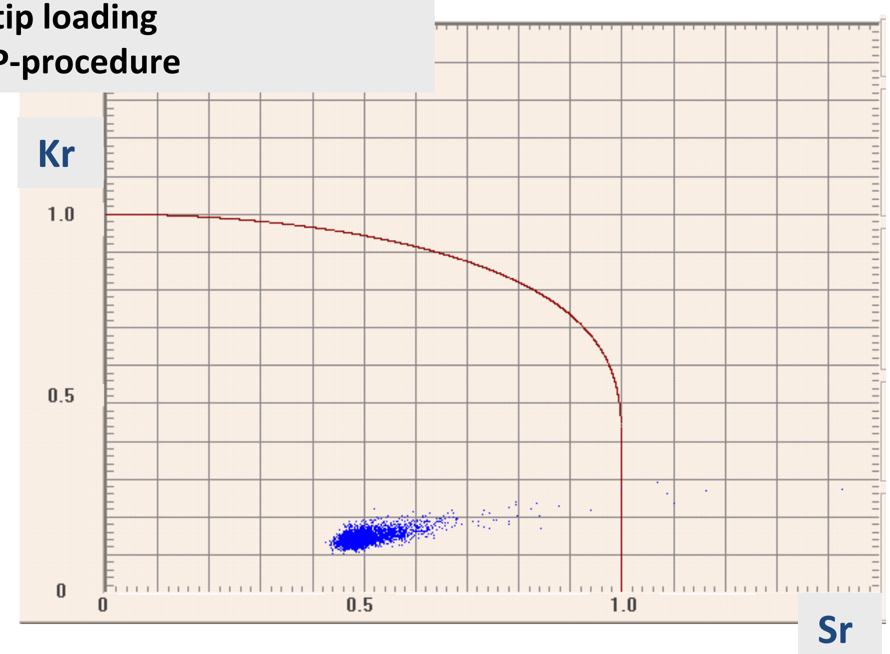
Defect Contour **Simplification**



THE VALUE OF NONDESTRUCTIVE TESTING

Sr – plastic deformation degree of ligament
Kr – normalized crack tip loading
according to S.I.N.T.A.P-procedure

