Secondary Circuit Mapping of FAC and High Velocity -Two Phase Flow Mechanical Degradation Effects

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Contents

Overview: Operating N.P.Ps.

Atucha I – PVHWR – SIEMENS KWU - 1974

Embalse CANDU®600 PHWR- AECL-Cordoba-1984

Atucha II – PVHWR – SIEMENS KWU – Buenos Aires – In Construction

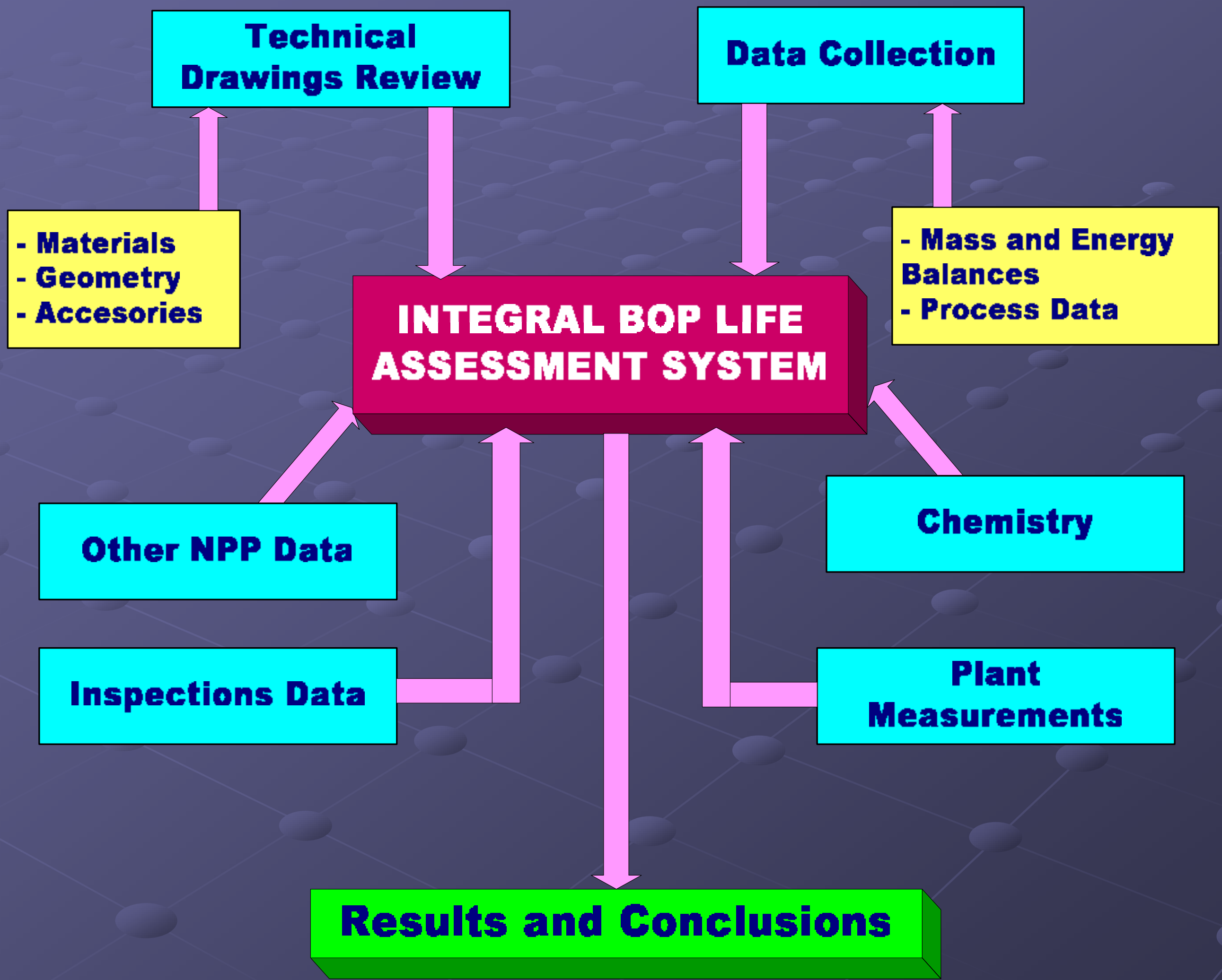
Objectives

- Since the start-up (1984) Embalse has been carrying out a program of ***Piping Thickness Inspection*** guided by measurement results

- Since 2004, with the start up of the ***PLiM/LTO Project***, an integrated program for FAC evaluation began to be developed in order to determine the wall thinning rate of the Secondary Circuit piping and components

- The Program has been developed by Embalse NPP engineering staff along with the Comision Nacional de Energia Atómica (National Atomic Energy Commision). It is documented in several international workshops and conferences.

Objectives


Technical Drawings Review
Data Collection
- Materials
- Geometry
- Accesories
- Mass and Energy Balances
- Process Data
INTEGRAL BOP LIFE ASSESSMENT SYSTEM
Other NPP Data
Chemistry
Inspections Data
Plant Measurements
Results and Conclusions

Evaluation of FAC

- Understanding the Flow Assisted Corrosion Degradation Mechanism and its related variables (hydrodynamics, chemistry, etc.), already acquainted after PHTS components.

$$m' = \frac{(S_w - C)}{(\frac{1}{k_d} + \frac{1}{k_m k_e})}$$

- ***Development of a Calculation Code*** to predict thinning rate in relevant steam/water cycle points based on FAC theory and assisted by CFD tools.
- ***Creation of a detailed Data Base*** for piping and accessories (dimensions, materials, process data, chemistry conditions, inspection data, etc.)
- ***Identification and Screening*** of components to be inspected, repaired or replaced (ISI optimization).

