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FAC PREDICTION AT EDF : A COMPARISON OF THE VERSIONS 2 AND 3 OF BRT-CICERO™

Stéphane TREVIN,
Matthieu PERSOZ, Thomas KNOOK,
(EDF/DTG – Grenoble, France)

EDF

FAC PREDICTION AT EDF : A COMPARISON OF THE VERSIONS 2 AND 3 OF BRT-CICERO™

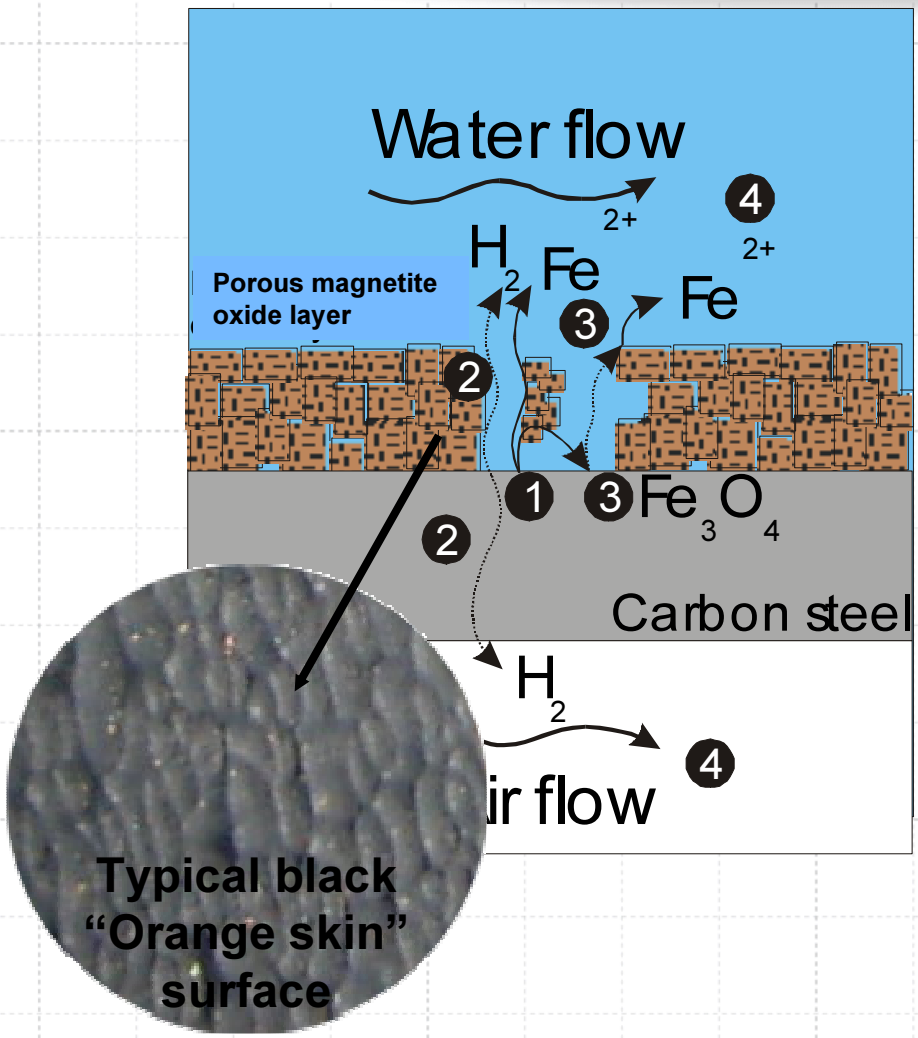
Summary of presentation

1. Flow Accelerated Corrosion Model
2. BRT-CICERO™ software description
3. BRT-CICERO™ performances and advantages

- MECHANISM -

- Occurs on carbon steel in contact with water or wet steam at temperatures between 80 and 300°C.
- Chemical process accelerated by flow rates (mass transfer).
- Main wear mechanism in feedwater circuits.
- FAC is influenced by:
  - ✓ Flow rates and pipe geometry
  - ✓ Steam quality
  - ✓ Chemical conditions (pH)
  - ✓ Oxygen content
  - ✓ Temperature
  - ✓ Alloy impurity contents of the carbon steel.
  - ✓ ……

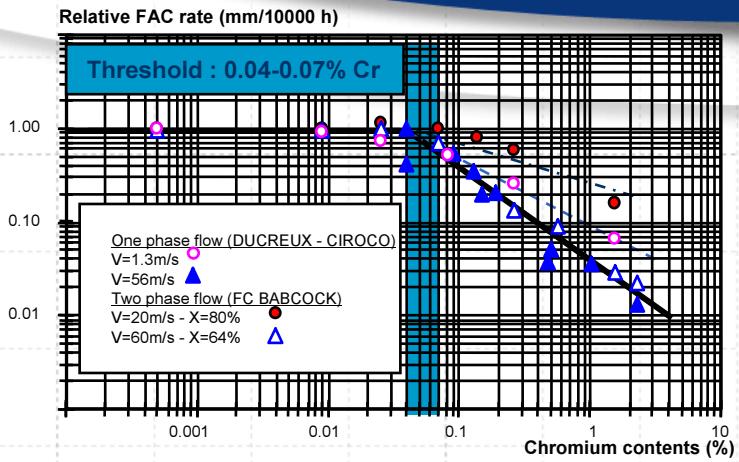
- MECHANISM -



1. Steel oxidation at the metal/oxide interface.
2. Soluble iron diffusion through porous oxide layer.
2. Hydrogen diffusion in both water and steel.
3. Dissolution of Magnetite at oxide/water surface.
4. Soluble iron transfer into water flow

   Hydrogen transfer into steel structure.

- PHYSICO-CHEMICAL MODEL -



$$C_{eq} = [Fe(II)]_{total} = pH_2^{1/3}.\,[K_1[H^+]^2 + K_2[H^+] + K_3 + K_4/[H^+]]$$

Porosity & chromium effect

$C_\infty \neq 0$

$$FAC\_Rate = \frac{\theta.(C_{eq} - C_\infty)}{\frac{1}{K^*} + (1-f).\left[\frac{1}{k} + \frac{\delta_{(t)}}{D}\right]}$$

$\delta < 3\ \mu m$

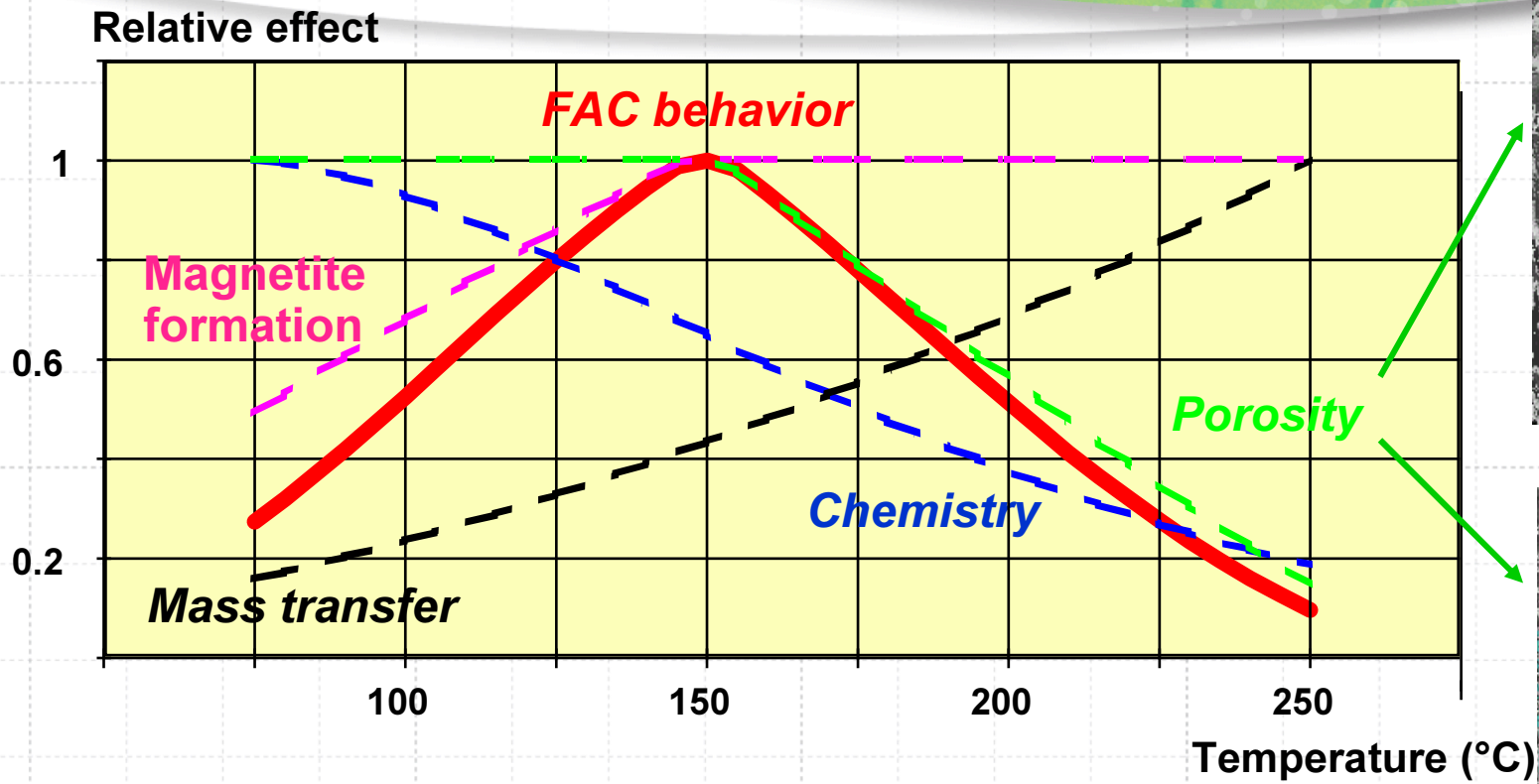
$D = 2.5.10^{-15}\ T/\mu$
(T = temperature
μ = dynamic viscosity)

