Flow Assisted Corrosion
Integral Assessment System and Monitoring at Embalse Nuclear Power Plant

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NUCLEOELÉCTRICA ARGENTINA S.A.

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Introduction

- Embalse is a CANDU® 600 NPP located in Córdoba, Argentina
- Designed and built by AECL and operated by NA-SA (Nucleoeléctrica Argentina S.A.)
- Started commercial operation in 1984
- 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

Introduction

- The Program has been developed by Embalse NPP engineering staff along with the National Atomic Energy Commission (Comisión Nacional de Energía Atómica-CNEA). It has been documented in the following international workshops/conferences:

- IAEA Second International Symposium on Nuclear Power Plant Life Management. Shanghai, China. October 15-18, 2007.
- IAEA National Training Course on CANDU Issues on Ageing Management. Embalse, Argentina. April 16-19, 2007.
- IAEA Regional Workshop on Optimization of Service Life of Operating NPPs. Angra Dos Reis, Brazil. May 14-17, 2007.

Introduction

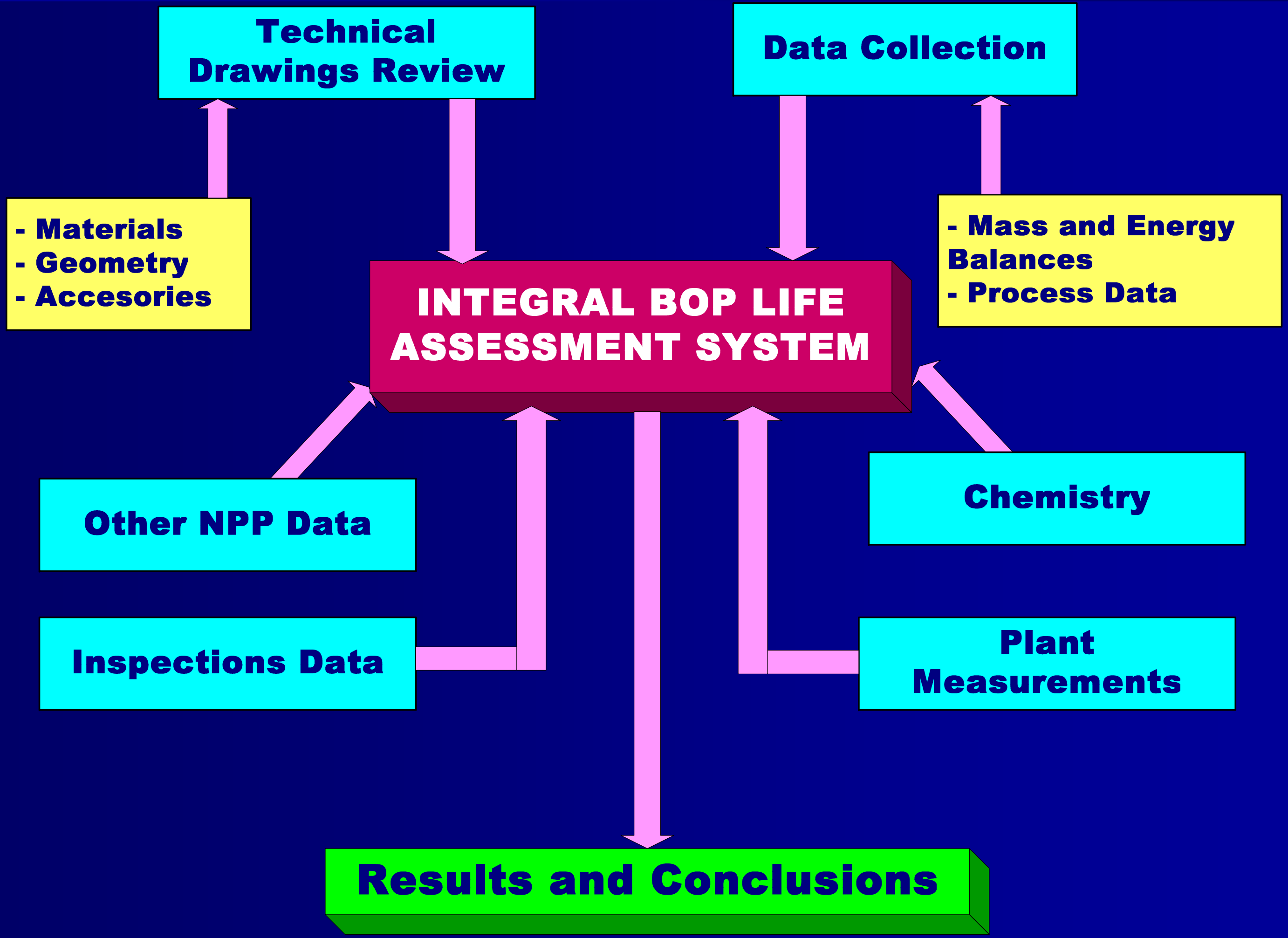
- Twenty-Third Annual Meeting. Argentine Association of Nuclear Technology (Asociación Argentina de Tecnología Nuclear). Buenos Aires, Argentina. November 2006.

