The COMSY - code for the Detecting of Piping Degradation due to Flow-accelerated Corrosion

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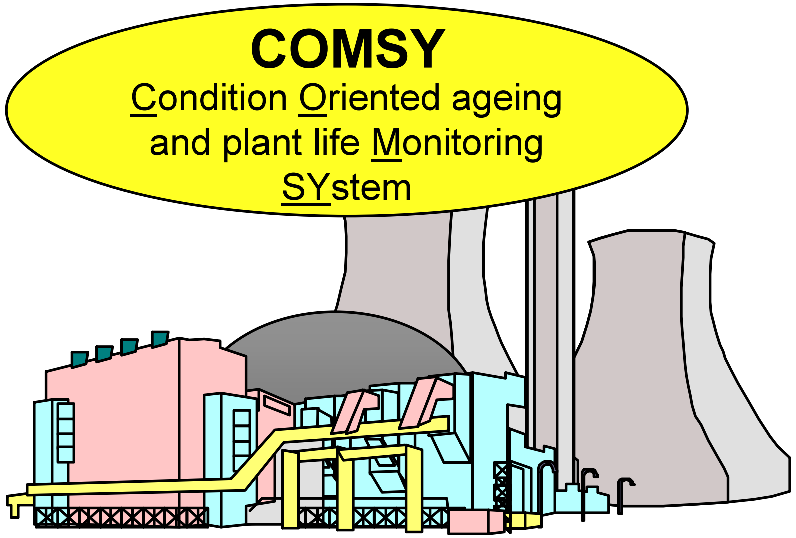
AREVA

Flow-induced material degradation - Contents

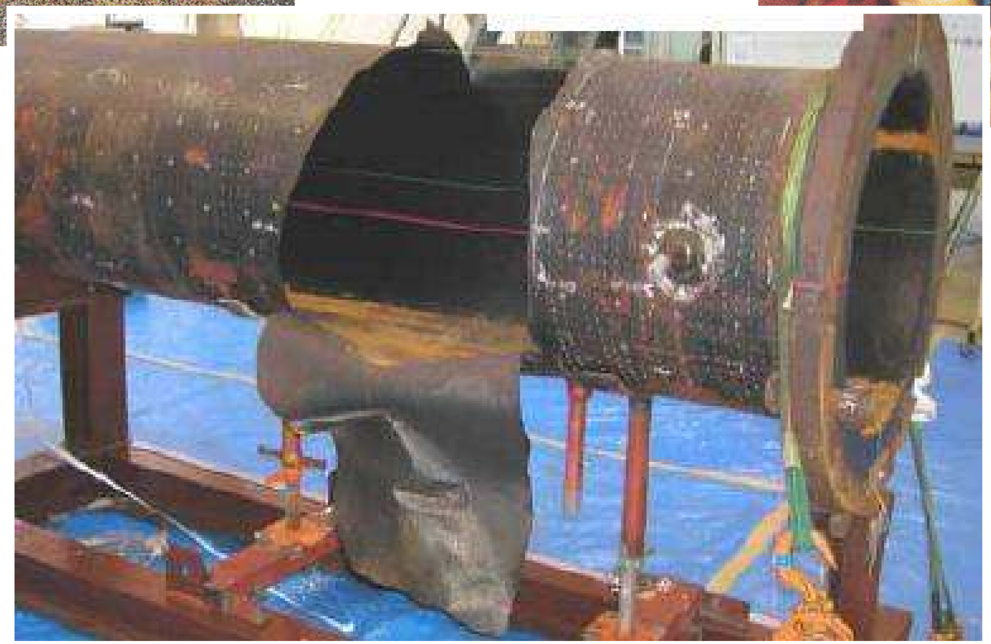
- *Introduction / Incidents in Power Plants*
- *Flow-induced material degradation mechanism*
- *Flow-accelerated corrosion*
  (Characterization, Influence parameter, Combined effects, History)
- *COMSY program*
  (Strategy, Screening and Detailed analysis)
- *Life Time Prediction Process*
  (Overview, Boundary conditions, Prediction philosophy)
- *Inspection and examination record management*
- *COMSY Closed Loop Process*
- *Conclusions*
  (Software modules, Characteristics)

Introduction
Incidents in power plants caused by FAC



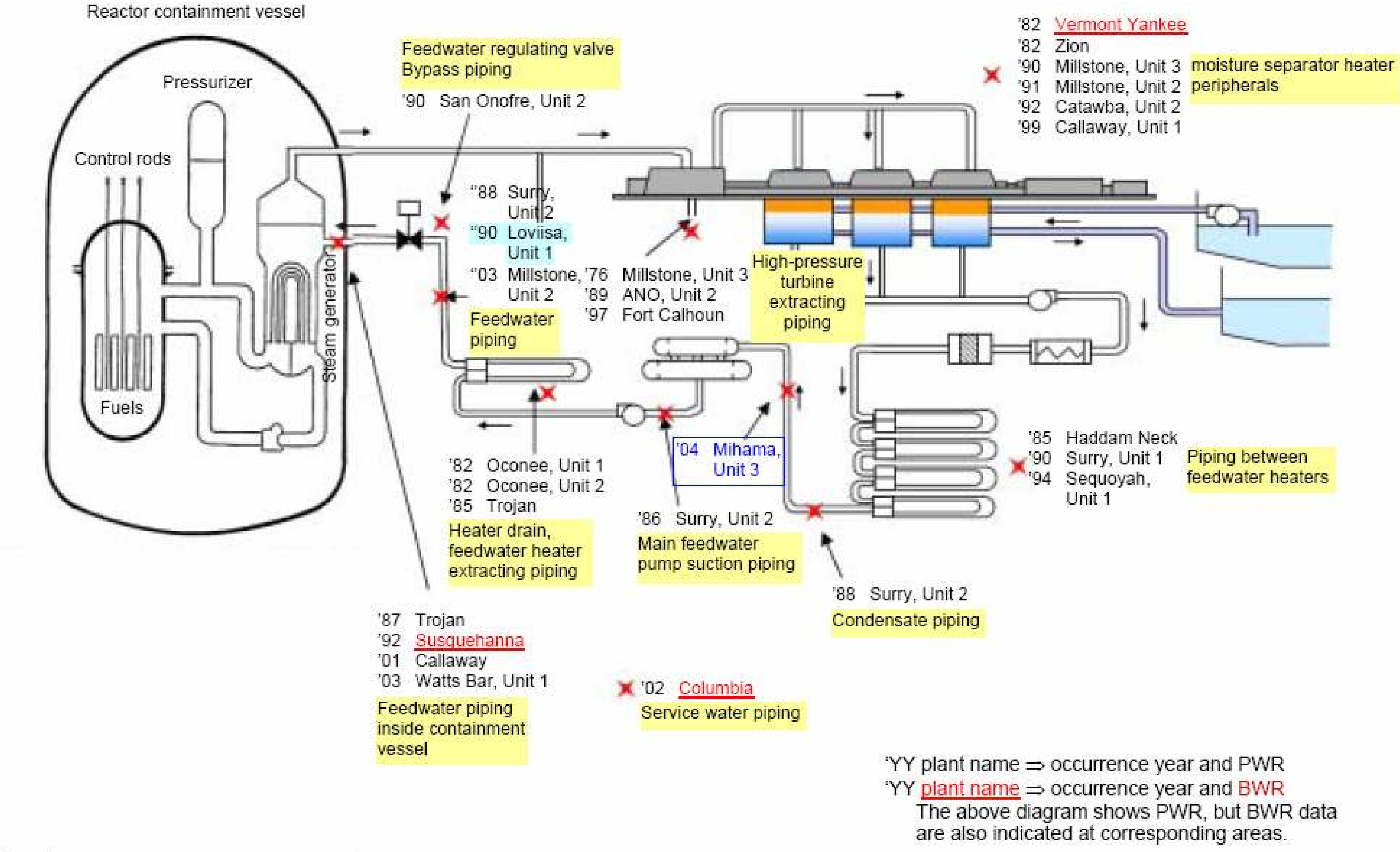
Flow-induced material degradation – Introduction (1)

Pipe failures due to FAC



Flow-induced material degradation – Introduction (2)

Incidents in power plant piping caused by FAC



Flow-induced material degradation – Introduction (3)

Lines commonly affected by FAC attacks are:

- *Feedwater lines*
- *Condensate lines*
- *Extraction lines*
- *Discharge lines*
- *MS and reheater drainage lines*
- *Condensate drain lines and drain valves*
- *Cold crossover lines from HP-turbine to the reheater*
- *Connection lines and nozzles on the feedwater tank*
- *Blow-down lines*
- *etc.*

Areas suffering from FAC are difficult to locate, as FAC occurs only locally under specific conditions of flow, water chemistry, temperature and material behavior.

In most cases were failures occur, inspection programs have been established by 'engineering judgment'

Flow-induced material degradation
- Types, definitions, influencing parameters

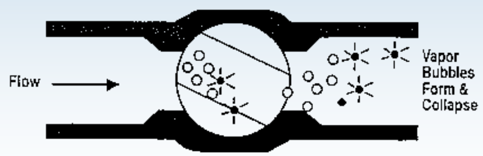
Flow-Induced Material Degradation

Single-Phase Flow (Water)

Two-Phase Flow (Water / Steam)

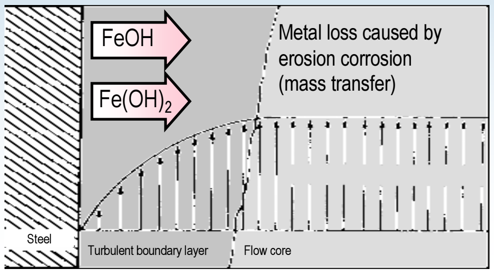
Cavitation Erosion

Definition:
Deep localized degradation in pumps, but also down-stream of internals and valves, caused by cavitation, i.e. violent collapse of steam bubbles in water flow near solid parts, governed by physical fluid and material properties



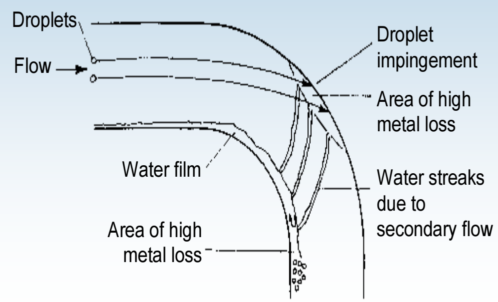
Flow-Accelerated Corrosion

Definition:
Erosive destruction of oxide layers due to turbulent water or wet steam flow followed by corrosion and dissolution of the unprotected wall, leads to a coherent area of degradation, governed by thermal-hydraulic properties, water chemistry, composition of material



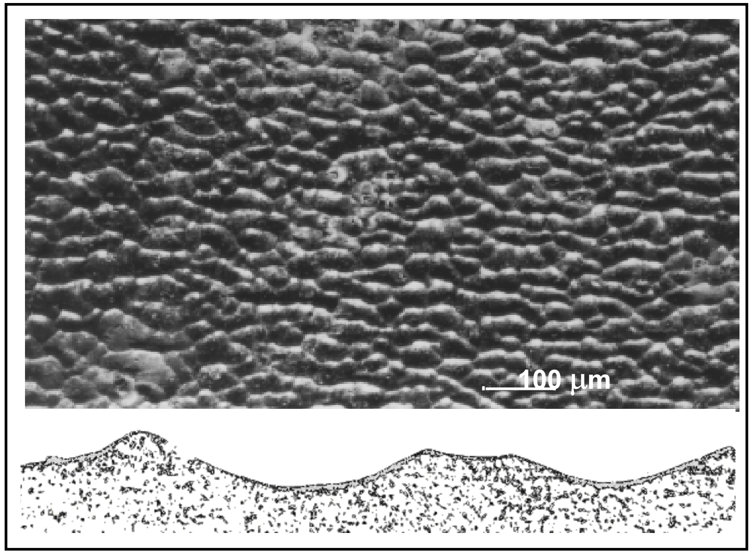
Droplet Impingement Erosion

Definition:
Deep localized degradation due to the impact of liquid drops carried by wet steam flow, governed by physical fluid and material properties

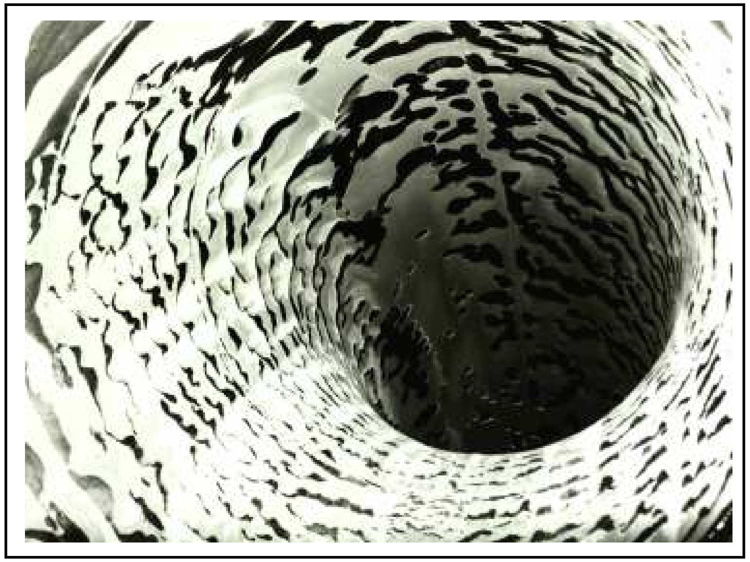


Flow-accelerated corrosion - Characterization

Horse shoe pits in single phase flow



Tiger striping in two-phase flows



Flow Accelerated Corrosion is a chemical corrosion process which affects metals which owe their corrosion resistance to the formation of oxide layers. If the fluid at the oxide-water interface is moving, the oxide layer may be dissolved. The corresponding corrosion rate is strongly influenced by solubility of the oxide layer and the mass transfer imposed by the moving fluid.

