Workshop on Optimization of Service Life of Operating Nuclear Power Plants

Participation of Research Institutes in Angra´s PLiM

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. Center of Nuclear Engineering (CEN)

. Division of Structural Mechanics (CENM)

Activities to Support ETN

(on demand)

1. Structural Integrity of SG Tubing

. Deterministic Approach (*Initial*)

. Probabilistic Approach
(Based on EPRI´s Correlations with Monte-Carlo Simulations)

2. Courses

. Fracture Mechanics
. Structural Integrity Assessment
. Codes and Standards
. Piping and Mechanical Components

Deterministic Approach

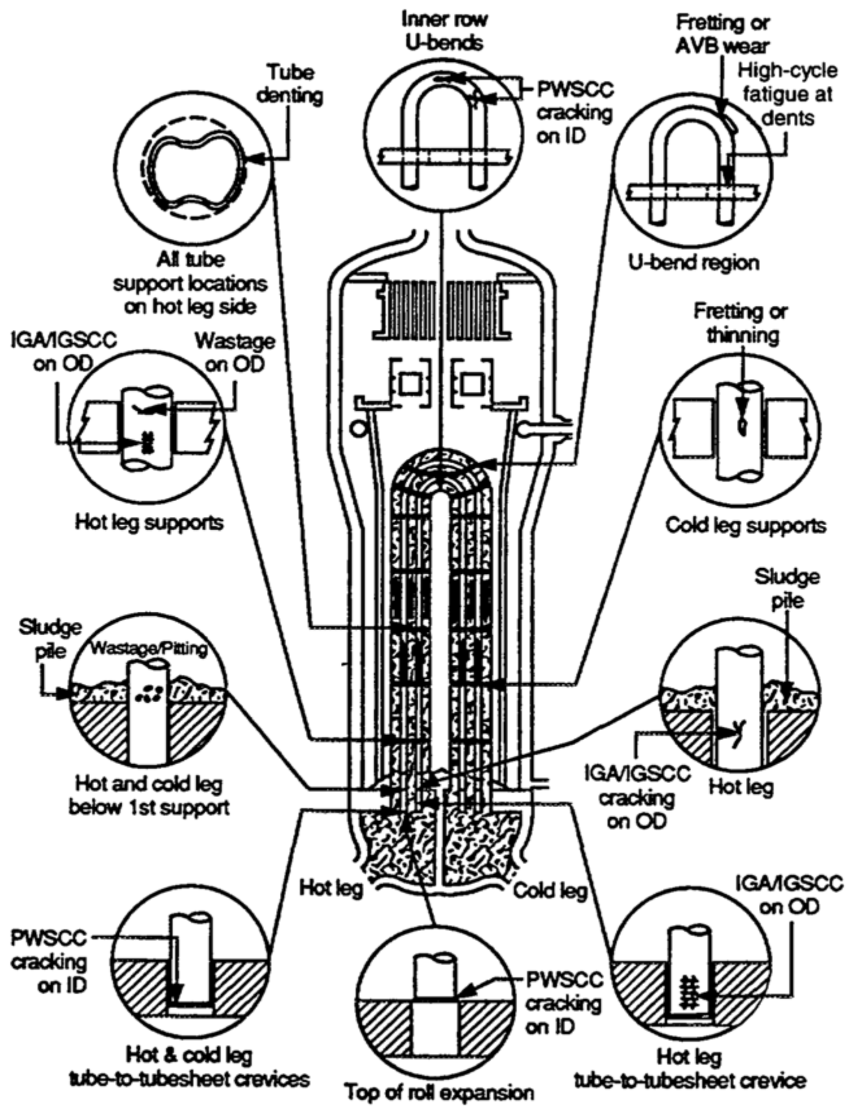


FIG. 14. Locations of known tube wall degradations in recirculating steam generators. (Courtesy of K. J. Krzywosz of the Electric Power Research Institute NDE Center; modified.)

1998-1999
Research on the degradation mechanisms in PWR Steam generators

IAEA-TECDOC-981 (1997)

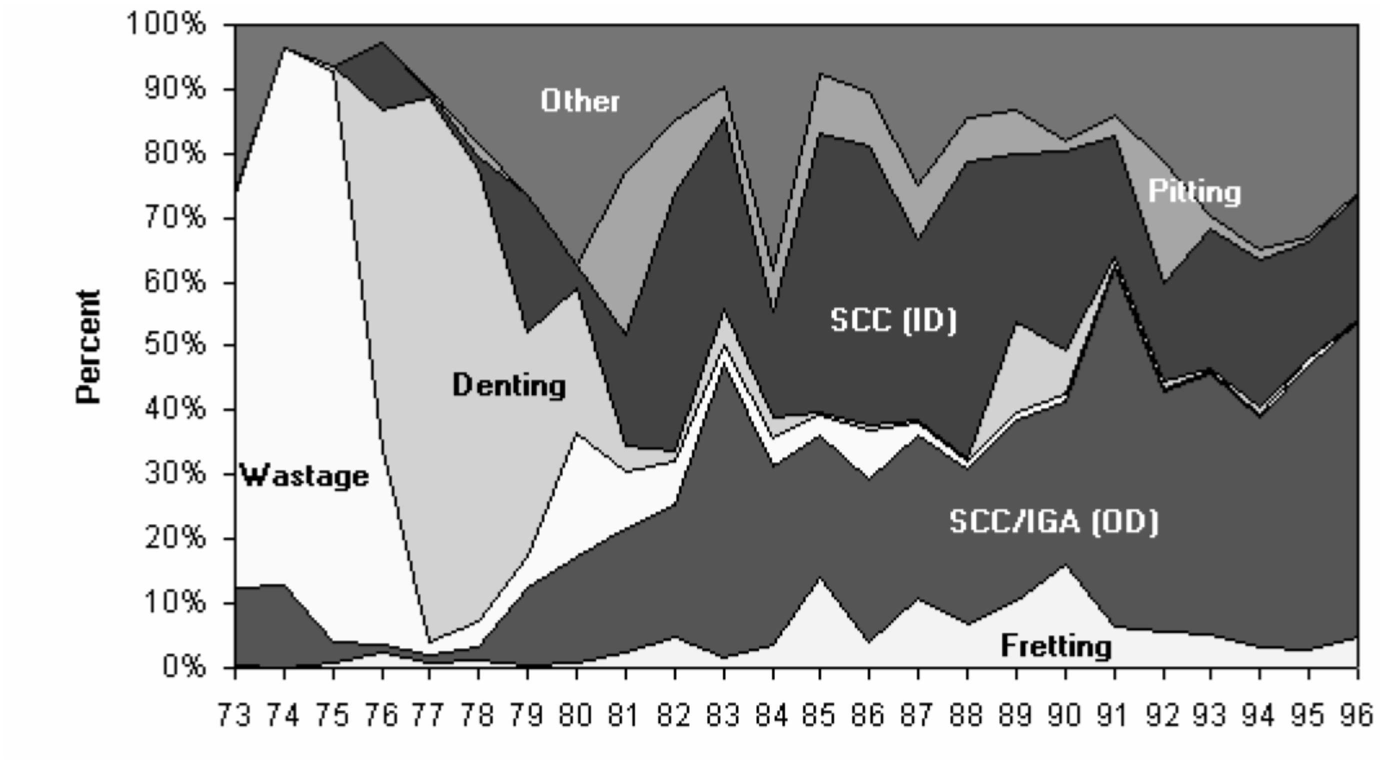
Assessment and management of ageing of major nuclear power plant components important to safety:

Steam generators

Deterministic Approach

1998-1999

Research on the degradation mechanisms in PWR Steam generators



Worldwide causes of SG plugging (EPRI, 1997)