- NA-SA/CNEA contracts have come to an end and they are related to “Life Management of Embalse NPP Secondary Circuit. Flow Assisted Corrosion Analysis”:
  - ✓ CP-E 13/04 (Part I)
  - ✓ CP-E 05/06 (Part II)

Objectives

- Understanding the Flow Assisted Corrosion Degradation Mechanism and its related variables (hydrodynamics, chemistry, etc.)
- Development of a Calculation Code to predict thinning rate in relevant steam/water cycle points
- 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

Diagram of BOP Life Assessment System
Related Variables



Examples of Data Base and Calculations for a Low Pressure Turbine Extraction Line

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

IDENTIFICACION

Accesorio	Descripción-Ubicación	Radio de curvatura (m)	Angulo (0-45-90-180)	Código Factor de Keller
Caño	(H). 24". Después de la válv.neumática PV 2#2. Tiene el SO165/2.		0	1
Codo	24". Después de la PV 2#2.	0,914	90	7

Examples of Data Base and Calculations for a Low Pressure Turbine Extraction Line

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

Examples of Data Base and Calculations for a Low Pressure Turbine Extraction Line

DATOS TERMODINAMICOS Y PROPIEDADES					
T ºC	**P** bar	**T Proyecto** ºC	**P Proyecto** bar	**Densidadf** Kg/m3	**Viscosidadf** Kg/m seg
118,6	1,9	139	17	944,2	2,35E-04
118,6	1,9	139	17	944,2	2,35E-04

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

Examples of Data Base and Calculations for a Low Pressure Turbine Extraction Line

CALCULOS DE FLUJO BIFASICO

W Kg/seg	Fracción de vacío α	Vs m/seg	Vf m/seg	Ref	Scf	Kd kg/m2 s	Kmf m/seg	Kk
11,398	0,999947231	36,97	36,83	8,74E+07	29,22	7,77	2,66E-02	1,00
11,398	0,999947231	36,97	36,83	8,74E+07	29,22	7,77	2,66E-02	7,50

PARAMETROS QUIMICOS

O2 ppb	Base M(1)-E(2)-A(3)	Morfolina ppm	NH3 ppm	NH4 ppb	pHamb	pHT	pHT neutro
0,00017	1	29,6	0,0689	1	9,5	7,62	6
0,00017	1	29,6	0,0689	1	9,5	7,62	6

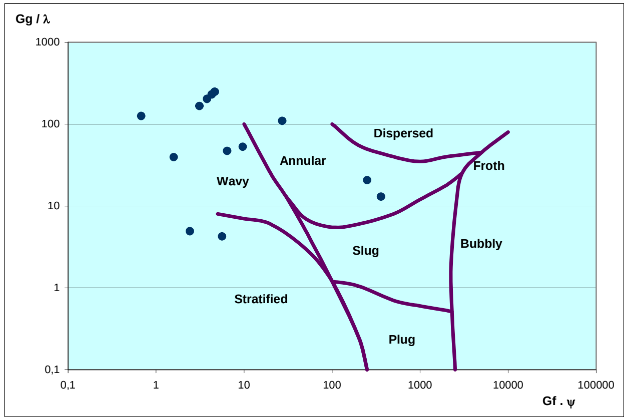
MODELO SEMI-TEÓRICO

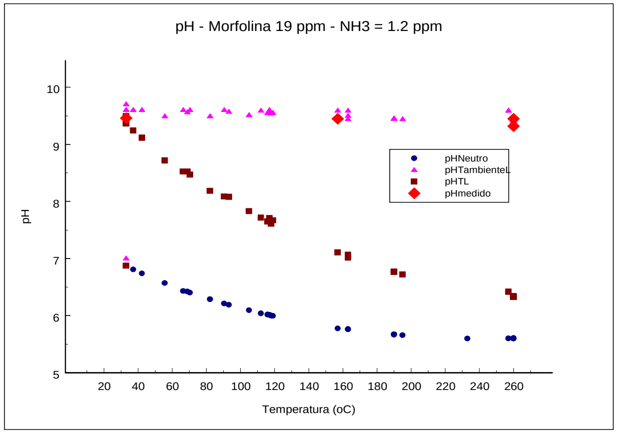
m' m/seg	m' um/año
2,46E-11	700,84
3,67E-11	1047,48

