



# *The KKL Program for the Prevention of Piping Degradation due to FAC Phenomena*

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*Kernkraftwerk Leibstadt AG*

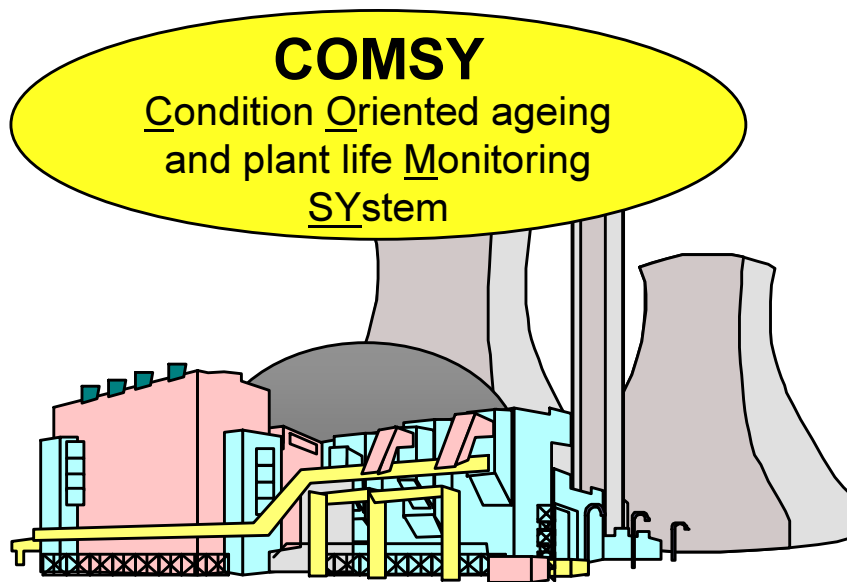
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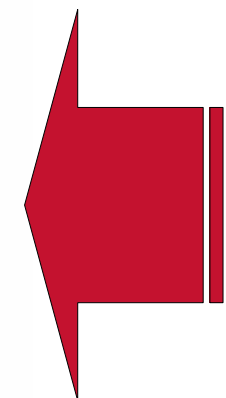
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- > *Introduction*
- > *Application in case of Leibstadt NPP*
- > *Identification of FIC potential*
- > *Performing of Inspections*
- > *Examination Result Assessment*
- > *Summary of KKL FAC program*
- > *Influence of hydrogen dosing on the FAC rate*
- > *Conclusions*

# *Introduction*



# Approaches for FAC assessment – Objectives



*The following six parameters form the columns of an effective FAC program.*

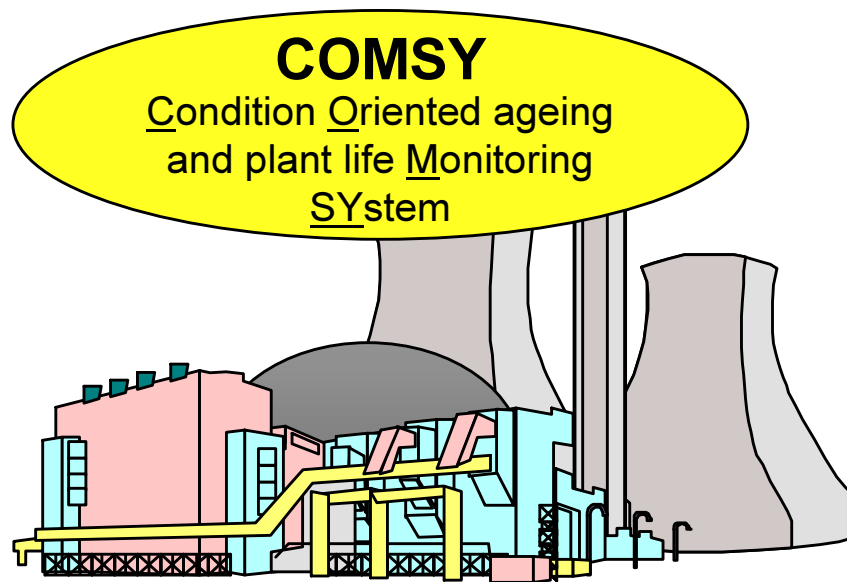
*Note: All of the six key elements are interrelated and must be used together, not as substitutes for each other.*



# Approaches for FAC assessment – Long-Term Strategy

- > *The establishment and implementation of a long-term strategy is essential to the success of a plant FAC program. Effective measures to reduce FAC effects are e.g.:*
  - ❑ *Optimizing the water chemical treatment*
  - ❑ *Apply improved material concepts for replaced components or lines and/or sufficient wall thickness margins*
  - ❑ *Apply qualified repair technologies (e.g. METCO spraying, sheet metal cladding)*
  
- > *In case of changes in system operation conditions (e.g. power uprate) the effect on FAC degradation rates should be analyzed before implementation and appropriate precautions should be initiated.*

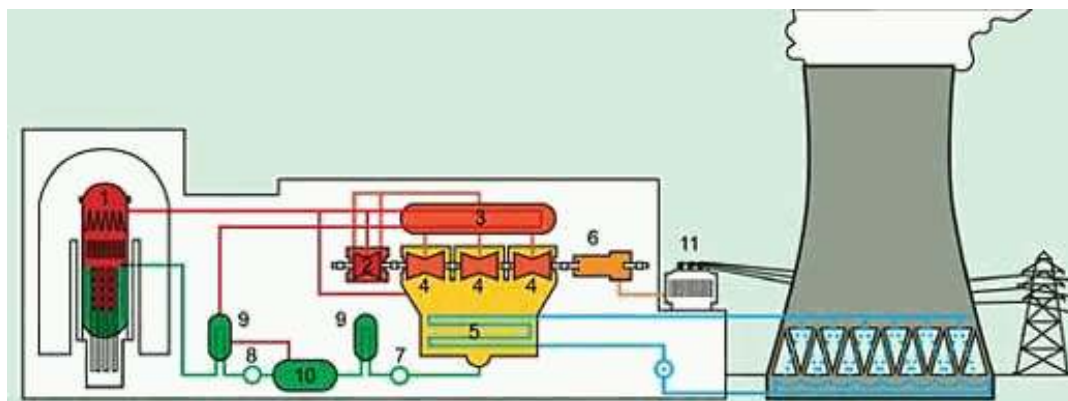
# *Application in case of NPP Leibstadt*



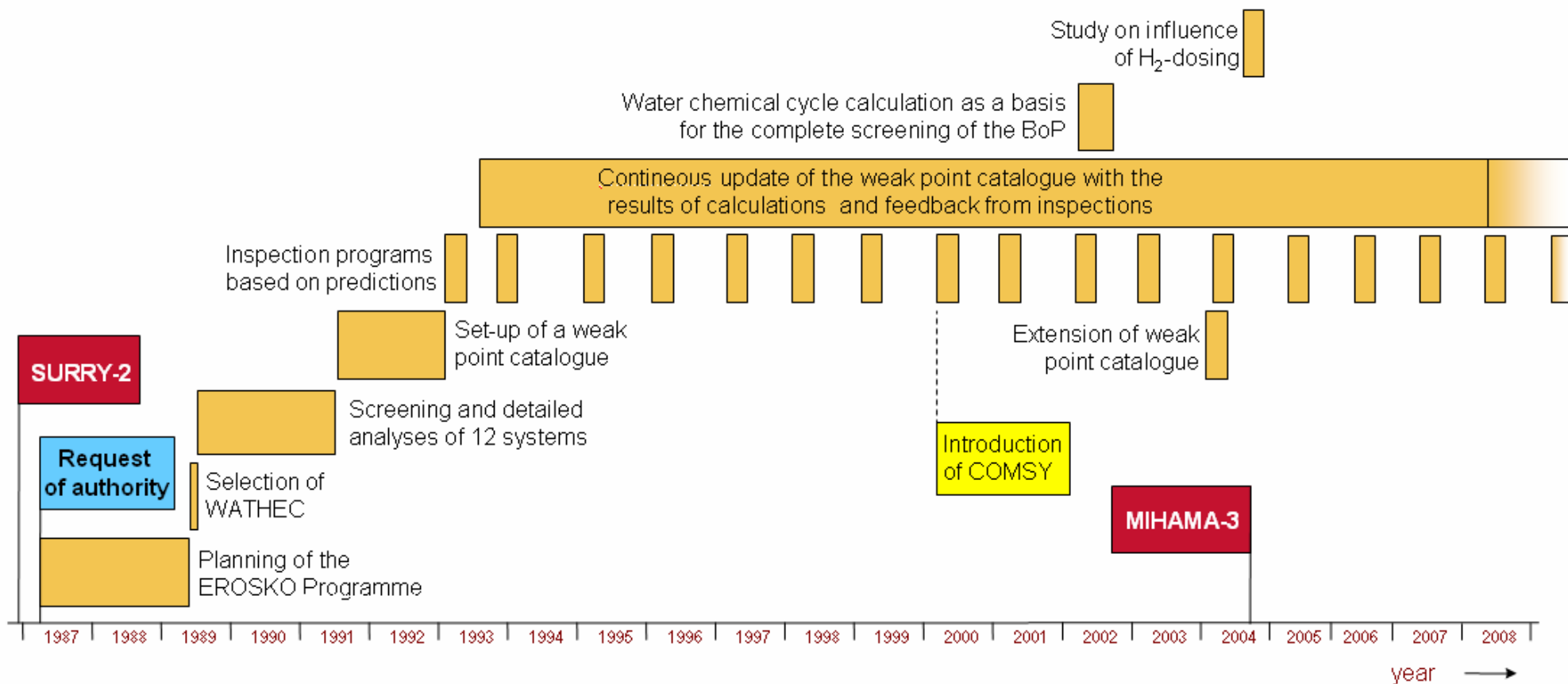
# Leibstadt NPP



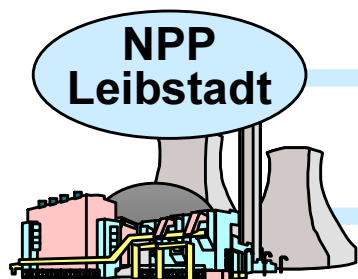
- 1984** Start-up (December 15th)  
Net power 950 MW
- 1986** Net power uprate to 990 MW
- 1995** Net power uprate to 1035 MW
- 1999** Net power uprate to 1080 MW
- 2000** Net power uprate to 1'115 MW
- 2001** Net power uprate to 1145 MW
- 2003** Net power uprate to 1'165 MW,  
Net production 9'300'000 MWh,  
Load factor 91.4 %, 8'204 hours of operation



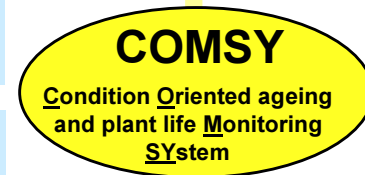
# History of NPP Leibstadt Activities



# Approach of NPP Leibstadt FAC Program

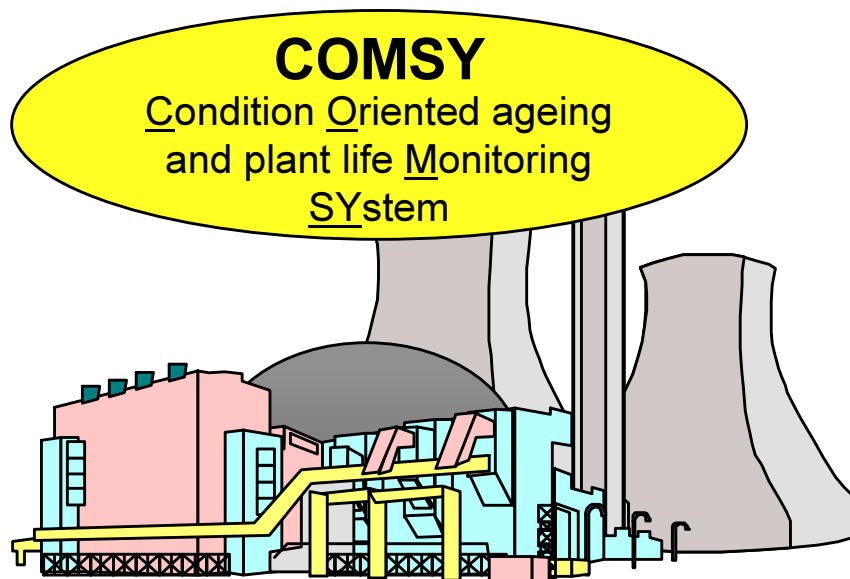


- ❑ *Identification of pipes and piping components potentially susceptible to FIC*
- ❑ *Targeted inspection of components by means of wall thicknesses measurements*
- ❑ *Visual inspections for large-diameter piping*
- ❑ *Evaluation and documentation of wall thickness measurements and inspections including examination result assessment*
- ❑ *Initiation of repair and replacement measures, if indicated*