Flow-accelerated corrosion
- Influence Parameter

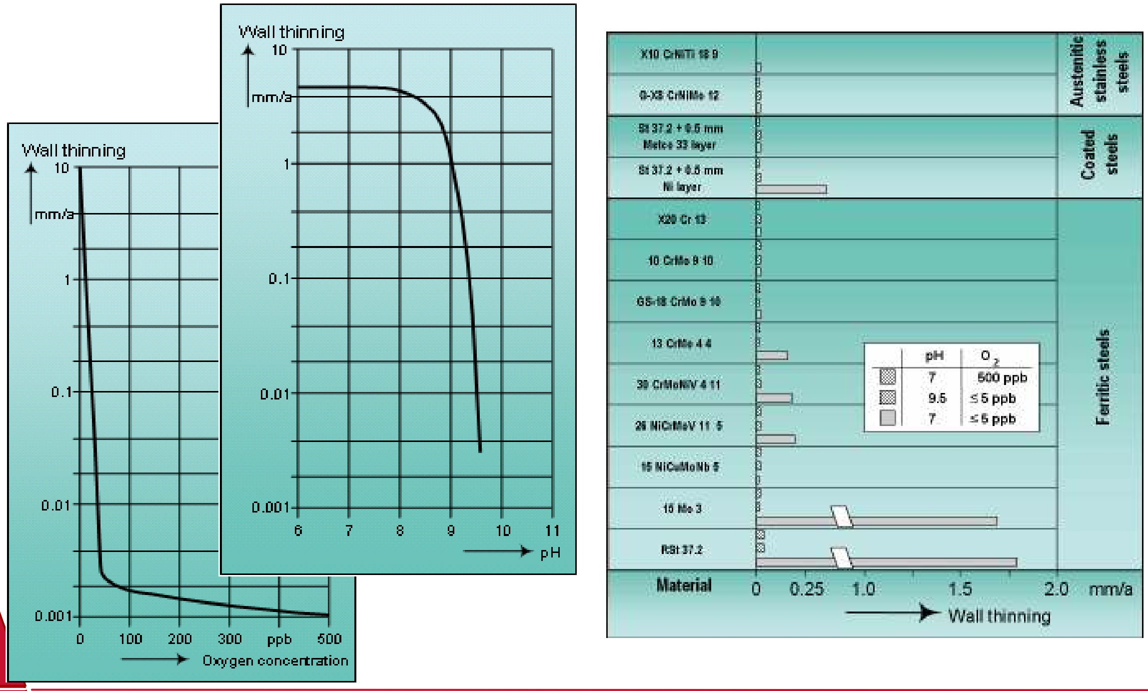
> pH value and O_2 concentration of the water phase

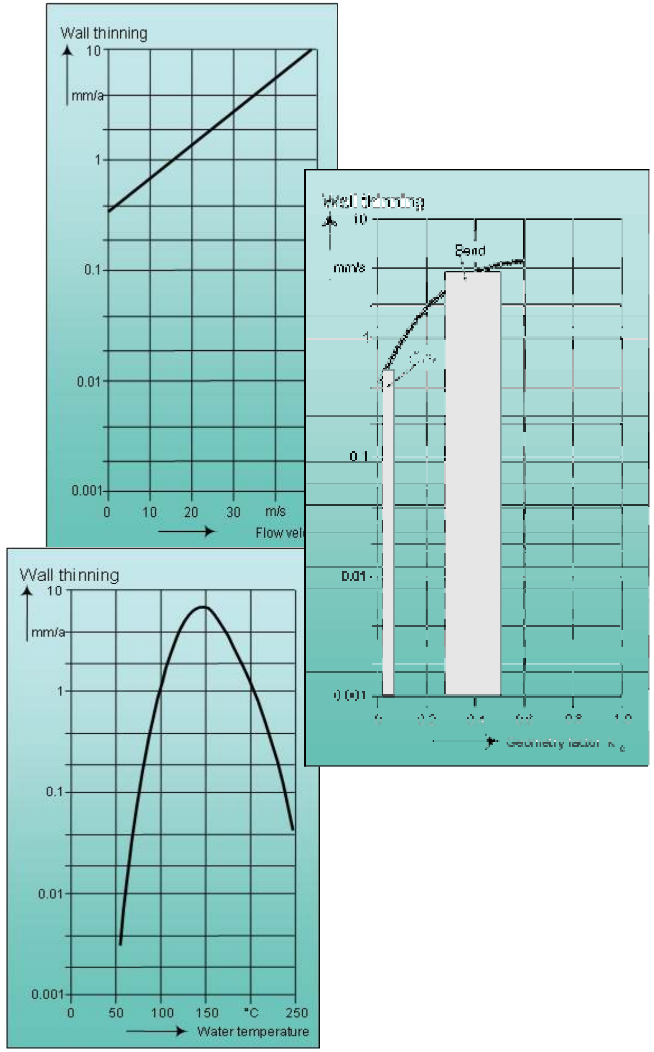
> Material (alloy content Cr, Mo & Cu)

> Temperature

> Flow velocity

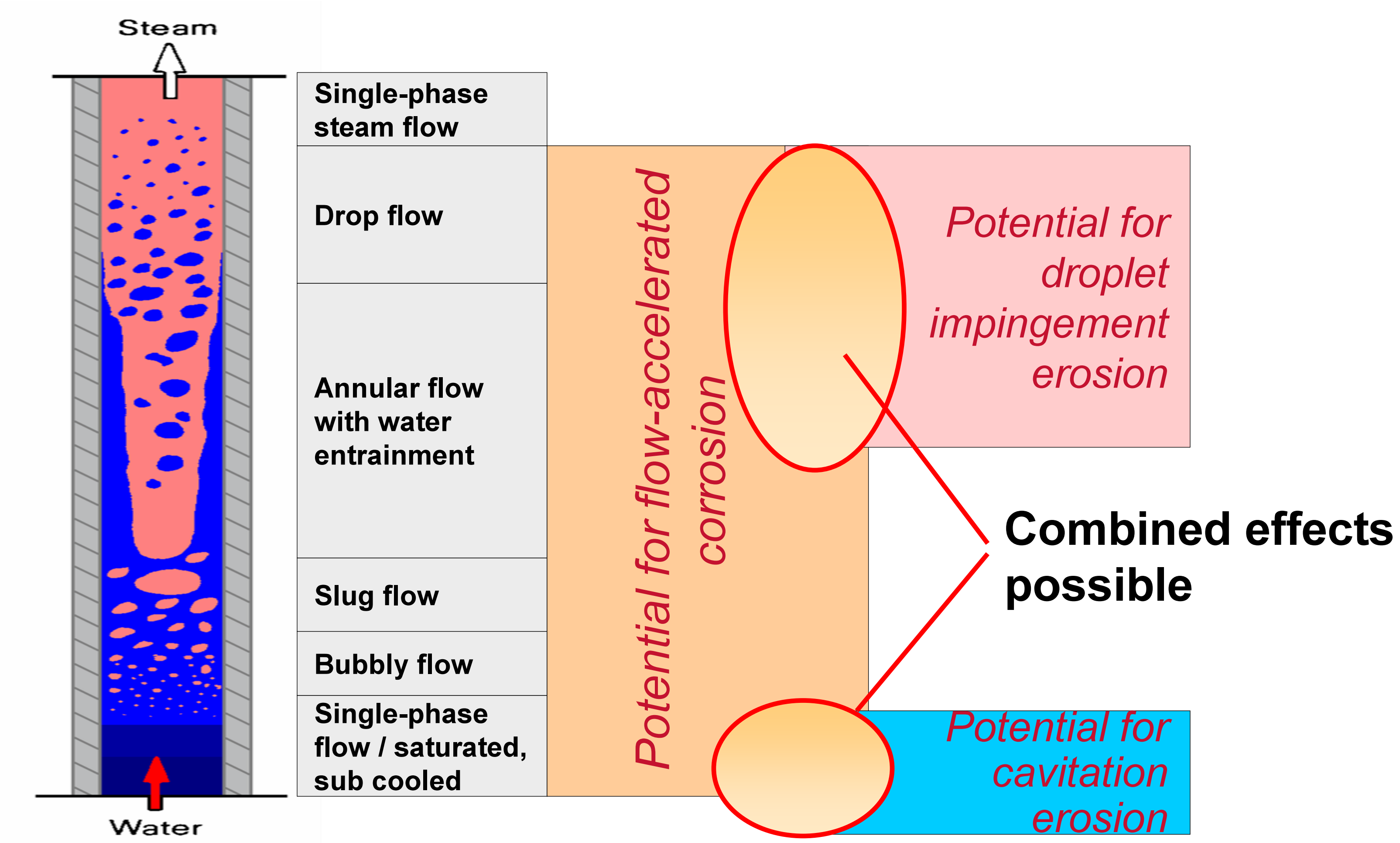
> Local turbulence, Flow profile, Pipe roughness





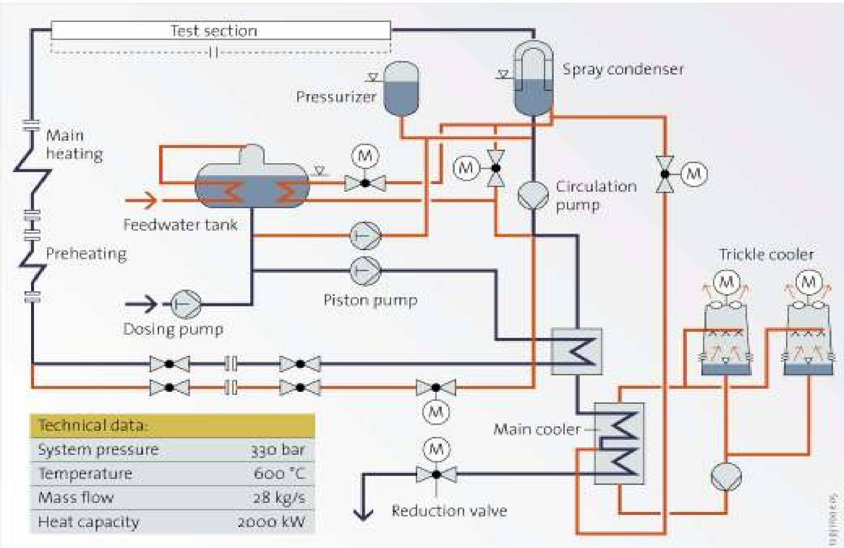
Flow-induced corrosion
- Superposition of different flow-induced mechanisms

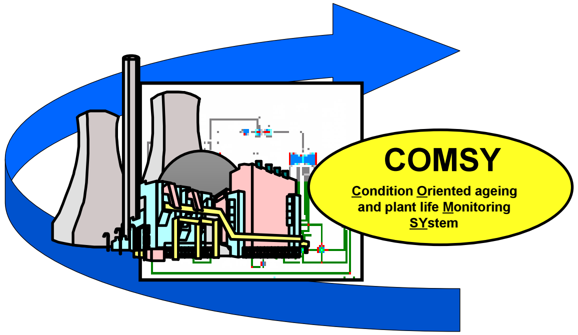
Enhancement of FAC by droplet impingement and cavitation effects

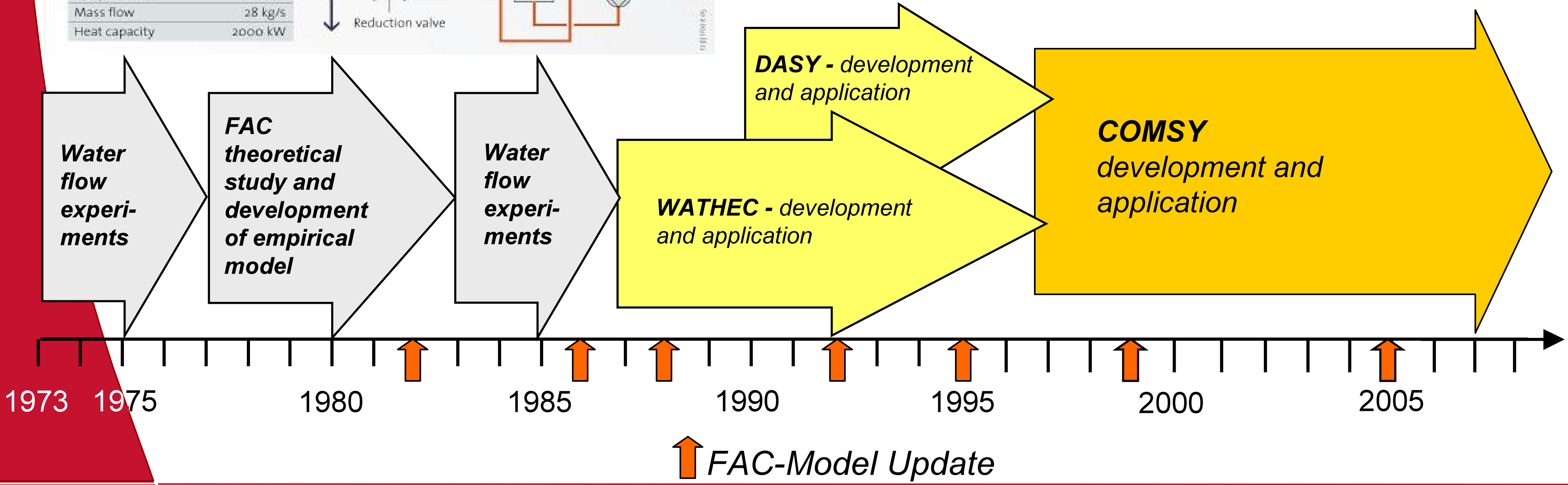


Flow-accelerated corrosion
- History of FAC model development

Benson test facility





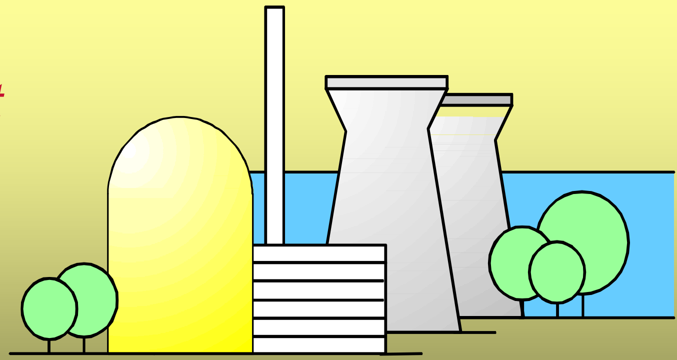


Ageing and Plant Life Management Strategy - Introduction

COMSY is a software tool for the aging and plant life management of mechanical components in power plants. The degradation analysis functions include lifetime prediction in respect to e.g. flow accelerated corrosion (FAC), droplet impingement corrosion, cavitation corrosion, etc.