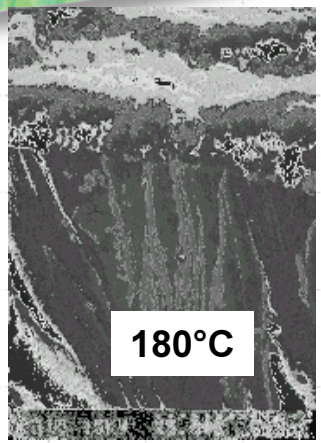
$$K^* = 2.348.10^{14}.\exp\left(\frac{-147888}{8.314 * T}\right)$$

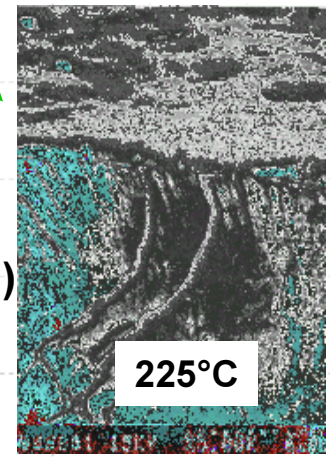
$f = 0,5$

$$k = Sh \times D/d = 0.0193 \times Geox \times (roughness/d)^{0.2} \times Re \times Sc^{0.4} \times D/d$$

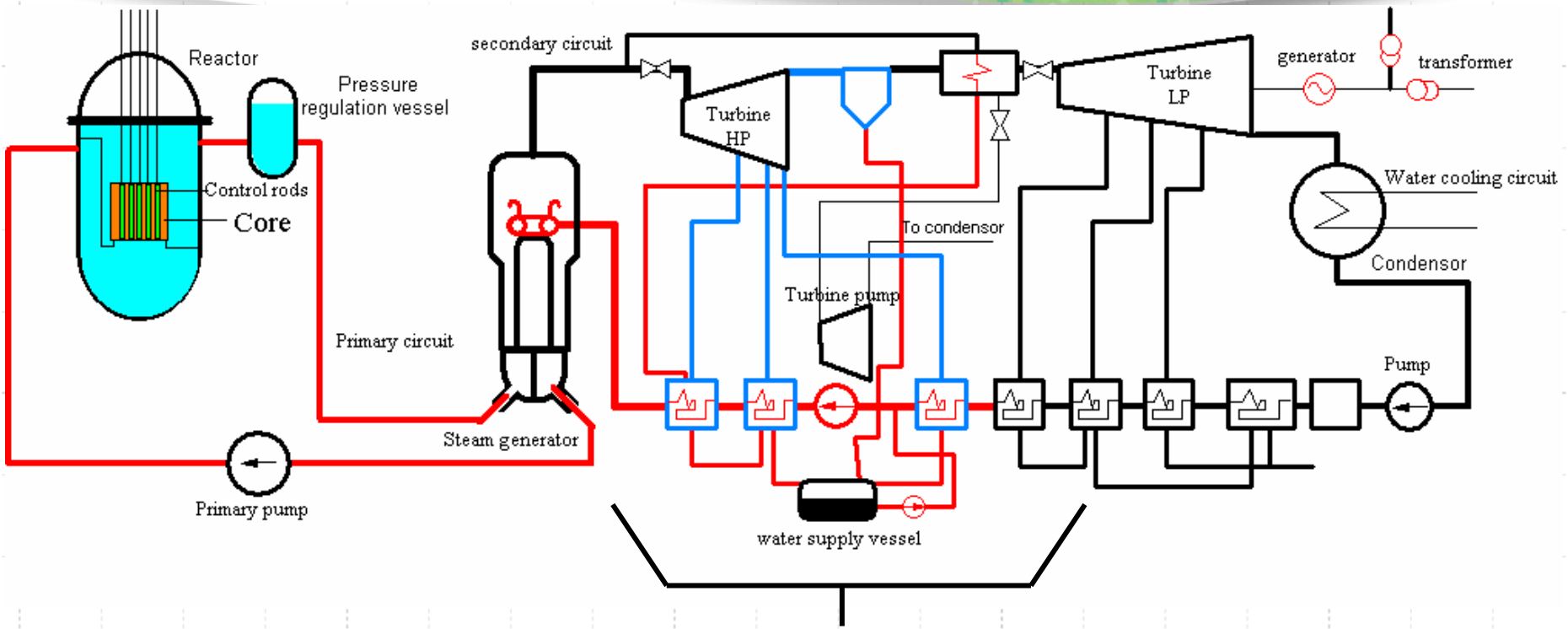
- PHYSICO-CHEMICAL MODEL -







- WATER STEAM CIRCUIT -

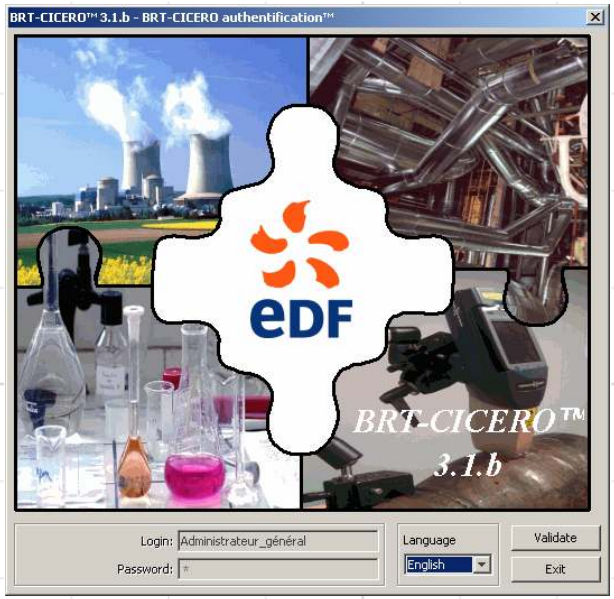


Circuits concerned by FAC

Responsible for global wall thickness loss in condensate and feed water systems.

FAC PREDICTION AT EDF : A COMPARISON OF THE VERSIONS 2 AND 3 OF BRT-CICERO™

FAC monitoring software



Prediction tool to calculate wall thickness loss by FAC

Mandatory for all 58 PWR in France

Used by Daya-Bay / Ling Ao NPP in China

Used by Koeberg NPP in South Africa

- INPUT DATA -

Pipe design

- Isometric design
- Mechanical characteristics
- Design code
- Manufacturing tolerances
- Chromium contents (if available)

Operating conditions

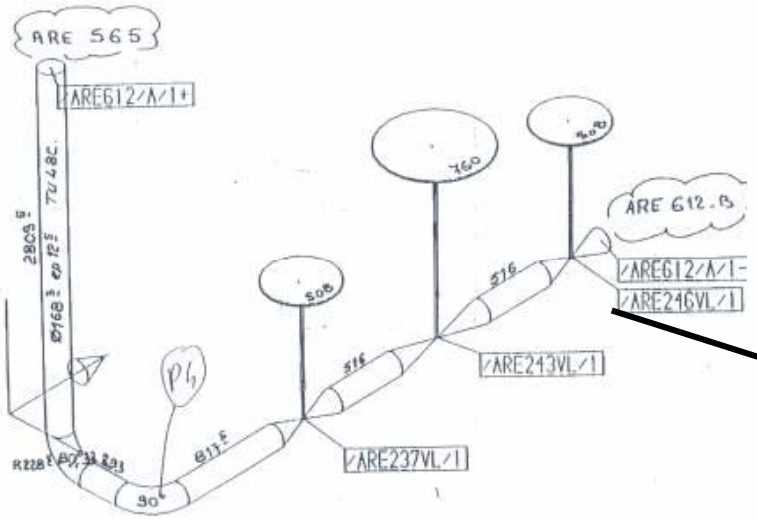
- Flow rates
- Chemical specifications (pH, chemicals)
- Cycles duration
- Temperature and Pressure (Service and Design)

Inspection data

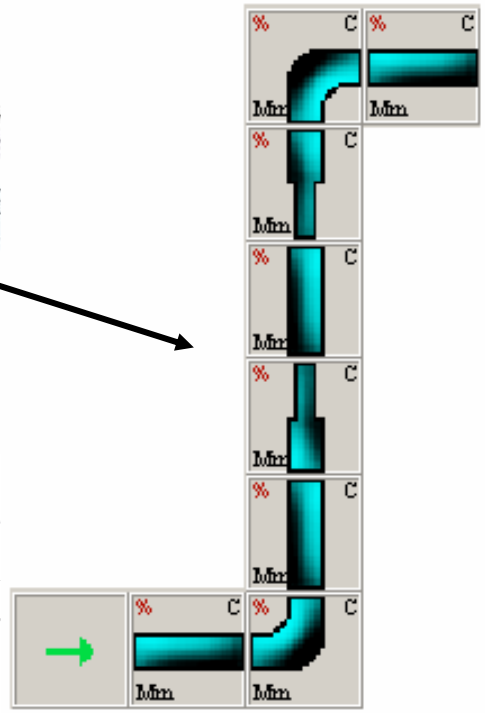
- Wall thickness measurements
- Chromium measurements