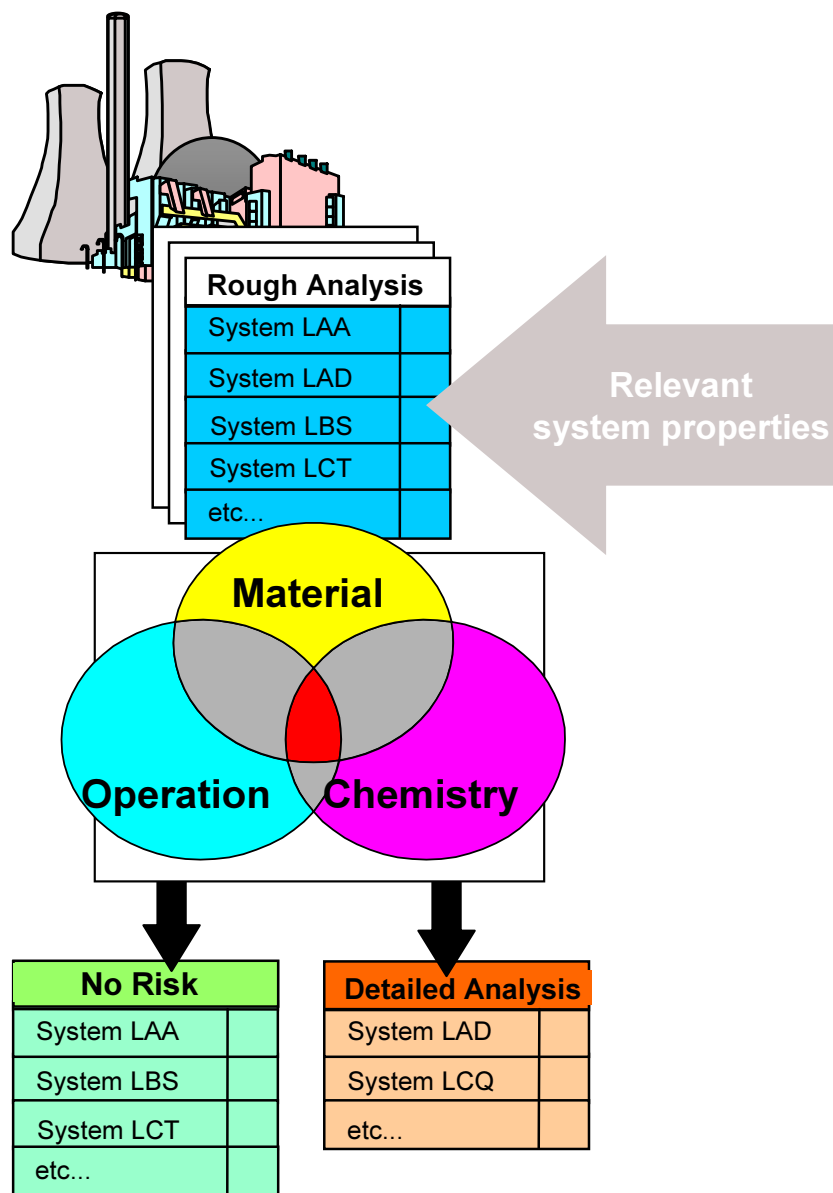


# *Identification of FIC potential*

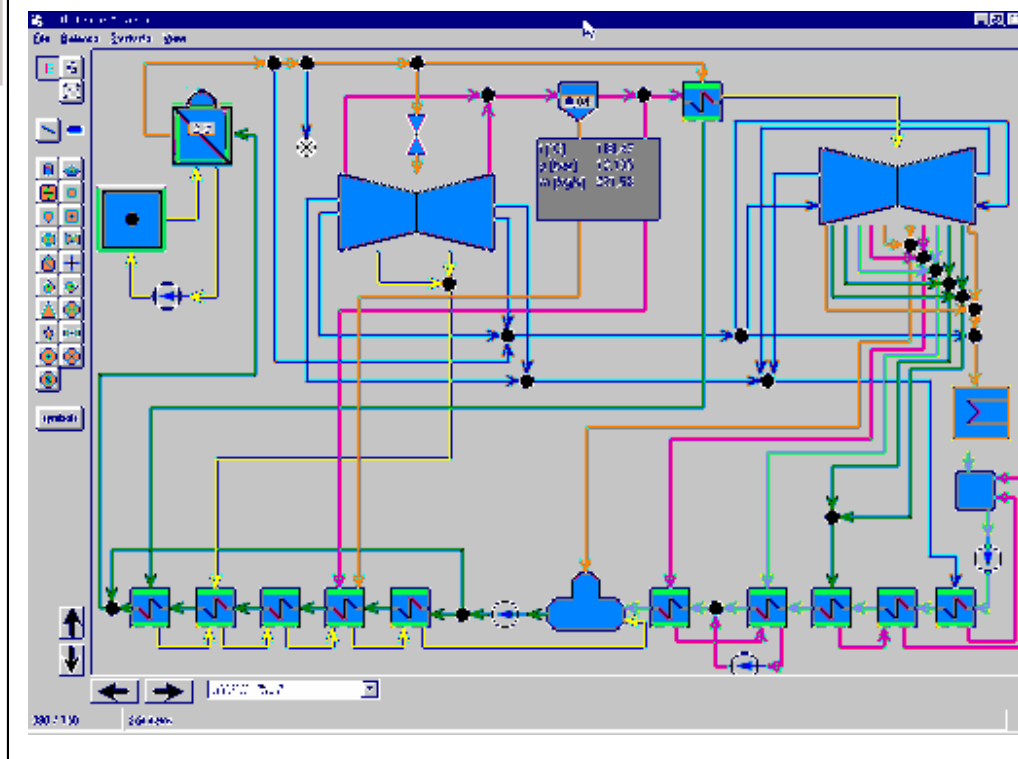
*(Screening of the BoP, Detailed analysis)*



# Screening process - Identification of Degradation Sensitivity

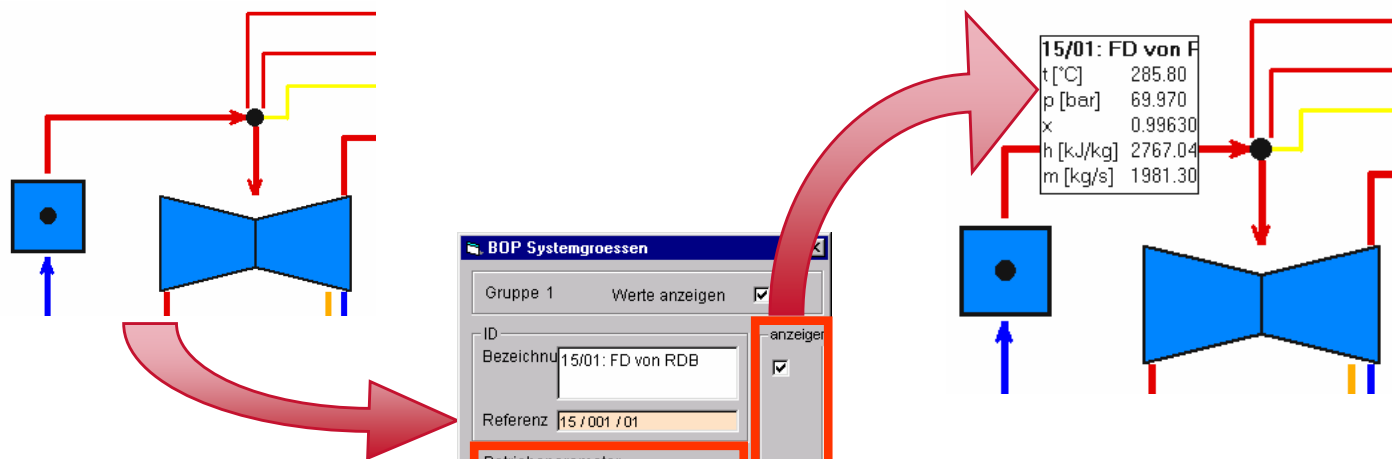


- > **Thermal-hydraulic properties**
- > **Water chemistry cycle analysis**
- > **Material properties**

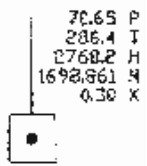


# Screening process - Modeling of the BoP

Each system is represented by the connecting lines of two symbols



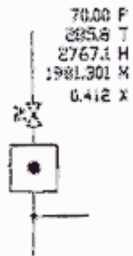
before power uprate



Power uprate, step 1



step 2



**BOP Systemgroessen**

Gruppe 1 Werte anzeigen

ID:

Bezeichnung: 15/01: FD von RDB

Referenz: 15/001/01

**Betriebsparameter**

Temperatur	285,80	[°C]	<input checked="" type="checkbox"/>
Druck	69,970	bar	<input checked="" type="checkbox"/>
Dampfgehalt	0,99630		<input checked="" type="checkbox"/>
Enthalpie	2767,04	kJ/kg	<input checked="" type="checkbox"/>
Durchsatz	1981,30	kg/s	<input checked="" type="checkbox"/>

bearbeiten

Wasserchemie

	total	Wass
pH Wert [°C]	7,00	7,00
O <sub>2</sub> [ppb]	9000,00	55,17

bearbeiten

Werkstoff

X6CrNiMoTi17-12-2

bearbeiten

**Betriebsparameter**

bis	Temperatur	Druck	Dampfgehalt	Durchsatz
1994,08	286,40	70,59	0,998	1698,86
1996,08	286,40	70,59	0,998	1698,86
*NIA*	285,80	69,97	0,996	1981,30

Durchsatz [kg/s]:  Kommentar fuer Periode: LE-2: Neue HD-Beschaufelung

Temperatur [°C]:

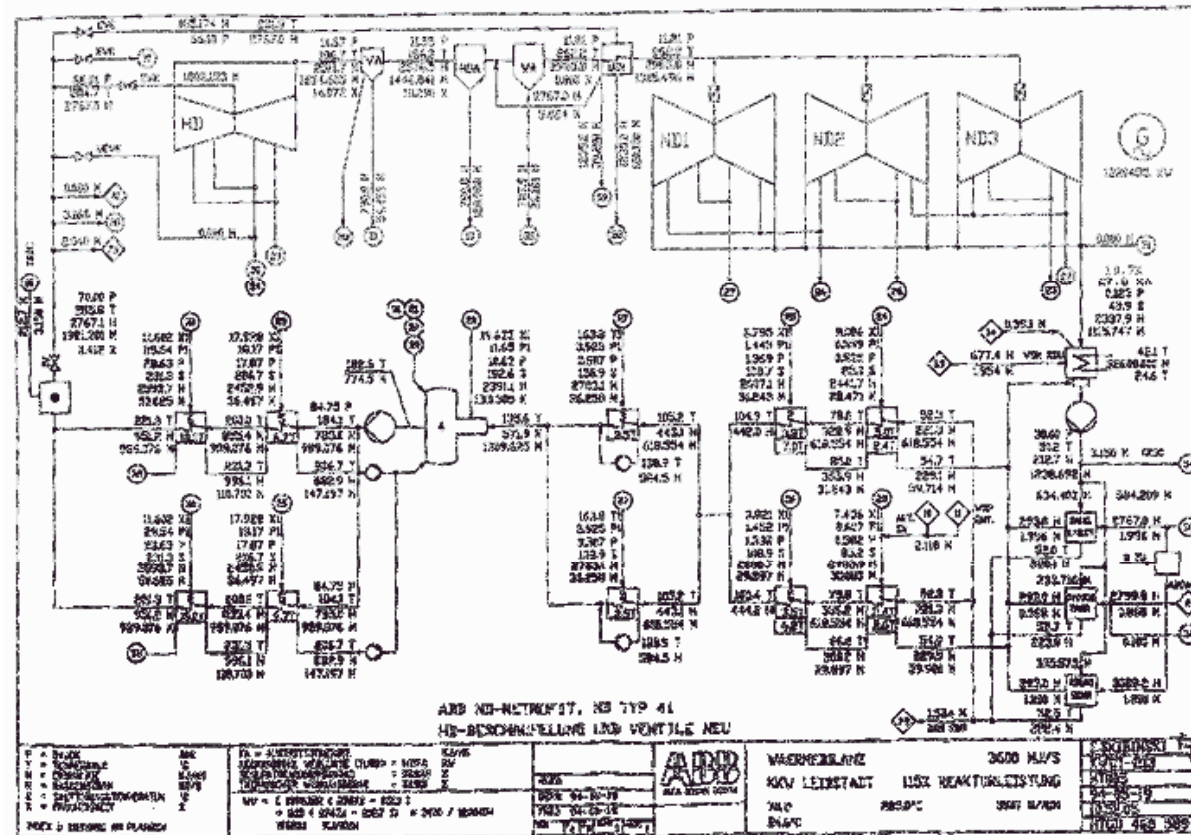
Druck [bar]:

Dampfgehalt:  Enthalpie [kJ/kg]:

bearbeiten Periode

Operating parameters are specified for systems modelled

- > *The BoP of the power plant is the basis for the screening process and used to create the structure of the virtual data model.*
- > *The results of the screening process allow to focus activities on systems which are endangered by FAC according their design, operating and water chemical parameters as well as the materials used.*

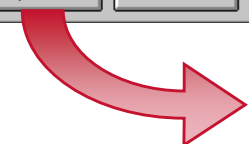
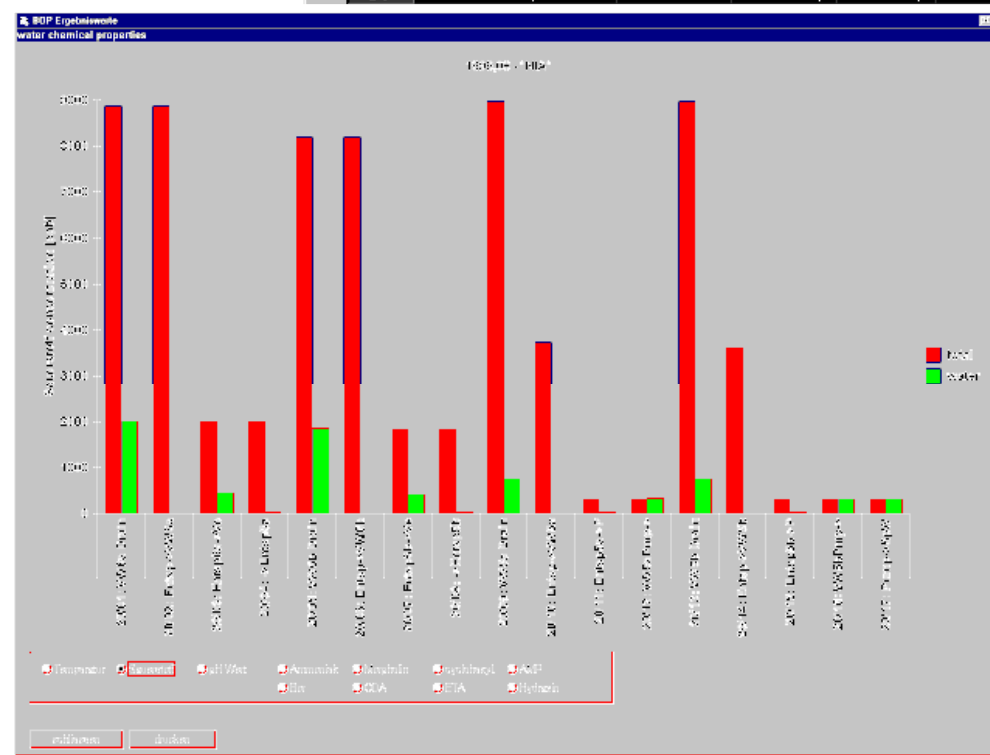


# Screening process - Evaluation

Wasserchemie-Analyse

BOP properties for operating period : 1996,08 - \*NIA\*

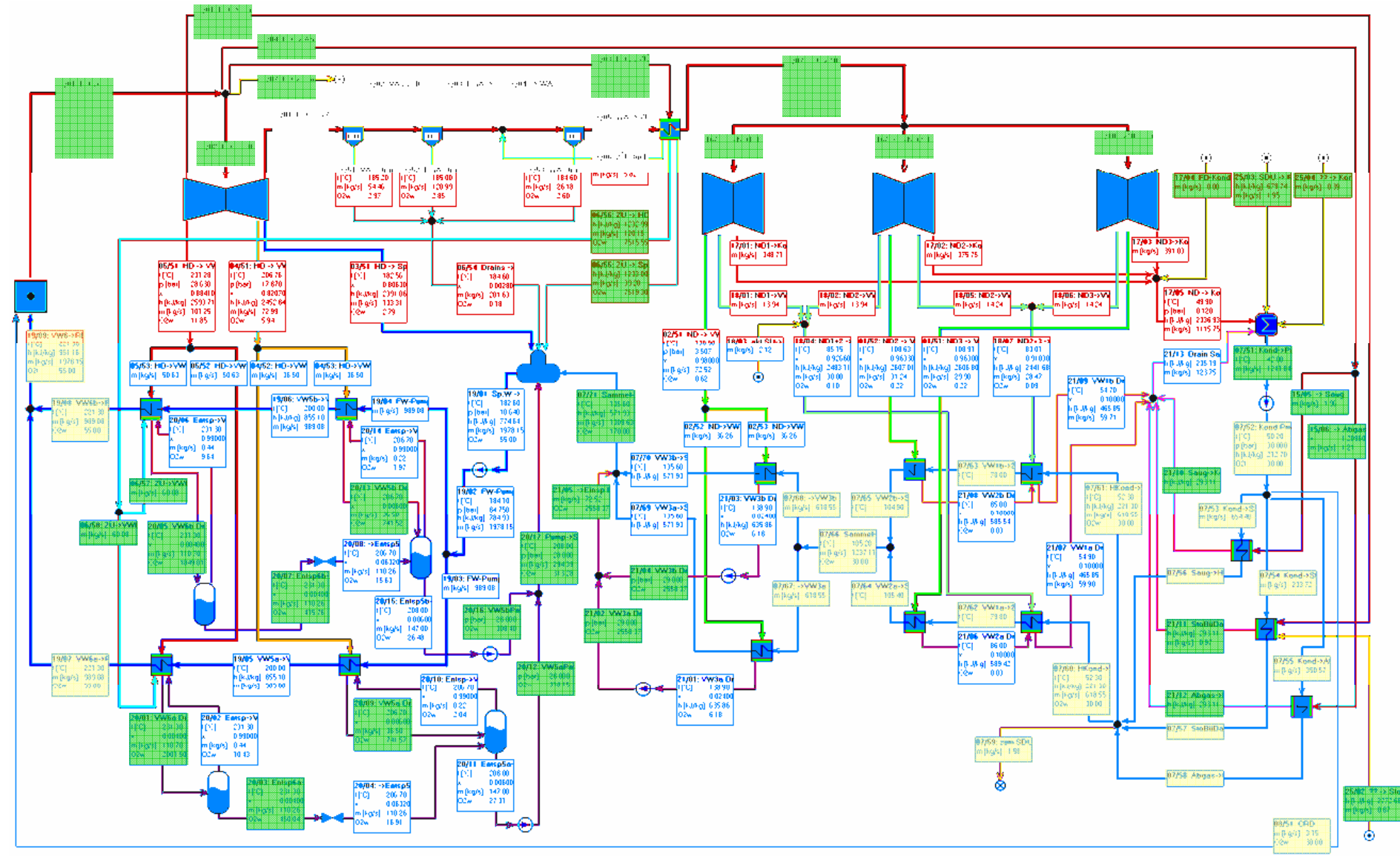
	Gruppenkennung	PADcode	Temperatur [°C]	Druck [bar]	Dampfgehalt	Enthalpie [kJ/kg]	Durchsatz [kg/s]	Medium	O2total [ppb]	O2wasser [ppb]	pH total 25°C	wa
73	19/02: FW-Pump->VW	19/002/01	184,1	84,8	0	784,9	1978,152	subcooled	55	55	7	
74	19/03: FW-Pump->VW	19/003/01	184,1	84,8	0	784,9	989,076	subcooled	55	55	7	
75	19/04: FW-Pump->VW	19/004/01	184,1	84,8	0	784,9	989,076	subcooled	55	55	7	
76	19/05: VW5a->VW6a	19/005/01	200	82	0	855,1	989,076	subcooled	55	55	7	
77	19/06: VW5b->VW6b	19/006/01	200	82	0	855,1	989,076	subcooled	55	55	7	
78	19/07: VW6a->RDB	19/007/01	221,3	80	0	951,2	989,076	subcooled	55	55	7	
79	19/08: VW6b->RDB	19/008/01	221,3	80	0	951,2	989,076	subcooled	55	55	7	
80	19/09: VW6->RDB	19/009/01	221,3	80	0	951,2	1978,152	subcooled	55	55	7	
81	20/01: VW6a Drain	20/001/01	231,3	28,6	0,004	1003,5	110,7	saturated	8865,8	2001,5	7	
82	20/02: Entsp->VW6a	20/002/01	231,3	28,6	0,99	2785,1	0,443	wet steam	8865,8	10,4	7	
83	20/03: Entsp6a->Ve	20/003/01	231,3	28,6	0,004	1003,5	110,257	saturated	1993,5	450	7	
84	20/04: ->Entsp5a	20/004/01	206,7	17,9	0,063	1003,6	110,257	two-phase	1993,5	16,9	7	
004						1003,5	110,7	saturated	8190,3	1849	7	
99						2785,1	0,443	wet steam	8190,3	9,6	7	
004						1003,5	110,257	saturated	1841,6	415,8	7	
063						1003,6	110,257	two-phase	1841,6	15,6	7	
006						894,2	36,497	saturated	8968,6	741,6	7	
99						2776,6	0,219	wet steam	3728,2	2	7	
006						900	147	saturated	318,2	27,3	7	
0						888,9	147,197	subcooled	318,2	318,2	7	
006						894,2	36,497	saturated	8967,9	741,5	7	
99						2776,6	0,219	wet steam	3613,9	2	7	
006						900	147	saturated	308,4	26,5	7	
0						888,9	147,197	subcooled	308,4	308,4	7	
0						888,9	294,394	subcooled	313,3	313,3	7	
024						635,9	36,258	saturated	2558,4	6,2	7	
0						586,1	36,258	subcooled	2558,4	2558,4	7	
024						635,9	36,258	saturated	2558,4	6,2	7	
0						586,1	36,258	subcooled	2558,4	2558,4	7	
0						586,1	72,516	subcooled	2558,4	2558,4	7	
0.1						500,4	20,907	two-phase	404,9	0	7	