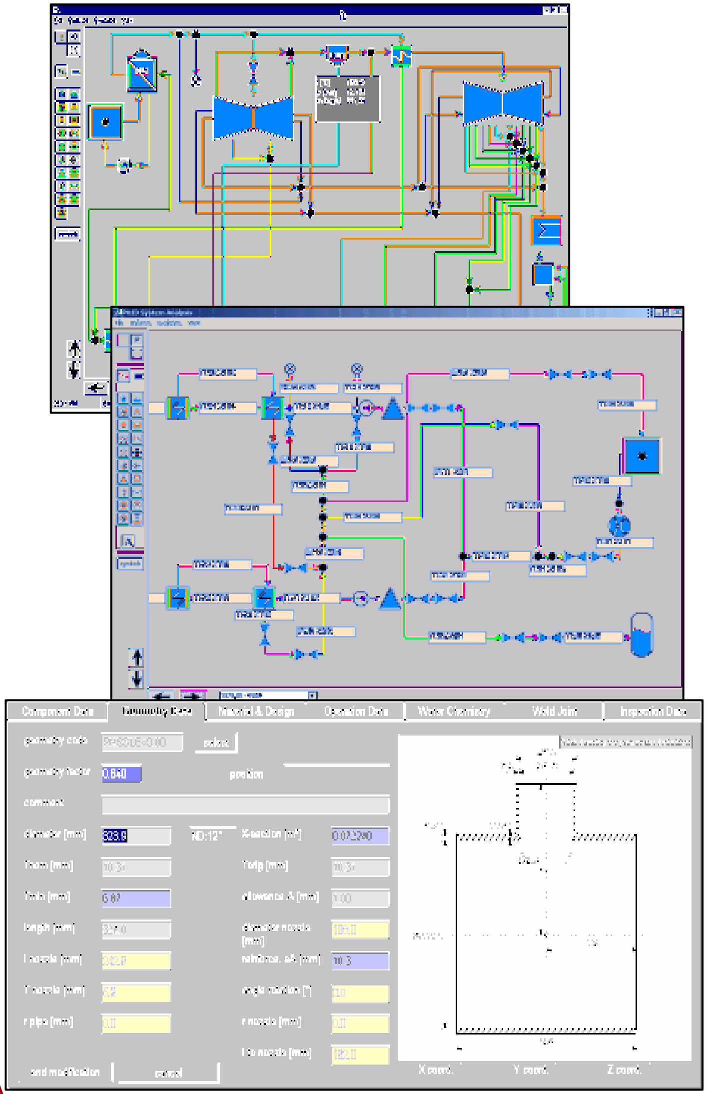
This is accomplished by:

- *Focusing inspection activities on the safety relevant components with an existing degradation potential*
- *Reduction of inspection effort for components with insignificant safety relevance and negligible degradation potential*
- *Applying appropriate inspection techniques for the anticipated degradation mechanism*



This task can be accomplished with a powerful software tool, specifically designed for plant life management in nuclear power plants.

COMSY
- Strategy for ageing and plant life management (1)

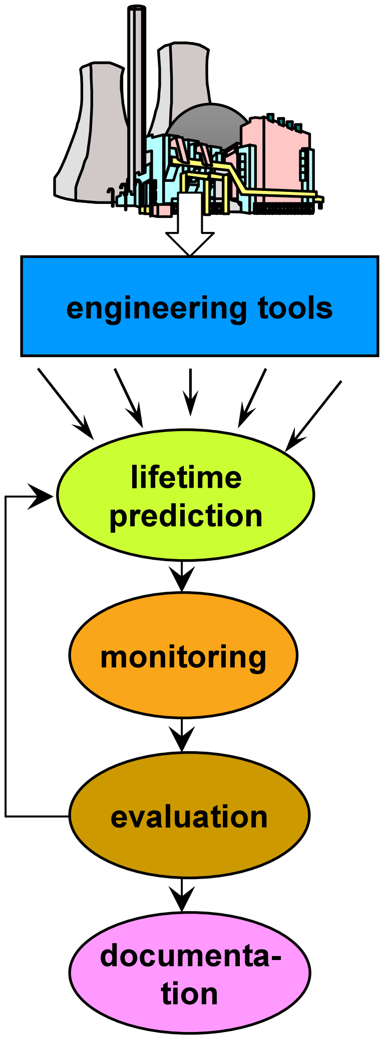


The modeling is performed in three levels:

1. *Heat balance diagram*
   Degradation potential screening, risk input
2. *P&ID diagram*
   Degradation sensitivity assessment, detailed risk assessment
3. *Component data sheet*
   Lifetime predictions, examination record management

The application of modeling levels flexibly depends on the necessity imposed by safety relevance and degradation potential

COMSY
- Strategy for ageing and plant life management (2)

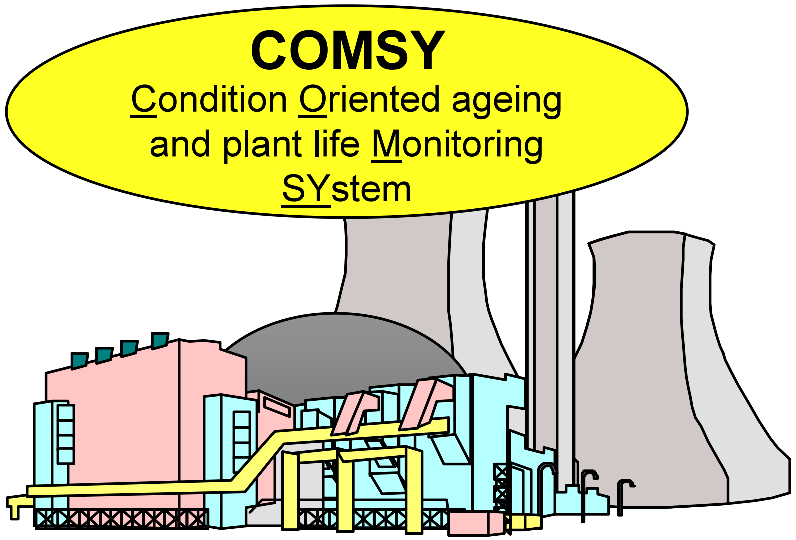


> *Screening process*
> *Identification of susceptible systems, so resources can be focused on systems where ageing potential exists*

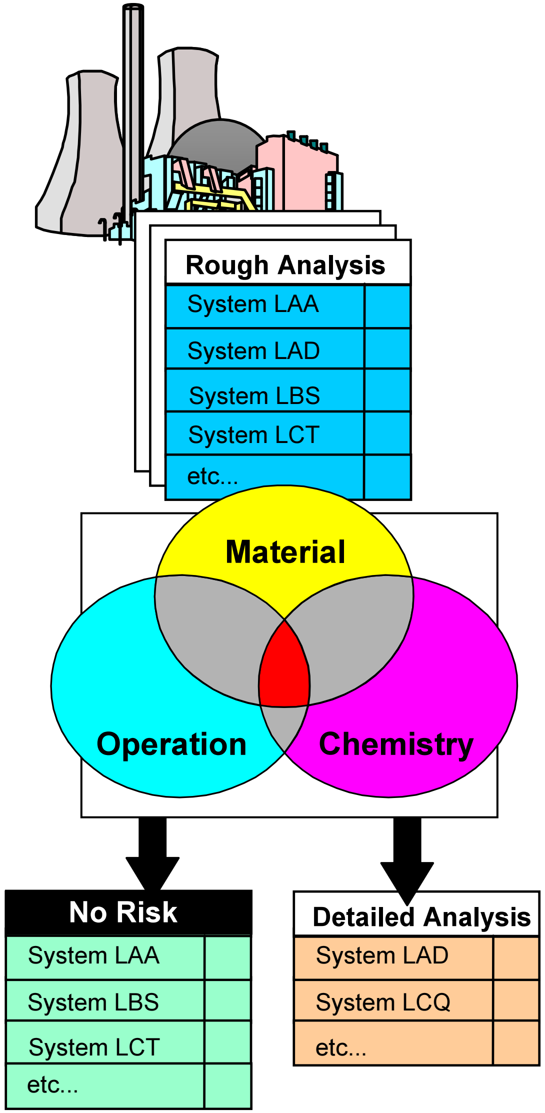
> *Detailed analysis Modeling of relevant systems, lines and vessels:*
> > *Prediction of minimum lifetime for plant elements*
> > *Identification of degraded plant elements for inspection activities*
> > *Evaluation of examination results*
> > *Assessment on current ageing status*
> > *Validation / update on lifetime prediction*

> *Documentation of the as-is state of systems and components*

Screening of the BoP for FAC



Plant-Wide Screening Analysis
- Methodology for Identification of Degradation Sensitivity

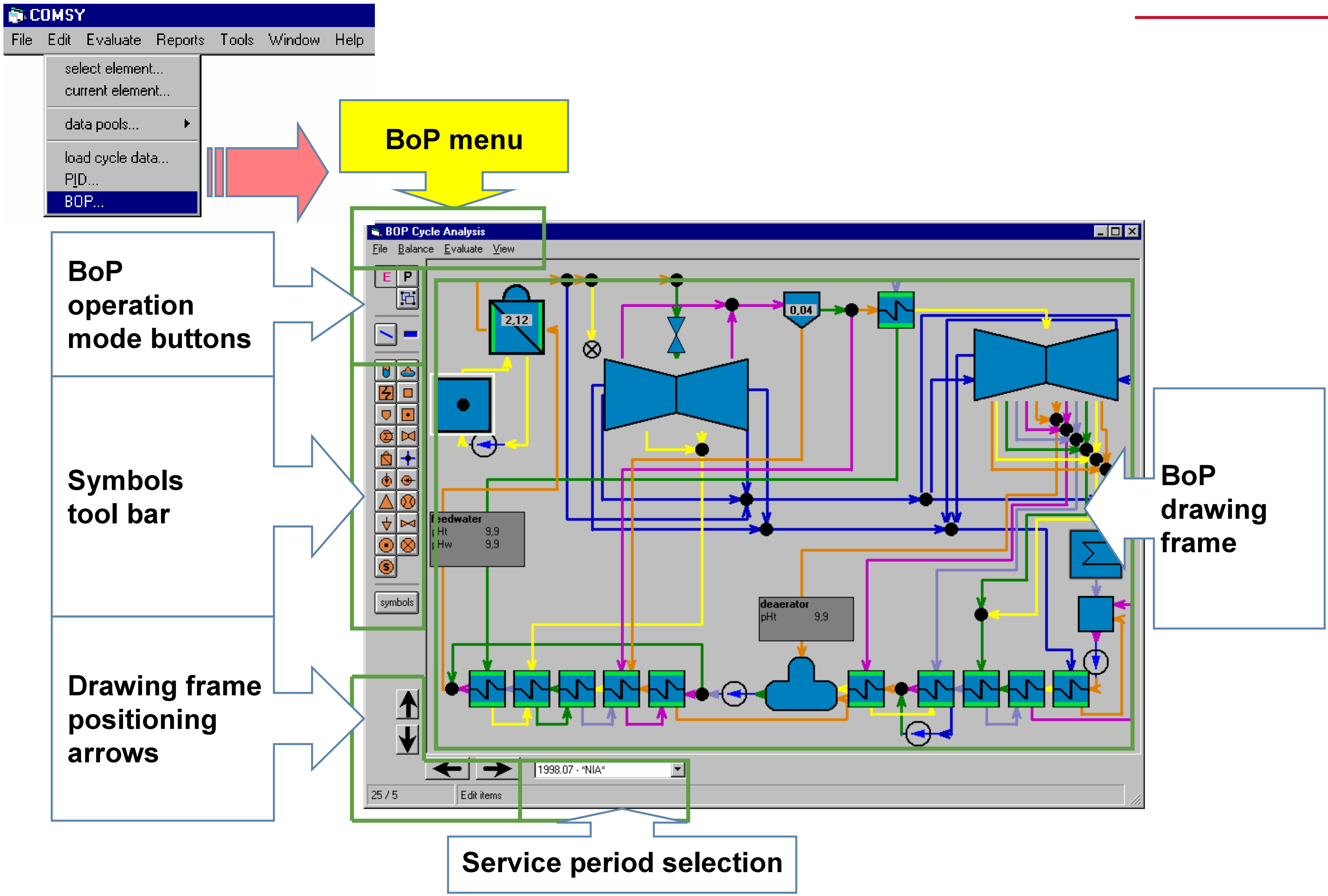


AREVA NP has developed a systematic screening procedure reliably identifying system areas, which may be subject to degradation mechanisms like e.g. flow-accelerated corrosion.