- INPUT DATA -

Original pipe design



Pipe representation in BRT-CICERO™ software



Water chemistry (pH, …)
Flow rates
Temperature
Pressure

Mechanical characteristics (Re, Rm, …)

Geometrical characteristics

Chromium contents in steel

At EDF about 60.000 pipe components are modelled

FAC PREDICTION AT EDF : A COMPARISON OF THE VERSIONS 2 AND 3 OF BRT-CICERO™

Version 2	Version 3
MS Windows based environment – NT4 & 2000	MS Windows based environment – NT4, 2000, XP, Vista.
Database use Borland Database format	Database use an .xml format
Available since 2000	Available since 2009 in France and ~ end 2009 for foreign customers
Design thickness from design codes	Design thickness from design codes or direct input
Direct input of measured thickness from one column text file	Direct input of measured thickness from one column text file or Excel-based file
Calculation for thermodynamics from IAPWS 1967	Updated calculation for thermodynamics (IAPWS 1997)
Calculation for chemistry from EDF R&D studies (1980)	Updated calculation for chemistry (EPRI – MULTEQ database V4.0)

- OUTPUT DATA -

Result of calculations:

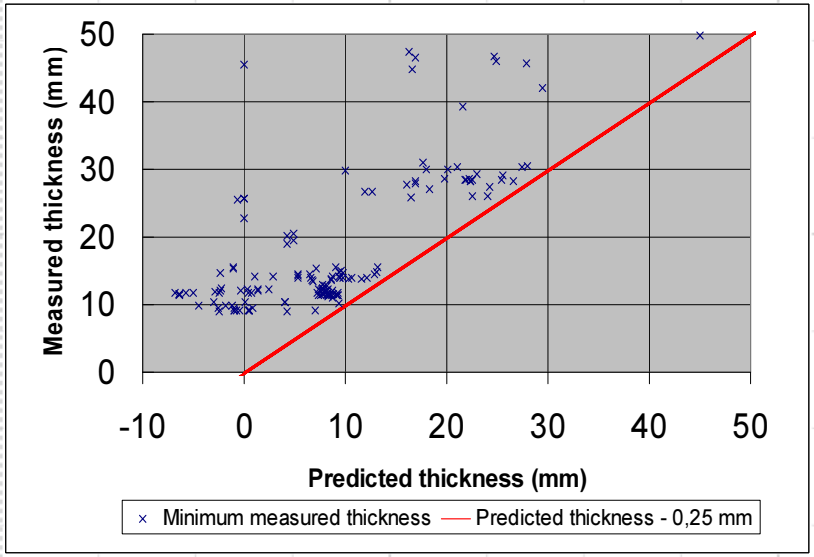
- ✓ FAC wear rate calculation for each pipe component
- ✓ Wall thickness loss over defined periods
- ✓ Identification of critical components
- ✓ Ranking of elements regarding margin between residual & design
- ✓ thickness, time to reach design thickness, etc
- ✓ Pipe components life time predictions
- ✓ Inspection programs
- ✓ Maintenance optimization

FAC PREDICTION AT EDF : A COMPARISON OF THE VERSIONS 2 AND 3 OF BRT-CICERO™

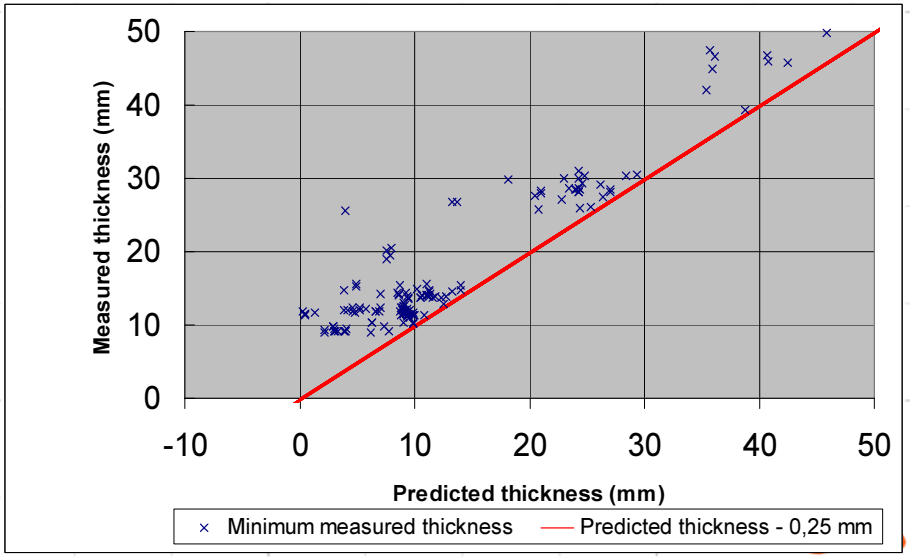
Version 2	Version 3
Chemicals : ammonia, hydrazine, morpholine	Chemicals : ammonia, hydrazine, morpholine, ethanolamine, boric acid, formiate, acetate, glycolate and user defined
Only for PWR	Oxygen effect for each lines and cycle (BWR)
Direct input of chromium contents	Direct input of chromium contents and input of heat (cast) number.
Geometric factors based on NPP feedback from analysis made in 2000.	Geometric factors based on NPP feedback from analysis made in 2007 & 2008. Easy to be regularly updated.

- ANALYSIS TO OPTIMISE GEOMETRY COEFFICIENTS -

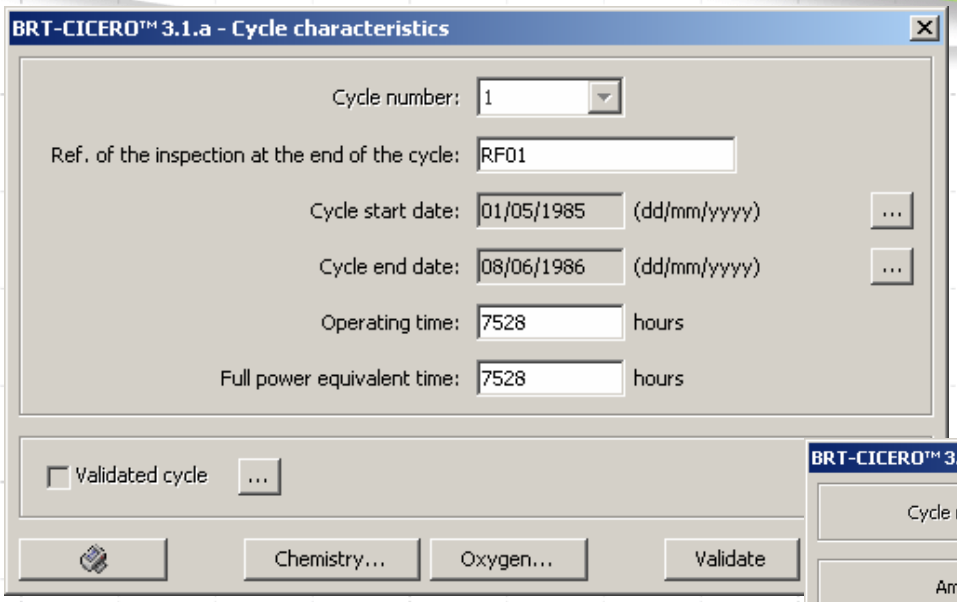
In 2008, it has been observed that the distribution of points corresponding to the lateral branch of flow junctions had an important scatter.

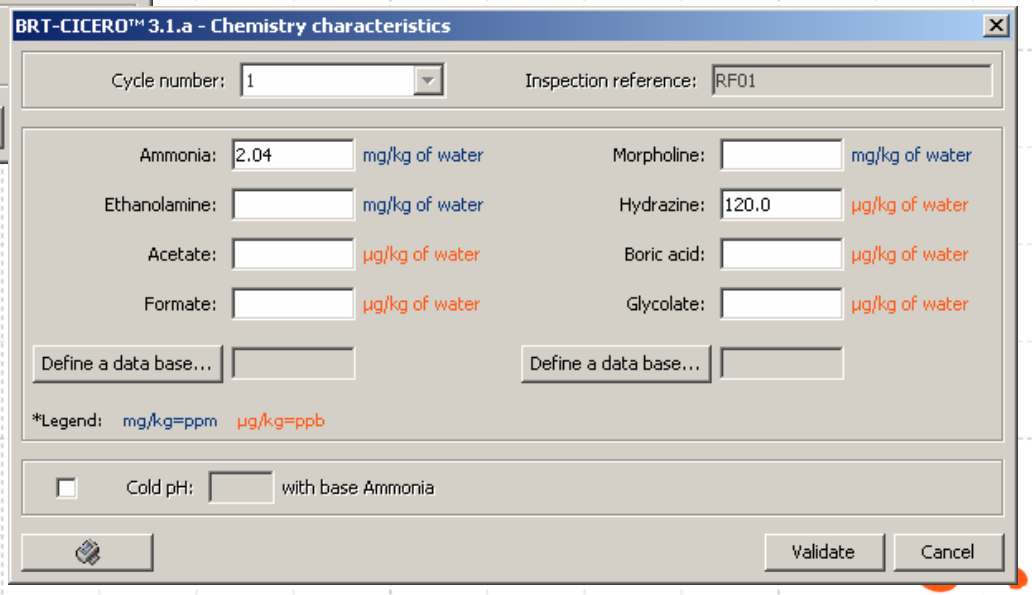


This scatter was reduced in BRT-CICERO™ version 3 by introducing a less conservative geometry factor for the lateral branch of flow junctions.