Deterministic Approach

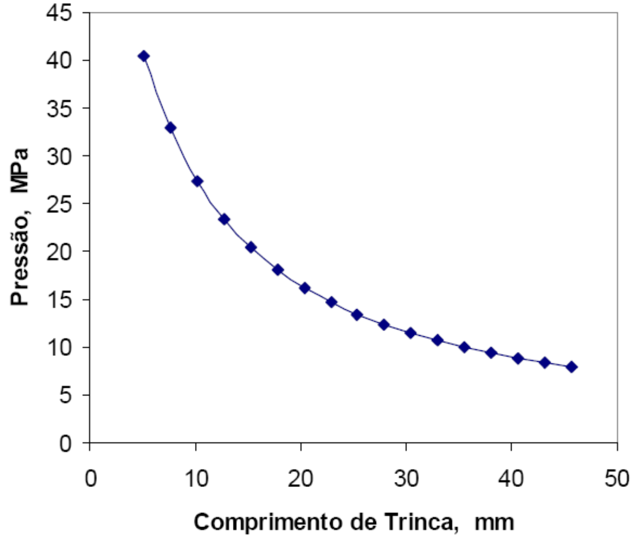
1998-2000

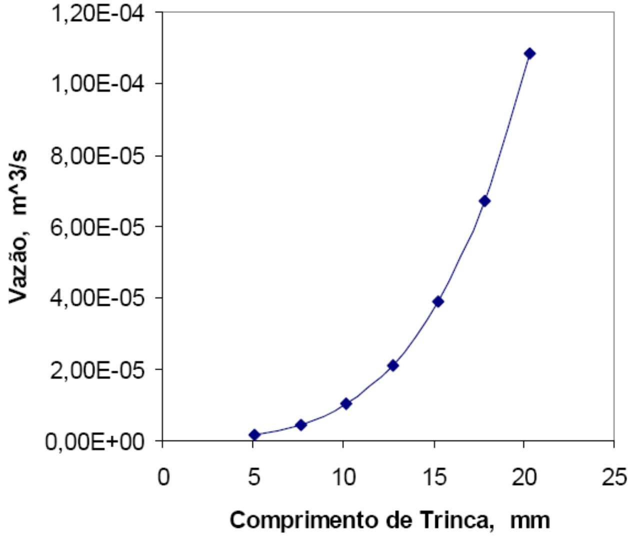
SG Tubes Plugging Criteria – PWSCC in Roll Transition Zone (near the tube sheet)

Axial cracks, with any depth, in RTZ are acceptable if

$$A = a + a_{esp} - a_{cres} - a_{ins}$$

where **A** is the crack length over the tube sheet, **a** is the burst crack length for the worst pressure condition, $\mathbf{a_{esp}}$ is the correction due to the tube sheet, $\mathbf{a_{cres}}$ is the tolerance for the crack growth to the next inspection and $\mathbf{a_{ins}}$ is the measurement error in inspections





Deterministic Approach

2000

SG Tubes Plugging Criteria – ODSCC in Support plates - Based on Bobbin coil voltage limits

Probabilistic Approach

2000 - …

STRUCTURAL INTEGRITY ASSESSMENT OF STEAM GENERATOR TUBES USING PROBABILISTIC APPROACHES

A fundamental step in tube plugging management is the tube structural integrity evaluation considering different defects, found in in-service inspections (Non-Destructive Examination - NDE), and how to consider the involved uncertainties. These defects arise from different degradation modes under several reactor operational conditions.

The probabilistic approaches, based on experimental results obtained from several and different tube defects morphology, use statistics to consider the uncertainties to assess structural limits of PWR SG tubes.

Besides, more sophisticated statistics methods, as Monte Carlo, allow simplified and less conservative analyses as well.

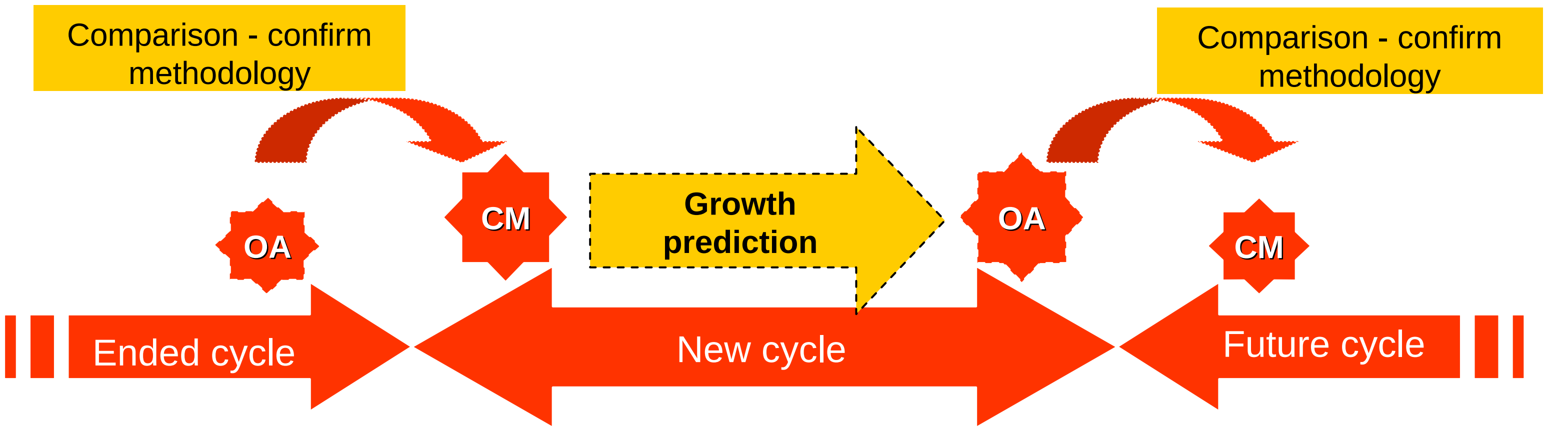
Probabilistic Approach

CM & OA

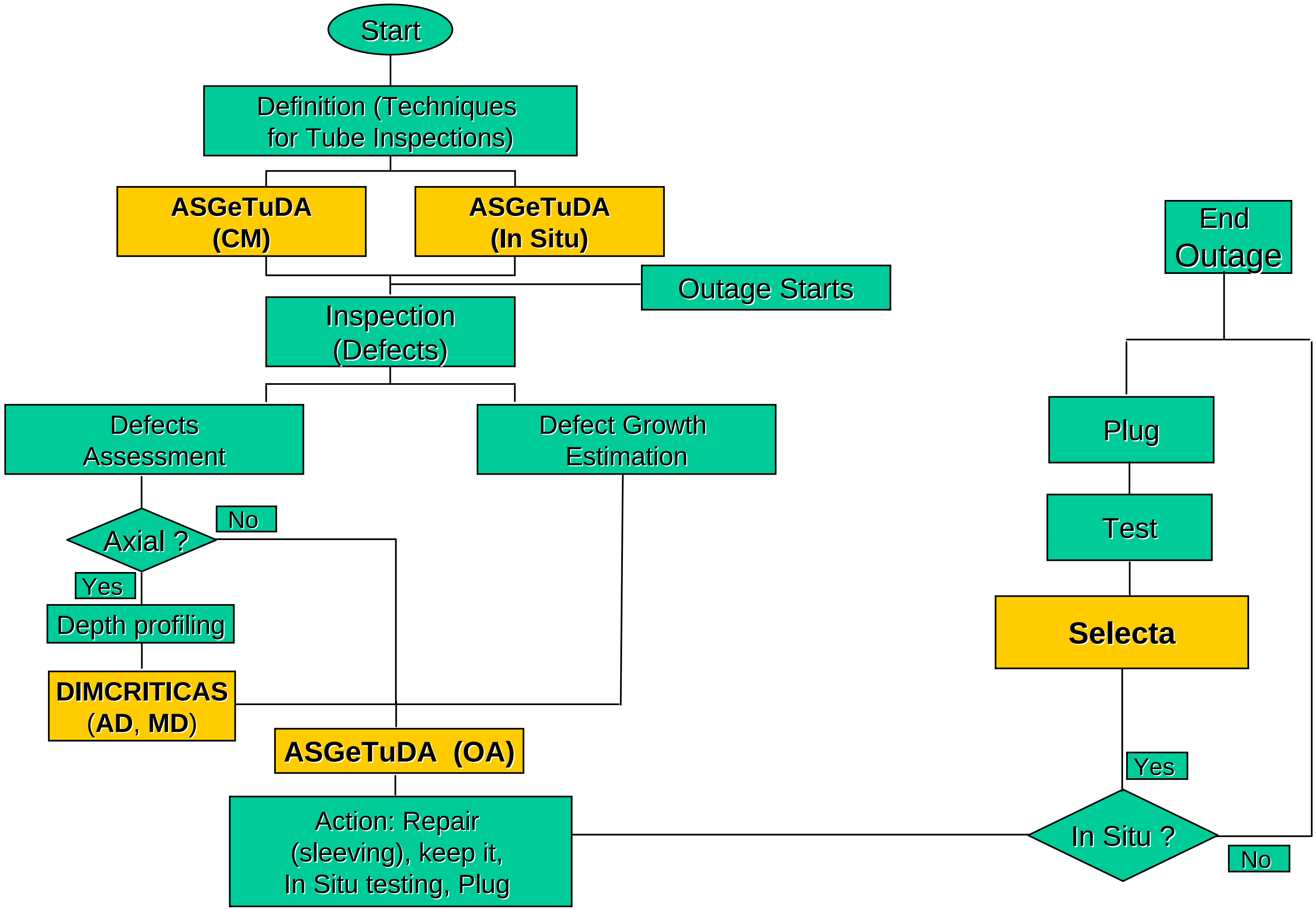
$$PB_{des}\ (= \Delta P) = \max(3{,}0*\Delta P_{oper},\ 1{,}4*\Delta P_{acid})$$