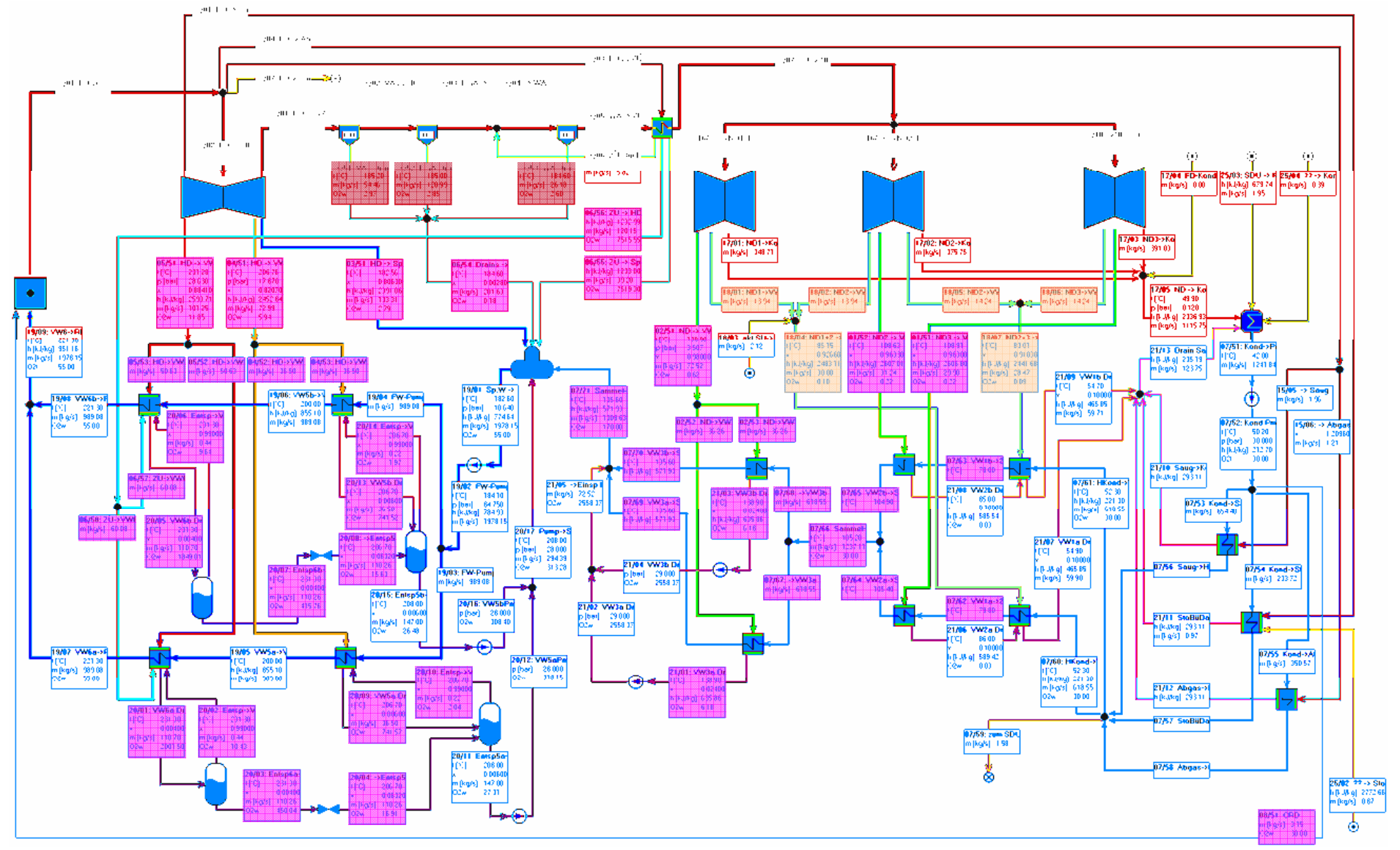
# Screening of the BoP - Results

No activities necessary

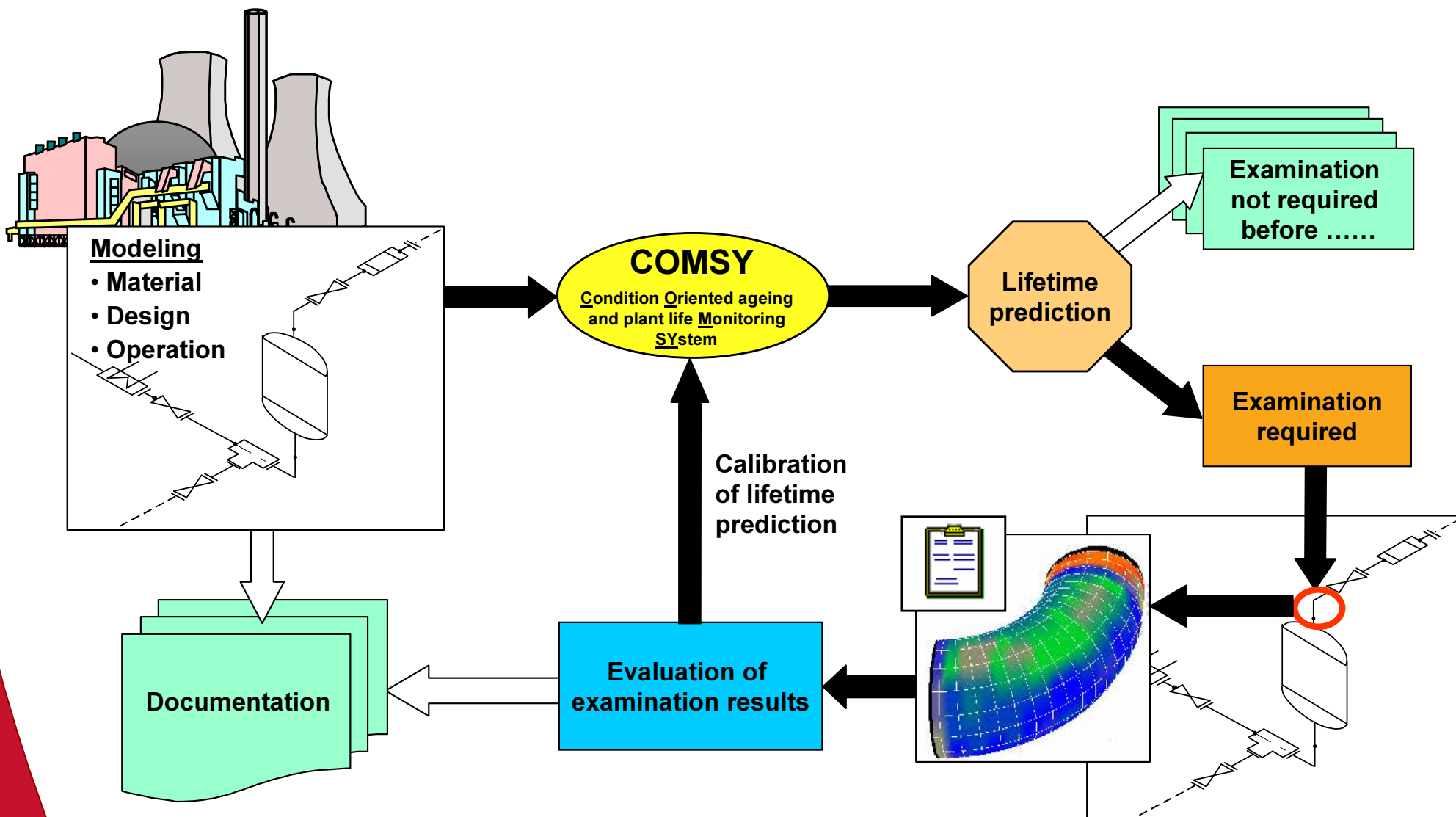
Long term activities



## Under surveillance Further analyses recommended

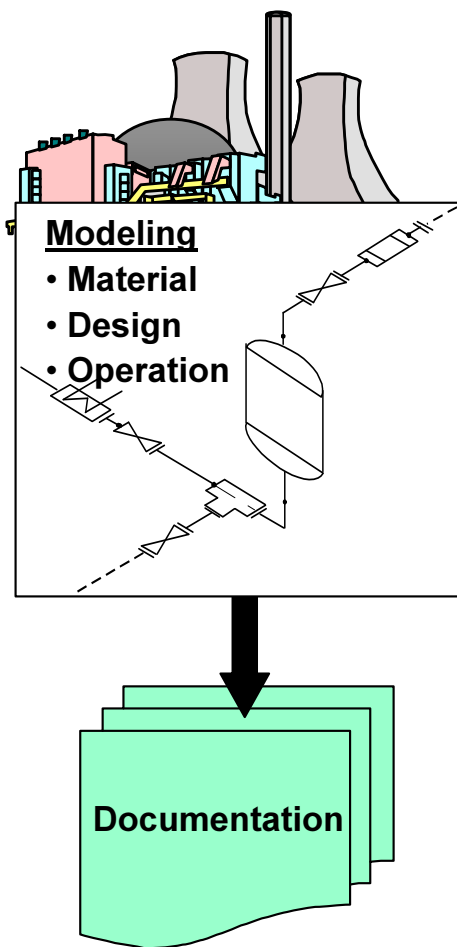


# Detailed analysis of components and systems



# 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

The screenshot displays the COMSY v2.08.1d KKL - [Plant data addressing] software interface. The main window is divided into two panes: 'segment / section' on the left and 'element / sub-element' on the right. The left pane shows a hierarchical tree of piping elements, with '05: RG 52 Z 200' selected. The right pane shows a detailed data sheet for the selected element, '05: RG 52 Z 200'. The data sheet includes fields for geometry, material, operation, and water chemistry data.

**Element data sheet: 06/005/25**

segment	06	Abscheider-Kondensat (RG50)	UID=633	Rec-ISI	2024.05	pheno	type
section	005	RG 52 Z 200		priority		FIC	*EC*
element	25	Bogen 90 Grad		Sched-ISI			wall thickness 4.6 [mm]
drawing		MW 313.303-1 KKL:3010/832118		calibration factor	0.47		thinning rate 0.147 [mm/a]

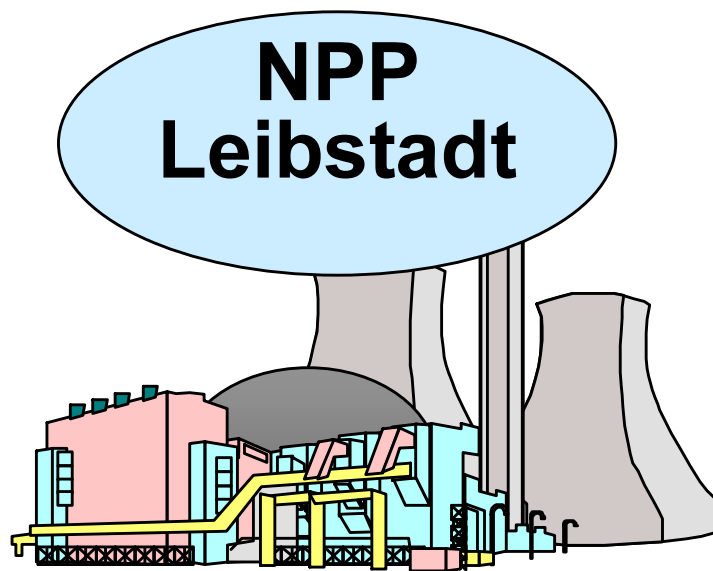
**Element Data**

Geometry	Material+Design	Operation Data	Water Chemistry	Weld Joint	Inspection Data		
location		start-up	1984.05	AAP [%]	86.00	HOO total [h]	187711
Geometry Data		temperature [°C]	180.00	pressure [bar]	14.50	steam quality	0.000000
geometry code	BECOLE+0.00	geometry factor	0.312	flow rate [kg/s]	86.0000	enthalpy [kJ/kg]	763.37
diameter [mm]	273.00	DN:250   -NS-		velocity [m/s]	1.849	oxygen water [ppb]	5.4854
Tnom [mm]	7.30	Torig [mm]	7.30	pH water at 25°C	7.000	UT wall thickness	1997.08 Tlow= 6.10[mm] accuracy: 3% ,176 points
Tmin [mm]	2.64	allowance A [mm]	0.00	documentation			(1 documents)
length [mm]	598.00	angle [°]	90.0				
Design Data		pressure [bar]	25.00	temperature [°C]	200.0		
Material Data		material code	St 35.8 / 1.0305				