Evaluation of FAC

- **Examples of Data Bases**

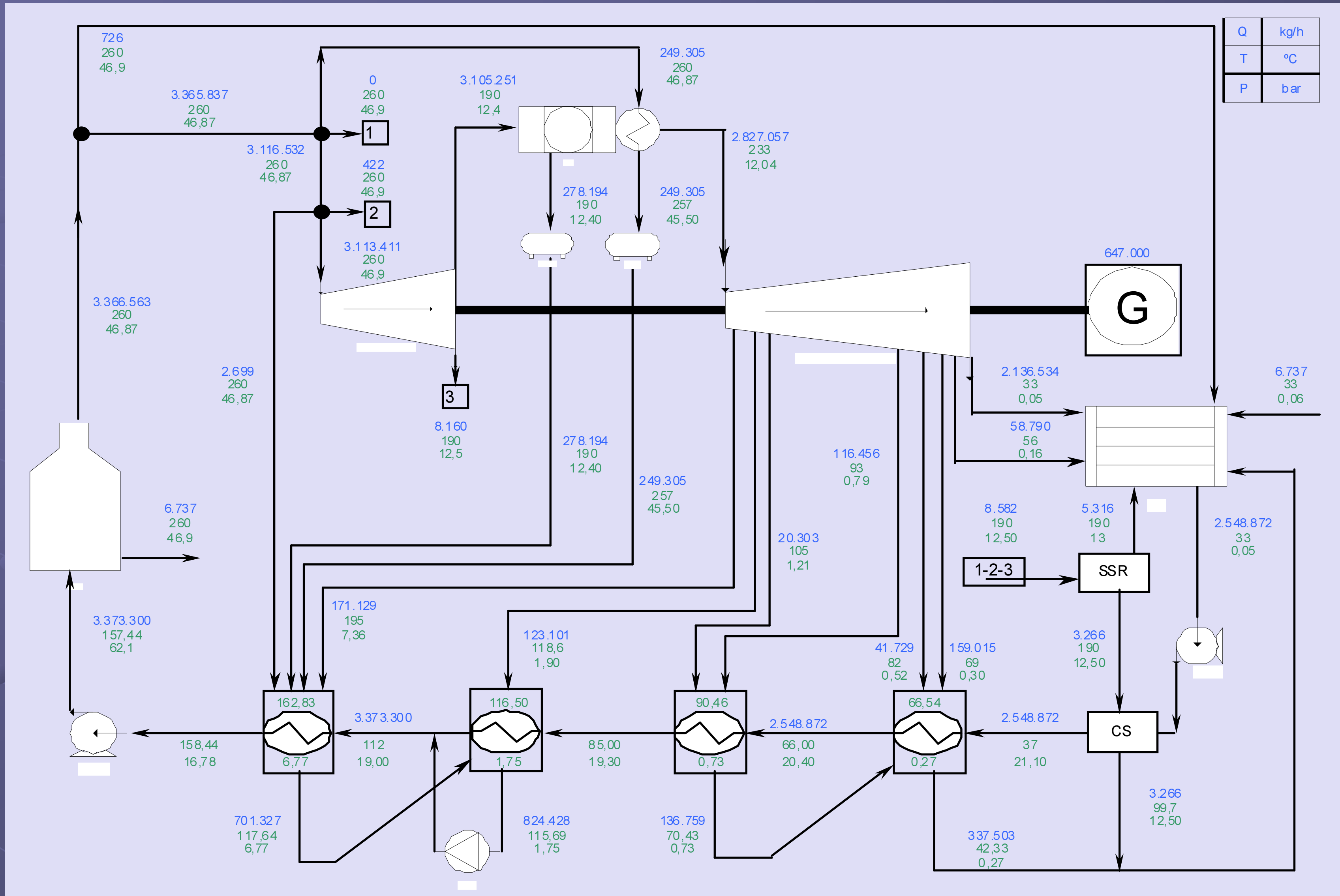
IDENTIFICACION			
Descripción	**Código BSI**	**Número de línea**	**Plano Isométrico**
Extracción de turbina BP A (VEX TBP) al precalentador E-102A - DN 600	43119	**0165**	43119-5004-01-DD
VEX TBP A a E-102A - DN 600	43119	0165	43119-5004-01-DD

MATERIAL Y DATOS GEOMETRICOS							
Material	**Composición**		σ (N/m2)	**De 1** (m)	**De 2** (m) (Sólo para reducciones)	**S** (m2)	**Sch**
	% Cr	% Mo					
A106B	0,03	0,03	1,031E+08	0,6096		0,2739	20
A234WPB	0,03	0,03	1,031E+08	0,6096		0,2739	20

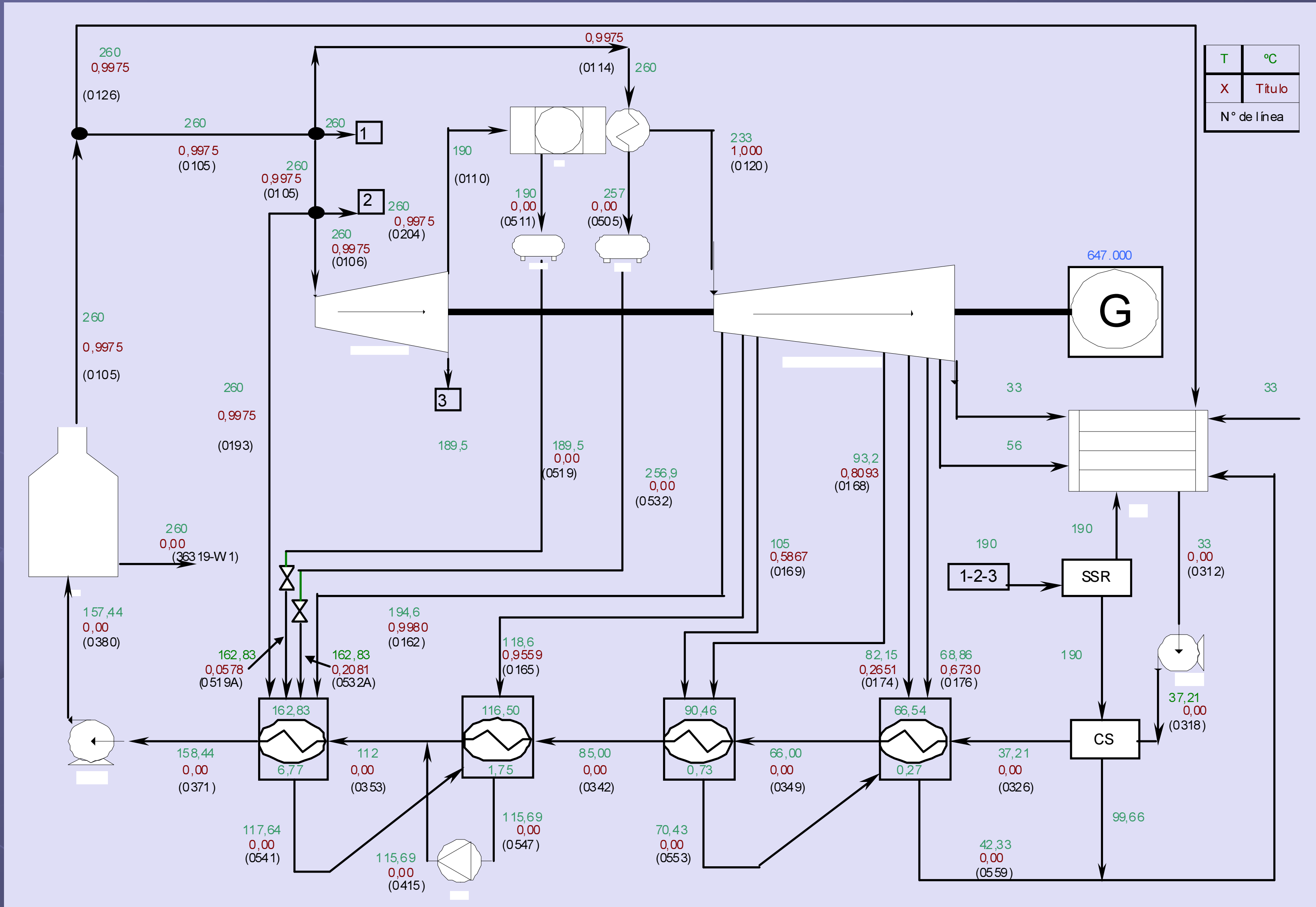
MATERIAL Y DATOS GEOMETRICOS							
e1 (m)	**e2** (m) (Sólo para reducciones)	**e calc** (m)	**e tf** (m)	**Di 1** (m)	**Di 2** (m) (Sólo para reducciones)	**L** (m)	**St** (m2)
0,0095		0,007	0,008	0,59056		0,46	0,853
0,0095		0,007	0,008	0,59056			2,664