- CYCLE & CHEMISTRY WINDOWS -



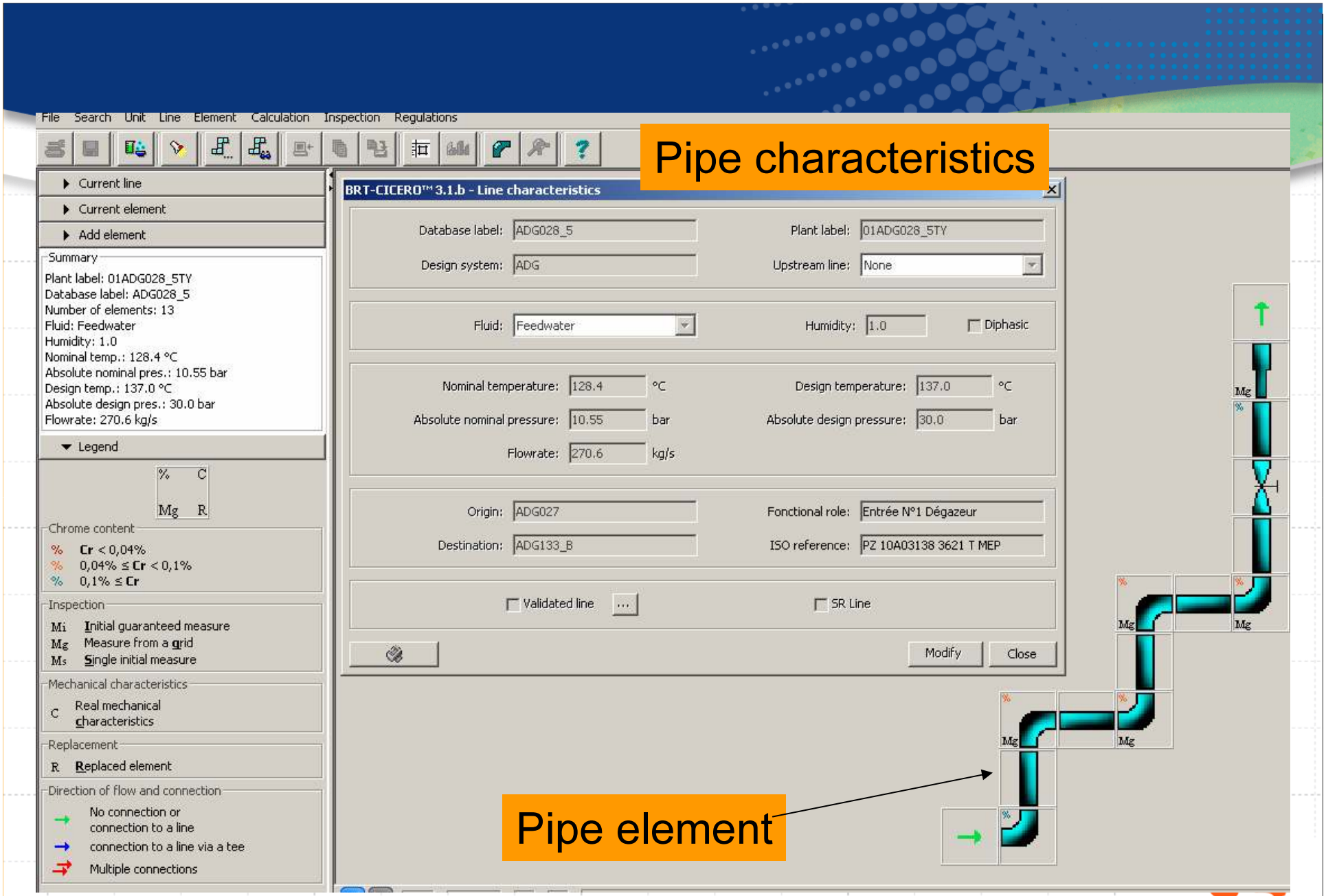


- HISTORY OF CHEMISTRY -

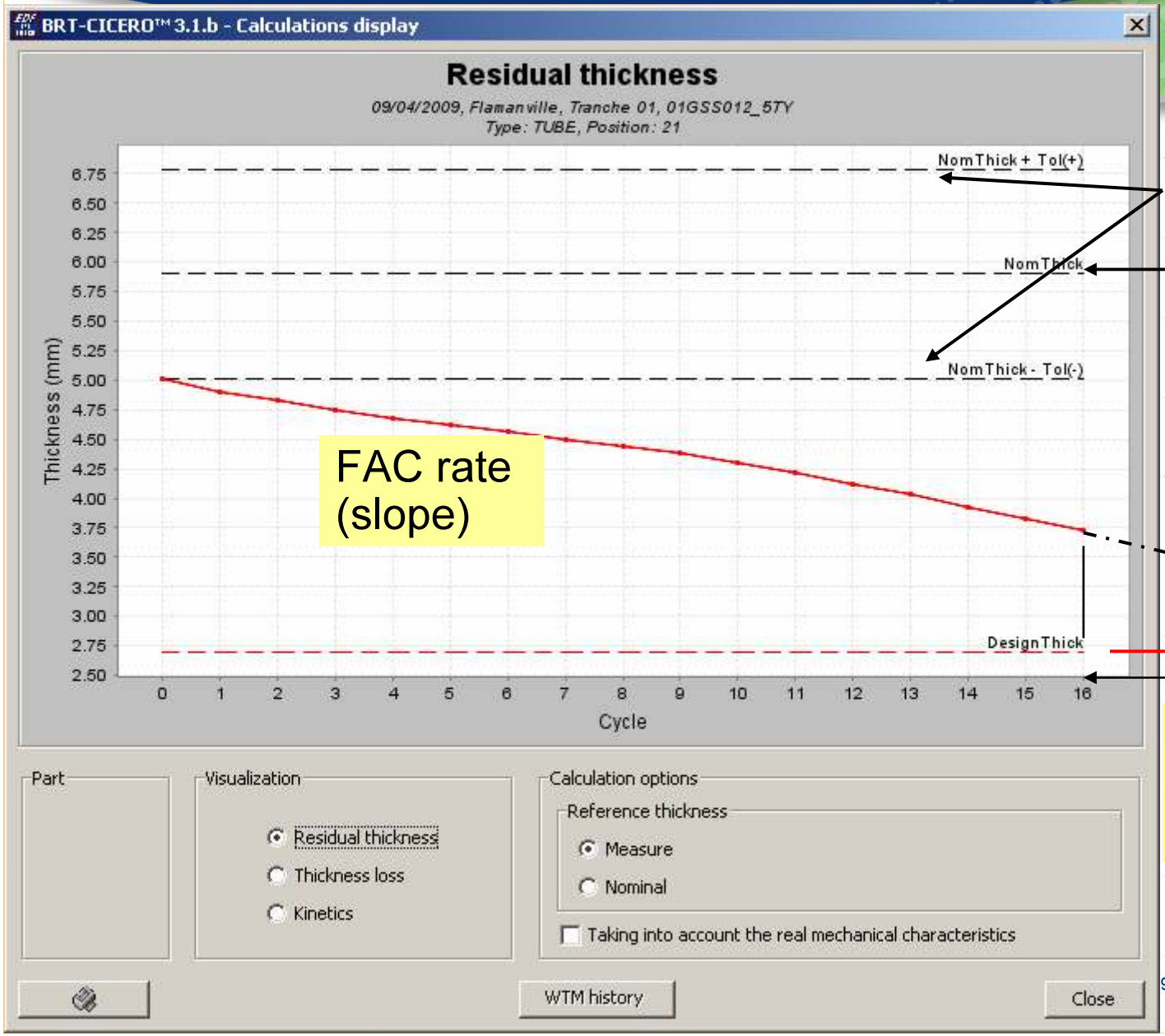
BRT-CICERO™ 3.1.a - Chemistries history display

Cycle nu...	Referenc...	Duration ...	Full pow...	Cycle sta...	Cycle en...	pH at 25°C	pH origin	Ammonia...	Morpholi...	Ethanola...	Hydrazin...	Acetate (...	Boric aci...	Formate ...	Glycolate...
1	RF01	7528	7528	01/05/1985	08/06/1986	9.573	Calculated	2.04			120				
2	RF02	7436	7436	11/07/1986	24/05/1987	9.602	Calculated	2.29			18				
3	RF03	7479	7479	24/06/1987	15/05/1988	9.687	Calculated	3.2			60				
4	RF04	8484	8484	17/06/1988	04/06/1989	9.73	Calculated	3.8			20				
5	RF05	9921	9921	14/07/1989	01/09/1990	9.75	Calculated	4.13			33				
6	RF06	9500	9500	05/10/1990	15/10/1991	9.789	Calculated	4.84			30				
7	RF07	10110	10110	30/11/1991	27/02/1993	9.894	Calculated	7.47			30				
8	RF08	9527	9527	04/04/1993	07/05/1994	9.822	Calculated	5.55			30				
9	RF09	10333	10333	20/06/1994	26/08/1995	9.856	Calculated	6.38			100				
10	RF010	9164	9164	09/10/1995	30/11/1996	9.9	Calculated	7.66			50				
11	RF011	12336	12336	01/01/1997	29/05/1998	9.904	Calculated	7.82			50				
12	RF012	12792	12792	14/08/1998	29/01/2000	9.95	Calculated	9.49			111				
13	RF013	13296	13296	24/02/2000	31/08/2001	9.956	Calculated	9.7			105				
14	RF014	13440	13440	28/09/2001	14/04/2003	9.96	Calculated	9.88			93				
15	RF015	12292	12292	18/05/2003	25/09/2004	9.99	Calculated	11.24			87				
16	RF016	11684	11684	28/10/2004	27/02/2006	9.95	Calculated	9.49			78				