- ✓ *Modeling of the heat balance diagram*
- ✓ *Specification of system configuration*
- ✓ *Thermal-hydraulic parameters*
- ✓ *Water chemistry cycle calculation*
- ✓ *Specification of materials used in systems*

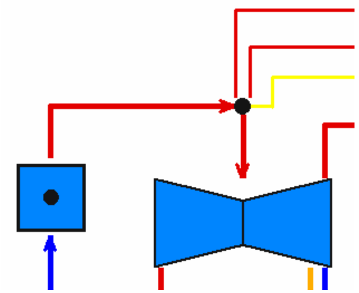
Identification of FAC degradation potential

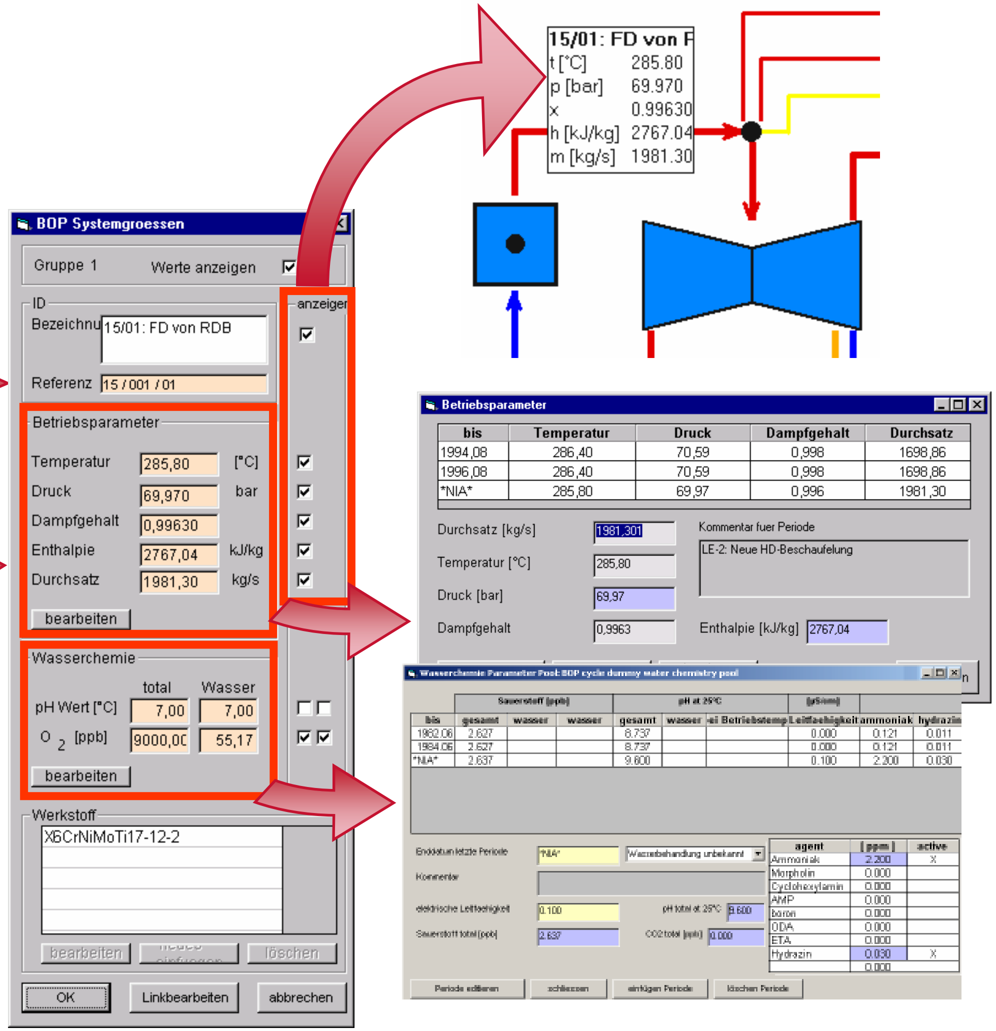
Plant-Wide Screening Analysis
– BoP graphical functions



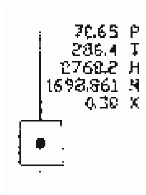
Plant-Wide Screening Analysis
- Modeling of the BOP

Each system is represented by the connecting lines of two symbols

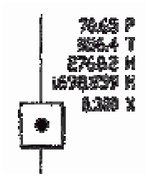




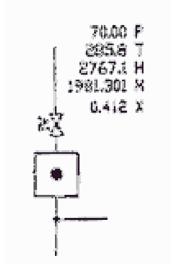
Start-up



1. Power uprate



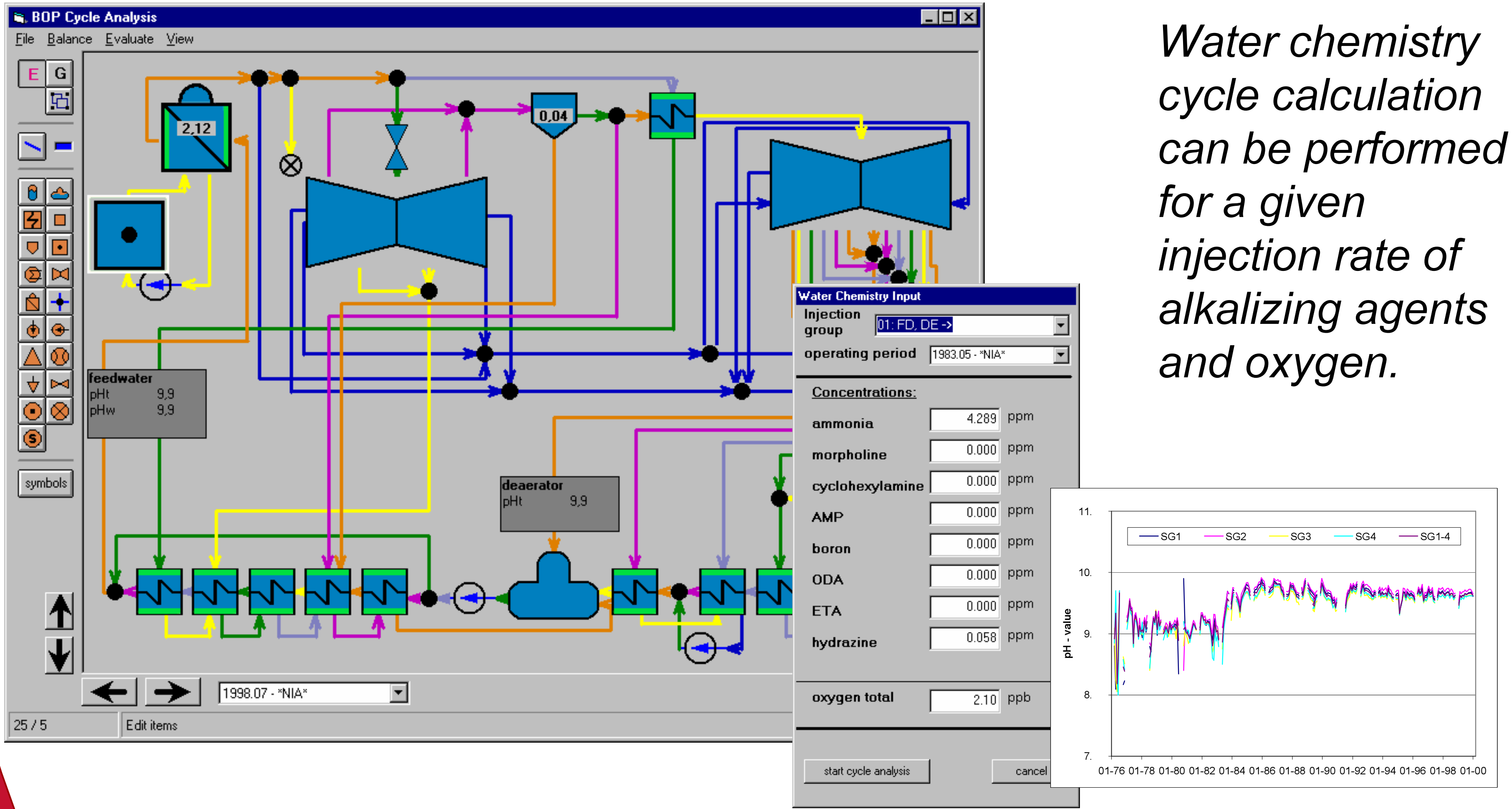
2. Power uprate



For each modeled system the operating parameter will be generated.

Changing in water chemistry will be included.

Plant-Wide Screening Analysis – Water chemistry calculation

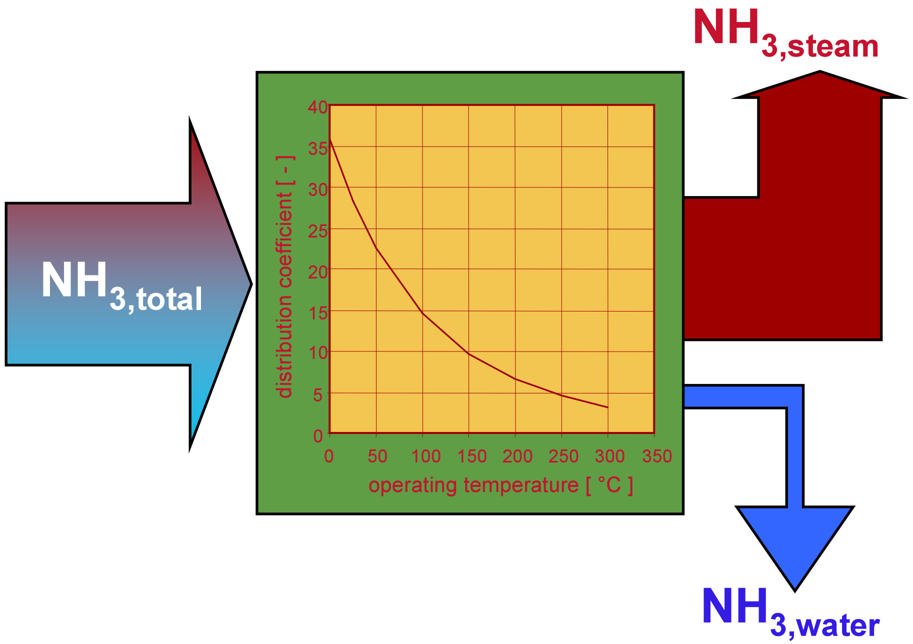


Water chemistry cycle calculation can be performed for a given injection rate of alkalizing agents and oxygen.

Plant-Wide Screening Analysis – Two-phase flow considerations

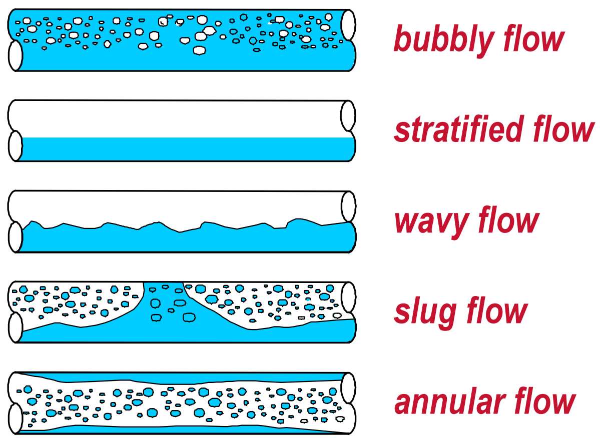
Volatility of water chemical substances

Two-phase flow influences water chemical parameters of the water film due to the distribution behavior of alkalizing agents and oxygen

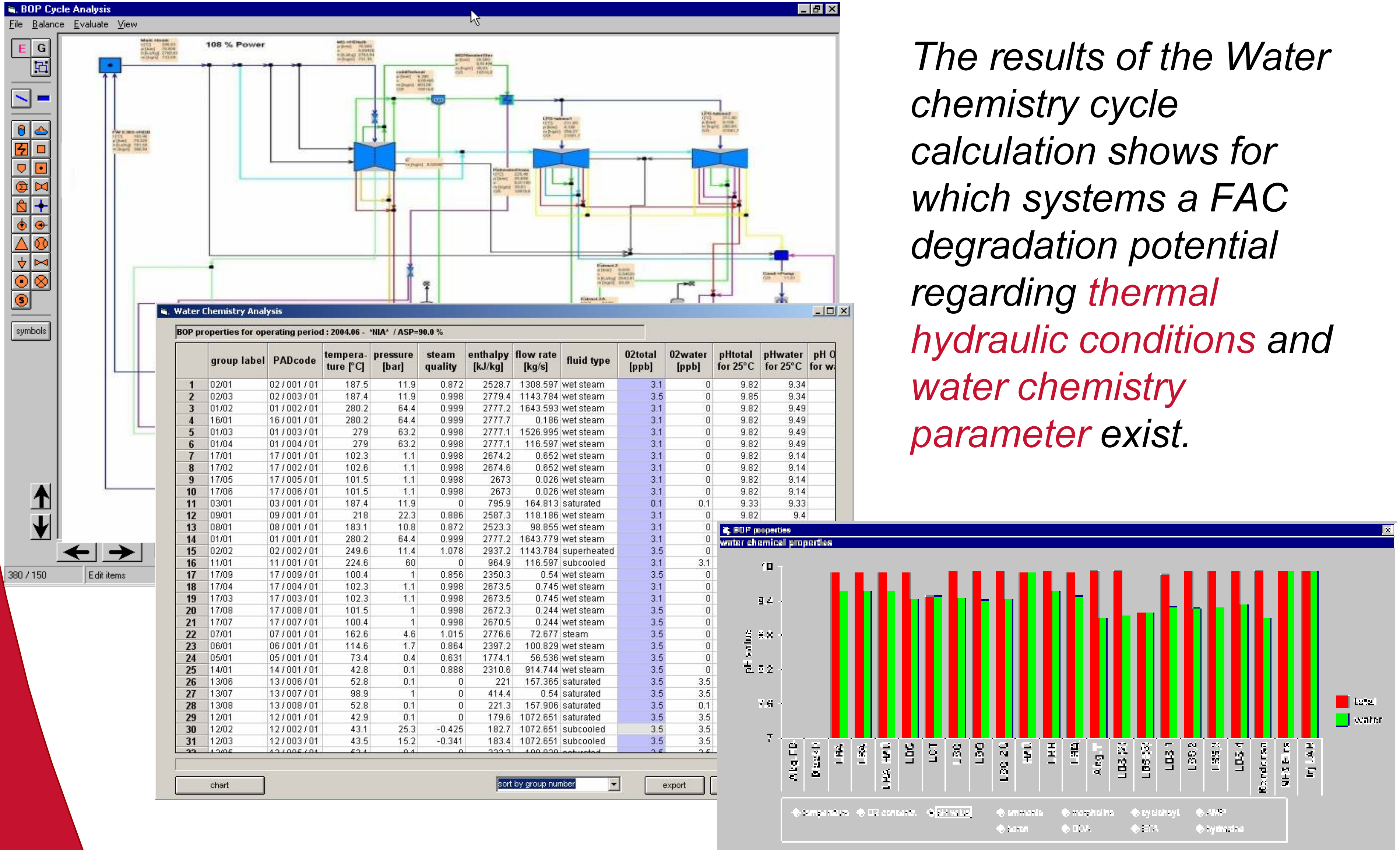


Two-phase flow patterns

The flow pattern influences water/steam velocities and the local turbulence of the flow