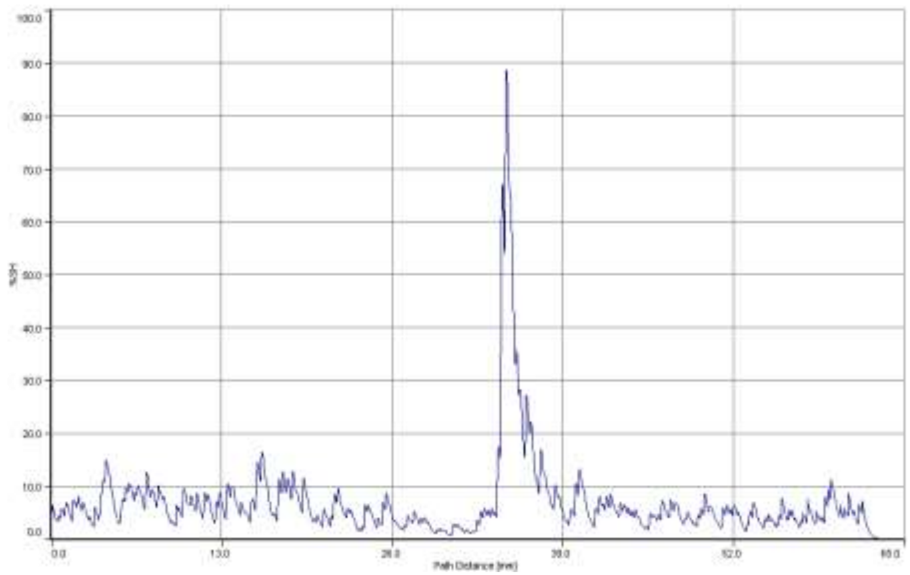




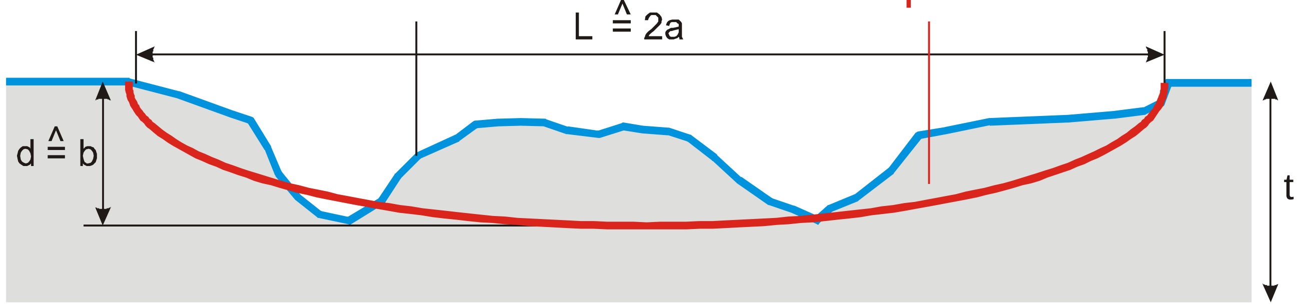
FA-Diagram without (left) and with (right) consideration of NDT

A Correlation Problem

45º/4 MHz A-scan of ID Crack



Correlation of Actual Flaw to Modeled Flaw



REQUIREMENT

To predict the behavior of a crack, it is essential to know its location, geometry and dimensions.

Nondestructive Testing and Evaluation (NDT&E) Methods have to reveal these data.

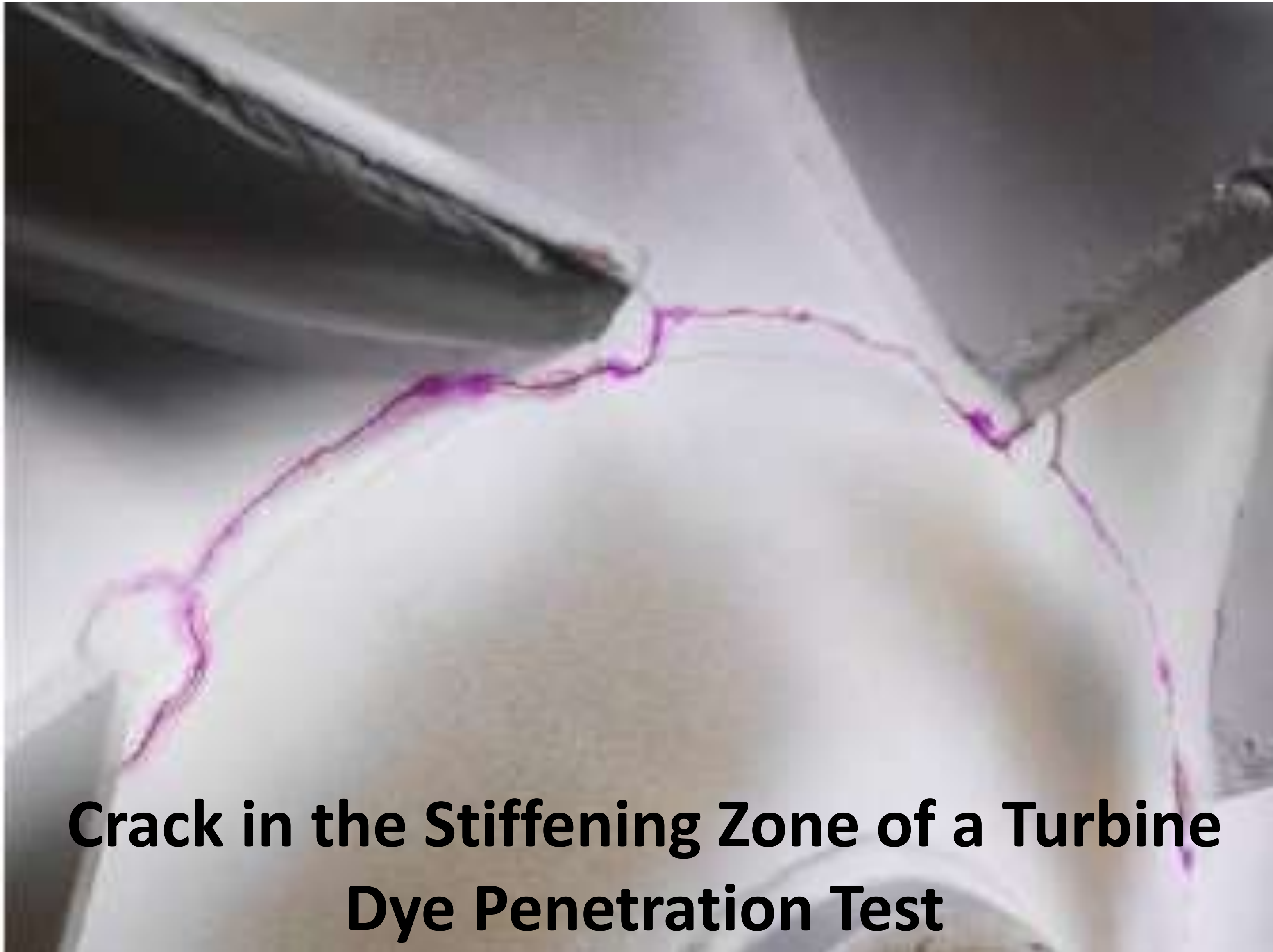
In view of limited Flaw Evaluation capability, new methods and procedures are in progress.