For any defect, the tube burst pressure PB, associated with the "CM" or with the "OA" condition should be evaluated with probability of 0.95 with 50% confidence

➔ in 95% of the occasions the tubes with some defect (size) will not burst when the pressure reaches PB_{des}



Programs


Start
Definition (Techniques for Tube Inspections)
ASGeTuDA (CM)
ASGeTuDA (In Situ)
Outage Starts
Inspection (Defects)
Defects Assessment
Defect Growth Estimation
Axial ?
No
Yes
Depth profiling
DIMCRITICAS (AD, MD)
ASGeTuDA (OA)
Action: Repair (sleeving), keep it, In Situ testing, Plug
In Situ ?
Yes
No
Selecta
Test
Plug
End Outage

Program ASGeTuDA

. Obtain the defect critical parameters/dimensions against tube burst to:

. Structural integrity analyses (CM & OA)

. Selection of tubes candidates to be tested In Situ

. Developed in MATLAB language

. Customized to Angra 1 (*generic data not associated with defects*):

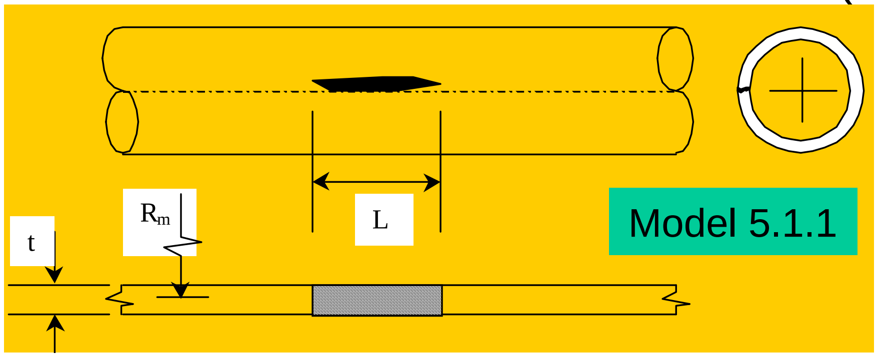
. differential pressure (primary – secondary)

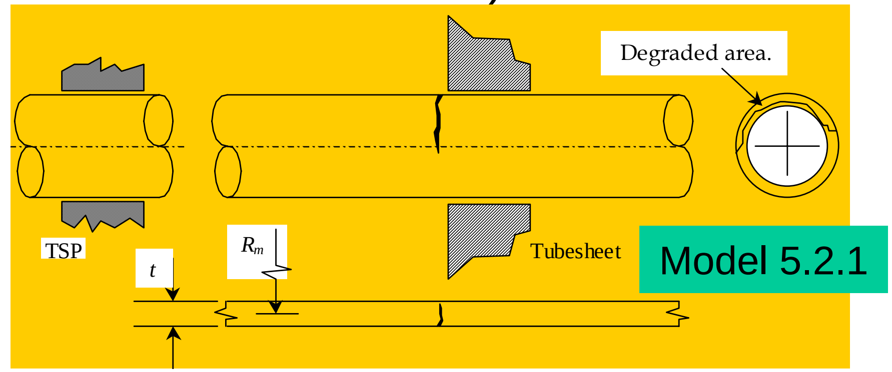
. Tube geometry – nominal diameter, thickness and internal radius

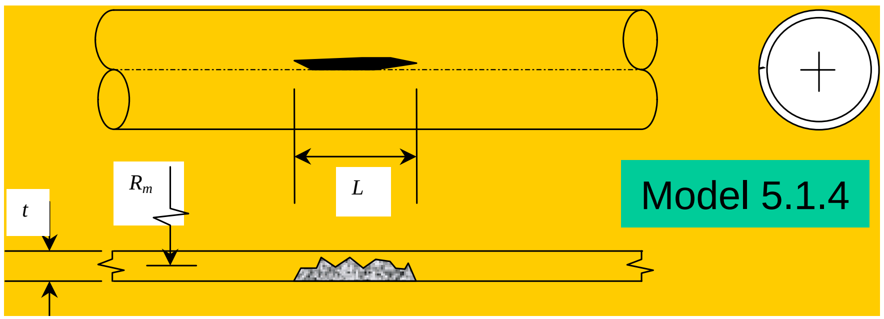
. Tube material - (Sy+Su) average and standard deviation

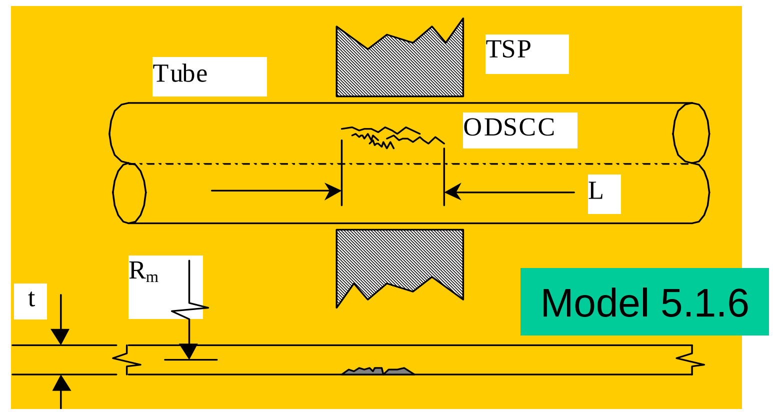
. Number of the Monte Carlo Simulations

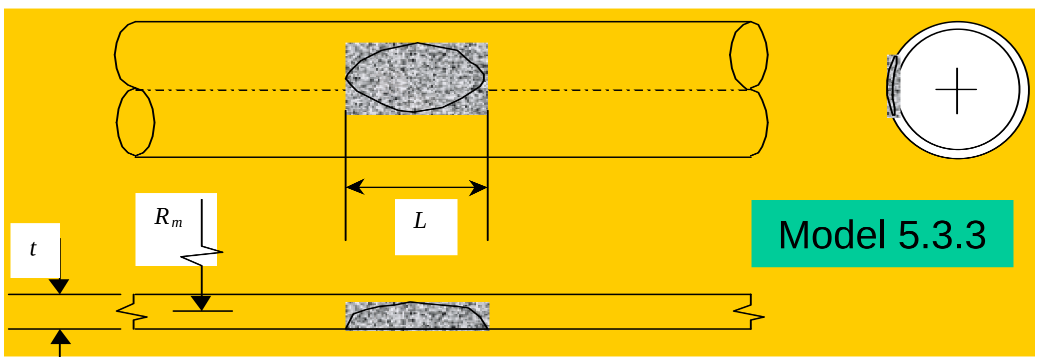
Some Models/Defects (from EPRI *Flaw Handbook*):