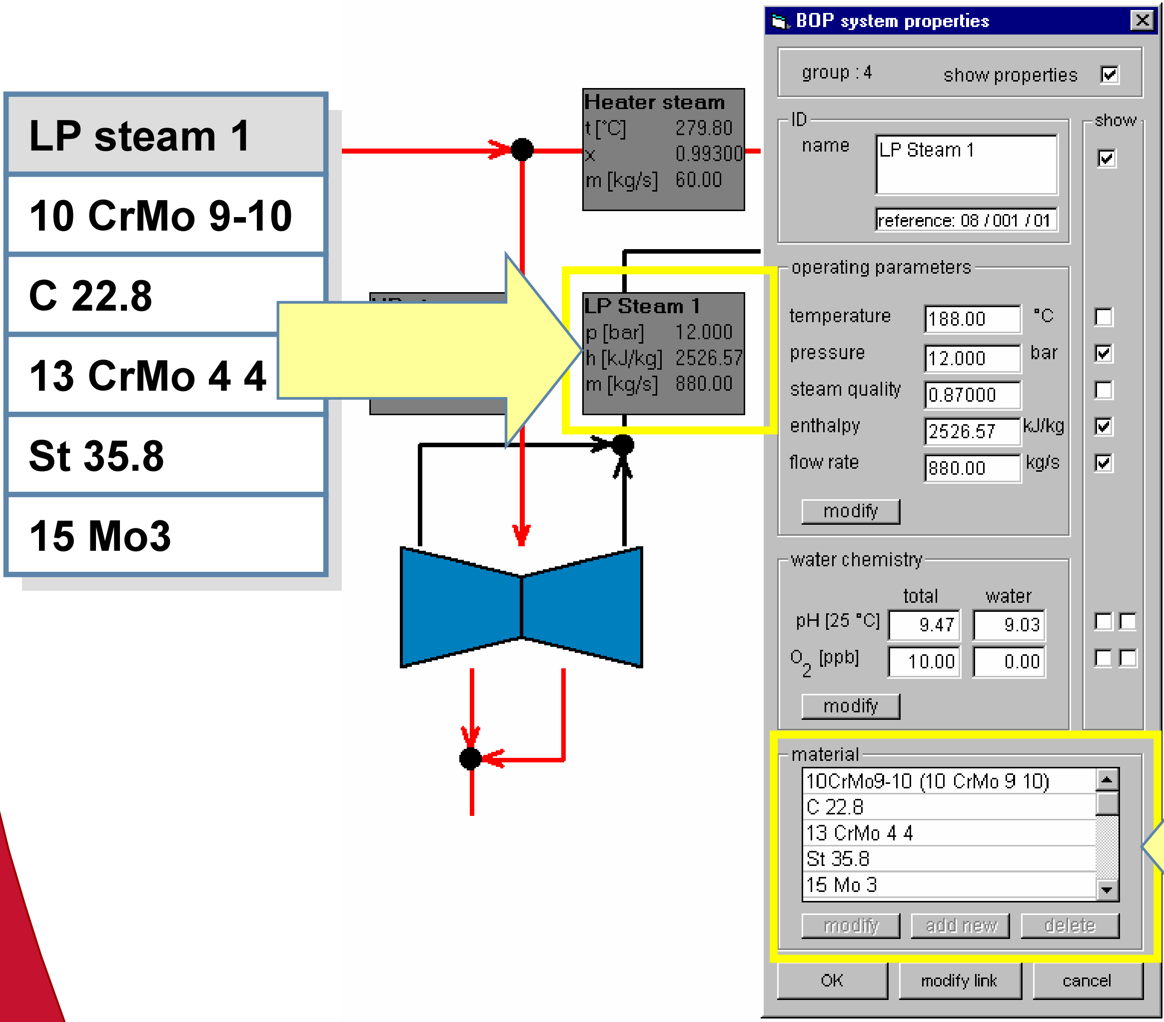
Plant-Wide Screening Analysis
– Using the Heat Balance Diagram



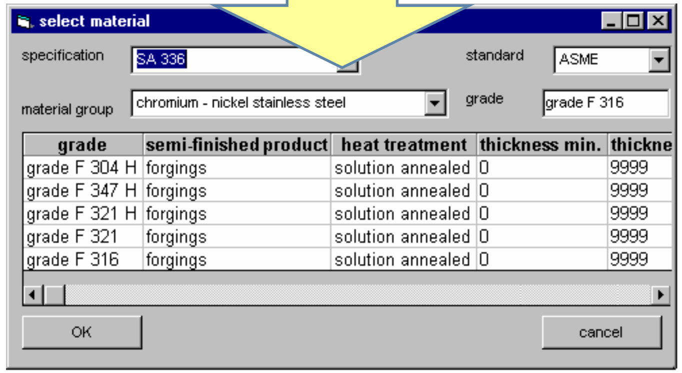
	group label	PADcode	tempera-ture [°C]	pressure [bar]	steam quality	enthalpy [kJ/kg]	flow rate [kg/s]	fluid type	02total [ppb]	02water [ppb]	pHtotal for 25°C	pHwater for 25°C
1	02/01	02 / 001 / 01	187.5	11.9	0.872	2528.7	1308.597	wet steam	3.1	0	9.82	9.34
2	02/03	02 / 003 / 01	187.4	11.9	0.998	2779.4	1143.784	wet steam	3.5	0	9.85	9.34
3	01/02	01 / 002 / 01	280.2	64.4	0.999	2777.2	1643.593	wet steam	3.1	0	9.82	9.49
4	16/01	16 / 001 / 01	280.2	64.4	0.999	2777.7	0.186	wet steam	3.1	0	9.82	9.49
5	01/03	01 / 003 / 01	279	63.2	0.998	2777.1	1526.995	wet steam	3.1	0	9.82	9.49
6	01/04	01 / 004 / 01	279	63.2	0.998	2777.1	116.597	wet steam	3.1	0	9.82	9.49
7	17/01	17 / 001 / 01	102.3	1.1	0.998	2674.2	0.652	wet steam	3.1	0	9.82	9.14
8	17/02	17 / 002 / 01	102.6	1.1	0.998	2674.6	0.652	wet steam	3.1	0	9.82	9.14
9	17/05	17 / 005 / 01	101.5	1.1	0.998	2673	0.026	wet steam	3.1	0	9.82	9.14
10	17/06	17 / 006 / 01	101.5	1.1	0.998	2673	0.026	wet steam	3.1	0	9.82	9.14
11	03/01	03 / 001 / 01	187.4	11.9	0	795.9	164.813	saturated	0.1	0.1	9.33	9.33
12	09/01	09 / 001 / 01	218	22.3	0.886	2587.3	118.186	wet steam	3.1	0	9.82	9.4
13	08/01	08 / 001 / 01	183.1	10.8	0.872	2523.3	98.855	wet steam	3.1	0		
14	01/01	01 / 001 / 01	280.2	64.4	0.999	2777.2	1643.779	wet steam	3.1	0		
15	02/02	02 / 002 / 01	249.6	11.4	1.078	2937.2	1143.784	superheated	3.5	0		
16	11/01	11 / 001 / 01	224.6	60	0	964.9	116.597	subcooled	3.1	3.1		
17	17/09	17 / 009 / 01	100.4	1	0.856	2350.3	0.54	wet steam	3.5	0		
18	17/04	17 / 004 / 01	102.3	1.1	0.998	2673.5	0.745	wet steam	3.1	0		
19	17/03	17 / 003 / 01	102.3	1.1	0.998	2673.5	0.745	wet steam	3.1	0		
20	17/08	17 / 008 / 01	101.5	1	0.998	2672.3	0.244	wet steam	3.5	0		
21	17/07	17 / 007 / 01	100.4	1	0.998	2670.5	0.244	wet steam	3.5	0		
22	07/01	07 / 001 / 01	162.6	4.6	1.015	2776.6	72.677	steam	3.5	0		
23	06/01	06 / 001 / 01	114.6	1.7	0.864	2397.2	100.829	wet steam	3.5	0		
24	05/01	05 / 001 / 01	73.4	0.4	0.631	1774.1	56.536	wet steam	3.5	0		
25	14/01	14 / 001 / 01	42.8	0.1	0.888	2310.6	914.744	wet steam	3.5	0		
26	13/06	13 / 006 / 01	52.8	0.1	0	221	157.365	saturated	3.5	3.5		
27	13/07	13 / 007 / 01	98.9	1	0	414.4	0.54	saturated	3.5	3.5		
28	13/08	13 / 008 / 01	52.8	0.1	0	221.3	157.906	saturated	3.5	0.1		
29	12/01	12 / 001 / 01	42.9	0.1	0	179.6	1072.651	saturated	3.5	3.5		
30	12/02	12 / 002 / 01	43.1	25.3	-0.425	182.7	1072.651	subcooled	3.5	3.5		
31	12/03	12 / 003 / 01	43.5	15.2	-0.341	183.4	1072.651	subcooled	3.5	3.5		

The results of the Water chemistry cycle calculation shows for which systems a FAC degradation potential regarding thermal hydraulic conditions and water chemistry parameter exist.

Plant-Wide Screening Analysis – Specify material data



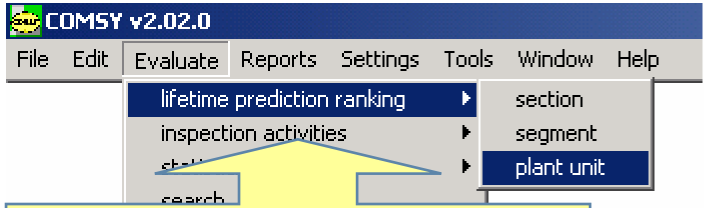
This activity is supported by the material data catalog functionality



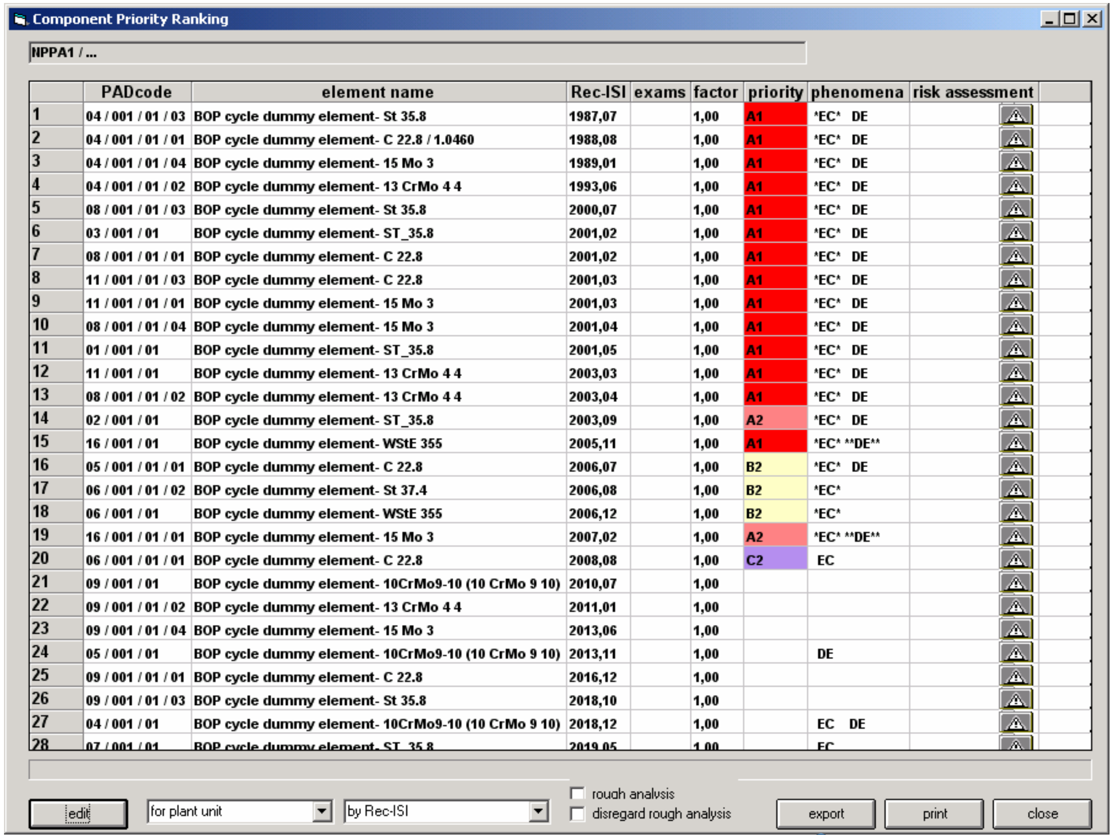
grade	semi-finished product	heat treatment	thickness min.	thickne
grade F 304 H	forgings	solution annealed	0	9999
grade F 347 H	forgings	solution annealed	0	9999
grade F 321 H	forgings	solution annealed	0	9999
grade F 321	forgings	solution annealed	0	9999
grade F 316	forgings	solution annealed	0	9999

Each material included with the material table is specified for the related system

Plant-Wide Screening Analysis – Lifetime prediction ranking



Select COMSY main menu function > Evaluate > lifetime prediction ranking evaluate data to generate the ranking table