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

# *Performing of Inspections*

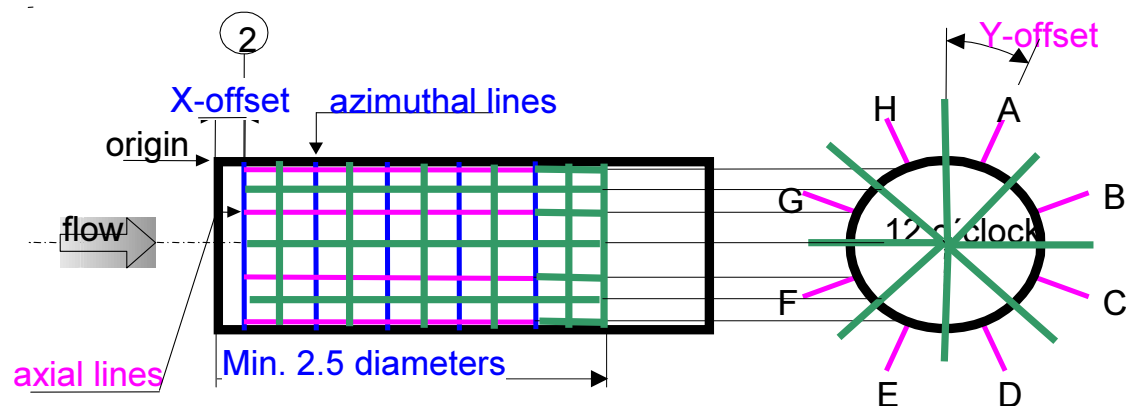
*(Wall thickness measurements, Visual inspections)*



# Wall thickness measurements – Inspection Preparation, Grid (1)



- > Currently approx. 20 to 30 components will be examined each year as result of the COMSY analysis
- > Specify grid layout to be applied according to
  - ❑ pipe diameter
  - ❑ flow conditions (single – or two phase flow)
- > If significant wall thinning is found for an element during inspection (Flow close to  $T_{min}$  or beyond), the examination will be repeated with  $\frac{1}{2}$  the grid size. For straight pipes the grid coverage are expanded to a minimum of 2.5 diameters (3 diameters for two-phase flow)



# Wall thickness measurements – Inspection Preparation, Grid (2)

## Grid specification

Nominal-Durchmesser [mm]	Aussen-Durchmesser [mm]	Umfang [mm]	X-delta [mm]	Einphasige Strömung		Zweiphasige Strömung		Y-delta [mm]									
				Raster-Mindestlänge 3D [mm]	Anzahl axiale Messebenen	Raster-Mindestlänge 5D [mm]	Anzahl axiale Messebenen										
25,4	33,4	104,9	25	100	4	167	7	26,2	17,5	13,1	8,7	6,6	5,2	4,4	3,3	2,9	
31,8	42,2	132,4	25	126	5	211	8	33,1	22,1	16,6	11,0	8,3	6,6	5,5	4,1	3,7	
38,1	48,3	151,5	25	145	6	241	10	37,9	25,3	19,0	12,6	9,5	7,6	6,3	4,7	4,2	
50,8	60,3	189,4	25	181	7	302	12	47,4	31,6	23,7	15,8	11,8	9,5	7,9	5,9	5,3	
63,5	73,0	229,3	25	219	9	365	15	57,4	38,2	28,7	19,1	14,3	11,5	9,6	7,2	6,4	
76,2	88,9	279,1	25	267	11	445	18	69,8	46,5	34,9	23,3	17,5	14,0	11,6	8,7	7,8	
88,9	101,6	319,0	25	305	12	508	20	79,8	53,2	39,9	26,6	19,9	16,0	13,3	10,0	8,9	
101,6	114,3	358,9	25	343	14	572	23	89,8	59,8	44,9	29,9	22,4	18,0	15,0	11,2	10,0	
127,0	141,3	443,7	25	424	17	707	28	111,0	74,0	55,5	37,0	27,7	22,2	18,5	13,9	12,3	
152,4	168,3	528,4	25	505	20	841	34	132,2	88,1	66,1	44,1	33,0	26,4	22,0	16,5	14,7	
203,2	219,1	687,9	50	657	13	1095	22	172,1	114,7	86,0	57,4	43,0	34,4	28,7	21,5	19,1	
254,0	273,1	857,4	50	819	16	1365	27	214,5	143,0	107,2	71,5	53,6	42,9	35,7	26,8	23,8	
304,8	323,9	1016,9	50	972	19	1619	32	254,4	169,6	127,2	84,8	63,6	50,9	42,4	31,8	28,3	
355,6	355,6	1116,6	50	1067	21	1778	36	279,3	186,2	139,6	93,1	69,8	55,9	46,5	34,9	31,0	
406,4	406,4	1276,1	50	1219	24	2032	41	319,2	212,8	159,6	106,4	79,8	63,8	53,2	39,9	35,5	
457,2	457,2	1435,6	50	1372	27	2286	46	359,1	239,4	179,5	119,7	89,8	71,8	59,8	44,9	39,9	
508,0	508,0	1595,1	75	1524	20	2540	34	399,0	266,0	199,5	133,0	99,7	79,8	66,5	49,9	44,3	
558,8	558,8	1754,6	75	1676	22	2794	37	438,9	292,6	219,4	146,3	109,7	87,8	73,1	54,9	48,8	
609,6	609,6	1914,1	75	1829	24	3048	41	478,8	319,2	239,4	159,6	119,7	95,8	79,8	59,8	53,2	
711,2	711,2	2233,2	75	2134	28	3556	47	558,6	372,4	279,3	186,2	139,6	111,7	93,1	69,8	62,1	
762,0	762,0	2392,7	75	2286	30	3810	51	598,5	399,0	299,2	199,5	149,6	119,7	99,7	74,8	66,5	
812,8	812,8	2552,2	75	2438	33	4064	54	638,4	425,6	319,2	212,8	159,6	127,7	106,4	79,8	70,9	
863,6	863,6	2711,7	75	2591	35	4318	58	678,3	452,2	339,1	226,1	169,6	135,7	113,0	84,8	75,4	
914,4	914,4	2871,2	75	2743	37	4572	61	718,2	478,8	359,1	239,4	179,5	143,6	119,7	89,8	79,8	
								4	6	8	12	16	20	24	32	36	azimutale Punkte
								90,00	60,00	45,00	30,00	22,50	18,00	15,00	11,25	10,00	Y-delta [°]

# Visual inspections – Basics, Procedure

**homogenous  
oxide layer**



**surface  
degradation of  
base material**



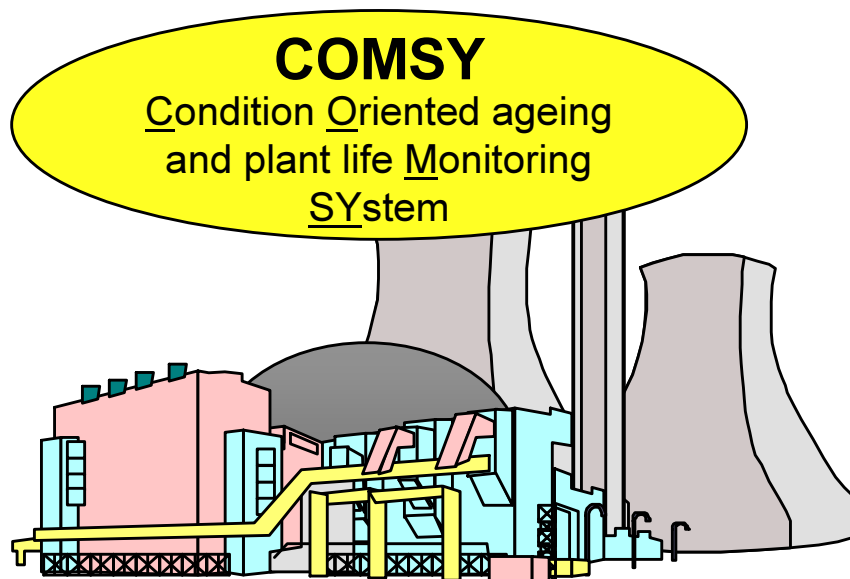
**local  
degradation**



- > *visually examining the inner surface of piping, valves, heaters, vessels, etc. can provide information about its condition (pits, gouges, grooves, tiger-striping, etc.)*
- > *visual techniques are used for rapid screening if the interior of a piping system*
- > *valves and pumps have nonparallel surfaces and often thick bodies, so optical inspection techniques are frequently used*
- > *heater shells and other vessels are difficult to exam by radiographic or UT techniques through the size and complexity. They are usually inspected visually.*
- > *endoscopes are used at inaccessible places, e.g. small pore piping, vessel shells, valves, pumps, etc.*

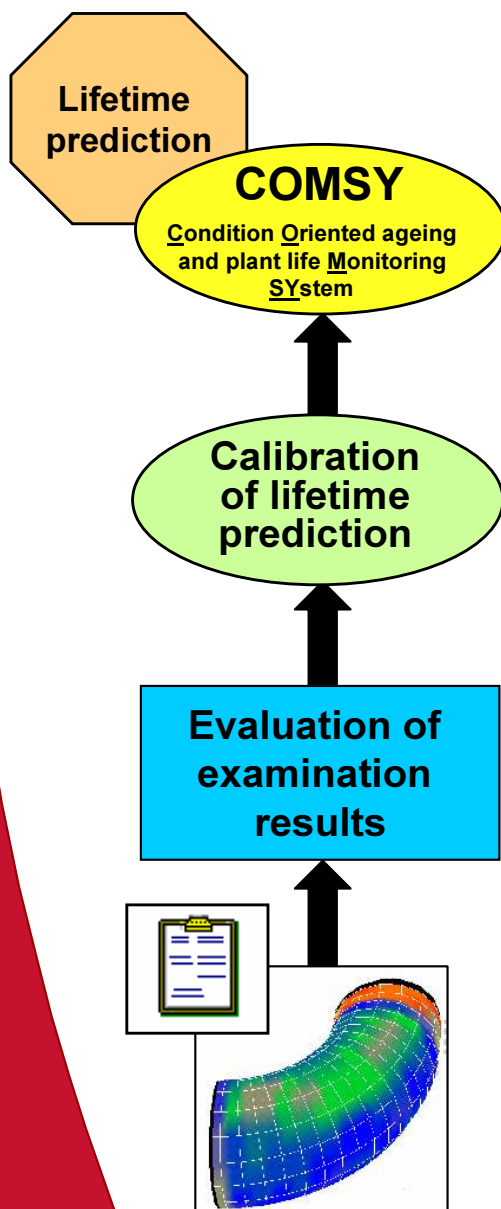
**Note:** *The main disadvantage of visual techniques is that the information is not objectively quantitative, so that a trending can hardly be performed.*

# *Examination Result Assessment*



# Examination Result Assessment

## – Overview

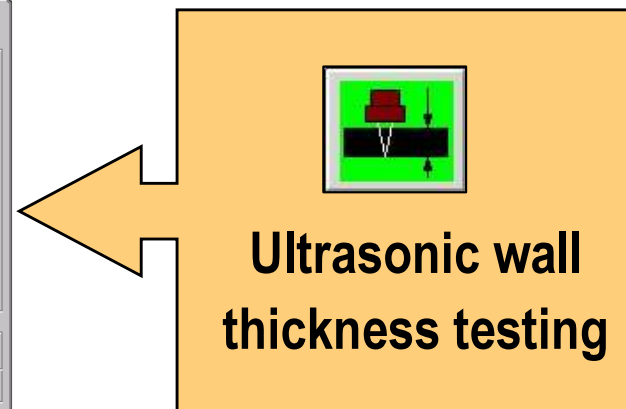


- > Examination results from UT wall thickness measurements and visual inspections are feedback into the COMSY program
- > The results are used for further optimization of service life predictions
  - ❑ to reduce the safety margin
  - ❑ to optimize the inspection scope
- > Geometry-specific evaluation of the UT data will be automatically performed by the COMSY program
- > If four measurements for one prediction area are available a calibration of lifetime predictions are performed

**This process increases the accuracy of future service life predictions**

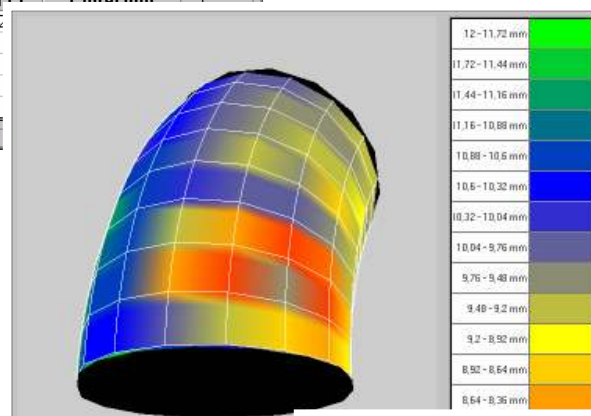
# Examination Result Assessment – Record management (1)