Para el Modelo Semi-Teórico

Espesor que se puede perder (mm)	Período (años)	Estado de la línea
2,8748	4,10	Rojo
2,8748	2,74	Rojo

Gráfico de Baker para Flujo Horizontal





Examples of Data Base and Calculations for a Low Pressure Turbine Extraction Line

DATOS DE INSPECCIONES

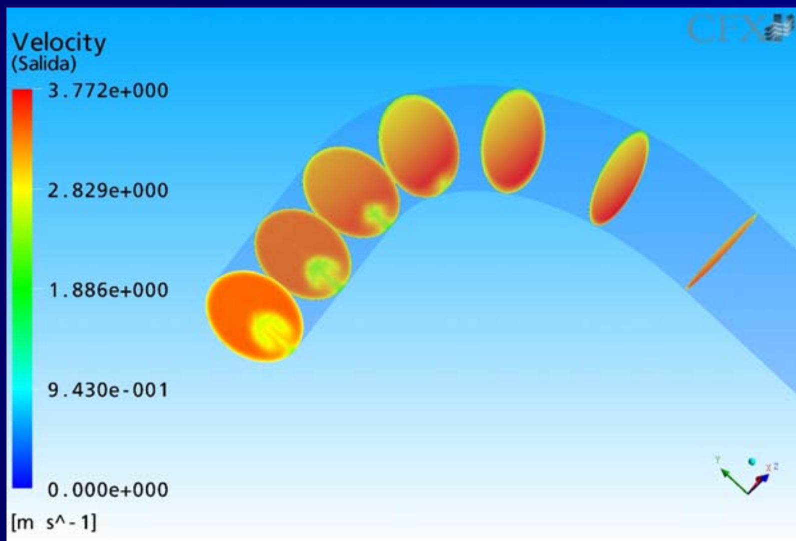
Zona Nº	Datos de inspecciones promedio				
	Dif.esp.prom.(mm)	Dif.esp.máx.(mm)	Años entre inspecc.	Rate dism.esp.prom.(μm/año)	Rate dism.esp.máx.(μm/año)
C2	0,62	1,05	9,6	64,58	109,38
C1	0,34	1,85	8	42,50	231,25

Período en alcanzar tmin diseño		Estado de la línea
Para rate prom.	Para rate máx.	
44,51	26,28	Amarillo
67,64	12,43	Naranja

Computational Modeling of Flow Regime

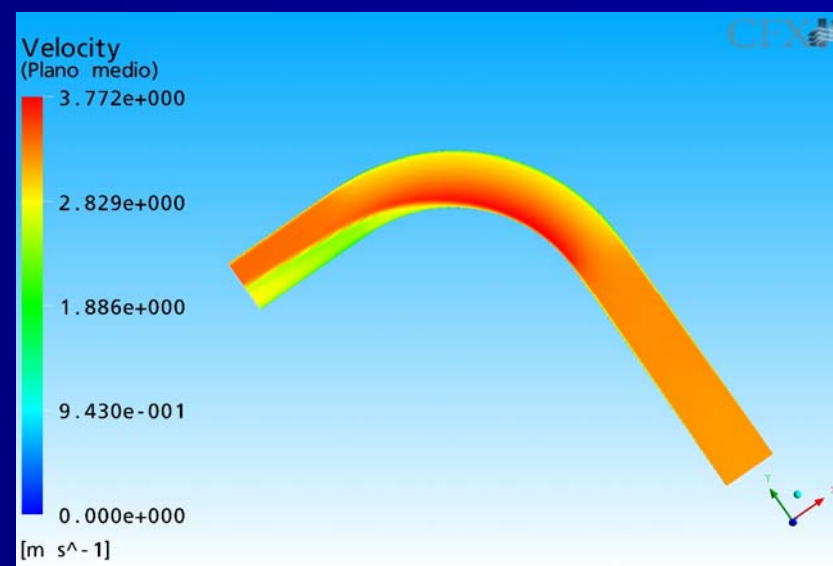
- A Computational Modeling of the flow regime in BOP's accessories and critical areas has been developed in collaboration with the Nuclear Safety and Thermohydraulics Section of Nuclear Power Plant and Reactor Activity Unit (Unidad de Actividad de Reactores y Centrales Nucleares- UARyCN-CNEA)
    - Flow velocity profiles
    - Flow pressure profiles
    - Shear stress profiles
    - Local mass transfer coefficient calculation
    - Better prediction of wall thinning rates