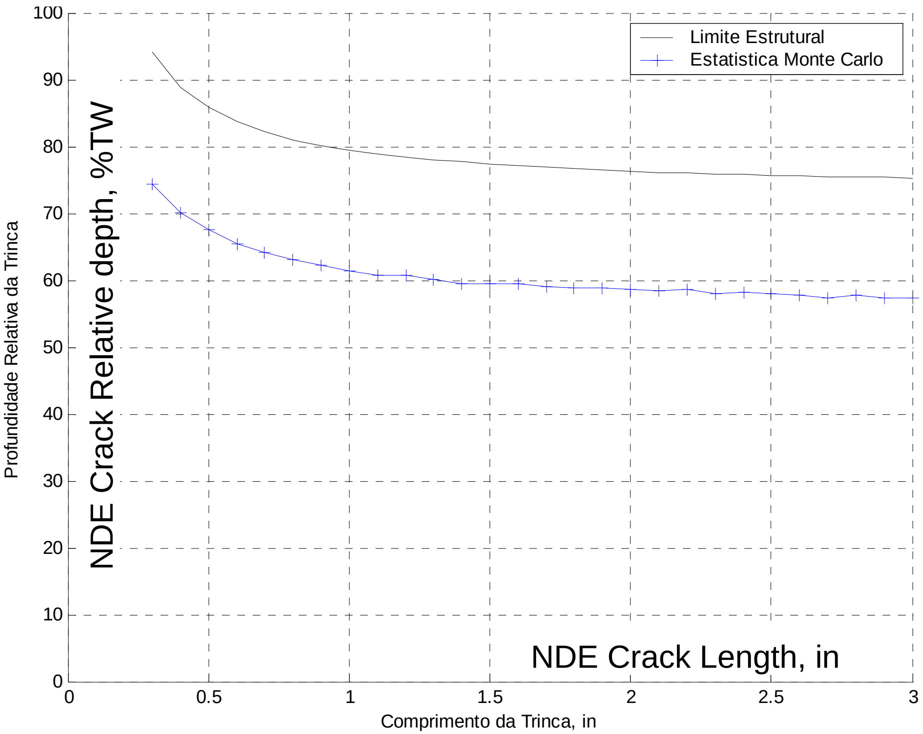


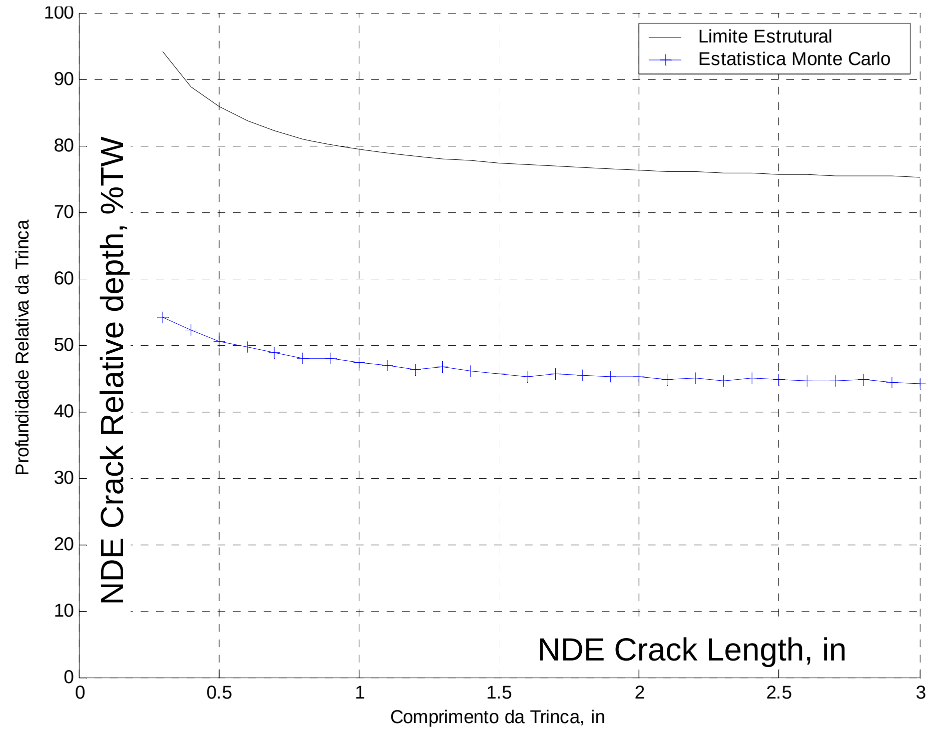
+ Model 5.3.1

Ex.1: Axial Partial Throughwall Defect (OD) - CM/OA

Length, L: $Lx = Ca_L * L_{NDE} + Cb_L$
$Ca_L = 1.00$; $Cb_L = 0.00$ in
Std dev, $\sigma L_{NDE} = 0.10$ in
} **CM**
Growth: $MeanGrowth_L = 0.25$ in
$SDevGr_L = 0.10$ in
} **OA**

Depth, h: $hx = Ca_H * h_{NDE} + Cb_H$
$Ca_H = 1.01$; $Cb_H = 0.00$ %
Std dev, $\sigma H_{NDE} = 11$ %
} **CM**
Growth: $MeanGrowth_H = 5.0$ %
$SDevGr_H = 5.0$ %
} **OA**





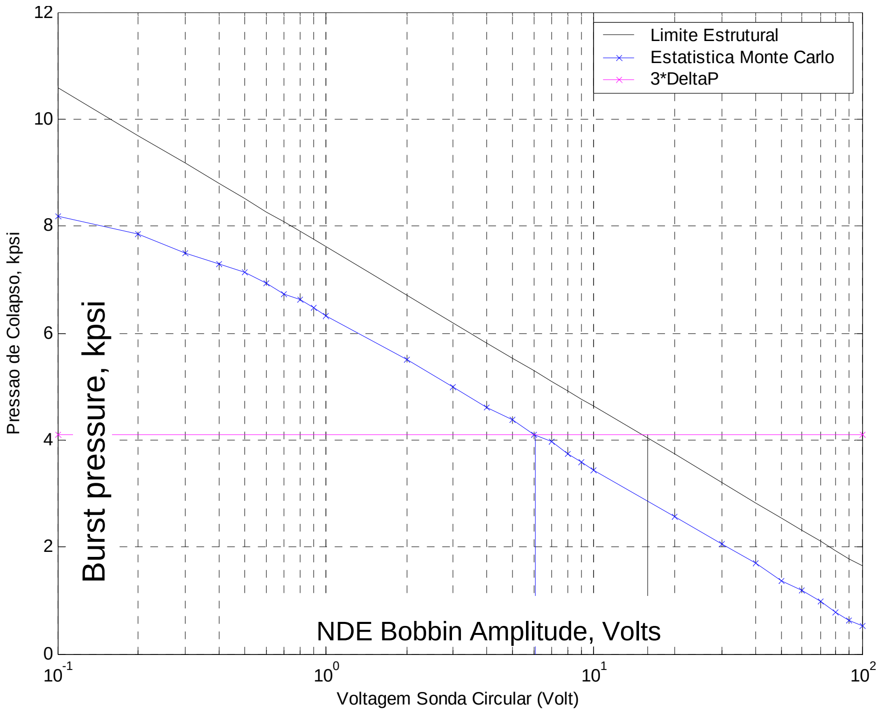
Ex. 2: ODSCC at TSP, ¾" Drilled Tube - CM/OA

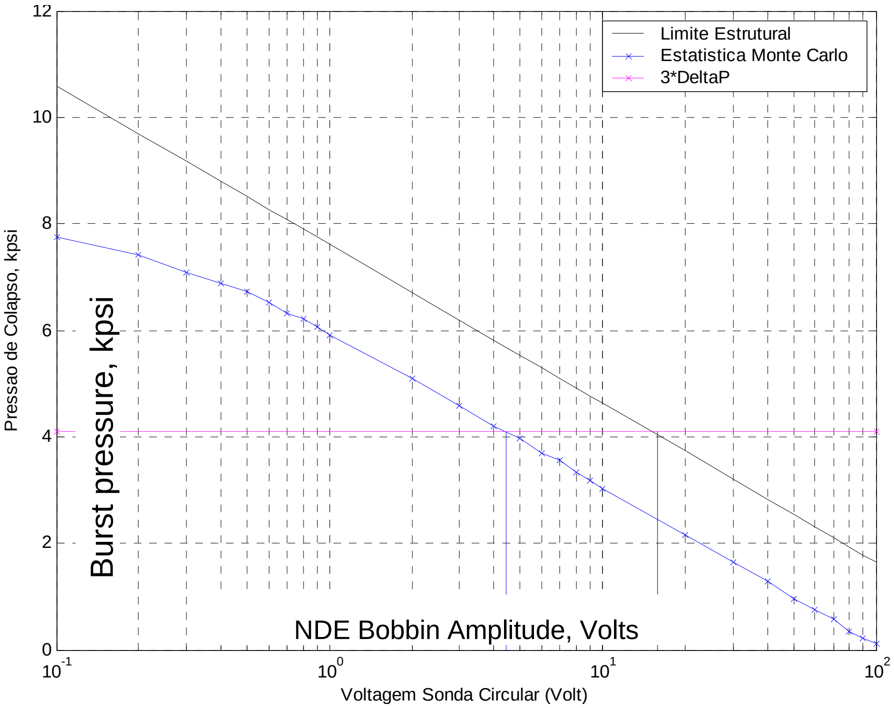
Bobbin Coil Voltage, BCV

$BCVx = Ca_{BCV} * BCV_{nde} + Cb_{BCV}$

Ca_{BCV} = 1.00
Cb_{BCV} = 0.00 (Volt)
Std deviation, σ_{BCV} = 0.30 (Volt)
} **CM**

Growth:
$MeanGrowth_{BCV}$ = 0.25 (Volt)
Std deviation, $\sigma_{Gr,BCV}$ = 0.10 (Volt)
} **OA**