Element Data	Geometry	Material + Design	Operation Data	Water Chemistry	Weld Joint	Inspection Data																
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><b>Examination Data</b></p> <p>examination date: 1995.05 supervisor: A. Kunbor</p> <p>record name: _____ examiner: B.O. Sonow</p> <p>location: _____ input by: Q. Wandurz</p> <p>comment: _____</p> <p><b>References</b></p> <p>reference file: _____ record number: _____</p> <p><b>Wall Thickness Data</b></p> <p>Tnom [mm]: 8.00 Torig [mm]: 10.60 Tmin [mm]: 3.75</p> </div> <div style="width: 45%;"> <p><b>Examination Procedure</b></p> <p>gauge: UDI-56+TS / AND-257-93 more...</p> <p>probe: SNQ-R27 / ANP-94-57-2 more...</p> <p>calibration: _____ more...</p> <p>couplant: _____ more...</p> <p>uncertainty [%]: 3.3 <input type="checkbox"/> scanned grid squares</p> <p><b>Surface</b></p> <p><input type="radio"/> painted <input type="radio"/> not painted <input type="radio"/> primed <input type="radio"/> unknown</p> <p><input type="radio"/> ground <input type="radio"/> unground <input type="radio"/> rough <input type="radio"/> unknown</p> </div> </div>																						
<p><b>Available Grids</b></p> <table border="1"> <thead> <tr> <th></th> <th>X-planes</th> <th>X-offset [mm]</th> <th>X-delta [mm]</th> <th>Y-planes</th> <th>Y-offset [°]</th> <th>Y-delta [°]</th> <th>Y-direction</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>8</td> <td>25.00</td> <td>25.00</td> <td>16</td> <td>0.00</td> <td>2</td> <td></td> </tr> </tbody> </table>								X-planes	X-offset [mm]	X-delta [mm]	Y-planes	Y-offset [°]	Y-delta [°]	Y-direction	1	8	25.00	25.00	16	0.00	2	
	X-planes	X-offset [mm]	X-delta [mm]	Y-planes	Y-offset [°]	Y-delta [°]	Y-direction															
1	8	25.00	25.00	16	0.00	2																



UT Data for element 08.004.11

	1/1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	Max	Min
° \ [mm]	15	65	115	165	215	265	315	365		
A	0	9.00	8.80	9.30	9.40	9.30	9.10	9.30	9.40	8.80
B	22	8.50	7.80	8.20	9.60	8.70	9.30	9.50	9.60	7.80
C	45	8.90	7.50	7.70	9.80	9.60	9.30	9.70	9.80	7.50
D	68	9.40	7.70	8.50	10.00	9.40	9.70	9.70	10.00	7.70
E	90	9.80	8.50	9.30	10.10	9.90	9.80	9.90	10.10	8.50
F	112	10.40	10.60	10.60	10.80	10.70	10.40	10.50	10.80	10.40
G	135	10.50	10.80	11.00	11.20	10.80	10.30	10.70	11.20	10.30
H	158	11.20	11.30	11.20	11.50	10.90	10.80	11.20	11.50	10.80
I	180	11.70	11.50	11.30	11.10	11.60	11.80	12.00	12.00	11.10
J	202	11.80	11.60	11.00	10.70	10.80	10.70	11.70	11.80	10.70
K	225	11.40	11.00	10.80	10.60	10.40	10.90	11.80	11.80	10.40
L	248	10.90	10.90	10.80	10.50	10.50	10.70	10.90	11.00	10.50
M	270	9.50	9.50	9.50	10.20	9.70	9.70	10.20	10.60	9.50
N	292	9.80	9.40	9.40	10.00	9.60	9.60	10.30	10.30	9.40
O	315	9.30	9.50	9.50	9.80	9.30	9.40	9.70	9.80	9.30
P	338	9.20	8.90	9.20	9.40	9.40	9.30	9.60	9.60	8.90



**Color Codes**

F5: old copy F7: average

F6: measured F8: none

T low inside radius

**Statistics**

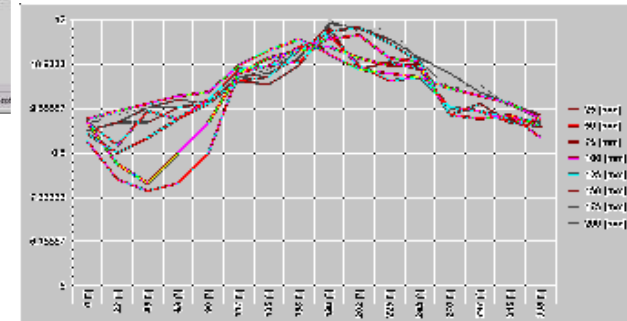
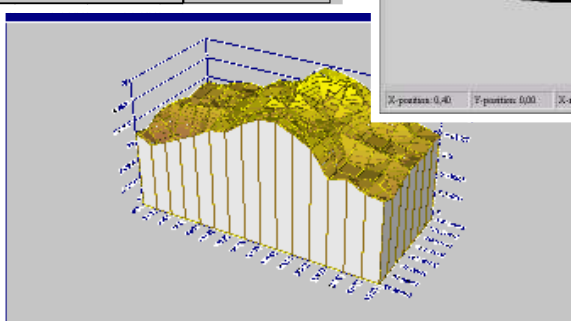
Tmax [mm]: 12.00

Tav [mm]: 10.10

Tlow [mm]: 7.50

number of grid points: 128

plot values 3D projection evaluate



# Examination Result Assessment – Record management (2)

Element data sheet 01/001/02

segment	01	HP drainage system	UID=1	initial start-up	1985_04	thinning rate [mm/a]	0,256
section	001	Condensate tank STD2 762		RecUT	2069_06	wall thickness[mm]	10,00
element	02	vessel flange		priority		phenomena FIC	EC
drawing	R51-6555/X-3-1333923 DOC-NR.462/L88/1			calibration factor	0,50	phenomena EAC	

Element Data | Geometry | Material+Design | Operation Data | Water Chemistry | Weld Joint | **Inspection Data**

**Examination Data**

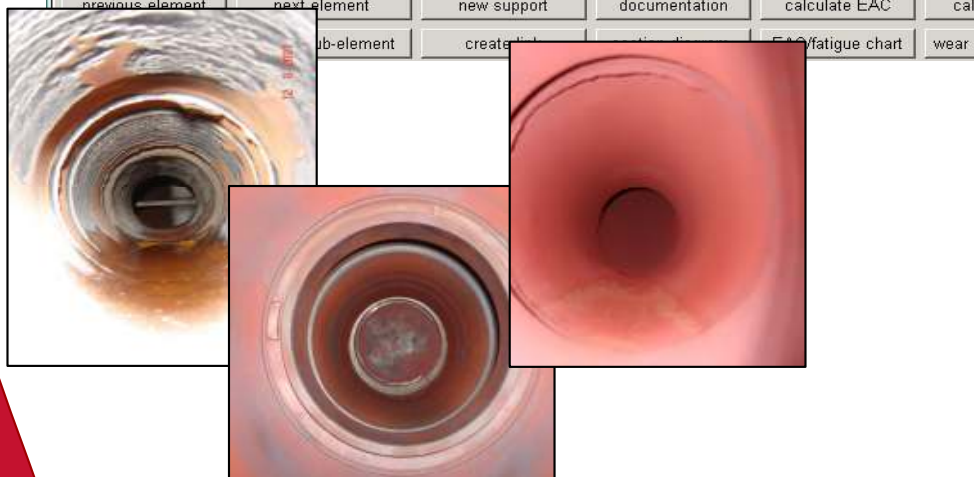
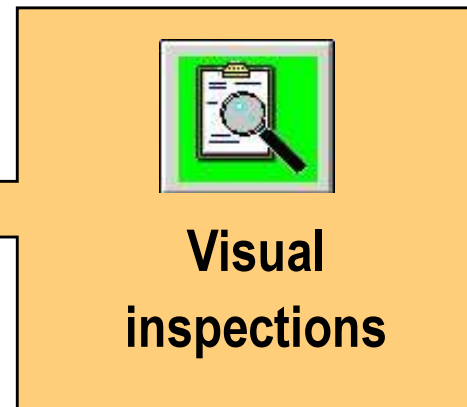
examination date	200310	supervisor	Bühlmann
record name	RA 06B101/II	examiner	Mustermann
location	A 03.10	input by	Meier
remarks			
reference file		record number	210

**Examination Tools**

lamp	Varta 2000×XL	more...
photo camera	Konica ZX 400	more...
video camera	SONSY DCR-PC 330	more...
further tools	sticky tape, marker	more...

**Visual Inspections**

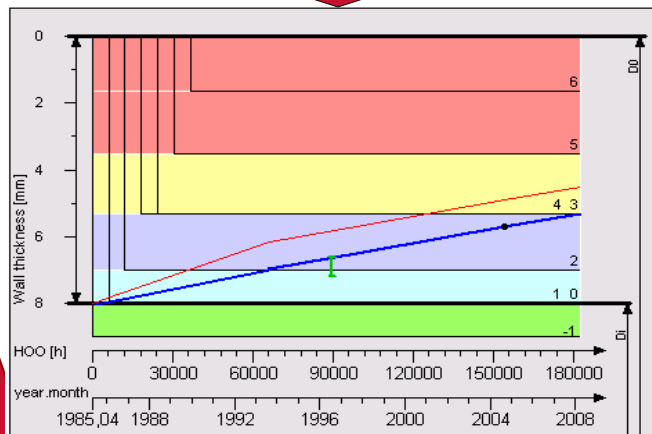
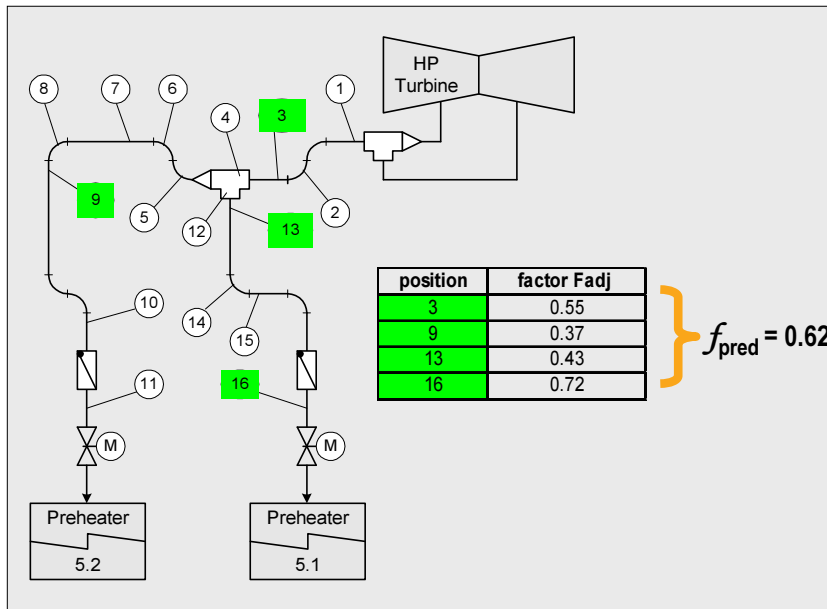
caption	type	revision	date	status	docu
CAD-Drawing	activeelement			invalid	
weld joint picture	valve	a	12.10.2...	valid	
movie	any documentation	a	12.10.2...	valid	
as-build	pressure vessel	d	13.06.1...	valid	



probabilistic assessment interface 07/003/03

element assessment	assessment remarks
RecUT date	Continuous oxide layer in and again flow direction
2015.08	
to be defined by engineering judgement	explanatory statement
<input checked="" type="checkbox"/> disregarded for any further inspection activities	<input type="radio"/> virtual element <input checked="" type="radio"/> visual inspection results <input type="radio"/> engineering judgement <input type="radio"/> not defined <input type="radio"/> risk assessment <input type="radio"/> probabilistic assessment <input type="radio"/> commercial considerations <input type="radio"/> other
OK	delete   cancel