Close

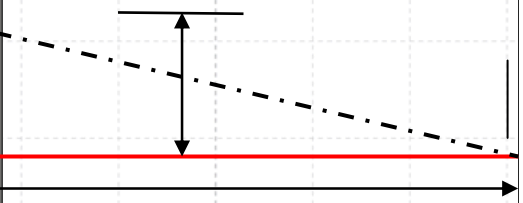

Pipe characteristics
File Search Unit Line Element Calculation Inspection Regulations
Current line
Current element
Add element
Summary
Plant label: 01ADG028_5TY
Database label: ADG028_5
Number of elements: 13
Fluid: Feedwater
Humidity: 1.0
Nominal temp.: 128.4 °C
Absolute nominal pres.: 10.55 bar
Design temp.: 137.0 °C
Absolute design pres.: 30.0 bar
Flowrate: 270.6 kg/s
Legend
% C
Mg R
Chrome content
% Cr < 0,04%
% 0,04% ≤ Cr < 0,1%
% 0,1% ≤ Cr
Inspection
Mi Initial guaranteed measure
Mg Measure from a grid
Ms Single initial measure
Mechanical characteristics
C Real mechanical characteristics
Replacement
R Replaced element
Direction of flow and connection
No connection or connection to a line
connection to a line via a tee
Multiple connections
BRT-CICERO™ 3.1.b - Line characteristics
Database label: ADG028_5
Plant label: 01ADG028_5TY
Design system: ADG
Upstream line: None
Fluid: Feedwater
Humidity: 1.0
Diphasic
Nominal temperature: 128.4 °C
Design temperature: 137.0 °C
Absolute nominal pressure: 10.55 bar
Absolute design pressure: 30.0 bar
Flowrate: 270.6 kg/s
Origin: ADG027
Fonctional role: Entrée N°1 Dégazeur
Destination: ADG133_B
ISO reference: PZ 10A03138 3621 T MEP
Validated line
SR Line
Modify
Close
Pipe element

- FAC RATE AND MARGIN CALCULATION-

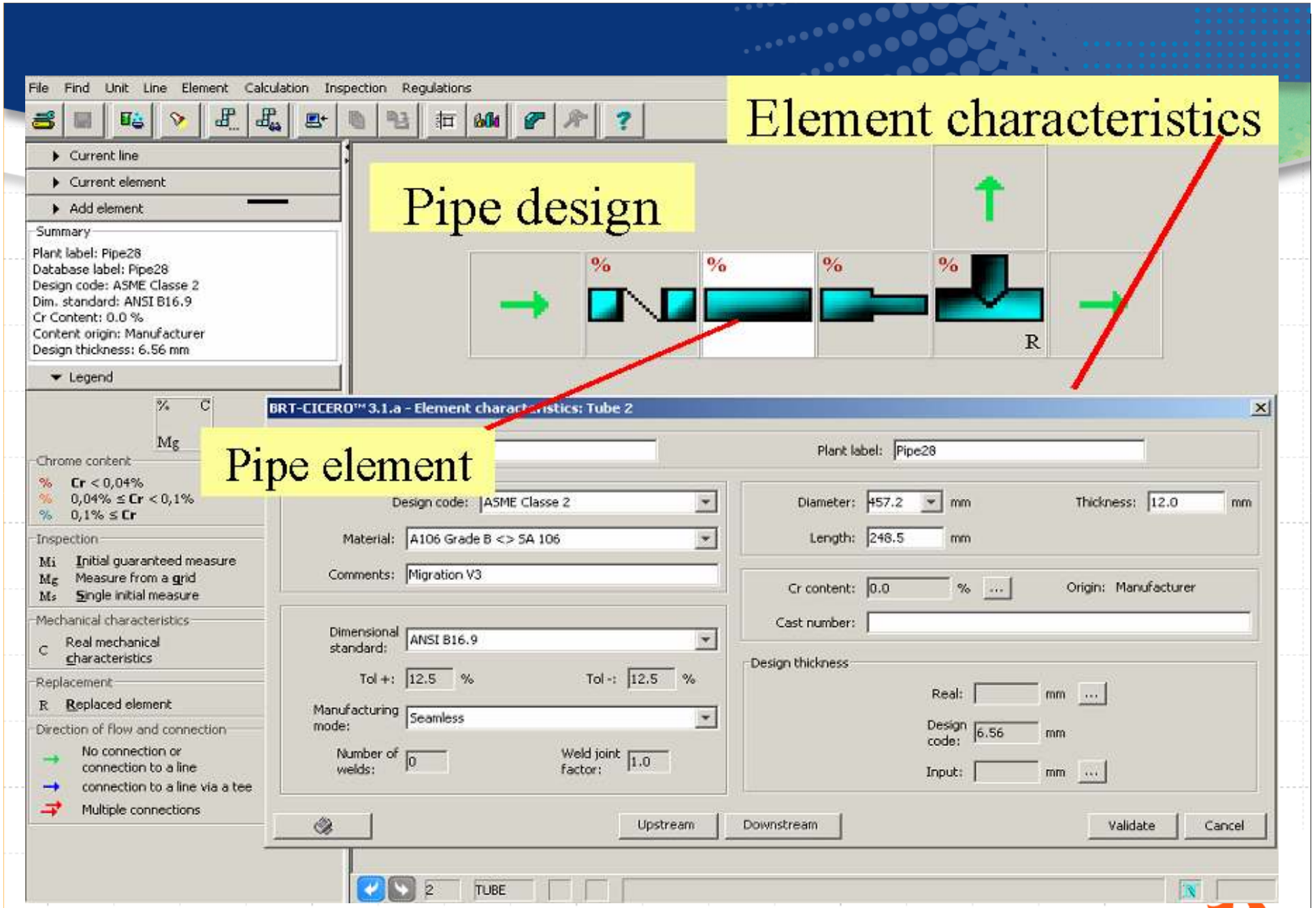


Manufacturing tolerances + and -

Nominal wall-Thickness (mm)



Margin to Design Thickness (mm) in cycles or hours


File Find Unit Line Element Calculation Inspection Regulations
Element characteristics
Current line
Current element
Add element
Summary
Plant label: Pipe28
Database label: Pipe28
Design code: ASME Classe 2
Dim. standard: ANSI B16.9
Cr Content: 0.0 %
Content origin: Manufacturer
Design thickness: 6.56 mm
Legend
Pipe design
%
%
%
%
R
Pipe element
BRT-CICERO™ 3.1.a - Element characteristics: Tube 2
Plant label: Pipe28
Design code: ASME Classe 2
Material: A106 Grade B <> SA 106
Comments: Migration V3
Diameter: 457.2 mm
Thickness: 12.0 mm
Length: 248.5 mm
Cr content: 0.0 %
Origin: Manufacturer
Cast number:
Dimensional standard: ANSI B16.9
Tol +: 12.5 %
Tol -: 12.5 %
Manufacturing mode: Seamless
Number of welds: 0
Weld joint factor: 1.0
Design thickness
Real: mm
Design code: 6.56 mm
Input: mm
Upstream
Downstream
Validate
Cancel
% C
Mg
Chrome content
% Cr < 0,04%
% 0,04% ≤ Cr < 0,1%
% 0,1% ≤ Cr
Inspection
Mi Initial guaranteed measure
Mg Measure from a grid
Ms Single initial measure
Mechanical characteristics
C Real mechanical characteristics
Replacement
R Replaced element
Direction of flow and connection
No connection or connection to a line
connection to a line via a tee
Multiple connections
2
TUBE

- TABLE OF MARGIN CALCULATION -

BRT-CICERO™ 3.1.a - Residual thickness prevision after inspection: 16 (RF016)

Additional time at the end of cycle: 0 hours

Cycle mean duration: 8000 hours

Line	Position	Type	Part	Element	Nominal...	Mini. manu...	Referen...	Ref. of reference...	Margin (mm)	Time (cycles)	Inspe...	Desig...	Ref. of ...	Kinetics ...
T1209	1	ELBO	Intrados	45Elbow80	8.00	7.00	7.00	Nominal	-1.30	--		5.09	Calculation	0.33
T1209	1	ELBO	Extrados	45Elbow80	8.00	7.00	7.00	Nominal	-1.30	--		5.09	Calculation	0.33
T1209	2	TUBE		Pipe81	8.00	7.00	6.79	WTM	1.32	5	15	5.09	Calculation	0.33
T1209	3	ELBO	Intrados	45Elbow82	8.00	7.00	3.64	WTM	-1.45	--	16	5.09	Calculation	0.23
T1209	3	ELBO	Extrados	45Elbow82	8.00	7.00	3.64	WTM	-1.45	--	16	5.09	Calculation	0.23
T1209	4	MAVALV		Valve83	10.00	8.75	8.75	Nominal	-3.43	--		5.09	Calculation	0.35
T1209	5	TUBE		Pipe84	10.00	8.75	7.68	WTM	2.20	8	15	5.09	Calculation	0.33
T1209	6	OLET		Tee85	10.00	8.75	8.75	Nominal	-4.20	--		5.09	Calculation	0.38
T1209	7	TUBE		Pipe86	10.00	8.75	8.75	Nominal	0.93	8		5.09	Calculation	0.13
T1209	8	ELBO	Intrados	90Elbow87	10.00	8.75	4.85	WTM	-0.24	--	16	5.09	Calculation	0.26
T1209	8	ELBO	Extrados	90Elbow87	10.00	8.75	4.85	WTM	-0.24	--	16	5.09	Calculation	0.26
T1209	9	TUBE		Pipe88	10.00	8.75	8.75	Nominal	-1.69	--		5.09	Calculation	0.26
T1209	10	ELBO	Intrados	90Elbow89	10.00	8.75	6.28	WTM	0.58	2	14	5.09	Calculation	0.26
T1209	10	ELBO	Extrados	90Elbow89	10.00	8.75	6.28	WTM	0.58	2	14	5.09	Calculation	0.26
T1209	11	ELBO	Intrados	45Elbow90	10.00	8.75	6.32	WTM	0.53	2	14	5.09	Calculation	0.30
T1209	11	ELBO	Extrados	45Elbow90	10.00	8.75	6.32	WTM	0.53	2	14	5.09	Calculation	0.30
T1209	12	TUBE		Pipe91	10.00	8.75	8.75	Nominal	-2.59	--		5.09	Calculation	0.30
T1209	13	ELBO	Intrados	45Elbow92	10.00	8.75	4.74	WTM	-0.35	--	16	5.09	Calculation	0.16
T1209	13	ELBO	Extrados	45Elbow92	10.00	8.75	4.74	WTM	-0.35	--	16	5.09	Calculation	0.16
T1209	14	TUBE		Pipe93	10.00	8.75	7.37	WTM	2.28	17	16	5.09	Calculation	0.16