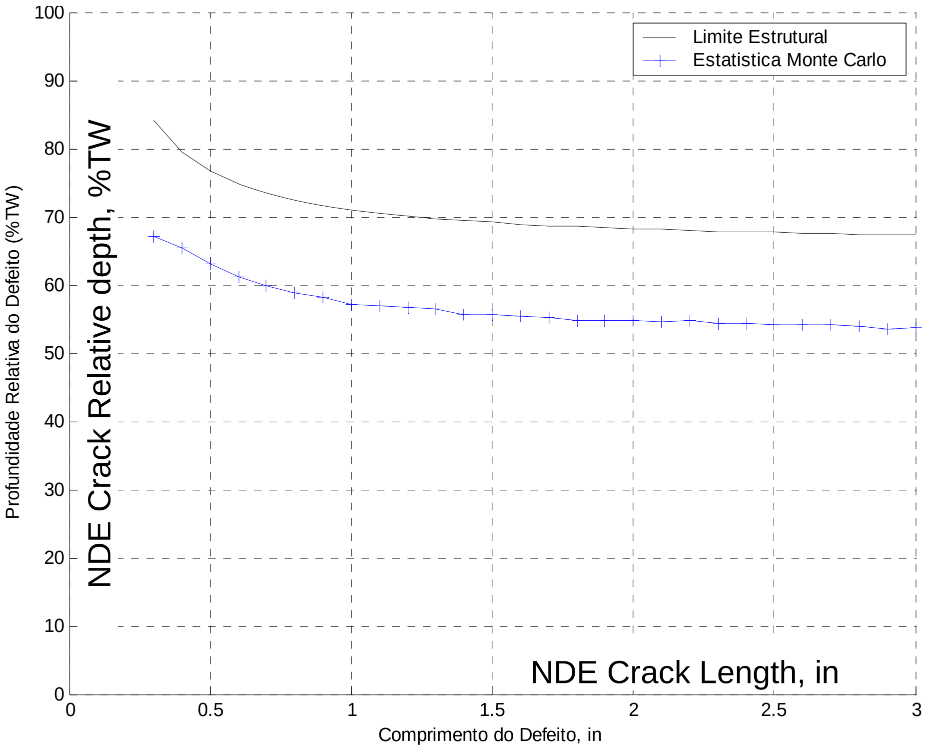


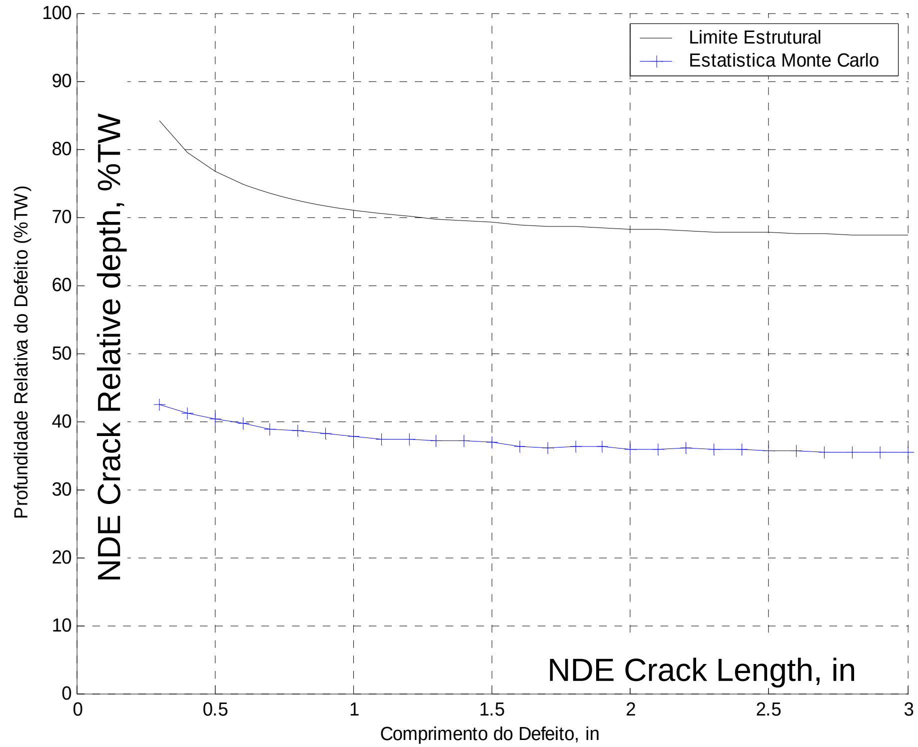
Ex. 3: Axial Thinning with Limited Circumferential Extent (Volumetric) - CM/OA

Ca_L = 1.0 Ca_h = 1.0 $MeanGrowth_L$ = 0.2 ; $MeanGrowth_h$ = 10 %

Cb_L = 0.0 Cb_h = 0.0 Std dev., $\sigma_{L,Gr}$ = 0.1 ; Std. dev., $\sigma_{h,Gr}$ = 5 %

$SDev_L$ = 0.15 $SDev_h$ = 10 %

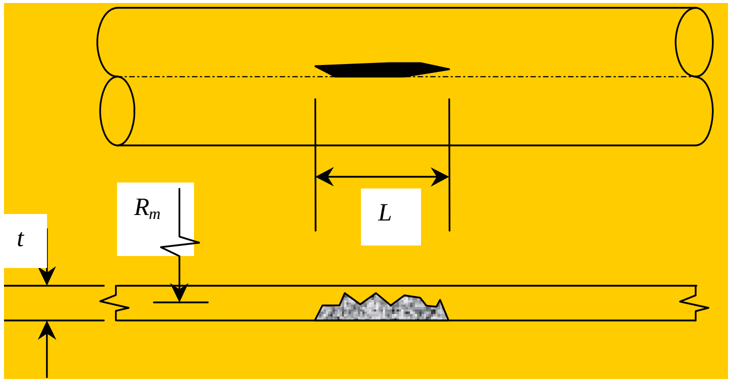


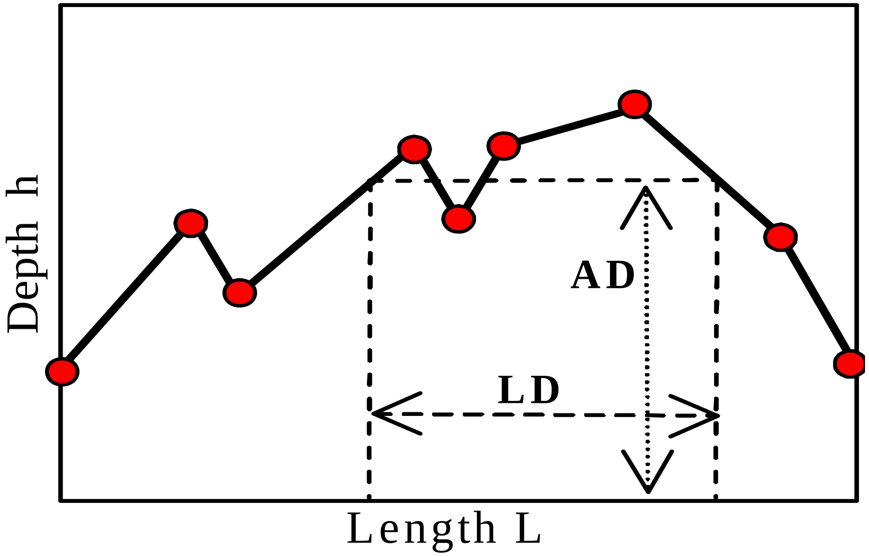


Program DIMCRITICAS

. Obtain the critical equivalent dimensions AD & LD for an axial defect from its irregular (actual) profile obtained during the tube inspection