Example of the First Modeling Results



- The figures represent the flow velocity profiles in a cross section and longitudinal section for a 90º elbow of a steam generator feed water line

- As it is shown, at the inner wall of the elbow inlet and at the outer wall of the outlet, high velocity zones and 3D vortex are produced
- They are related to high shear stress zones

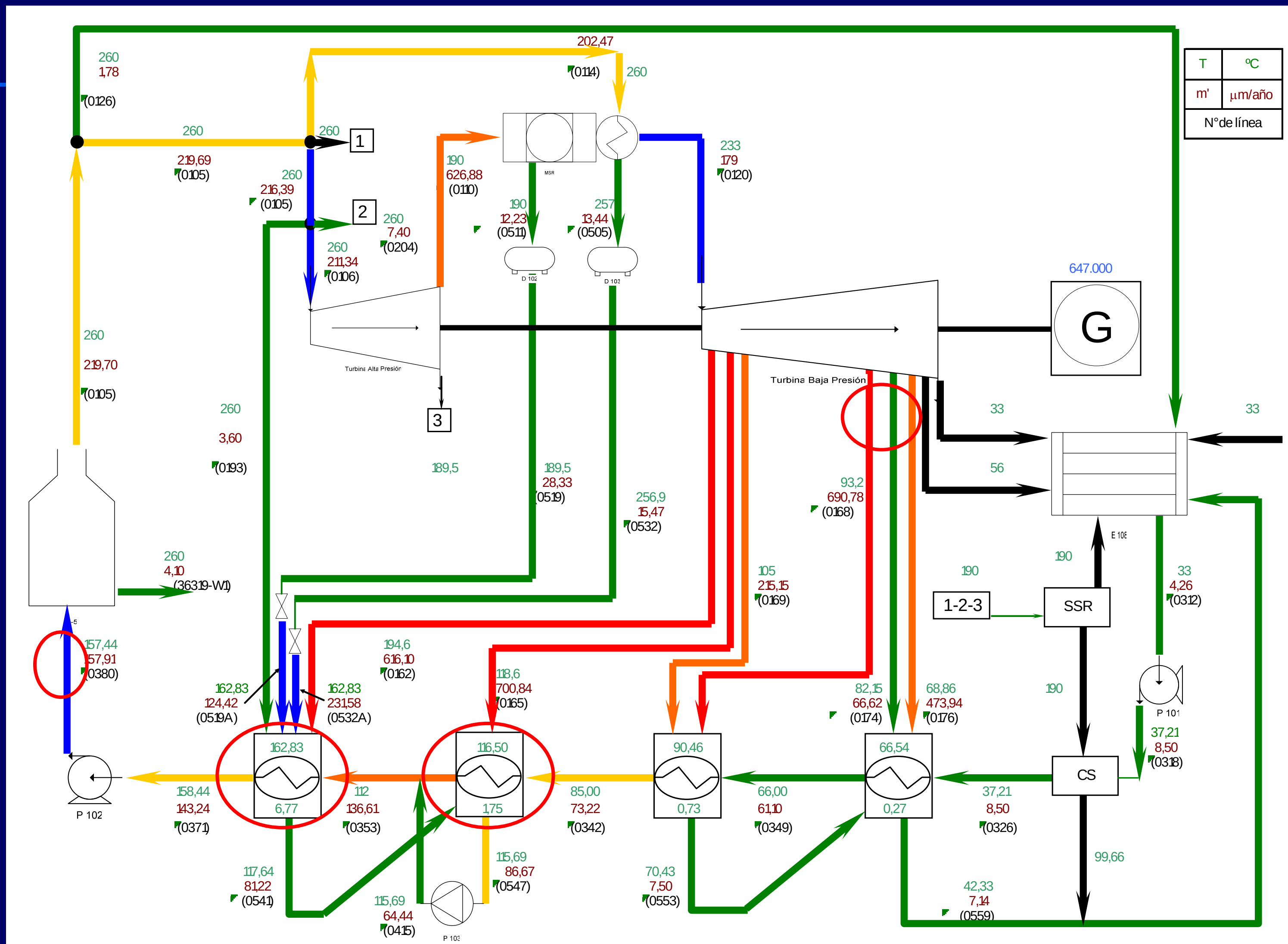


Relative Thinning Rate at Embalse Water/Steam Cycle

- 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

Diagram of the Relative Thinning Rate at Embalse Water/Steam Cycle



Monitoring of ENPP-SC

- DR 96618: Thickness measurement in turbine extraction lines (TBP-A) and drainage lines during 2005 Outage

  - Areas 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.