Display options

- Standard uncertainty
- Conservative uncertainty
- Restriction to piping components
- Taking into account Tol-
- Underthick

Calculation options

Reference thickness

- Measure

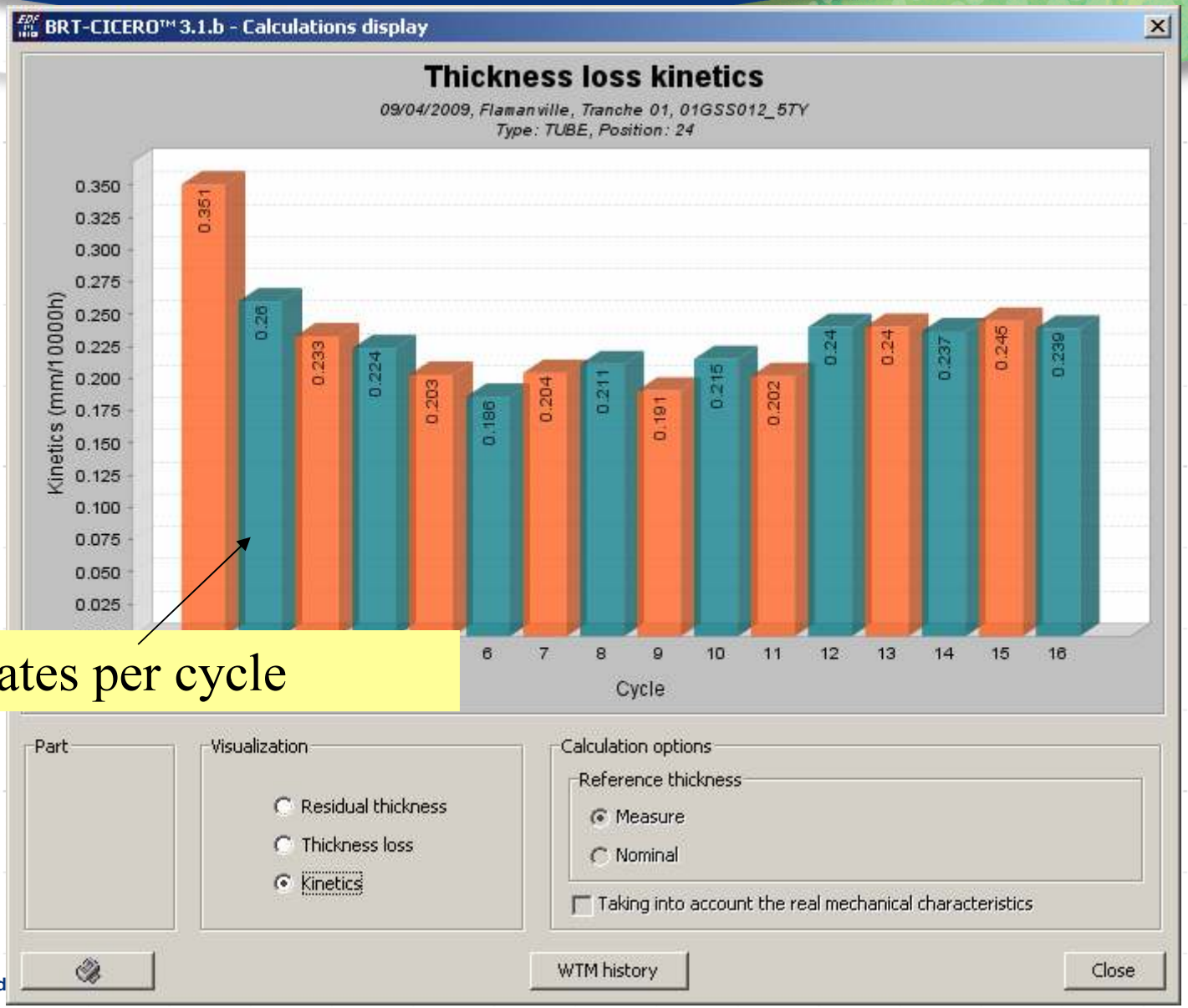
al mechanical characteristics

Close

Elements to be inspected

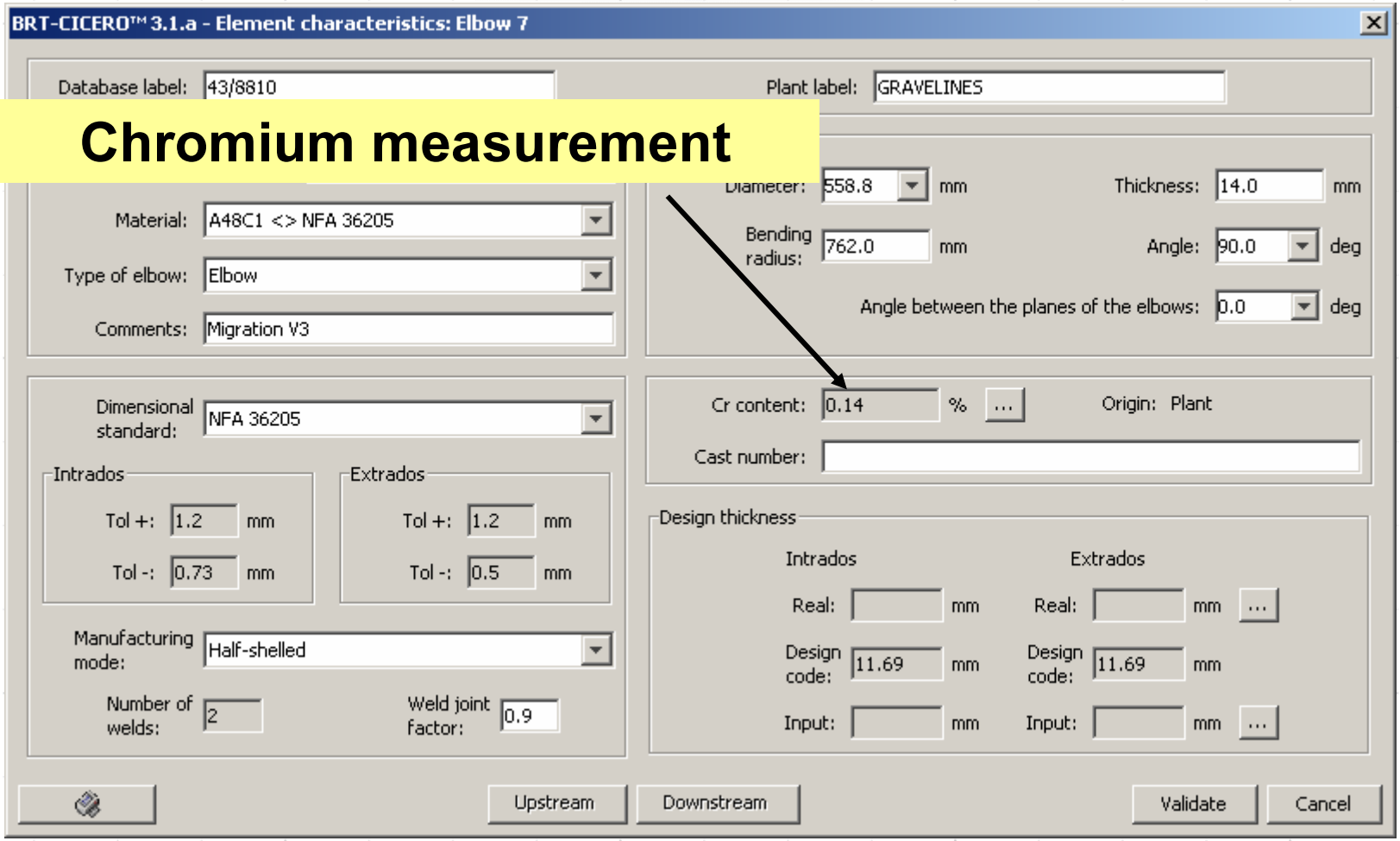
- **if margin < 0 mm**
- **If n° cycles < 1**