DATOS TERMODINAMICOS Y PROPIEDADES					
Densidads Kg/m3	**Viscosidads** Kg/m seg	**Título** xs	**DFe(OH)2** m2/seg	**Sw** (ppb)	**Co** (ppb)
1,08	1,29E-05	0,9559	8,52E-09	20,200	1
1,08	1,29E-05	0,9559	8,52E-09	20,200	1

Data: Temperature, Pressure and Flow Rate



Data: Temperature and vapor fraction



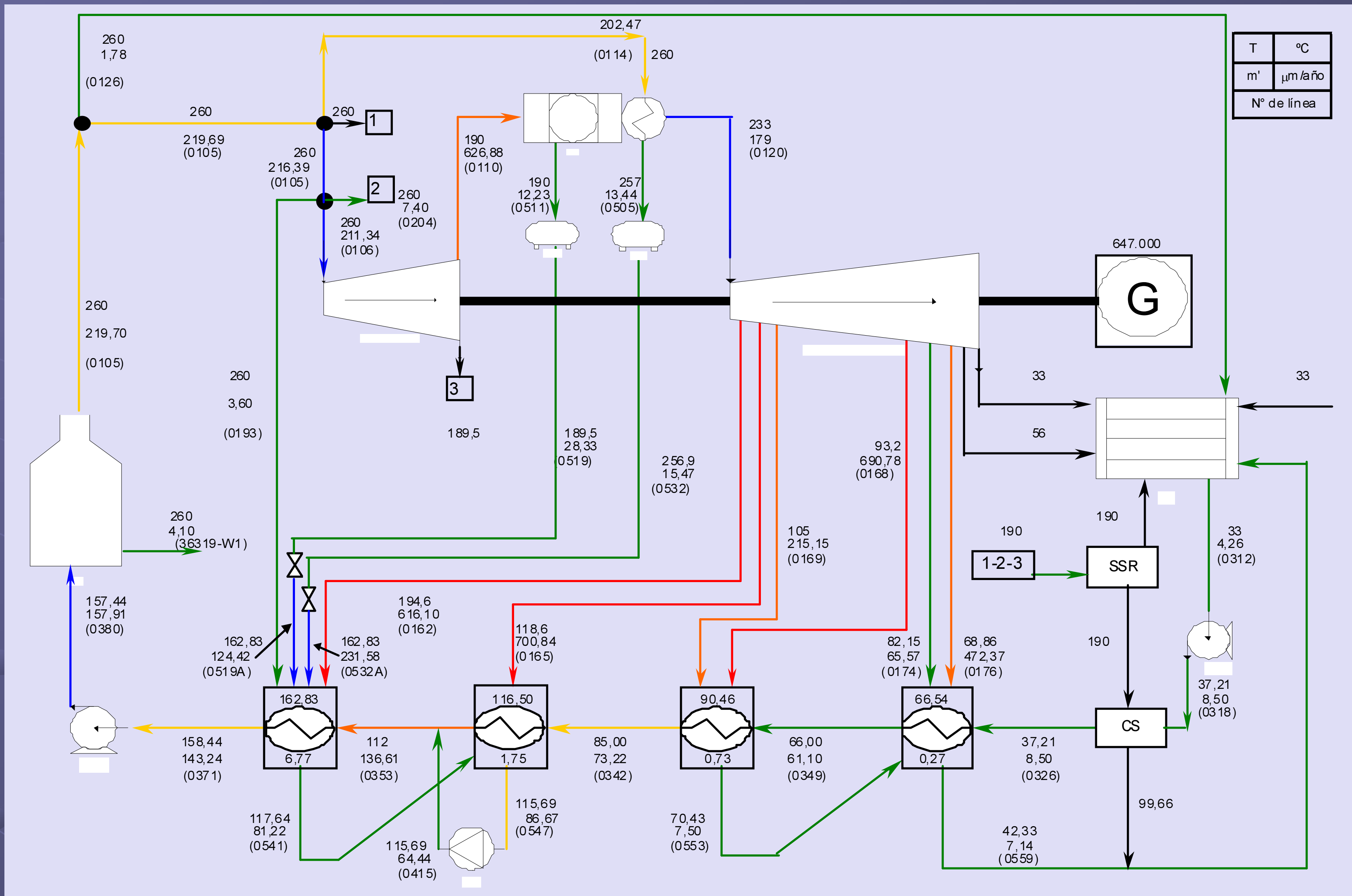
Evaluation of FAC

- As a result of the Integral BOP Life Assessment System, a wall ***thinning rate categorization*** is divided into five areas as shown in the following flow sheet:

  - Green lines (very low thinning rate)
  - Blue lines (low thinning rate)
  - Yellow lines (moderate thinning rate)
  - Orange lines (relevant thinning rate)
  - Red lines (high thinning rate)

This considers not only the predicted wall thinning rate but also the different manufacture thickness in their respective location

Evaluation of FAC: *Relative WTR due to FAC*



Mechanical degradation effects

- Under FAC conditions, mass transfer dominates while over a critical velocity-Two phase flow, the protective oxide is mechanically removed and even the base metal attacked.
- There are no theories at the macro level capable of predicting degradation as in the case of FAC.

It has been part of the BOP assessment program to ***develop a map*** for

1- Jet impingement

2- Cavitation-flashing

3- Dropplet erosion

Jet impingement

•Heat and mass transfer in turbulet jets extensively studied.

•Four zones can be distinguished: A-Laminar stagnation, B-High turbulence, C-Low turbulence and D-Turbulent Boundary layer as distance from jet increases.