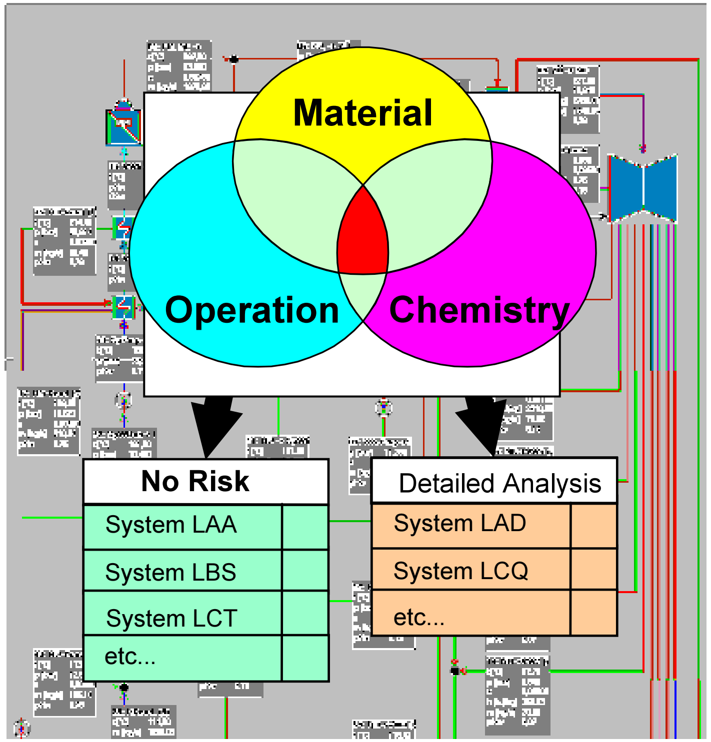


	PADcode	element name	Rec-ISI	exams	factor	priority	phenomena	risk assessment
1	04 / 001 / 01 / 03	BOP cycle dummy element- St 35.8	1987,07		1,00	A1	*EC* DE	
2	04 / 001 / 01 / 01	BOP cycle dummy element- C 22.8 / 1.0460	1988,08		1,00	A1	*EC* DE	
3	04 / 001 / 01 / 04	BOP cycle dummy element- 15 Mo 3	1989,01		1,00	A1	*EC* DE	
4	04 / 001 / 01 / 02	BOP cycle dummy element- 13 CrMo 4 4	1993,06		1,00	A1	*EC* DE	
5	08 / 001 / 01 / 03	BOP cycle dummy element- St 35.8	2000,07		1,00	A1	*EC* DE	
6	03 / 001 / 01	BOP cycle dummy element- ST_35.8	2001,02		1,00	A1	*EC* DE	
7	08 / 001 / 01 / 01	BOP cycle dummy element- C 22.8	2001,02		1,00	A1	*EC* DE	
8	11 / 001 / 01 / 03	BOP cycle dummy element- C 22.8	2001,03		1,00	A1	*EC* DE	
9	11 / 001 / 01 / 01	BOP cycle dummy element- 15 Mo 3	2001,03		1,00	A1	*EC* DE	
10	08 / 001 / 01 / 04	BOP cycle dummy element- 15 Mo 3	2001,04		1,00	A1	*EC* DE	
11	01 / 001 / 01	BOP cycle dummy element- ST_35.8	2001,05		1,00	A1	*EC* DE	
12	11 / 001 / 01	BOP cycle dummy element- 13 CrMo 4 4	2003,03		1,00	A1	*EC* DE	
13	08 / 001 / 01 / 02	BOP cycle dummy element- 13 CrMo 4 4	2003,04		1,00	A1	*EC* DE	
14	02 / 001 / 01	BOP cycle dummy element- ST_35.8	2003,09		1,00	A2	*EC* DE	
15	16 / 001 / 01	BOP cycle dummy element- WStE 355	2005,11		1,00	A1	*EC* **DE**	
16	05 / 001 / 01 / 01	BOP cycle dummy element- C 22.8	2006,07		1,00	B2	*EC* DE	
17	06 / 001 / 01 / 02	BOP cycle dummy element- St 37.4	2006,08		1,00	B2	*EC*	
18	06 / 001 / 01	BOP cycle dummy element- WStE 355	2006,12		1,00	B2	*EC*	
19	16 / 001 / 01 / 01	BOP cycle dummy element- 15 Mo 3	2007,02		1,00	A2	*EC* **DE**	
20	06 / 001 / 01 / 01	BOP cycle dummy element- C 22.8	2008,08		1,00	C2	EC	
21	09 / 001 / 01	BOP cycle dummy element- 10CrMo9-10 (10 CrMo 9 10)	2010,07		1,00			
22	09 / 001 / 01 / 02	BOP cycle dummy element- 13 CrMo 4 4	2011,01		1,00			
23	09 / 001 / 01 / 04	BOP cycle dummy element- 15 Mo 3	2013,06		1,00			
24	05 / 001 / 01	BOP cycle dummy element- 10CrMo9-10 (10 CrMo 9 10)	2013,11		1,00		DE	
25	09 / 001 / 01 / 01	BOP cycle dummy element- C 22.8	2016,12		1,00			
26	09 / 001 / 01 / 03	BOP cycle dummy element- St 35.8	2018,10		1,00			
27	04 / 001 / 01	BOP cycle dummy element- 10CrMo9-10 (10 CrMo 9 10)	2018,12		1,00		EC DE	
28	07 / 001 / 01	BOP cycle dummy element- ST_35.8	2019,05		1,00		EC	

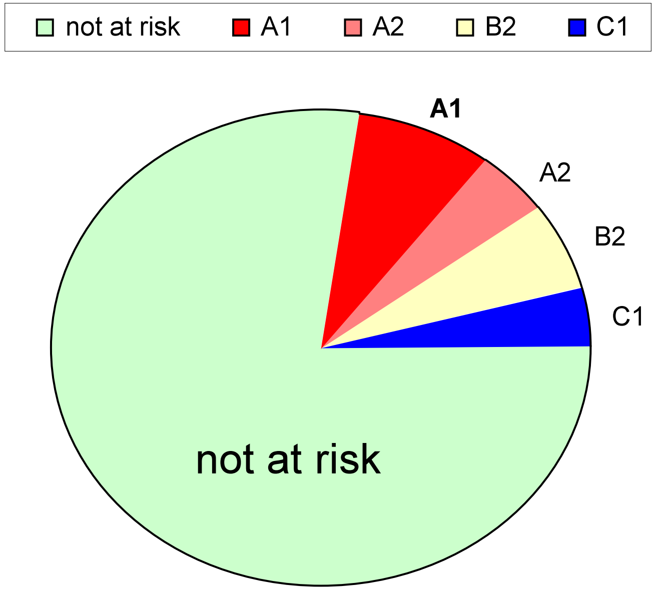
The ranking table serves to rank system risk potential for each system element considered.

Use export function to generate EXCEL table holding data displayed

Plant-Wide Screening Analysis – Benefit

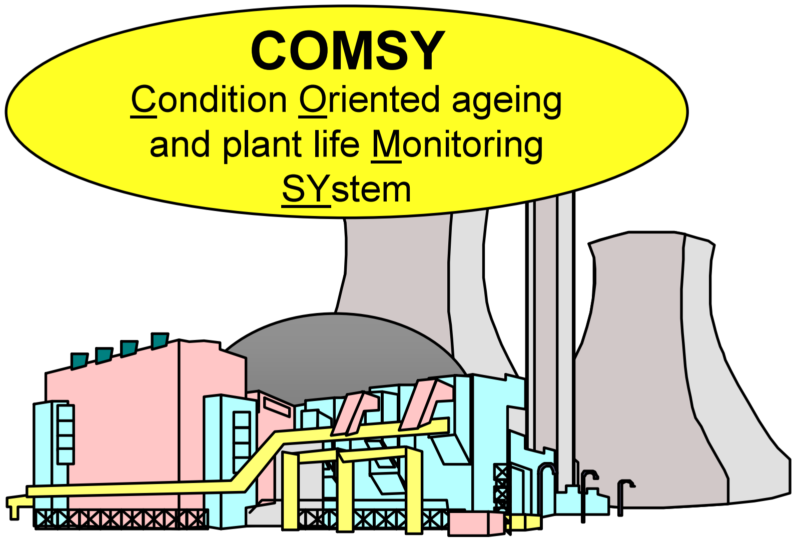


The rough analysis results indicate which systems have a limited service life based on the operating parameters and the materials used.

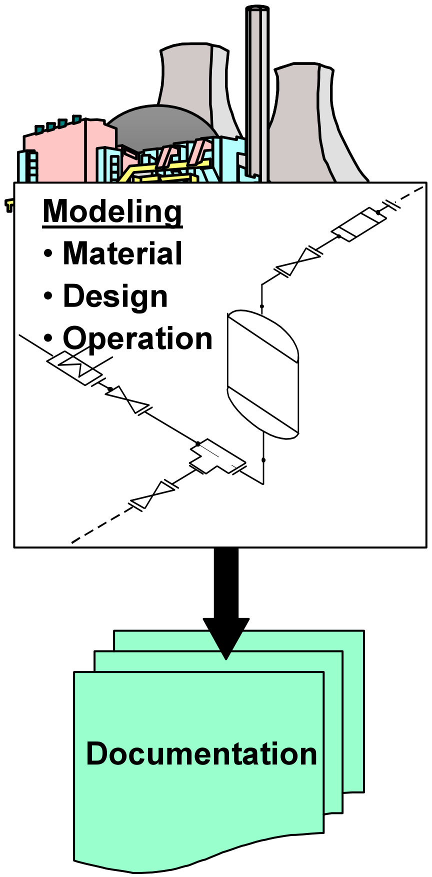


As indicated by the rough analysis for a typical PWR, some 77% of the systems are definitively not at risk due to relevant degradation and need not to be examined in the future.

Detailed analysis



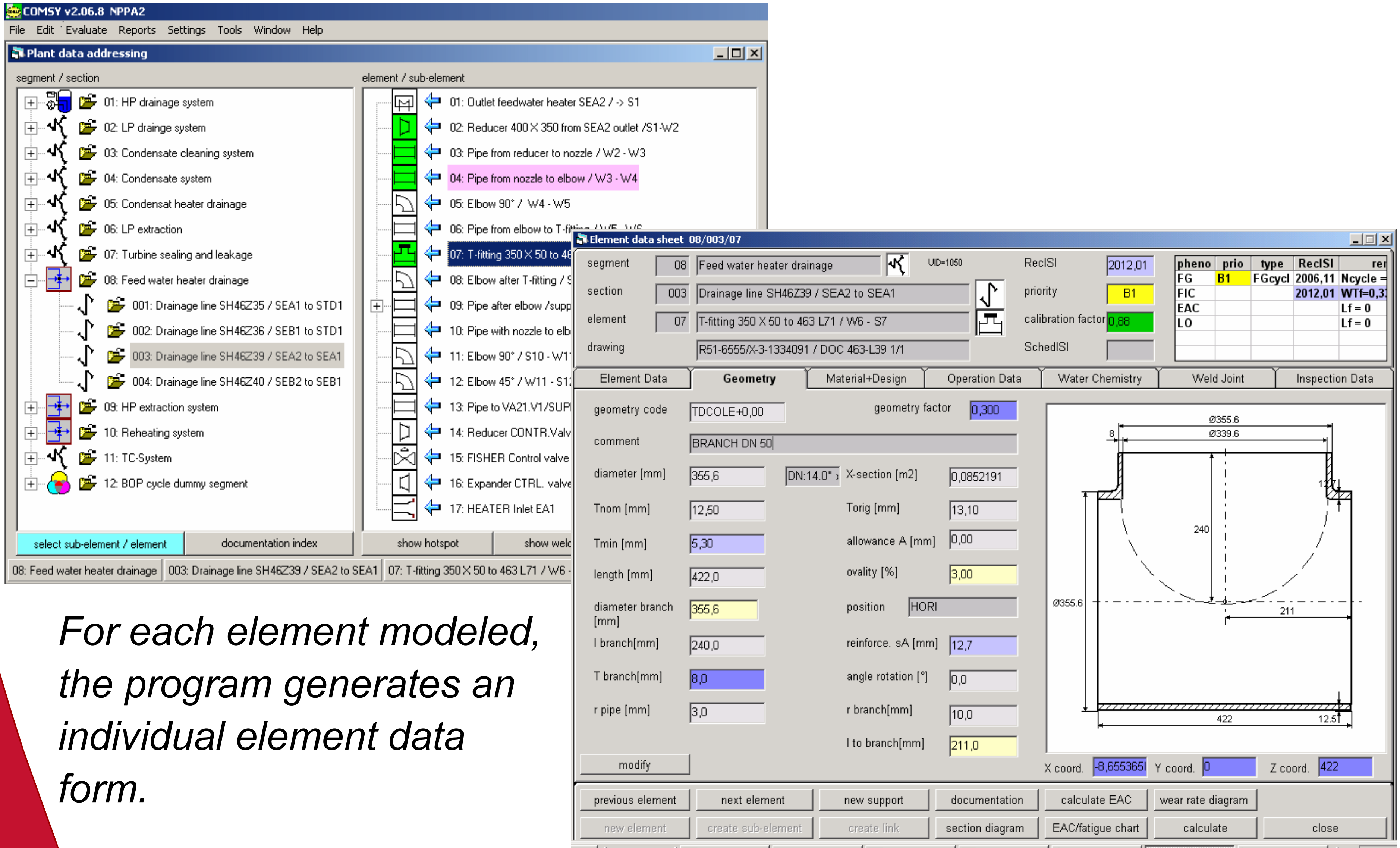
Detailed analysis
- Modeling of relevant systems, lines and vessels



> *Element geometry*
> *Design criteria*
> *Material specification*
> *Thermal-hydraulic operation*
> *Water chemical properties*
> *Mechanical loads*
> *Material certificate values, if available*

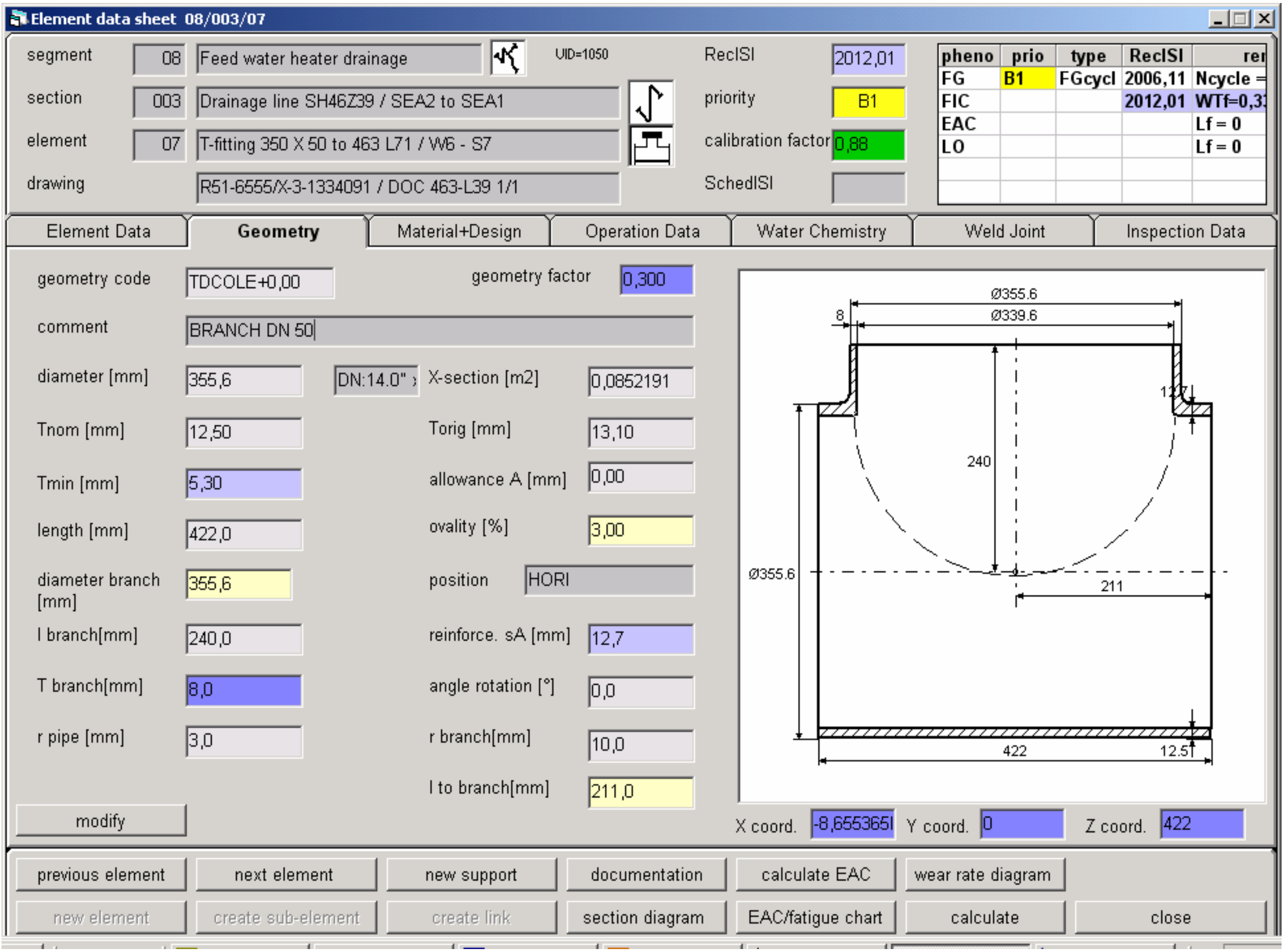
The modeling process is efficiently supported by useful engineering tools and a detailed material data library

Detailed analysis
- Managing piping and vessel data



For each element modeled, the program generates an individual element data form.