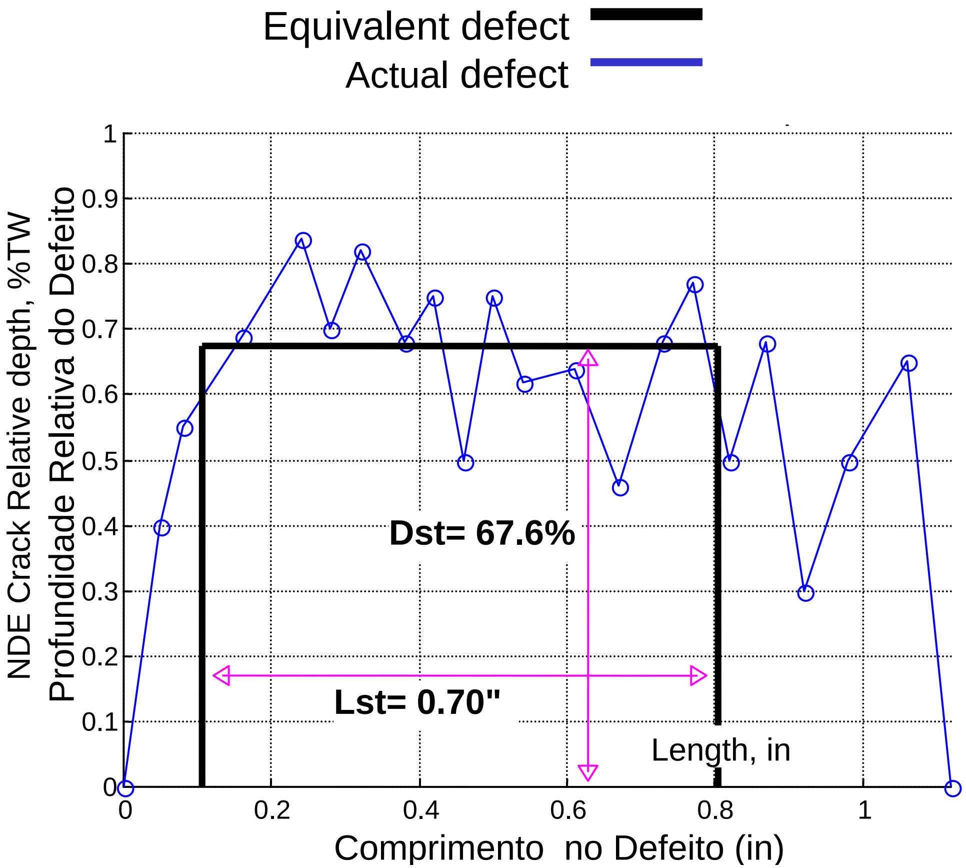
. Developed in MATLAB language



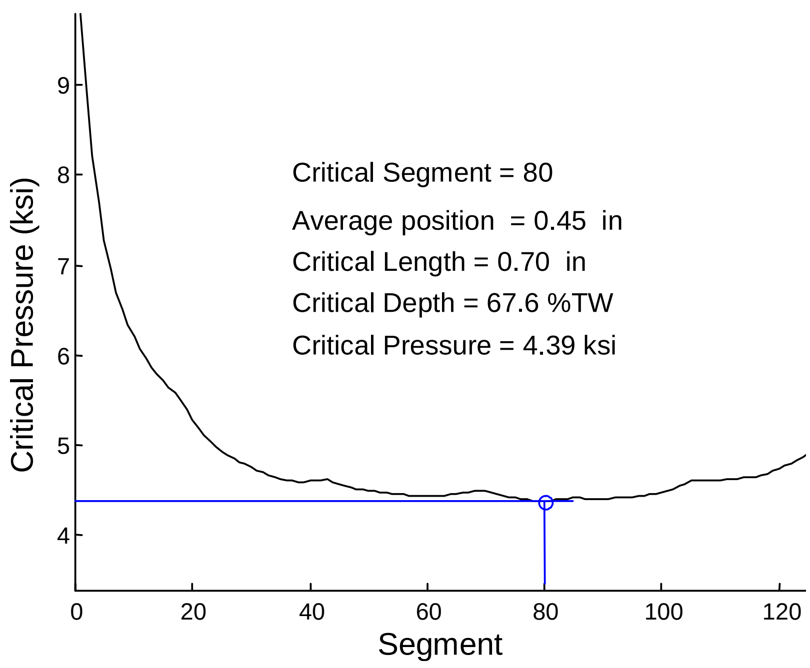


The tube with the idealized defect AD x LD will fail/burst with the same pressure PB from the actual defect/profile (hi, Li)

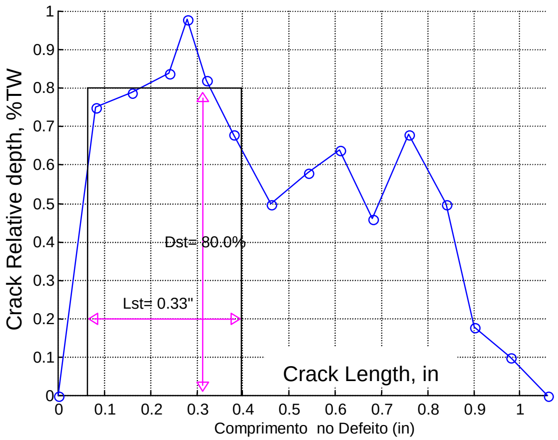
Example of a defect/profile & Results

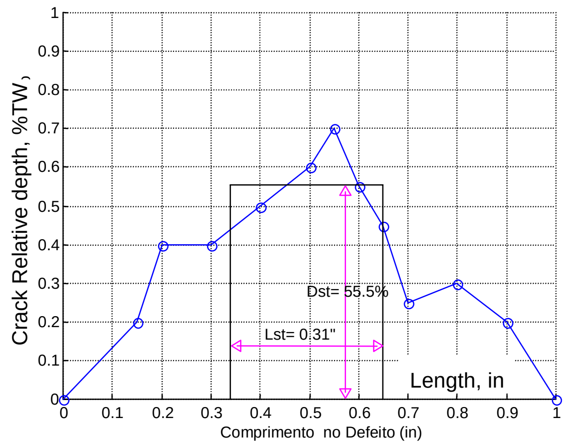


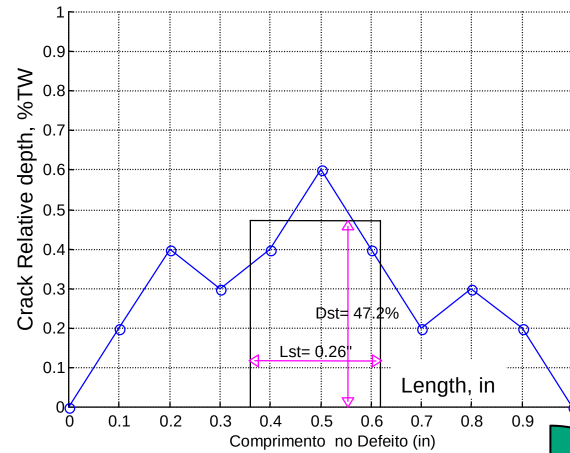
Critical Pressure associated with
the created segment defects

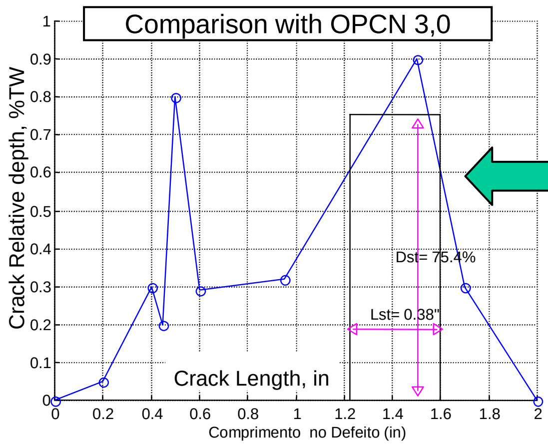


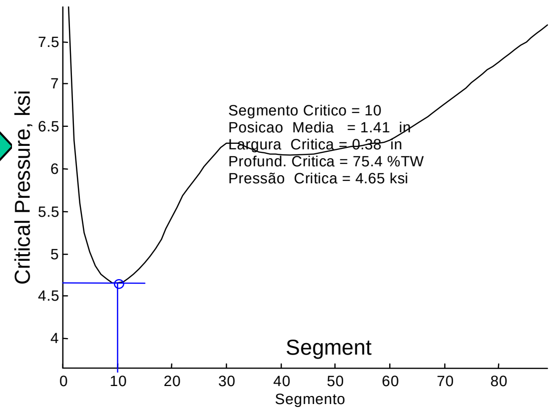
Other Tests & Results:

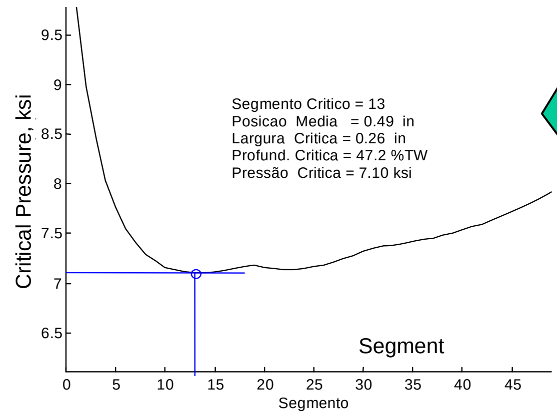












Program Selecta

. Select the defects/tubes of Angra 1 SG candidate to be tested *in situ* for burst (selection based on the defect dimensions)

The defects should be stratified (classified) based on:

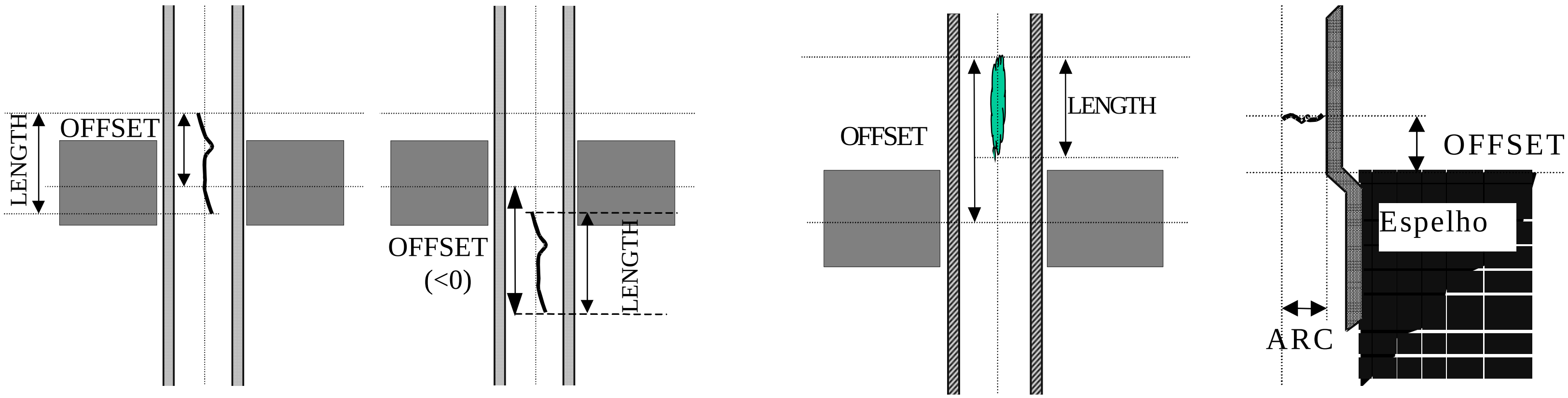
. Location along the tube/SG: . Tubesheet
. Support Plate 01H
. Support Plate (Other)
. Free span, etc.

. Orientation (with respect to the tube): . Axial
. Circumferential
. Volumetric

. Origin: . Internal
. External

. Developed in MATLAB language

Basic Defects – Dimensions (LENGTH / ARC) & OFFSET



Axial Defect

OFFSET > 0 **OFFSET < 0** **Volumetric** **Circumferential**

StrucLen - ‘effective’ defect length for Axial or Volumetric defects

→ it is the part of the defect outside of the TSP/TS

StrucLen ≤ LENGTH → defect partially inside

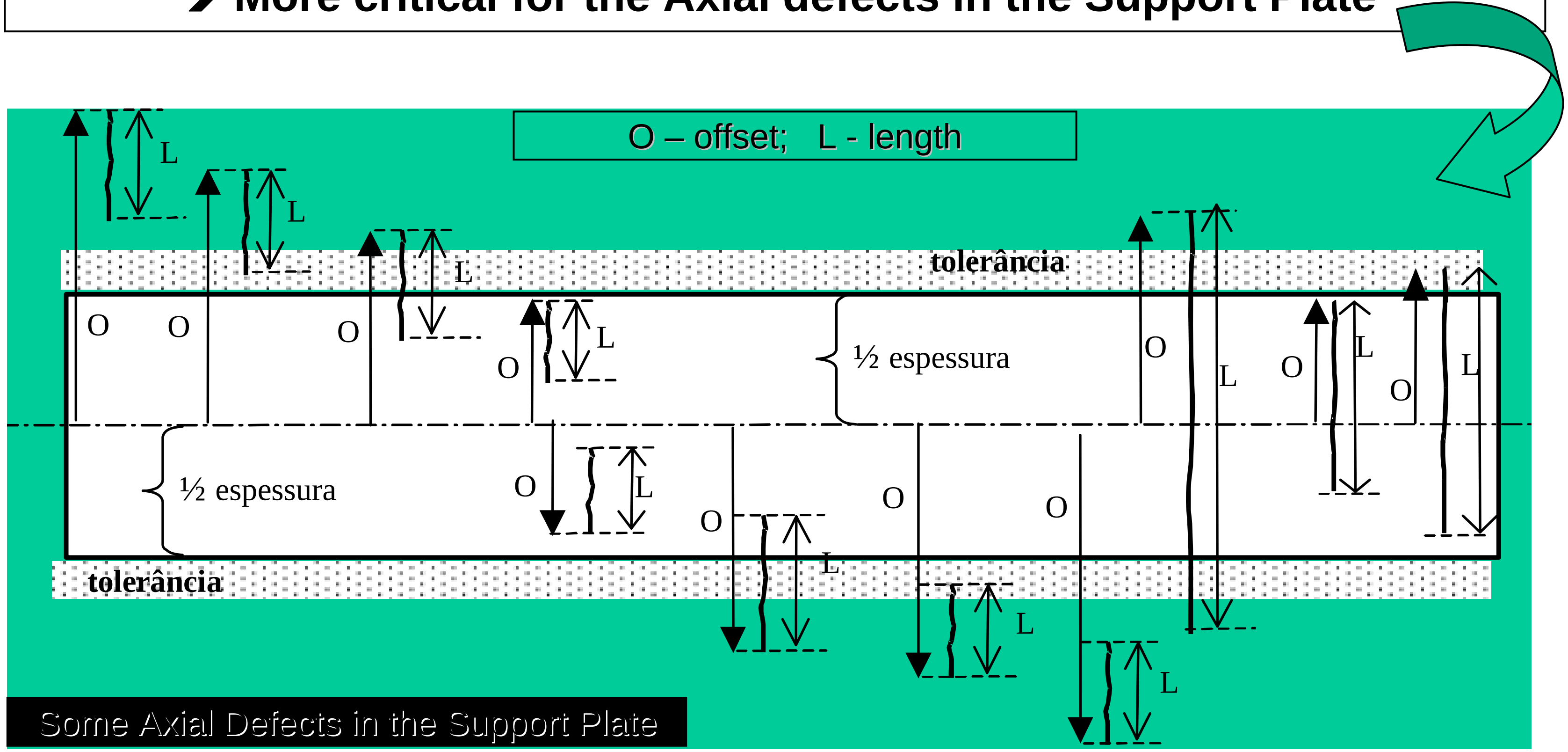
StrucLen = 0 → defect inside of the TSP/TS

Support Plate Thickness = 0,75”

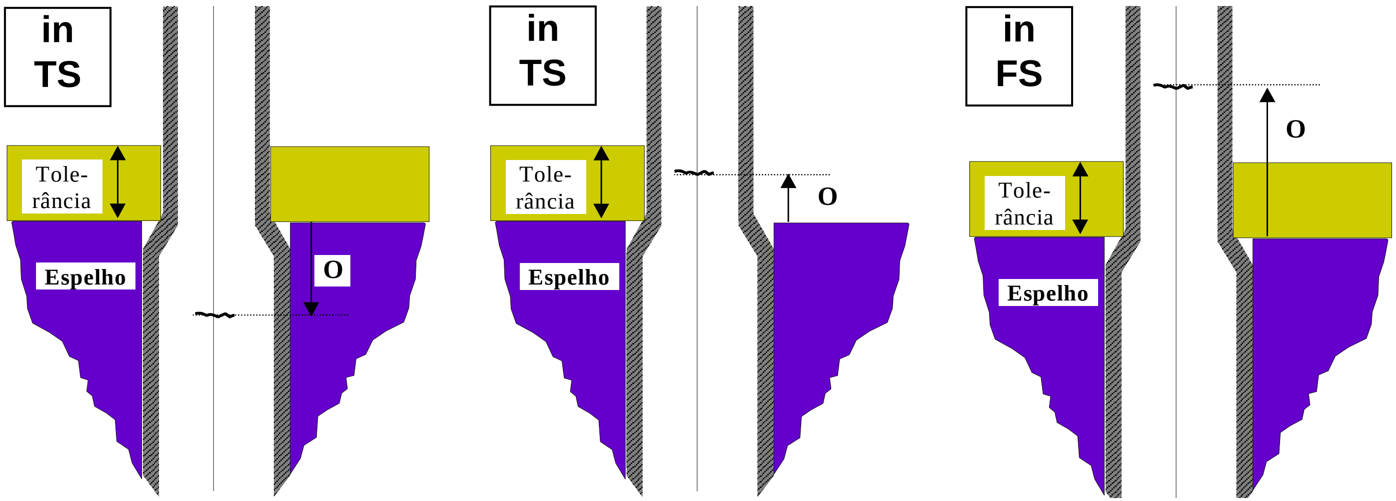
Defects in the Support Plates

The combination of the parameters (**Location, OFFSET** & **LENGTH**) gives multiple possibilities that should be tested one by one, being mutually exclusive