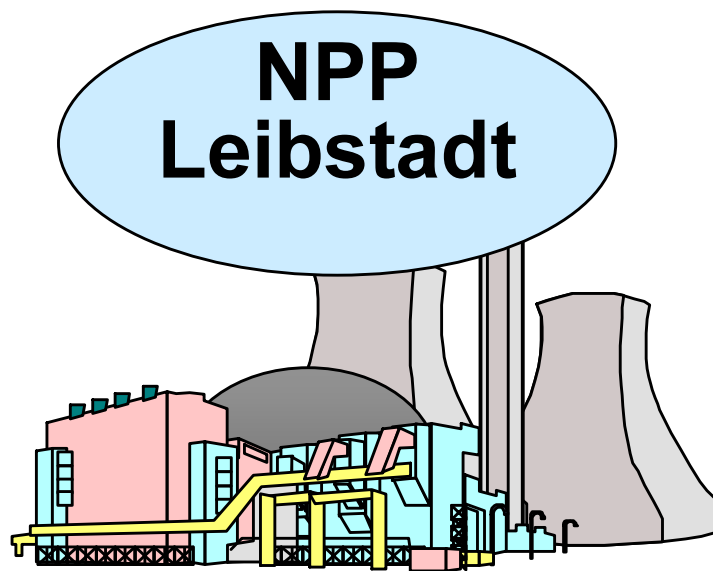
# Examination Result Assessment – Lifetime Prediction Calibration



- > the prediction NDT update function serves to extrapolate individual element calibration for related sections or segments
- > the program computes an extrapolation factor  $f_{pred}$  which is applied to calibrate the lifetime prediction for elements with no examination data existing
- > A recalculation of the lifetime predictions will be performed by using the individual calibration factor and extrapolated factor

**The calibration of the lifetime prediction reduce the safety margin and the measurement locations will continuously reduced.**

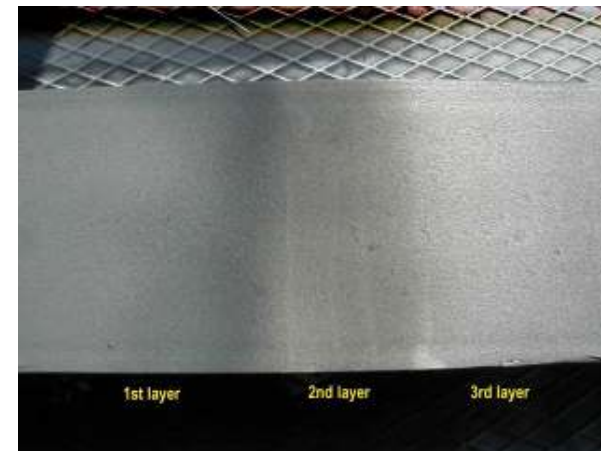
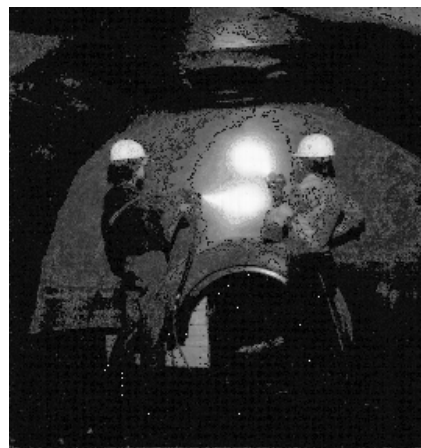
# *Repair and Replacement Measures*



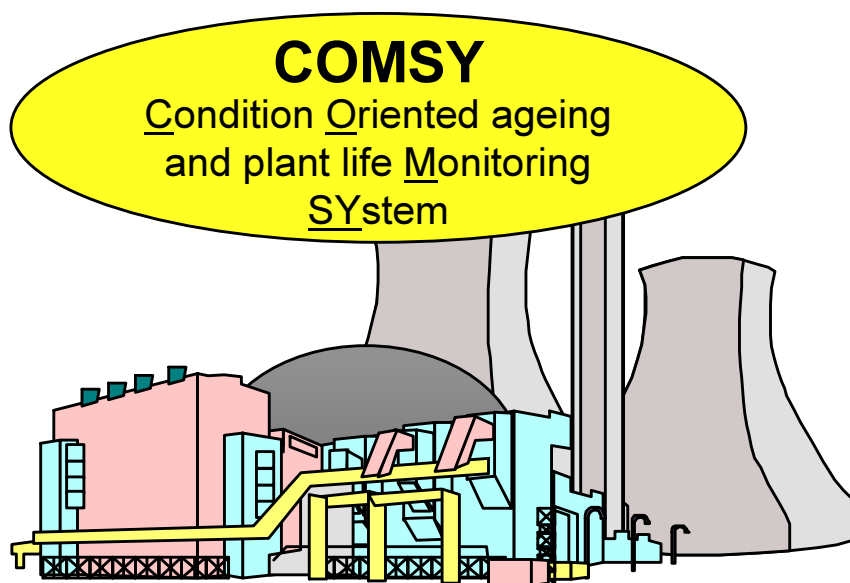
# Repair and Replacement Measures

## – Repair technologies

<i>Method</i>	<i>Welding material</i>	<i>Application range</i>
<i>METCO spraying (2 layer)</i>	<i>undercoating: Ni-Al protective coating: Cr-Ni-Fe-Alloy</i>	<i>Inner surface of</i> <input type="checkbox"/> <i>turbine casing,</i> <input type="checkbox"/> <i>vessels,</i> <input type="checkbox"/> <i>heater,</i> <input type="checkbox"/> <i>large bore piping</i>
<i>ARC spraying (3 layer)</i>	1. <i>Layer: Ni-Al</i> 2. <i>Layer: Cr-Alloy</i> 3. <i>Layer: Cr-Ni-Alloy</i>	

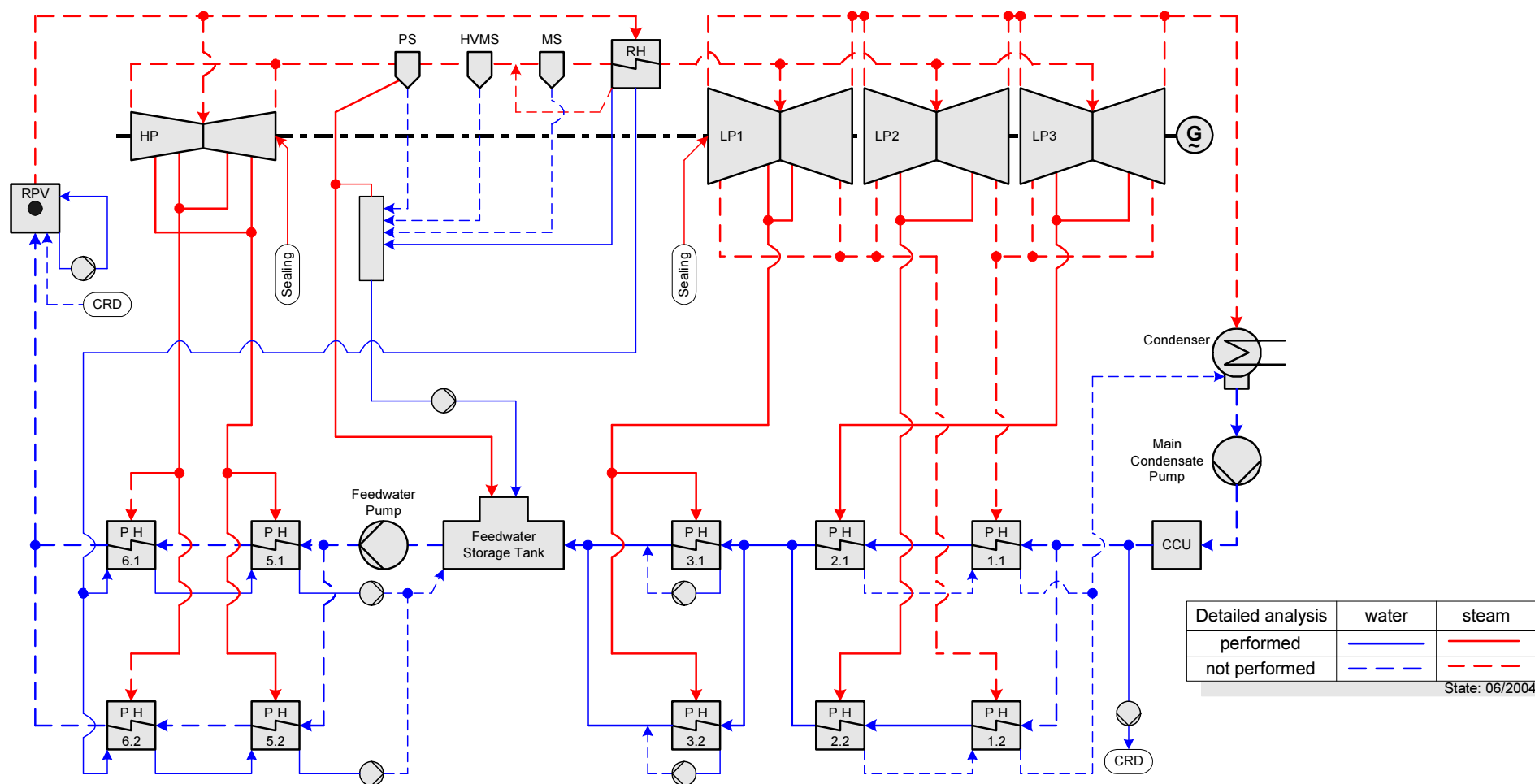


# Summary



# Piping systems for detailed analysis - Total scope of application since 1989

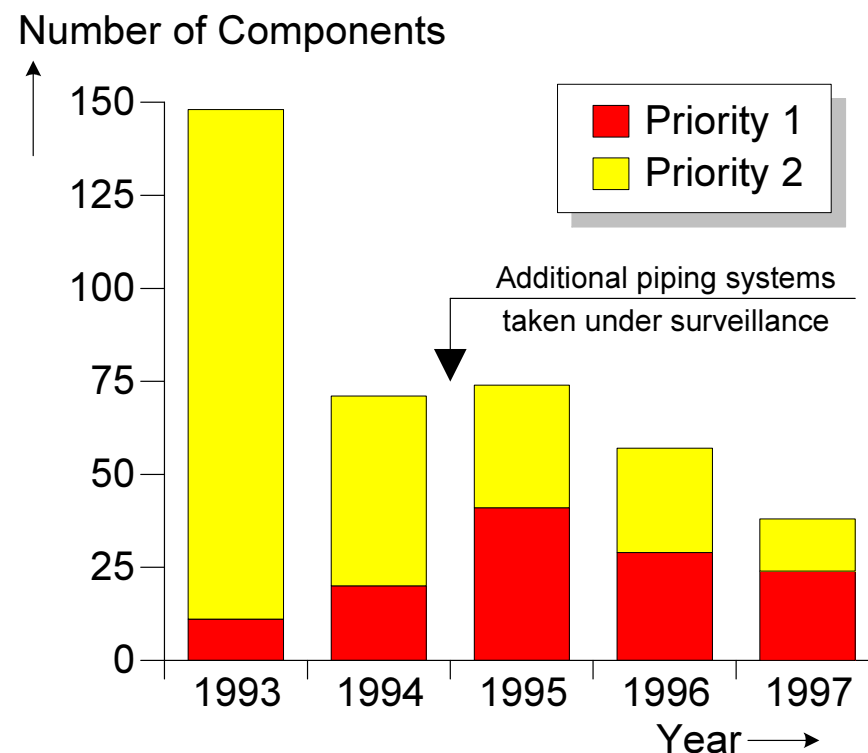
- > 20 systems with 269 piping sections comprising 2742 piping elements
- > 985 wall thickness measurements