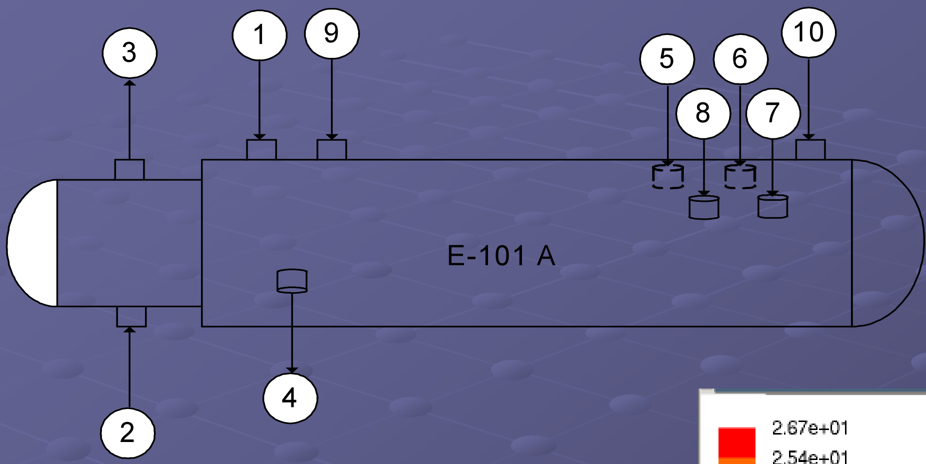
$$\Gamma_w = 0.179 \rho U_0^2 \mathrm{Re}^{-0.182} \left(\frac{r}{r_0}\right)^{-2.0}$$

•It can be related to FAC by shear stress analogy.

•However, CFD modeling helps with the location, extension and interpretation of damage.

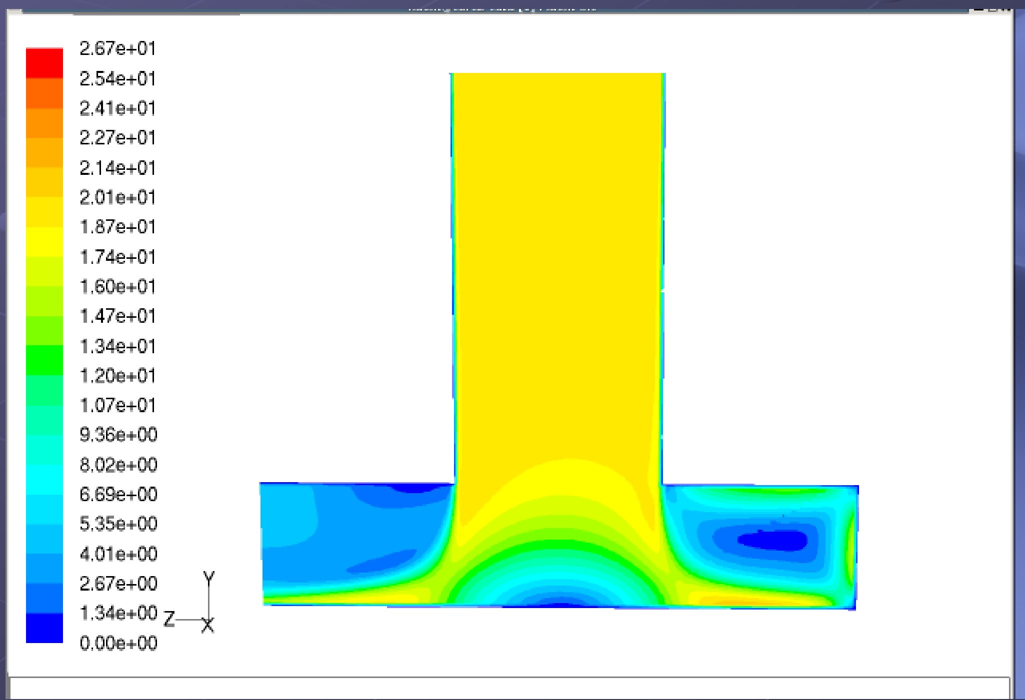
•Typical of Tees and Turbine extraction lines at preheater entrance shells.

Jet impingement



Preheater showing LPT extraction lines

CFD modeling at preheater entrance



Cavitation-flashing

•In cavitation, after a depression where the fluid approaches saturation, pressure is recovered and the bubbles implote creating a microjet that damages the surface

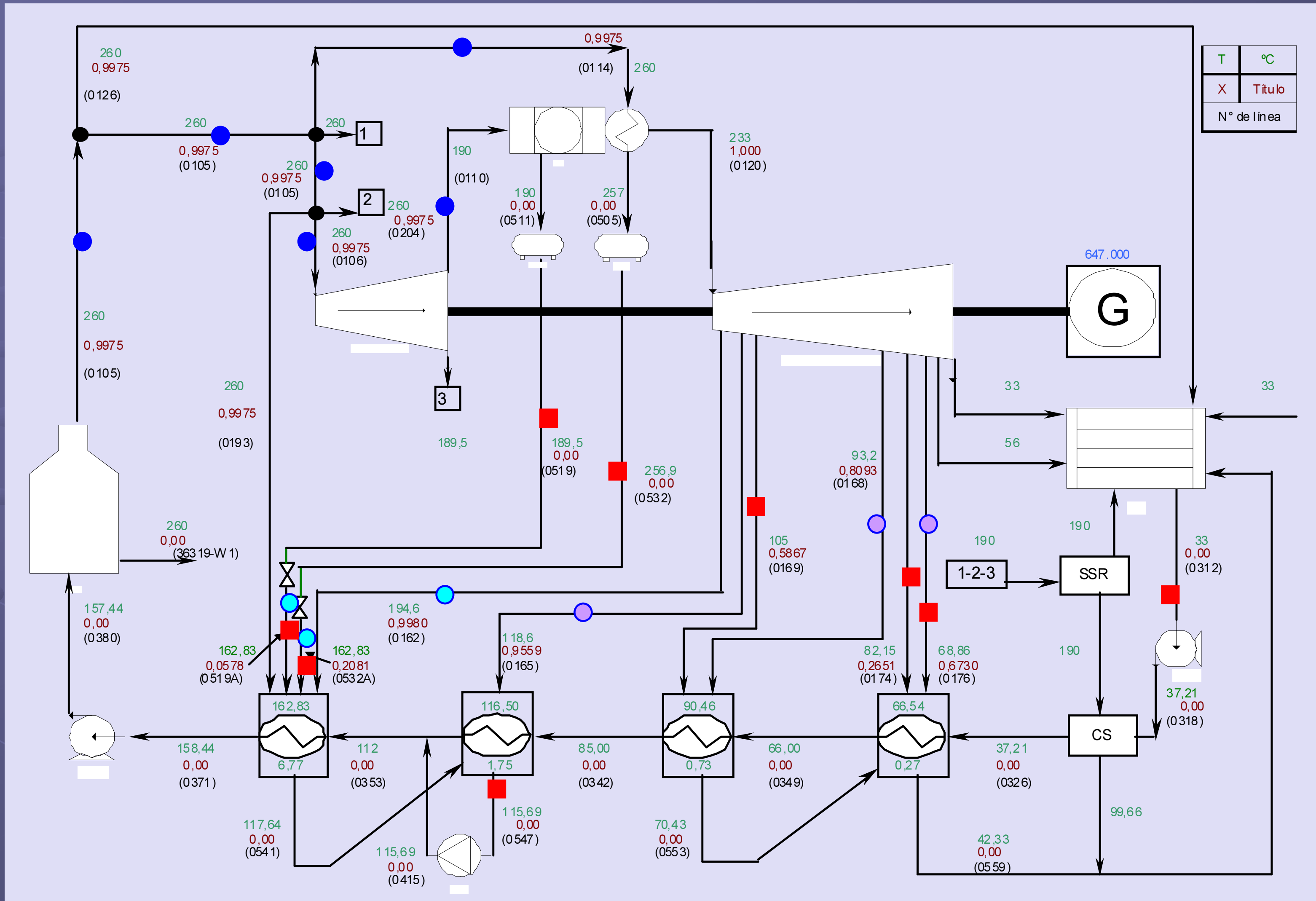
•In flashing, bubbles tend to remain eroding the surface