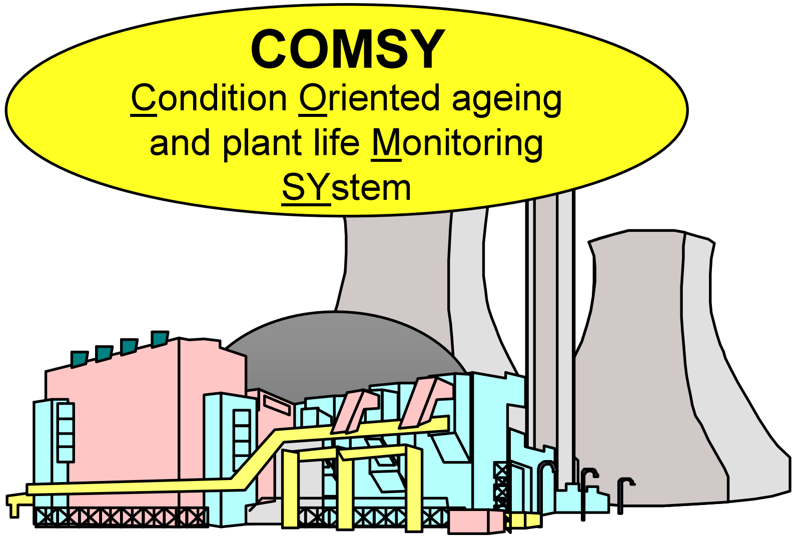
Detailed analysis – Component data sheet



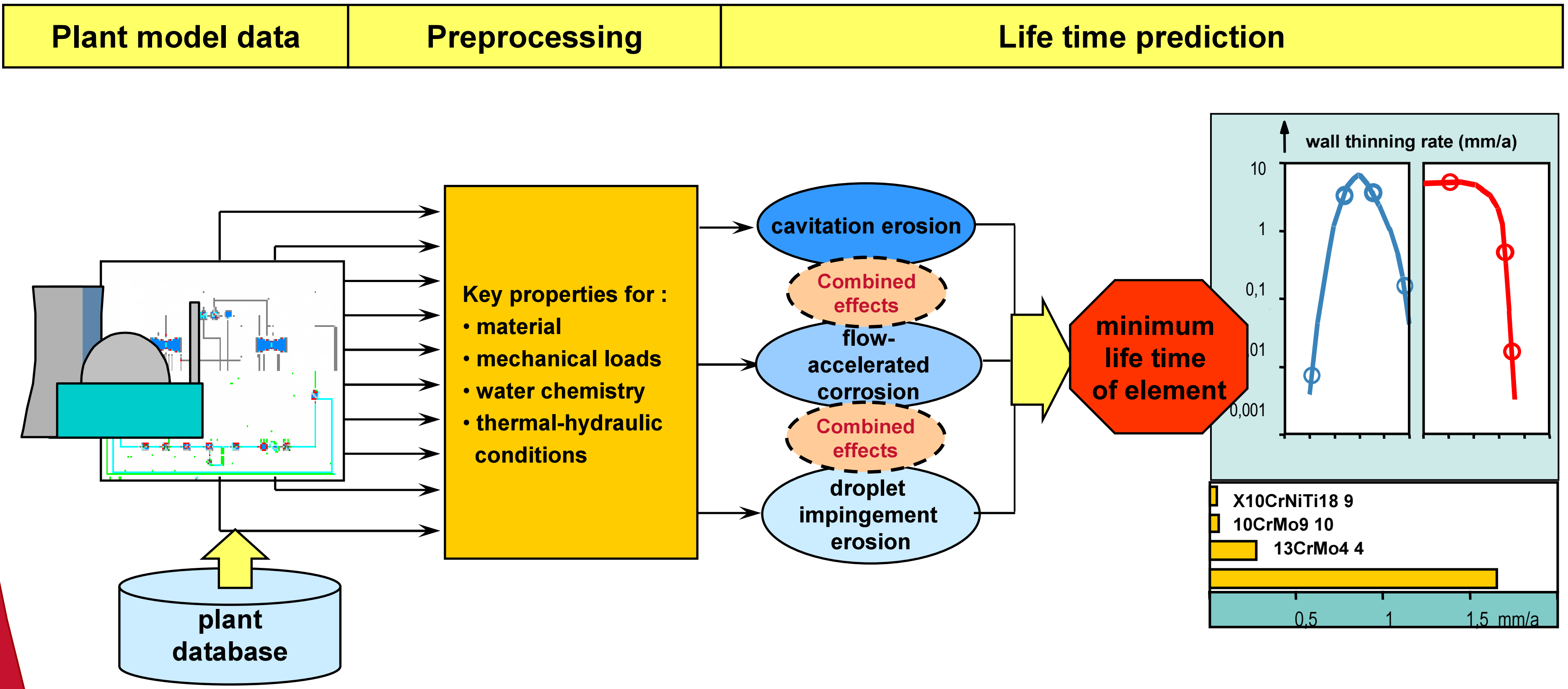
The component data sheet summarizes data on relevant degradation mechanisms, component design, operating conditions, water chemistry and materials applied.

Additional information are supplemented, e.g. examination records, load cycle or specific documents

Life Time Prediction Process

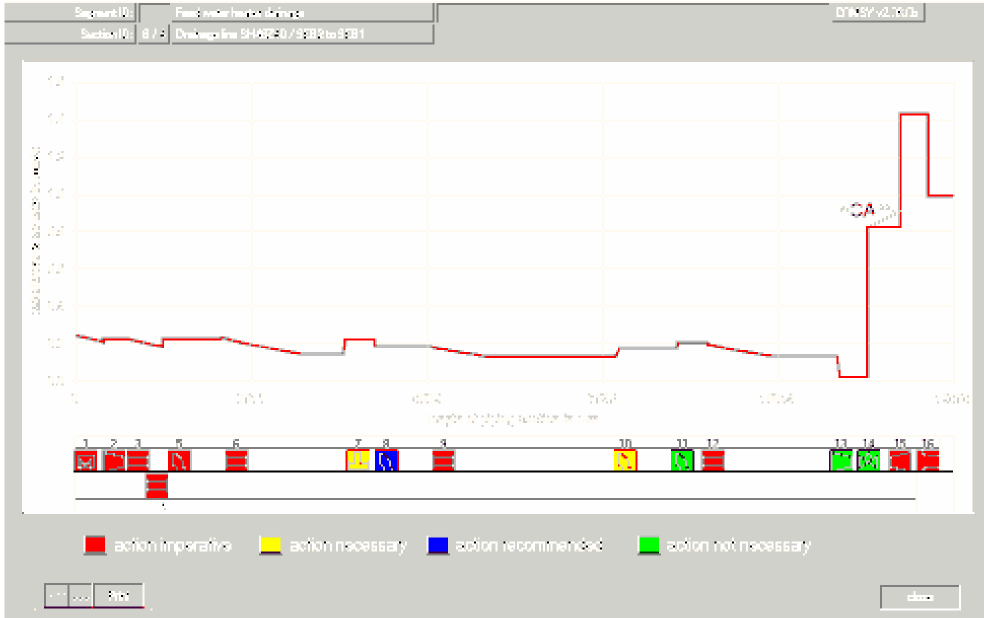


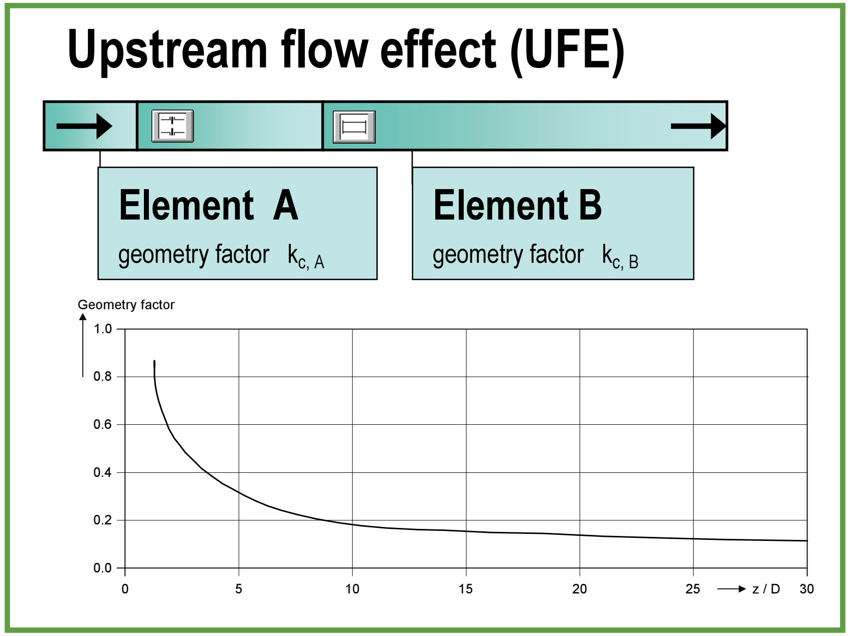
Life Time Prediction Process
- Overview



COMSY uses sophisticated corrosion models to conservatively predict the progress of material degradation for e.g. flow-accelerated corrosion and to determine the life expectancy for individual elements.

Life Time Prediction Process
- Boundary Conditions



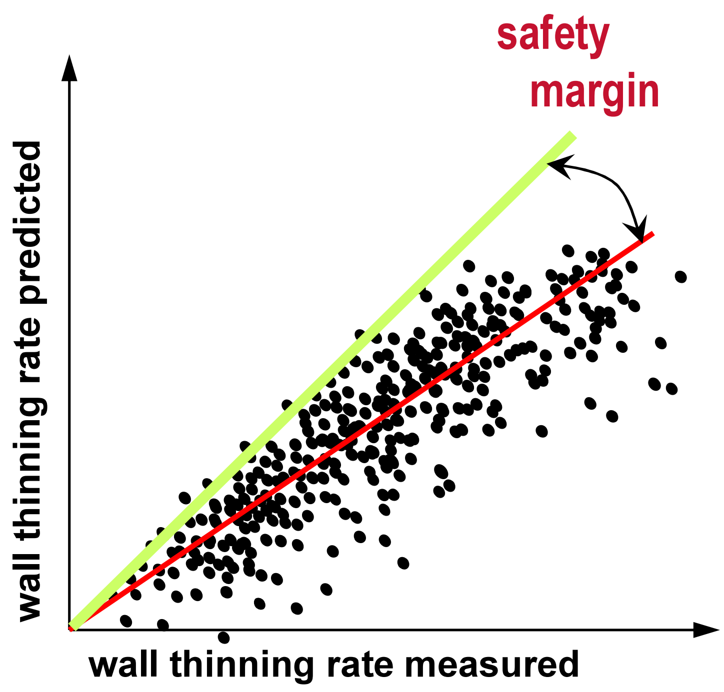


The evaluation of the flow-accelerated corrosion lifetime considers the influence of local turbulences in a continuous piping section.

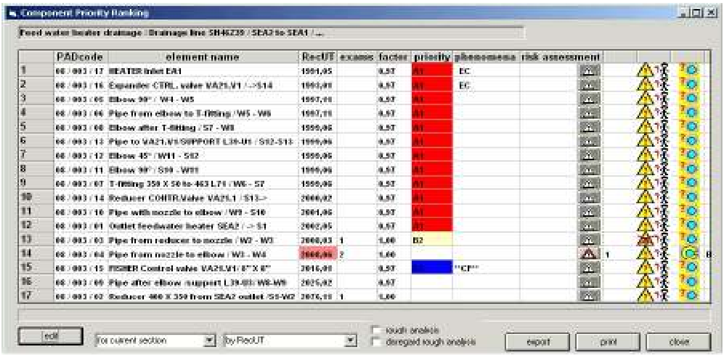
The profile illustrates the effect of, e.g. high local turbulence on the computed wall thinning.