Some of the NDT&E procedures use physical phenomena to gather information about a crack.

Other techniques strive towards visualization of the crack.

VISUAL INSPECTION

Advancing Optical Control Techniques



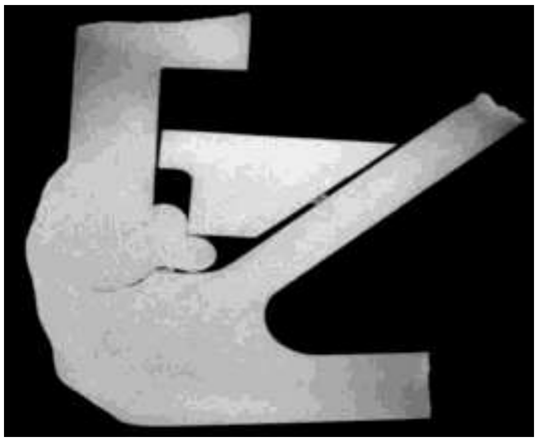
Crack in the Stiffening Zone of a Turbine
Dye Penetration Test

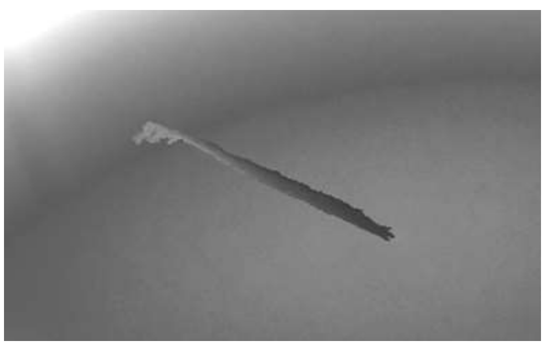

University of Strathclyde (2006)
X-Ray Crack Inspection by Robots

FLAW IMAGING BY X-RAY TOMOGRAPHY

Quantitative RT

3D Image
of
Transverse Crack





ULTRASONIC IMAGING

Acoustic Image of an unborn Child

O. Shechner, M. Sheinovitz, M. Feinberg, H. Greenspan: *Image Analysis of Doppler Echocardiography for Patients with Atrial Fibrillation,* http://www.eng.tau.ac.il/~shiri/mip_lab/publications/doppler_ISBI.pdf