•While principles are well fundamented at microscale, a SC map can only be based on the, rather obvious, cavitation number as a potential of approaching bubble pressure.

$$K = \frac{(P_{\infty} - P_v)}{\frac{1}{2}\rho V^2}$$

K>>1	Subcooled liquid with low linear velocity and absolute pressure higher enough than saturation pressure at temperature.
K<0	Supersaturated steam.
K=0	Local steam quality must be analized. If saturated liquid, the creation of bubbles is feasible. With high steam quality, there is no posibility of cavitation.
K≈0	High posibility of cavitation-flashing is expected at those locations.

Cavitation-flashing



Cavitation-flashing expected zones (red symbols)

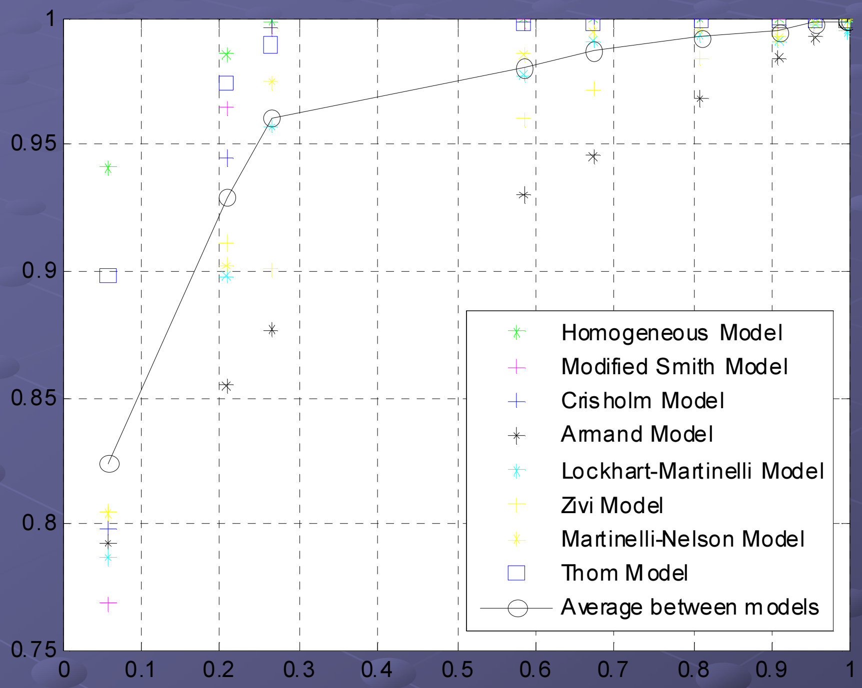
Dropplet erosion

•Depends on the flow, velocity, temperature, base metal and water chemistry (pH and ECP).

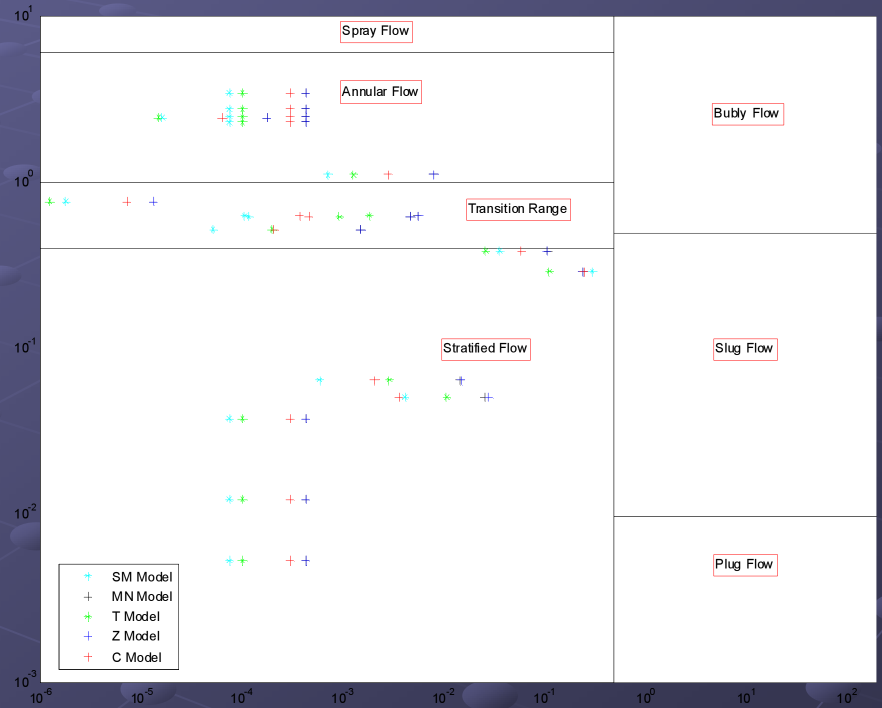
•In SCs of NPPs, dropplet erosion prone zones are those of straight pipes with annular flow or dropplet dispersed flow close to accesories (elbows, tees) where liquid phase impacts the walls.

•Therefore, effort has been devoted to better prediction of void fraction-TPF zones with ***annular flow by comparison among several correlations*** considering angles (Tandon, Baker and Taitel-Dukler for horizontal flow and Hewitt-Roberts for vertical flow).