Life Time Prediction Process
- Prediction philosophy for wall thinning rates

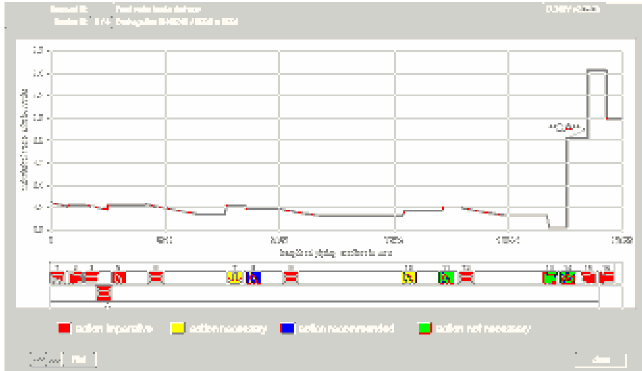
- Uncertainties on wall thinning computation are considered via a safety margin in order to ensure safe operation
- The computed wear is considered the maximum probable wall thinning rate for element under specified operating conditions. The result indicates the minimum life expectancy of the element
- The safety margin is reduced after measurement results are made available



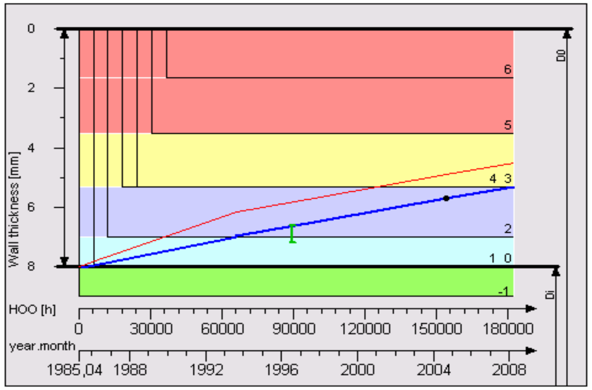
Prediction of Residual Lifetime for Plant Elements
e.g. FAC / EC (erosion corrosion)



After the modeling process is completed, a lifetime prediction can be initiated.

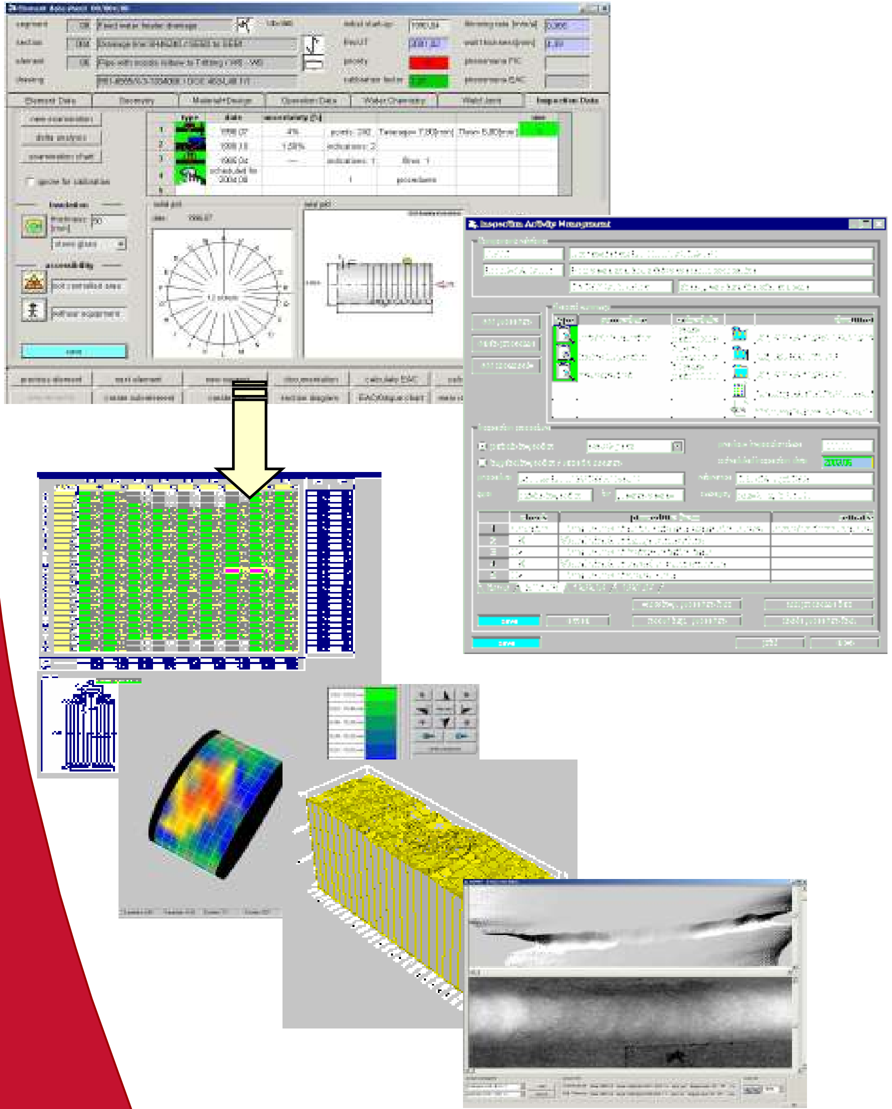


The diagram indicates predicted wall thinning rates caused by flow accelerated corrosion which are plotted versus the length of a line.



A lifetime chart demonstrates the predicted progress of wall thinning versus the operating time of the plant.

Inspection and examination record management



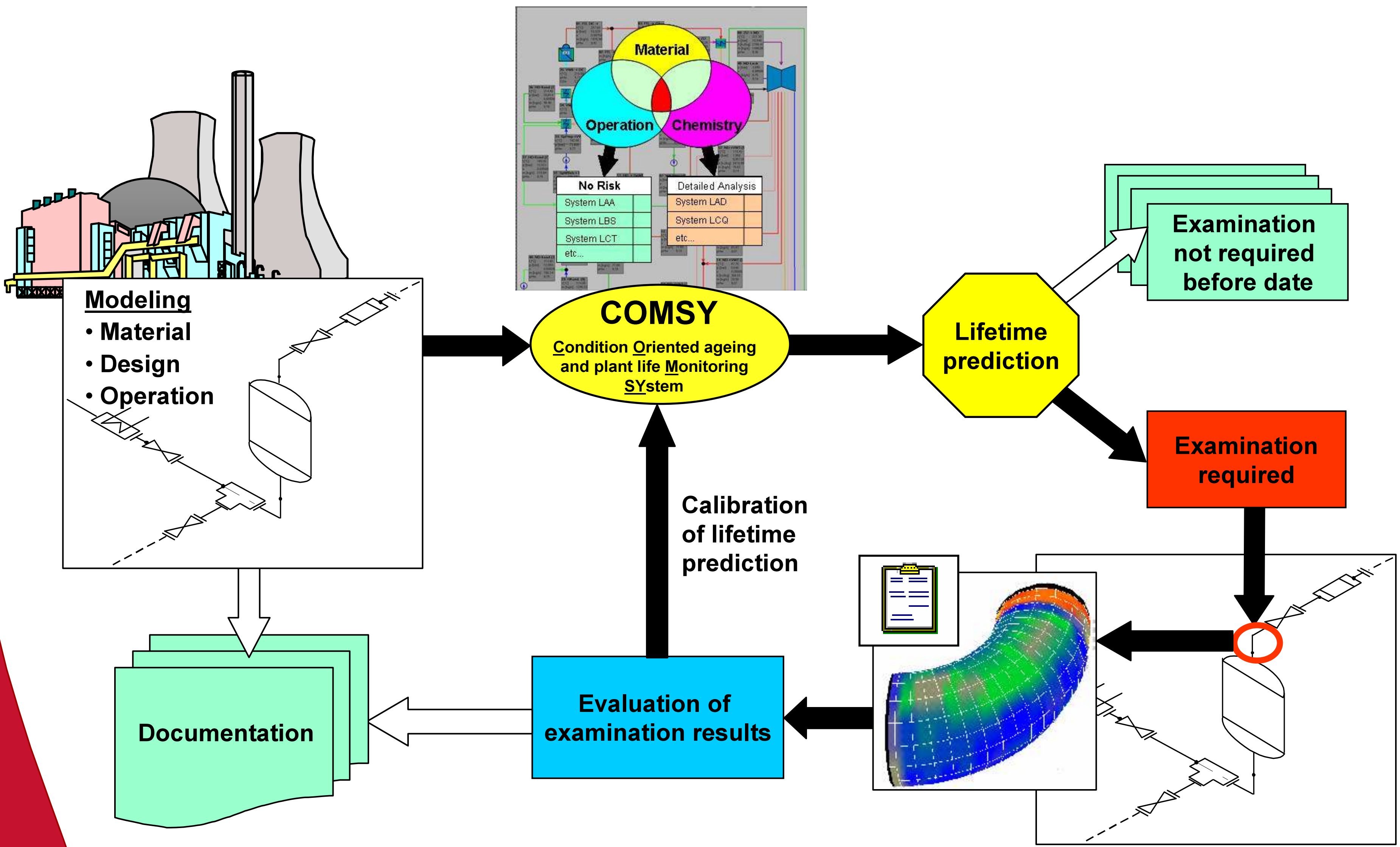
After an examination procedure is completed, the examination results are fed into the COMSY database. Subsequently they are used for further optimize the inspection scope.

COMSY acquires and assesses examination records from:

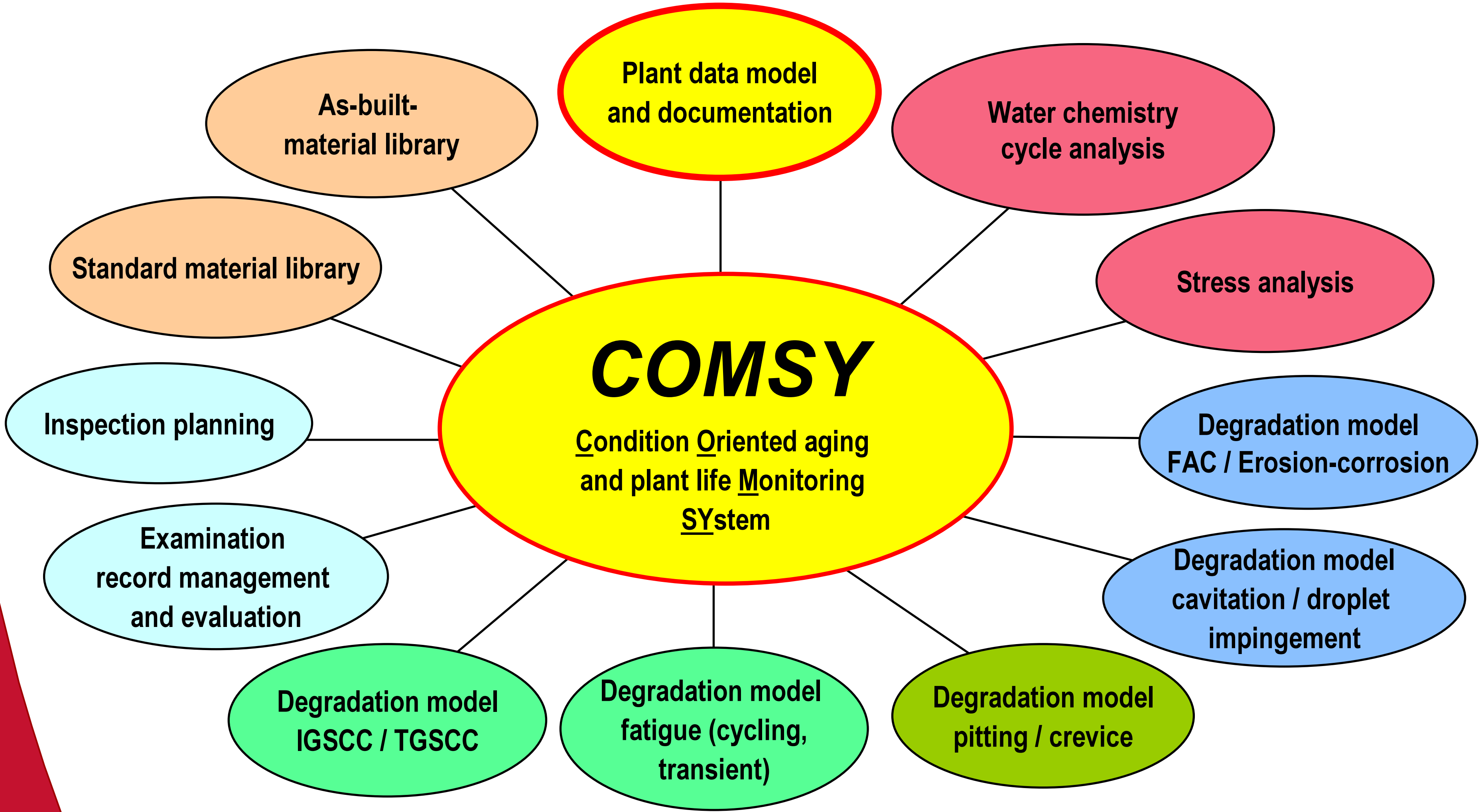
- ***UT wall thickness examination***
- ***UT flaw detection***
- ***Radiographic examination***
- ***Visual inspection***
- ***Liquid penetration examination***
- ***Magnetic particle examination***

and further the capability to manage periodic inspections.

The COMSY Closed Loop Process for Plant Life Management



Conclusions – Software modules



Conclusions – Characteristics

> COMSY copes with

- the large number of parameters affecting flow-induced corrosion (FAC, droplet impingement erosion and cavitation erosion) as well as
- the complexity of their functional interdependencies.

> COMSY allows

- the reliable identification of piping elements which may suffer material loss due to FIC,
- to calculate the minimum residual lifetime of piping elements affected by FIC to streamline inspection effort and
- to check countermeasures prior to their implementation.

COMSY is a proven and ready-to-use tool with user interfaces in different languages and provides common materials and stress calculation for various countries

COMSY – References

Service Applications

Philippsburg 1+2
Krümmel
Isar 1+2
Brunsbüttel
Biblis A+B
Gundremmingen B
Borssele
Beznau 1
Gösgen
Leibstadt
Almaraz 1+2
Oskarshamn 3
Forsmark 1+2
Fukushima 2-1
Different fossil fired plants
OL3 lifetime design services
Chinshan 1

Software Licenses

Spain :	Asco 1+2 Almaraz 1+2 Cofrentes St. Maria de Garona
Finland :	Loviisa 1+2
Hungary :	Paks 1 to 4
Bulgaria :	Kozloduy 1 to 4
Japan :	Tomari 1+2
Brazil :	Angra 1&2
Belgium:	8 fossil fired plants