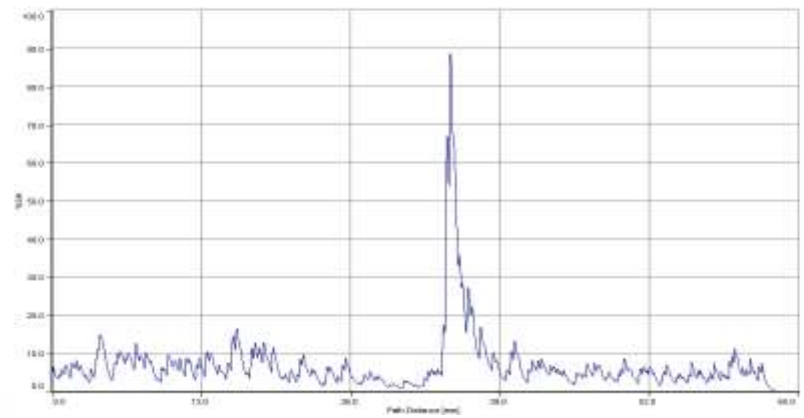
ULTRASONIC INSPECTION

ULTRASONIC TESTING

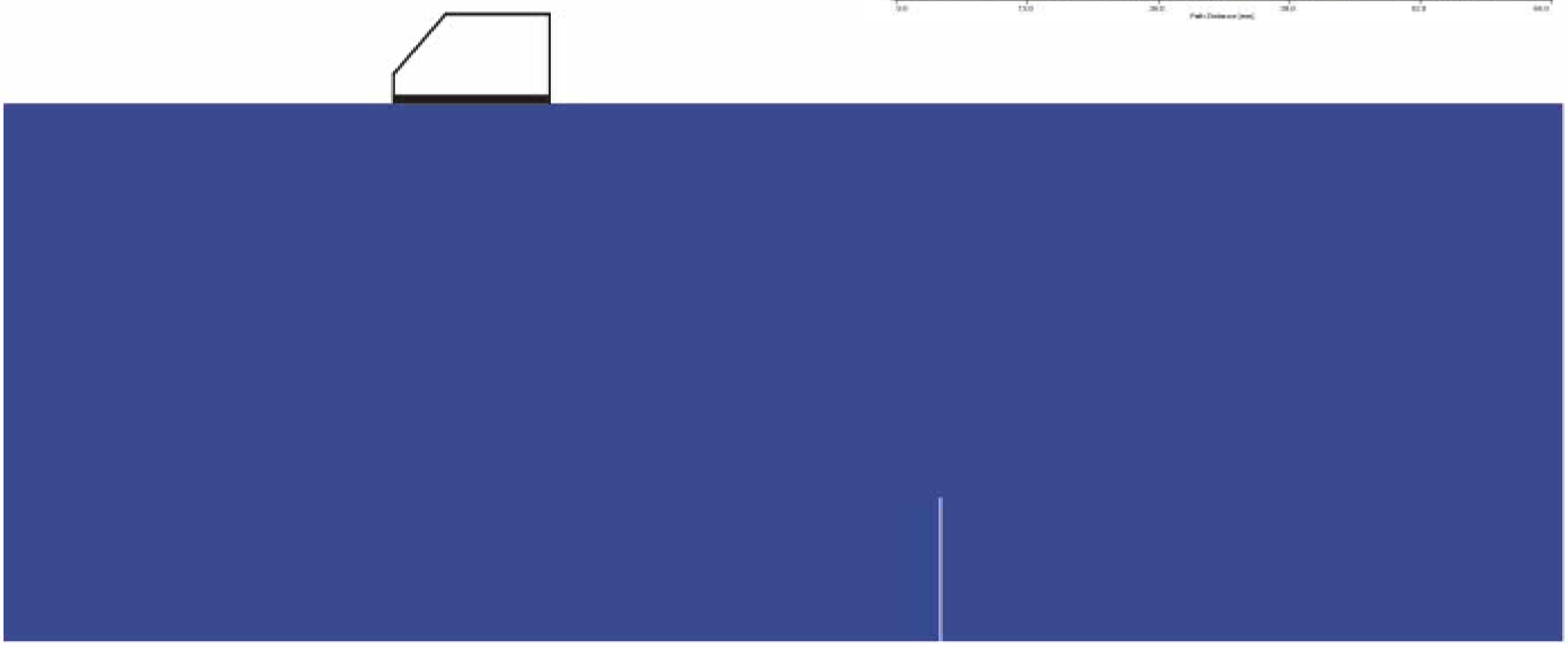
Impulse – Echo Technique

A-Scan Image

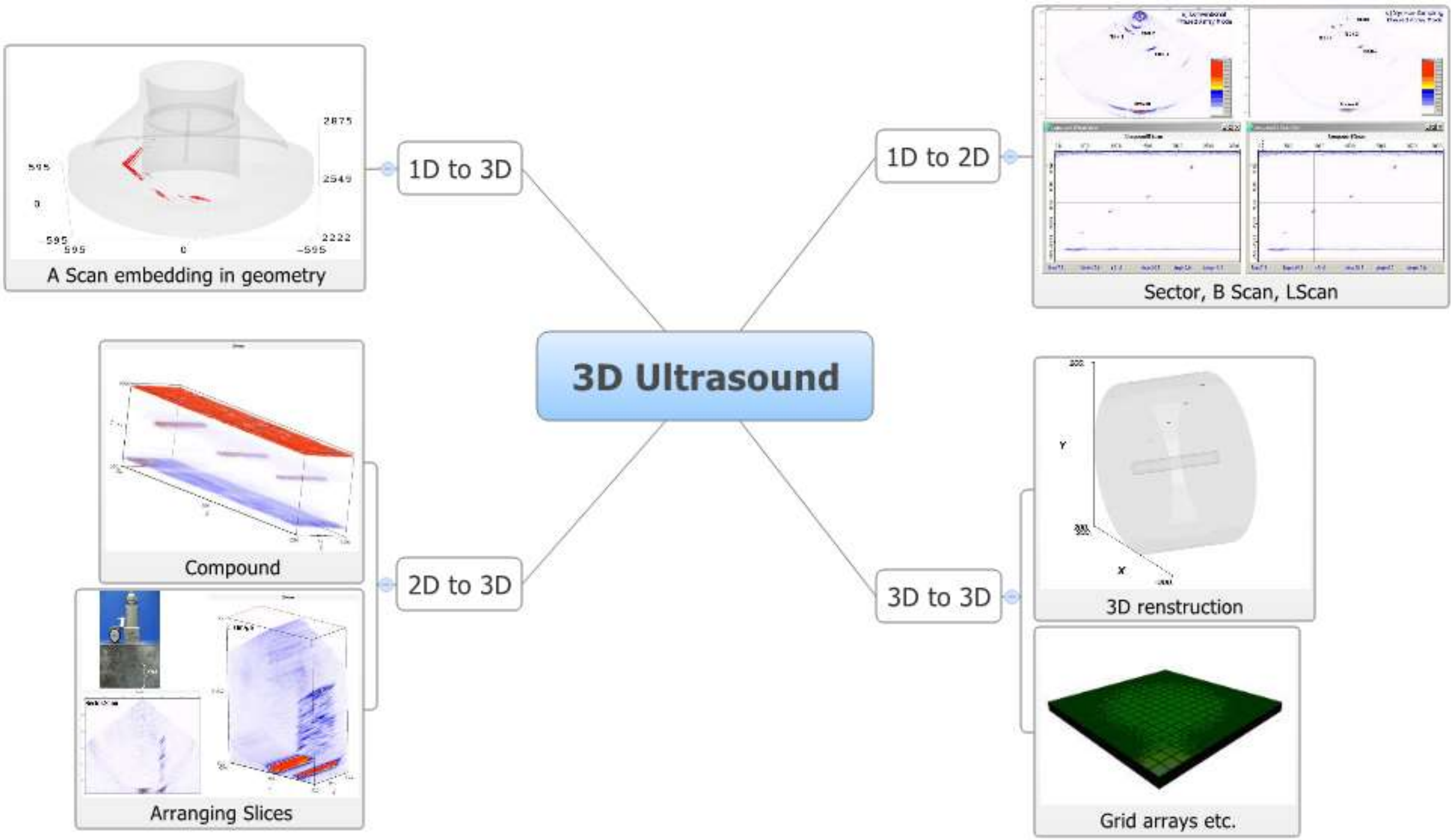
SIMULATION



45° Shear Wave Transducer



ULTRASONIC IMAGING IN NDT



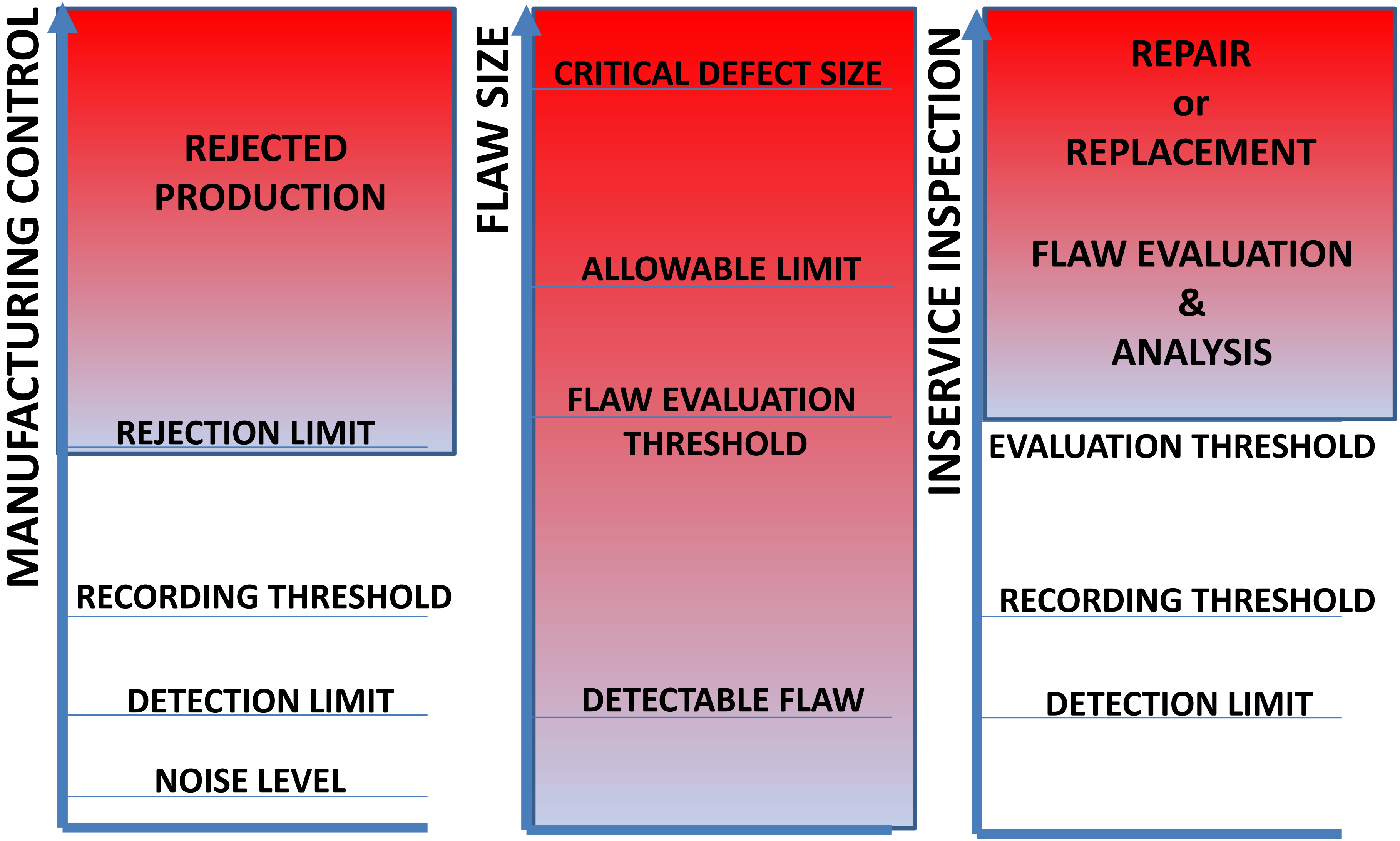
CONTRIBUTION OF NDT

Crack growth, as shown by fracture mechanics, is exponential in nature (Paris' law).

***A desire for reasonable inspection intervals,
combined with the exponential growth of cracks in structure