- FAC RATE AND MARGIN CALCULATION-

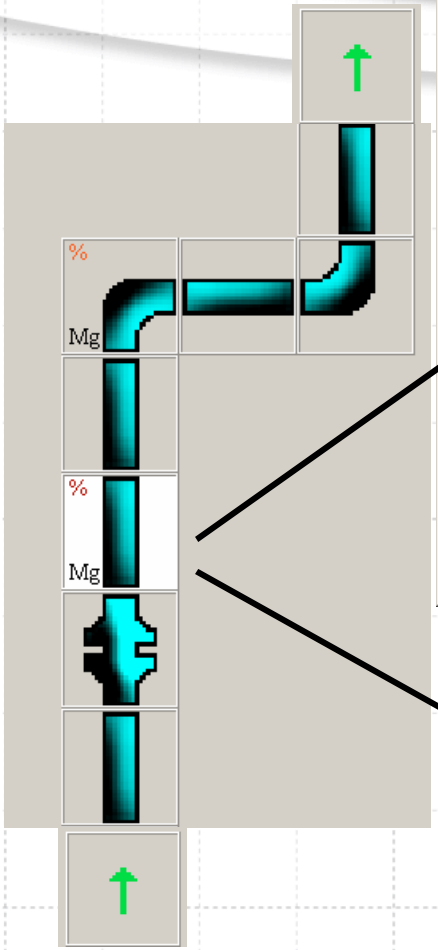


FAC rates per cycle

- INPUT OF CHROMIUM CONTENT -



- INPUT OF WALL THICKNESS MEASUREMENTS -



BRT-CICERO™ 3.1.b - Inspection measures visualization

Grid

Reference generator: A

Generator	1	2	3	4	5	6	7	8
A	5.5	5.4	3.9	3.8	4.1	4.6	4.2	4.3
B	5.8	5.4	4.4	4.0	4.0	4.0	4.3	4.1
C	5.8	4.9	4.2	4.0	3.8	4.3	4.0	4.0
D	xx	xx	3.9	3.4	3.8	3.7	3.8	3.9
E	4.2	3.9	3.1	3.5	3.5	3.7	3.8	4.0
F	xx	xx	3.9	3.7	3.6	4.1	4.9	4.5
G	xx	xx	4.0	3.8	3.8	4.3	4.1	4.2
H	4.5	4.9	3.9	3.8	3.6	3.9	4.1	4.5

Additional measures list

Points list	Min. value	Author	Date	Comment

Display options

Min. value Max. value UTH

Complementary informations

Nominal thickness: 5.9 mm Tol +: 15.0 % Tol -: 15.0 % Design thickness: 2.69 mm

Display WTM lines Modify Close

Line choice

All lines

B C A D H E G F

Measures distribution

Pitch Pitch d d d d upstream downstream

d: 30 Pitch: 60

All lines

09/04/2009, Flamanville, Tranche 01, 01GSS011_5TY
Inspection reference: VC 20/08, Gen reference: (A-H)x(1-8)
Type: TUBE, Position: 23

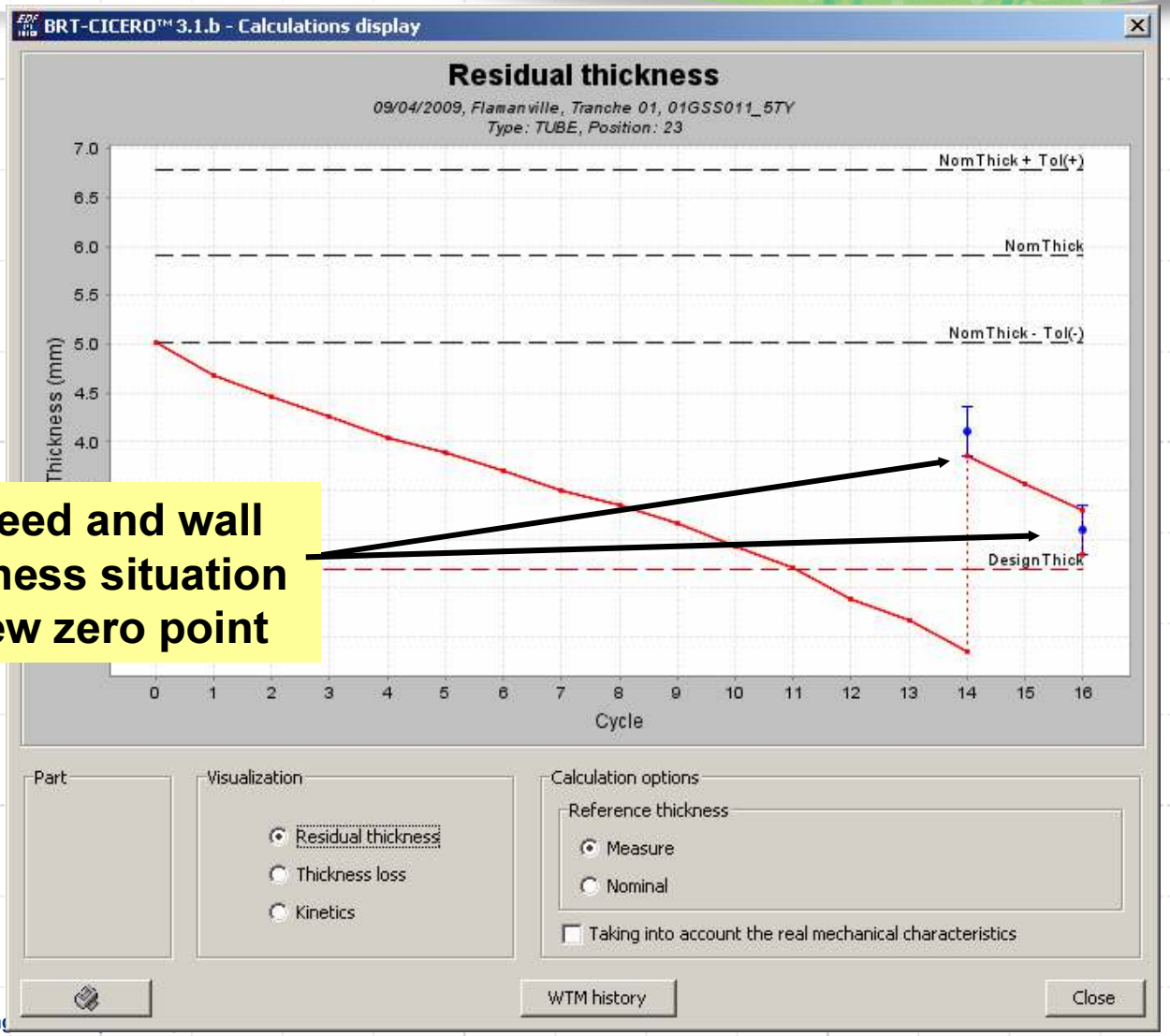
NomThick + Tol(+) + Abs.Unc.
NomThick
NomThick - Tol(-) - Abs.Unc.
DesignThick
Measure(mm)
Distance(mm)