Monitoring of ENPP-SC

- DR 98280: Thickness measurement in turbine extraction lines (TBP-A/C) during 2007 Outage

  - Areas with localized degradation (13 out of 20 measured areas have shown a localized degradation > 30%) have been found in the extractions of the TBP-A and TBP-C toward E-104A and E-104C preheaters.
  - As previously stated, the highest wall thinning has been observed in areas of the straight pipe toward preheaters, adjacent to 45º elbows.
  - In this case, for zones that have been previously measured (in 2005 outage) the maximum thinning rate was 0.77 mm/year. However, the average thinning rate was 0.16 mm/year.
  - It is necessary to collect more measurements to obtain a better evaluation.

Monitoring of ENPP-SC

- DR 99253: Extension of piping thickness measurements in steam generators feed water lines during 2007 Outage
  - In 2006, a break in feed water pipeline to steam generator, downstream of flow element occurred in other NPP .
  - Because of that event, at our Plant it was decided to extend the thickness measurement program and consider those critical zones.
  - As a conclusion, new 45 zones have been inspected.
  - Only 4 zones (90º elbows) have shown wall thinning >12.5% but <30% refer to nominal thickness.
  - No zone has shown wall thinning > 30% of the nominal thickness.

Monitoring of ENPP-SC

- DRs 102499/102500: Wall thickness measurements on carbon steel shells of feed water high pressure preheaters (E-101 and E-102), during 2008 Outage

  - The main objective is to obtain information about the equipment status in relation to FAC degradation

  - Results are still under evaluation

Conclusions

- By applying the FAC theory, a Wall Thinning Rate Model has been developed
- Theoretical results have been compared and fitted to historic data of the plant and to some published pipe thickness thinning data
- According to the Integral Life Assessment Program new locations to be inspected have emerged and residual pipe life can now be predicted
- Besides, other degradation mechanisms have been addressed (jet impingement, droplet impingement, cavitation, etc.)

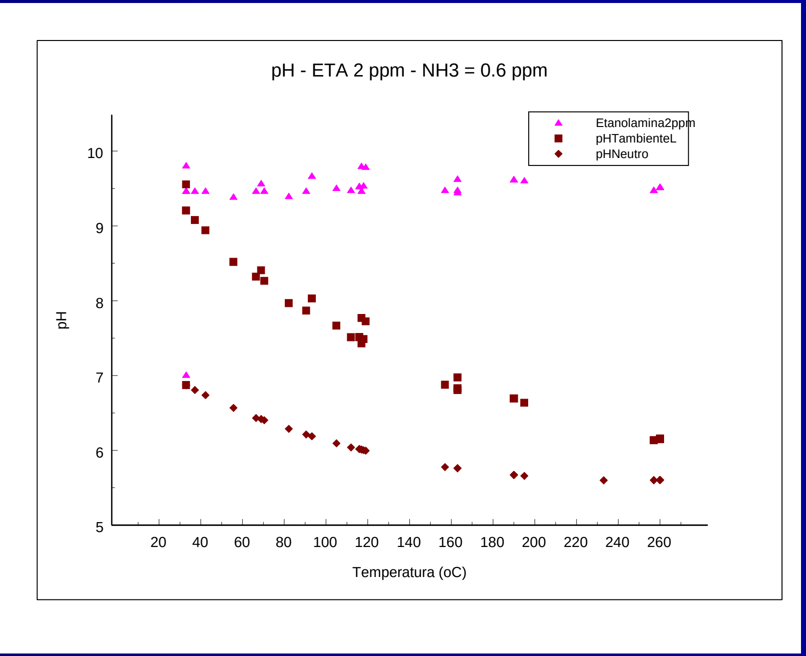
Conclusions

- The current ISI Program has been optimized
- Large sets of process and inspection data can be handled
- To mitigate FAC the plant has gradually modified the BOP chemistry by means of a Morpholine concentration increase, though it was recently replaced by Ethanolamine

Conclusions

- Different chemistries have been compared, which provide support for the Ethanolamine utilization

i.e. lower concentration in the feed water leads to higher pH at operating temperature in the steam generator and other liquid phase regions, as shown in the figure.



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Thank you for your attention
LEP Group