has led to the development of non-destructive testing methods
which allow inspectors to look for very tiny cracks.***

***Examples of this technology include
eddy current, ultrasonic, dye penetrant, and X-ray inspections.***

INDICATION-FLAW-DEFECT



NDT Level III

An NDT Level III individual should be capable of
developing, qualifying and approving procedures,
establishing and approving techniques,
interpreting codes, standards, specifications and procedures,
as well as **designating the particular NDT methods, techniques and procedures** to be used.

The NDT Level III should be **responsible for the NDT operations**
for which he is qualified and assigned
and should be **capable of interpreting and evaluating results**
in terms of existing codes, standards and specifications.

IT IS A REASONABLE
&
NESSECARY
REQUIREMENT

CONTRIBUTION OF NDT

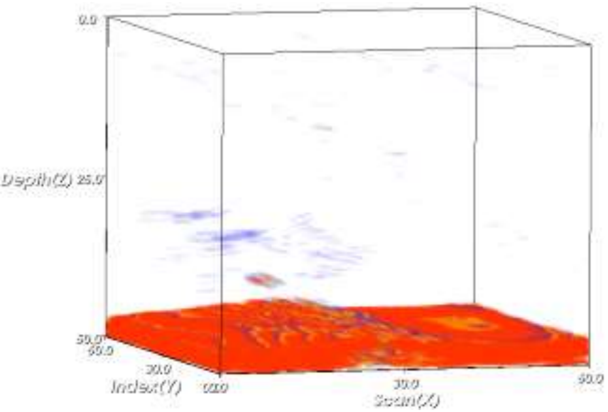
STILL LIMITED

- ACCESS
- FLAW TYPE & SIZE
- MATERIAL CHARACTERIZATION
- FLAW INITIATION & GROWTH
- CAUSE EVALUATION

TARGETED

- QUANTITATIVE NDT
- NEW METHODS
- HEALTH MONITORING

Key Objectives of Development



Quantitative UT

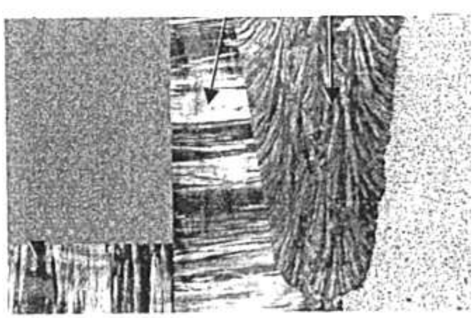
? MATERIAL CHARACTERIZATION ?

RISK INFORMED NDT

- Quantitative NDT
- Human Error

MATERIALS TESTABILITY

- Coarse Grain Material
- Dissimilar Welds (Anisotropy)



Dissimilar Weld

COMPONENT ACCESS

- Penetrations
- Core Structures


MTT-300M
ИНСТИТУТ ПРОБЛЕМ МОРСКИХ ТЕХНОЛОГИЙ

Literature

1. P. J. G. Schreurs: *Fracture Mechanics Lecture Notes - course 4A780*, Eindhoven University of Technology, Department of Mechanical Engineering, Materials Technology (2011)