Dropplet erosion

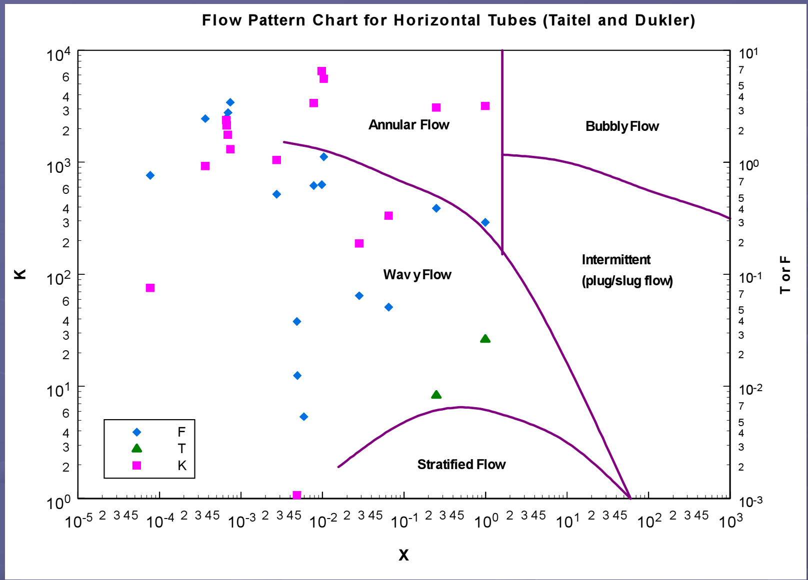


Predicted void fraction after several models



Predicted flow regime after Tandon Map for horizontal flow

Dropplet erosion



Predicted flow regime after Taitel-Dukler Map for horizontal flow

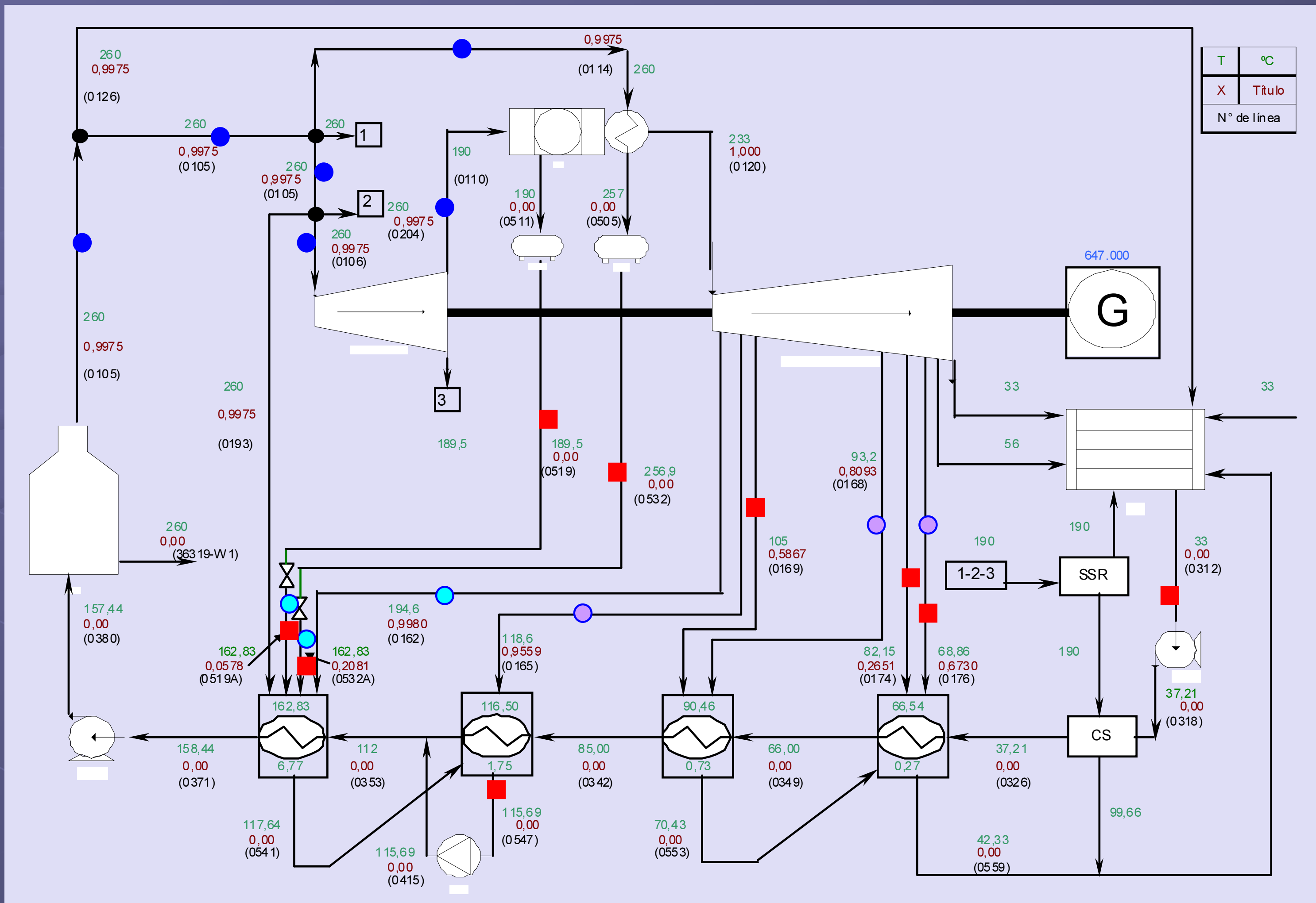
Annular flow prediction and comparison after several models

Table VI

Line Tag	T (°C)	P (bar)	x	W (Kg/s)	Taitel	Tandon SM	Tandon MN	Tandon T	Tandon Z	Tandon C	Baker	H-R (Vertical)
120	233	12	1	130.882								
162	194.6	7.36	0.998	15.845	*	*	*	*	*	*		*
105	260	46.9	0.998	935.156	*	*	*	*	*	*	*	*
105	260	46.9	0.998	934.955	*	*	*	*	*	*	*	*
126	260	46.9	0.998	0.202								
114	260	46.9	0.998	34.626	*	*	*	*	*	*	*	*
105	260	46.9	0.998	865.703	*	*	*	*	*	*	*	*
204	260	46.9	0.998	0.117								
106	260	46.9	0.998	216.21	*	*	*	*	*	*	*	*
193	260	46.9	0.998	0.25								
165	118.6	1.9	0.956	11.398								*
110	189.5	12.4	0.91	215.642	*	*	*	*	*	*	*	*
168	93.2	0.79	0.809	10.783								*
176	68.86	0.3	0.673	14.724								*
169	105	1.21	0.587	1.88								
174	82.15	0.52	0.265	3.864								
0532 A	162.8	6.77	0.208	11.542	*						*	*
0519 A	162.8	6.77	0.058	12.879	*						*	*

SM: Modified Smith; **MN**: Martinelli-Nelson; **Z**: Zivi; **C**: Crisholm; **T**: Thom; **H-R**: Hewitt-Roberts

Cavitation-flashing



Annular flow-Dropplet erosion according to different models (circles)

Monitoring Results

- ***Turbine extraction lines*** (TBP-A) and ***drainage lines*** during 2005 Outage. Regions with localized degradation (8 out of 21 measured areas show a localized degradation > 30%) have been found in the extractions of the TBP-A toward the preheater E-104A.