➔ **More critical for the Axial defects in the Support Plate**

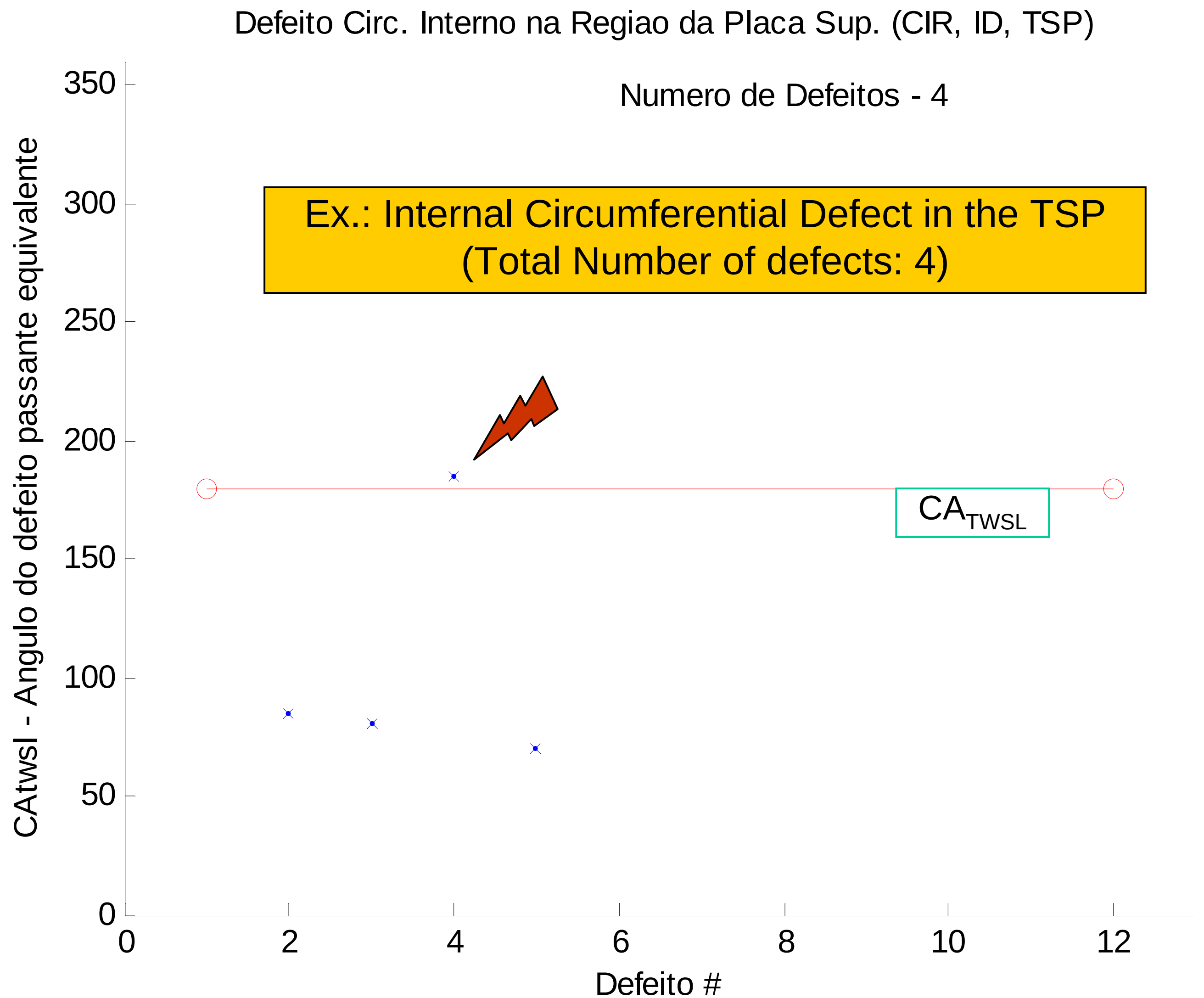


Examples of the Stratification/Classification for Circumferential Defects in the Tubesheet (TS) region

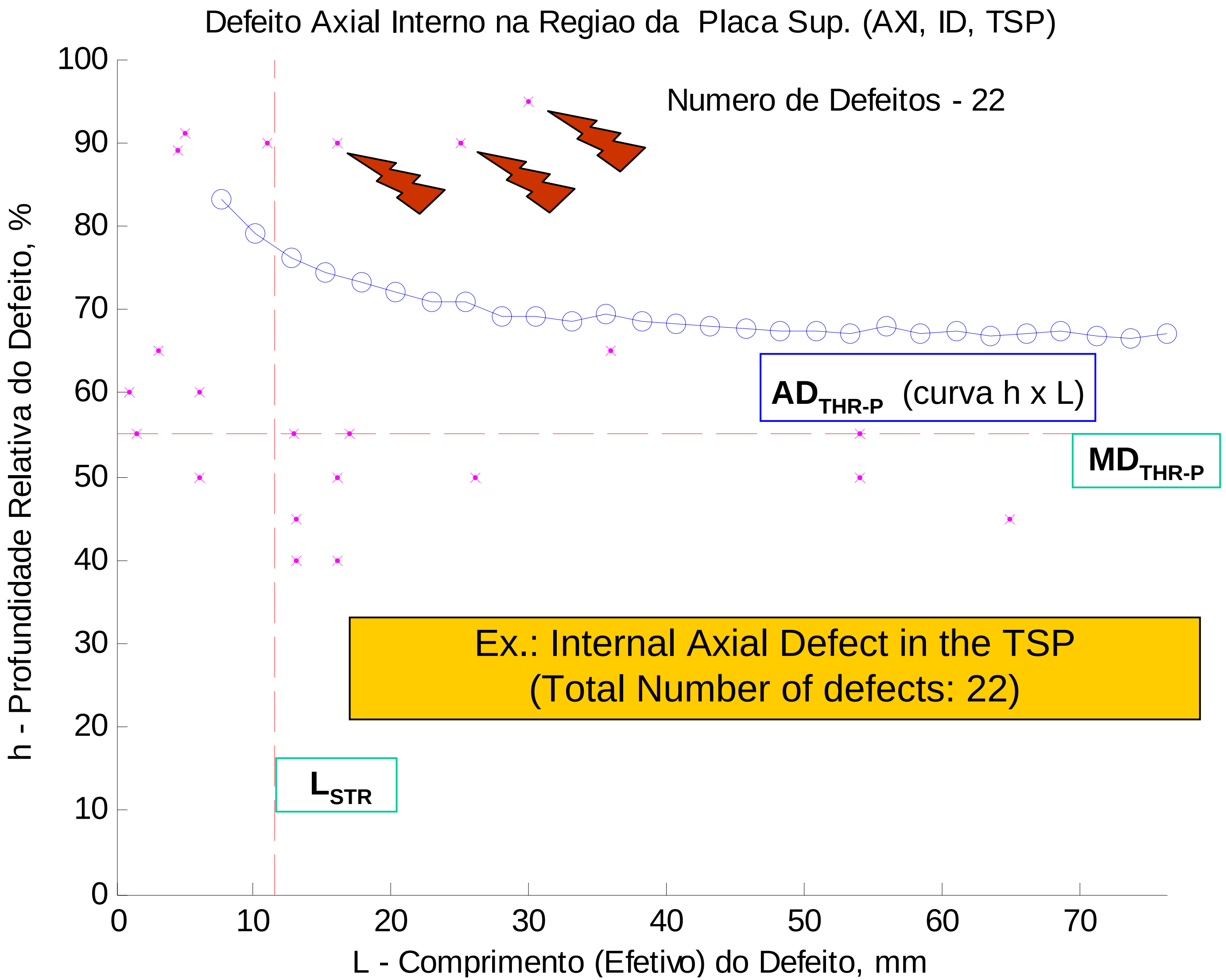


Defect in the TS	Defect in the (region of the) TS	Defect in the Free Span

Selecta (V2.0)


Defeito Circ. Interno na Regiao da Placa Sup. (CIR, ID, TSP)
Numero de Defeitos - 4
Ex.: Internal Circumferential Defect in the TSP
(Total Number of defects: 4)
CA_TWSL
CAtwsl - Angulo do defeito passante equivalente
Defeito #
0
50
100
150
200
250
300
350
0
2
4
6
8
10
12

Selecta (V2.0)


Defeito Axial Interno na Regiao da Placa Sup. (AXI, ID, TSP)
Numero de Defeitos - 22
h - Profundidade Relativa do Defeito, %
100
90
80
70
60
50
40
30
20
10
0
AD$_{THR-P}$ (curva h x L)
MD$_{THR-P}$
Ex.: Internal Axial Defect in the TSP
(Total Number of defects: 22)
L$_{STR}$
0
10
20
30
40
50
60
70
L - Comprimento (Efetivo) do Defeito, mm

Courses

Courses

I – Fracture Mechanics and Crack Propagation

II – Codes and Standards for:

a. Structural Integrity (*)
b. Piping Design (*)
c. Mechanical Equipment Design (*)

III – Structural Integrity Assessment in Angra 1 & 2

IV – Programs for Structural Integrity Assessment

(*) basically ASME Section III (Subsection NB) and Section XI