Visualization

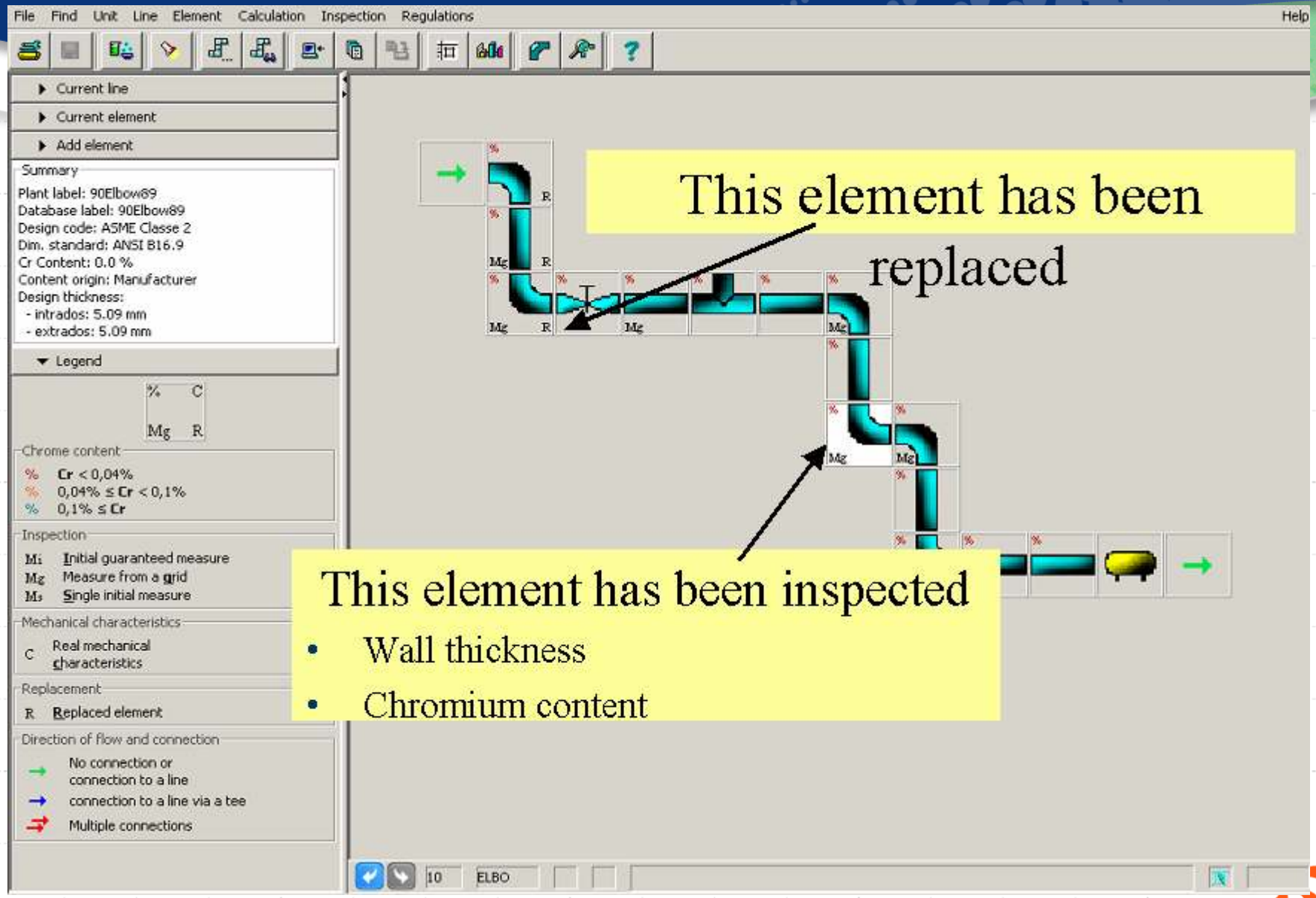
Design thickness Nominal thickness

Close

- INPUT OF INSPECTION DATA & MARGIN CALCULATION -



FAC speed and wall thickness situation at new zero point


File Find Unit Line Element Calculation Inspection Regulations Help
Current line
Current element
Add element
Summary
Plant label: 90Elbow89
Database label: 90Elbow89
Design code: ASME Classe 2
Dim. standard: ANSI B16.9
Cr Content: 0.0 %
Content origin: Manufacturer
Design thickness:
- intrados: 5.09 mm
- extrados: 5.09 mm
Legend
% C
Mg R
Chrome content
% Cr < 0,04%
% 0,04% ≤ Cr < 0,1%
% 0,1% ≤ Cr
Inspection
Mi Initial guaranteed measure
Mg Measure from a grid
M3 Single initial measure
Mechanical characteristics
C Real mechanical characteristics
Replacement
R Replaced element
Direction of flow and connection
No connection or connection to a line
connection to a line via a tee
Multiple connections
This element has been replaced
This element has been inspected
• Wall thickness
• Chromium content
10
ELBO

FEEDBACK

BRT-CICERO™ is :

- **In operation since mid 90's in France**
- **Mandatory for the 58 EDF PWR**

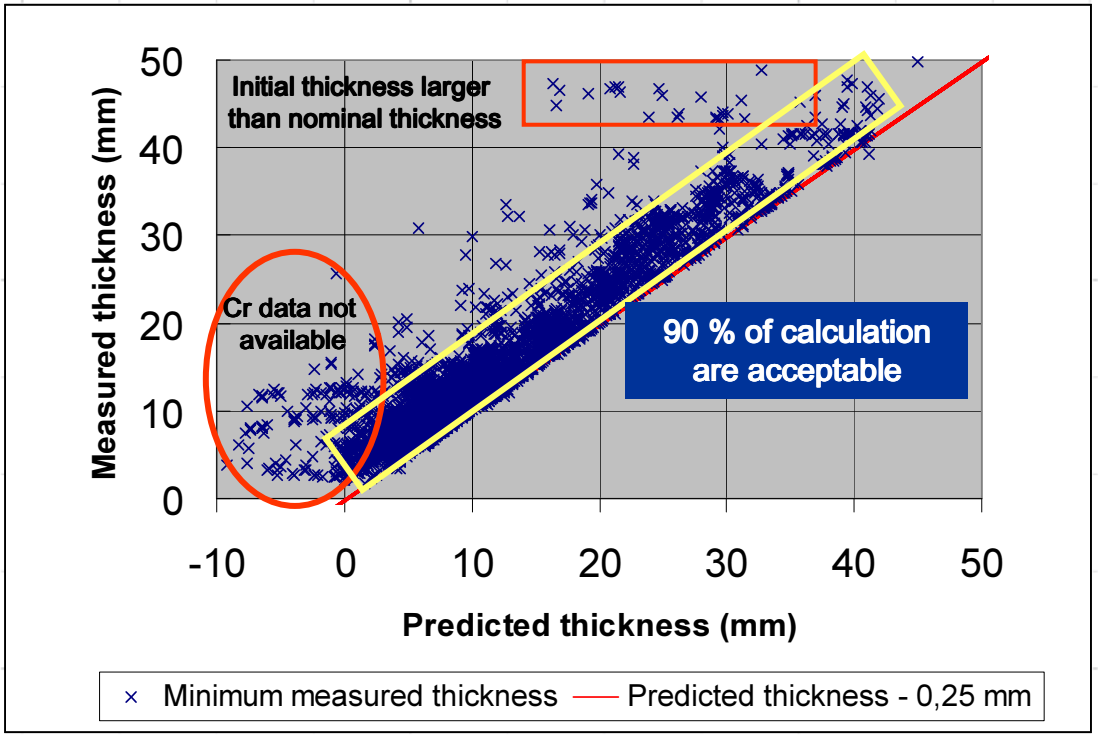
6300 pipe components were inspected by UT between 1980 and 2005

102 components found below wall design thickness and replaced

- **42 bends**
- **29 reducers**
- **31 tubes**

Only 11 cases of residual thickness underestimation (= 0,17 %)

Measured versus predicted thickness graph



A new feedback analysis is in progress for 2010

INSPECTION PROGRAM

Maintenance and inspections on critical components

- ✓ Based on BRT-CICERO™ calculations
- ✓ Wall thickness measurements by UT on defined grids
- ✓ Chromium measurements (XRF / documental analyses)
- ✓ Component replacements
- ✓ EDF develops and qualifies all necessary NDE procedures

GLOBAL BENEFITS & FEEDBACK

- ✓ Steam leak and pipe rupture prevention
- ✓ Optimisation of outage inspection programs (avoids systematic and unnecessary inspections)
- ✓ Long term maintenance strategy
- ✓ Cost benefits due to limited inspection volumes (no calibration measurements needed) – 20 to 100 components measured every second outages (~ 3000 € / component)
- ✓ Accepted by the French regulation authority, that authorizes to perform limited inspections based on BRT-CICERO™ predictions for regulated steam-water pipes

ADVANTAGES

- Turbine hall piping data in a single data base
- Identification of critical components, calculation of time to reach design thickness
- Thickness predictions are conservative (safe)
- Increased level of safety
- Optimised inspection programs
- Enables long term maintenance strategy
- No need to calibrate the model with prior UT inspections results. Minimum measured thickness only used as a new “zero” point
- No need to input the entire heat balance diagram
- Regularly updated : chromium, chemistry and geometrical effects, etc.
- Major skills on FAC are developed and maintained at EDF

LIMITS AND CONSTRAINTS

- Conservative assumptions must be made if some parameters are not available (operating times, flow rates, chromium contents, etc.)
- Needs to create a data base for each plant (~ 2 man.month if all data available for main FAC sensitive lines)
- Quality assurance must be spread out to guarantee the data validity (data input and control)
- Strong involvement of management needed

UNITS INVOLVED AT EDF INTO FAC MANAGEMENT

National Regulator

DARPMI
DGSNR
BCC-N

Nuclear Production Division
UNIE *(Operation Engineering)*

- Maintenance rules and strategy
- BRT-CICERO™ rules of use for CNPE
- Operation feedback treatment
- Relation with the National Regulator

Nuclear Production Division
UTO *(Mechanics & Repairs)*

- Spare parts management
- Mechanical calculations for under - thickness justifications

Nuclear Engineering Division
CEIDRE *(Chemistry, Metallurgical Analyses)*

- Specification of BRT -CICERO™ FAC algorithms
- Chemistry specifications for CNPE
- Laboratory analyses on damaged parts

EDF Users

Nuclear Production Division :CNPE
(Nuclear Centers of Electricity Production = NPP)

SIR *(Recognized Inspection Service)* in each NPP : h ave the delegation of the Regulator to control the NPP activity on regulated piping

900 MW : FES, BUG, BLA, DAM, GRA, TRI, CHB, CRU, SLB
1300 MW : PAL, FLA, SAL (« pilot » NPP), BEL, CAT, GOL, NOG, PEN
1450 MW : CHZB, CIV

Local Regulat or

DRIRE

R&D Division

- Parameter testing on the laboratory loop CIROCO

Contractors

- Scaffolding
- Insulation
- UT and Cr measurements

Nuclear Engineering Division
CNEN / CAO *(Software development and maintenance)*

- Development of BRT -CICERO™ Version 3
- Assistance to the users on Versions 2 and 3 for software problems
- Move to BRT -CICERO™ Version 3

General Technical Division
FAC Team

- FAC algorithms upgrade based on feedback data
- Lines modeling
- NDE methods qualification (TOFD for welds, DR, Chromium)
- Chromium measuremen ts
- Technical assistance and move to BRT -CICERO™ Version 3 for French and Foreign users (RSA, China)
- Studies and training sessions for Foreign customers (RSA, China, Japan, Belgium, UK)
- Participation to EPRI CHUG meetings
- FAC international conferences organ ization
- BRT-CICERO™ for fossil plants project

UFPI

- Training sessions for French users

THANK YOU FOR YOUR ATTENTION

For further information please contact :

Thomas KNOOK
EDF/DTG
+33 4 76 20 23 19
thomas.knook@edf.fr

Matthieu PERSOZ
EDF/DTG
+33 4 76 20 24 59
matthieu.persoz@edf.fr

Stéphane TREVIN
EDF/DTG
+33 4 76 20 24 99
stephane.trevin@edf.fr