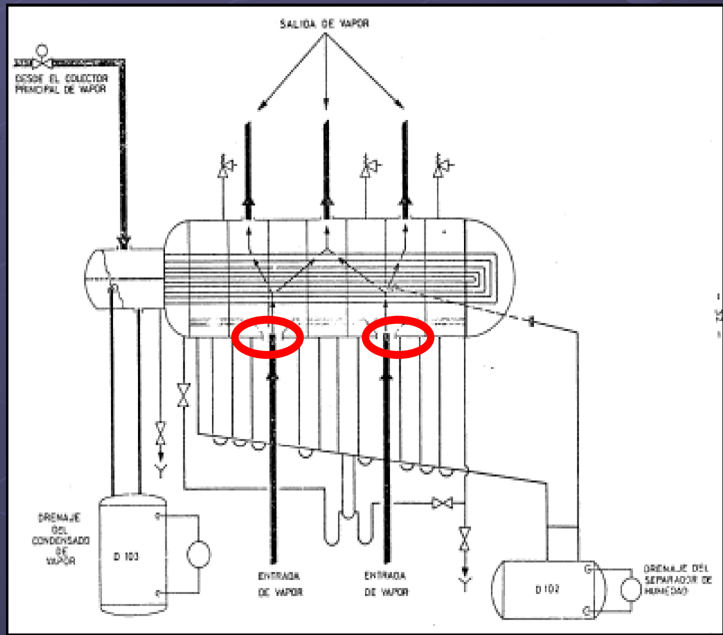
  The highest wall thinning has been observed in the areas of the straight pipe toward the preheater, adjacent to 45º elbow.

- ***Turbine extraction lines*** TBP-A/C during 2007 outage: regions with localized degradation (13 out of 20 measured areas have shown localized degradation > 30 %) have been found in the extractions of the TBP-A/C toward E-104-A/C preheaters., again close to 45º elbows.

Monitoring Results

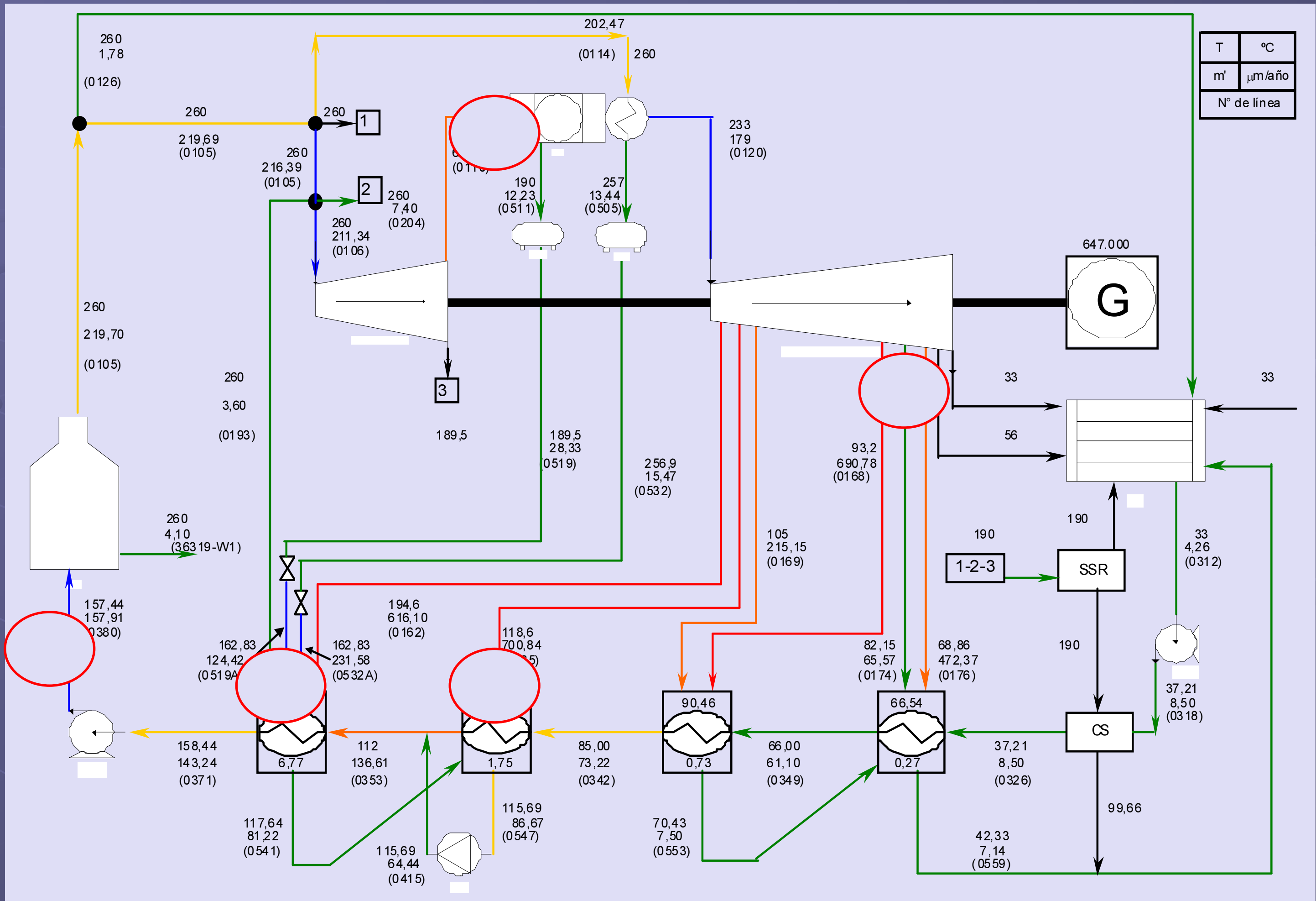
•Wall thickness measurements of CS high pressure preheater shells (E-101/102) to obtain information about the equipment status.

•Extension of piping thickness measurements in SGs feedwater lines during 2007 outage: given that in 2006 a break ocurred in other NPP, downstream of a flow element, the plant decided to extend program considering new 45 critical zones. Only 4 (90o elbows) have shown wall thinning > 12.5 % but < 30 % referred to nominal thickness.



•Moisture Separator Reheater entrance pipe.

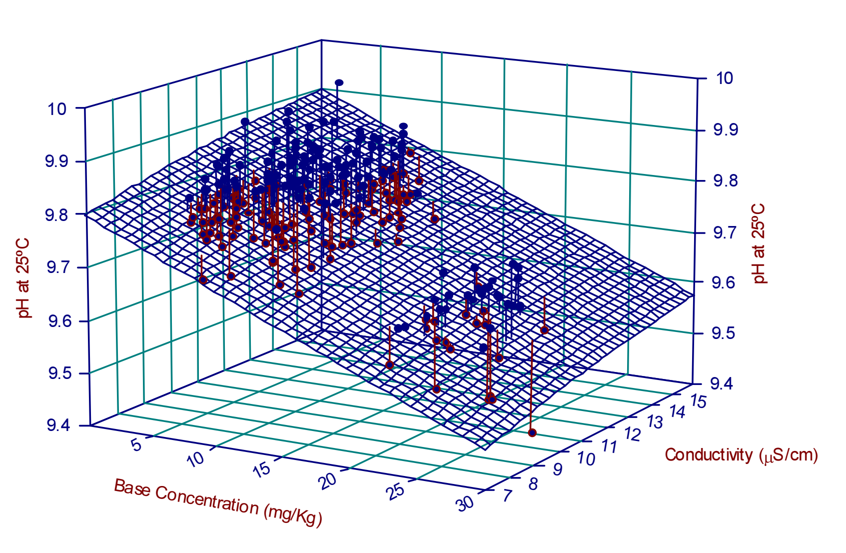
Monitoring Results

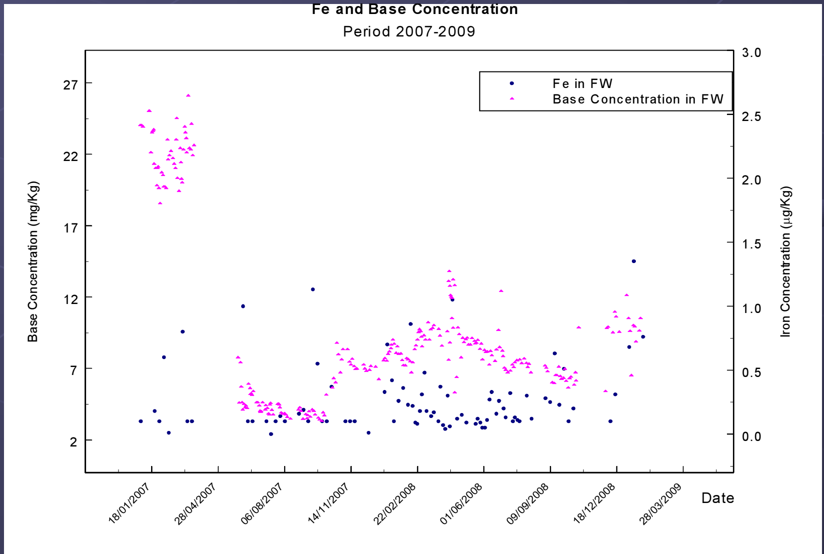


New specifically inspected zones

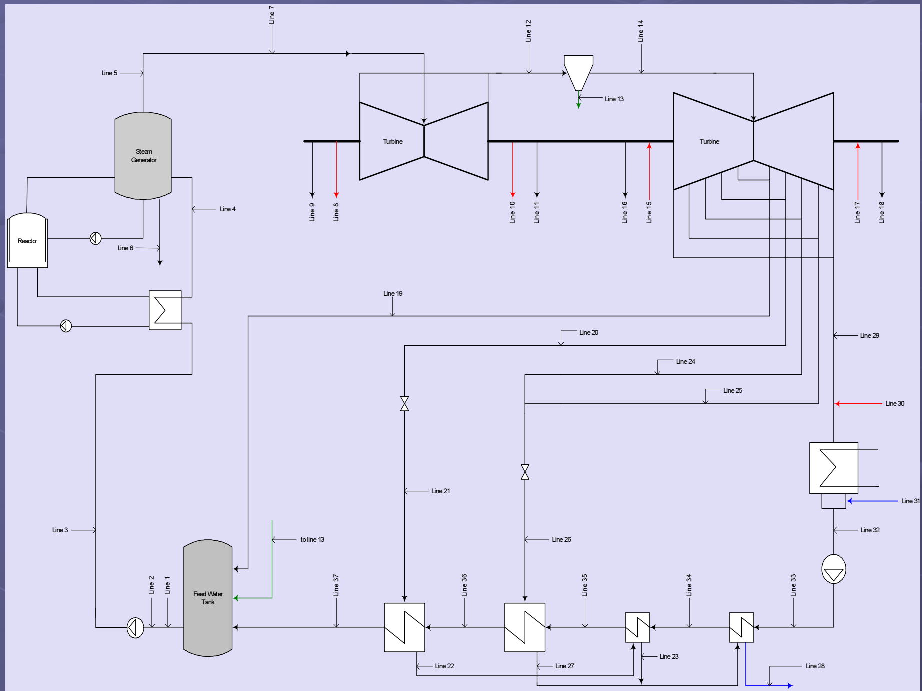
Water Chemistry Improvements

- pH has been gradually augmented with eventual replacement of Morpholine by ETA
- Highly beneficial impact on reduction of Fe transport along the circuit has been observed





Water Chemistry-Atucha II



Power	744.7/693 Mwe
Cycle water	Demineralized water
Thermal power	986,35 MW x 2 = 1972,7 MW
No of tubes in the SGs	6524 x 2 = 13.048
Tube material and dimensions	Incolloy 800/18 x 1 mm
TSPs	DIN 1-4550
U-bend	Incolloy 800
TP cladding	DIN 1-4550
Inlet and outlet SGs temperature	313,8/277,5 oC
Temperature and quality of steam	271,0 oC/54,9 bar/0,9975
Nº of Moderator HXs	4
Thermal power	50,7 x 4 = 202,8 MW
No of tubes	1065 x 4 = 4260
Material and dimensions	12 x 1 mm Incolloy 800
TSPs	DIN 1-4550
TP cladding	DIN 1-4550
Inlet and outlet Moderator HX	194,2/140,0 oC
FW train	St 37-0
Low pressure preheaters	AISI 316 L
High pressure preheaters	AISI 316 L
FW tank temperature	121 oC
Condenser tubing	AISI 316 L
Nº of tubes and dimensions	2 x 35.358 = 70.716 / 21 x 0,7 x 15239
Material	AISI 316 L
Gases extraction box	AISI 316 L
Chemistry	High AVT

Water Chemistry-Atucha II

Feed Water

Control Parameters	Normal Operation Values	Action Level 1	Action Level 2	Action Level 3
pH a 25ºC	> 9.8	< 9.8	---	---
Cationic Conductivity [µS/cm][1)]	< 0.15	> 0.2	---	---
Oxygen [mg/Kg]	< 0.005	> 0.005	> 0.02 [2)]	> 0.1

(1) Caused by only strong anions; organics and CO_2 are not to be considered.
(2) Power reduction is not required.

Diagnostic Parameters	Normal Operating Values
Hydrazine [mg/Kg]	> 0.02
Specific Conductivity [µS/cm]	< 15.0
Ammonia [mg/Kg]	10.0 - 12.0

Complementary Parameters	Normal Operating Values
Iron [mg/Kg]	< 0.001

Feed water specifications

Steam Generator Blowdown

Control Parameters	Normal Operation Values	Action Level 1	Action Level 2	Action Level 3
Cation Conductivity [µS/cm][1)]	< 0.2	> 1.0	> 2.0	> 7.0
Sodium [mg/Kg]	< 0.005	> 0.05	> 0.1	> 0.5

1) Caused by only strong anions; organics and CO_2 are not to be considered.

Diagnostic Parameters	Normal Operating Values
pH at 25ºC	> 9.6
Chlorides (Cl^-) [mg/Kg]	< 0.01
Sulphates ($SO_4^=$) [mg/Kg]	< 0.01
Ammonia [mg/Kg]	< 1,5

Complementary Parameters	Normal Operating Values
Iron [mg/Kg]	< 0.005
SiO_2 [mg/Kg]	< 0.1

Steam Generator specifications

Acknowledgements

• The IAEA is gratefully acknowledged for the support given through the Projects RLA 4021 and 4091

Thank you for your attention!

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