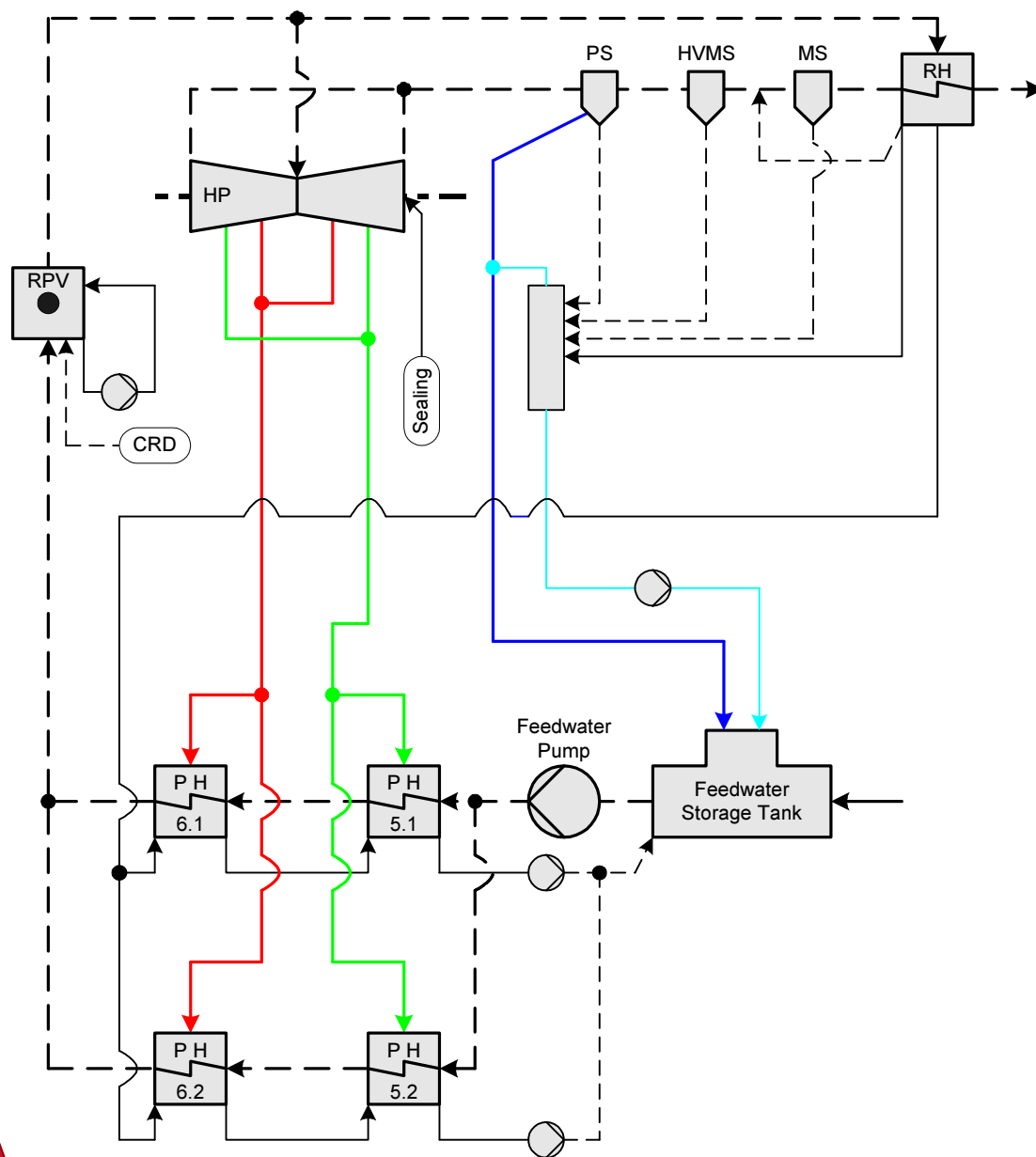
# Pinpointing of examination effort after systematic weak point analyses over the years

## Assessment of the result of optimization of the inspection program

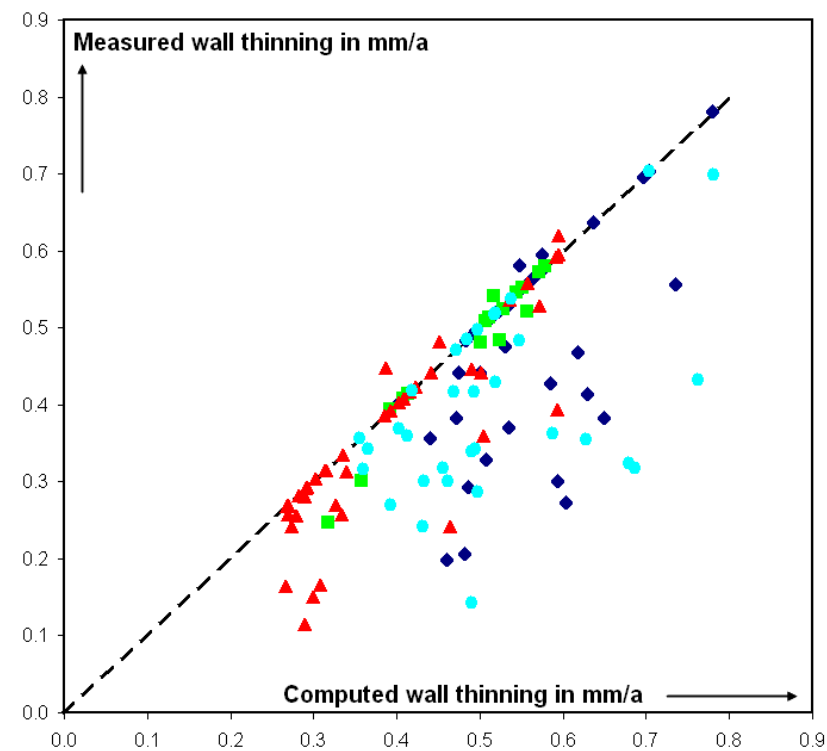
- > *The inspections have been focused to susceptible piping elements during the first years*
- > *Now some 35% of the number of components originally examined in 1993 are inspected based on prediction results.*
- > *The radiation exposure of personnel was reduced*
- > *The safety and reliability level was increased simultaneously*



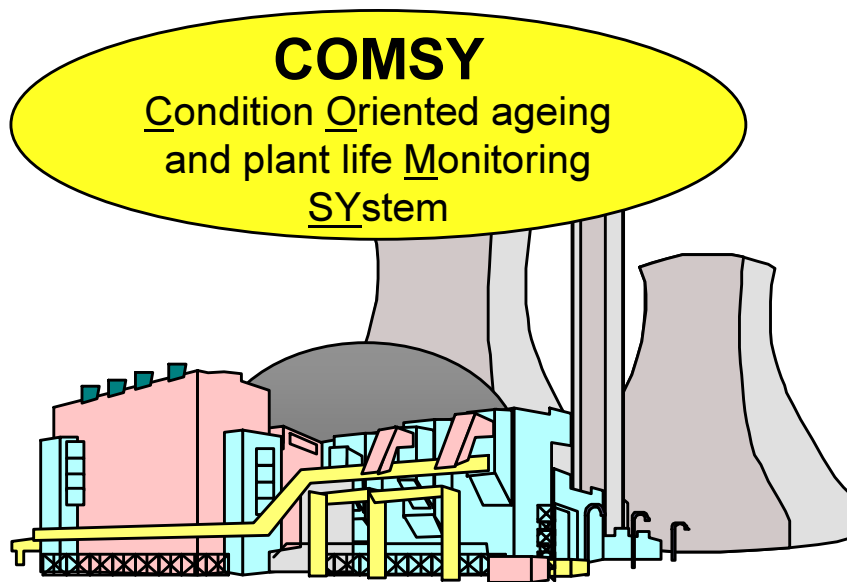
# Comparison of measurements vs. predictions



- ◆ Extraction line #4 ( 36 components )
- Extraction line #5 ( 16 components )
- ▲ Extraction line #6 ( 41 components )
- Moisture separator drains ( 32 comp. )



# *Influence of hydrogen dosing on the FAC rate*



# *Background*

# *Influence of hydrogen dosing on the FAC rate - Background*

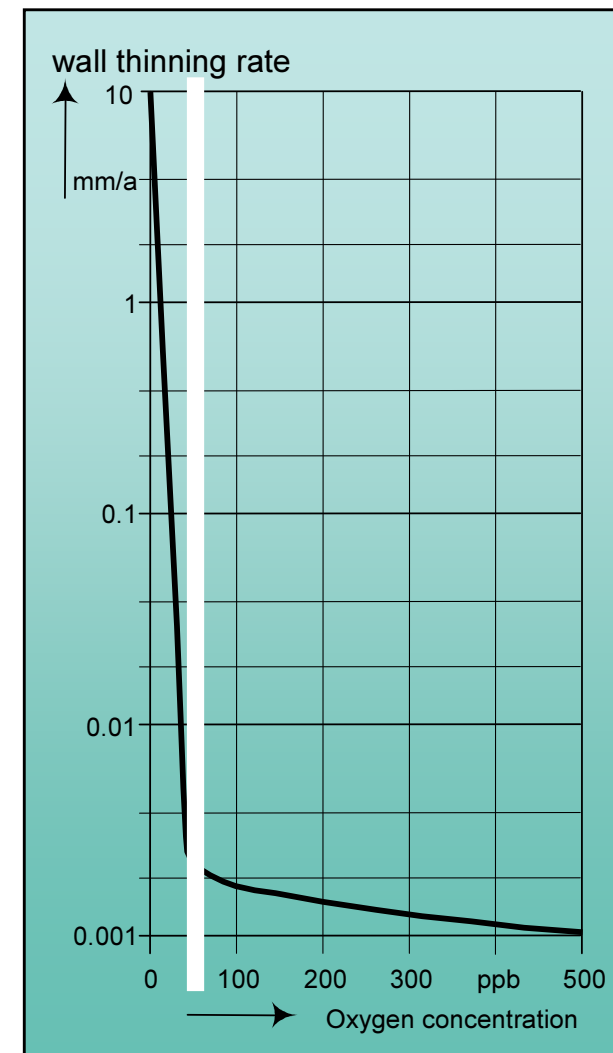
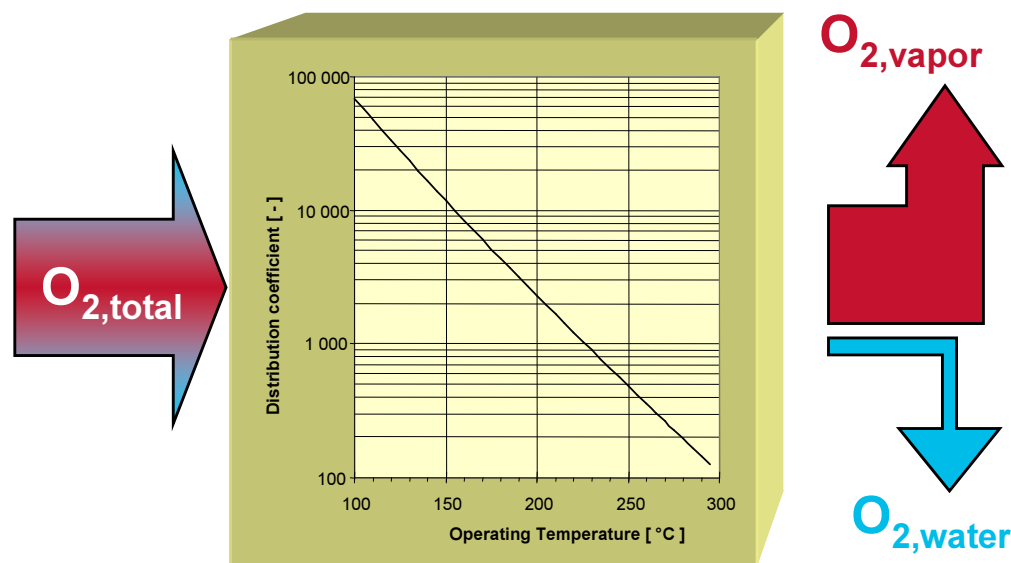
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*Hydrogen dosing through the feedwater changes the redox-potential in the RPV*

- > reduced potential for corrosion cracking in RPV interiors*
- > reduced radiolysis rate*
- > lower oxygen concentration in the main steam influences oxygen concentrations in the BoP systems*

# Influence of hydrogen dosing on the FAC rate - Background

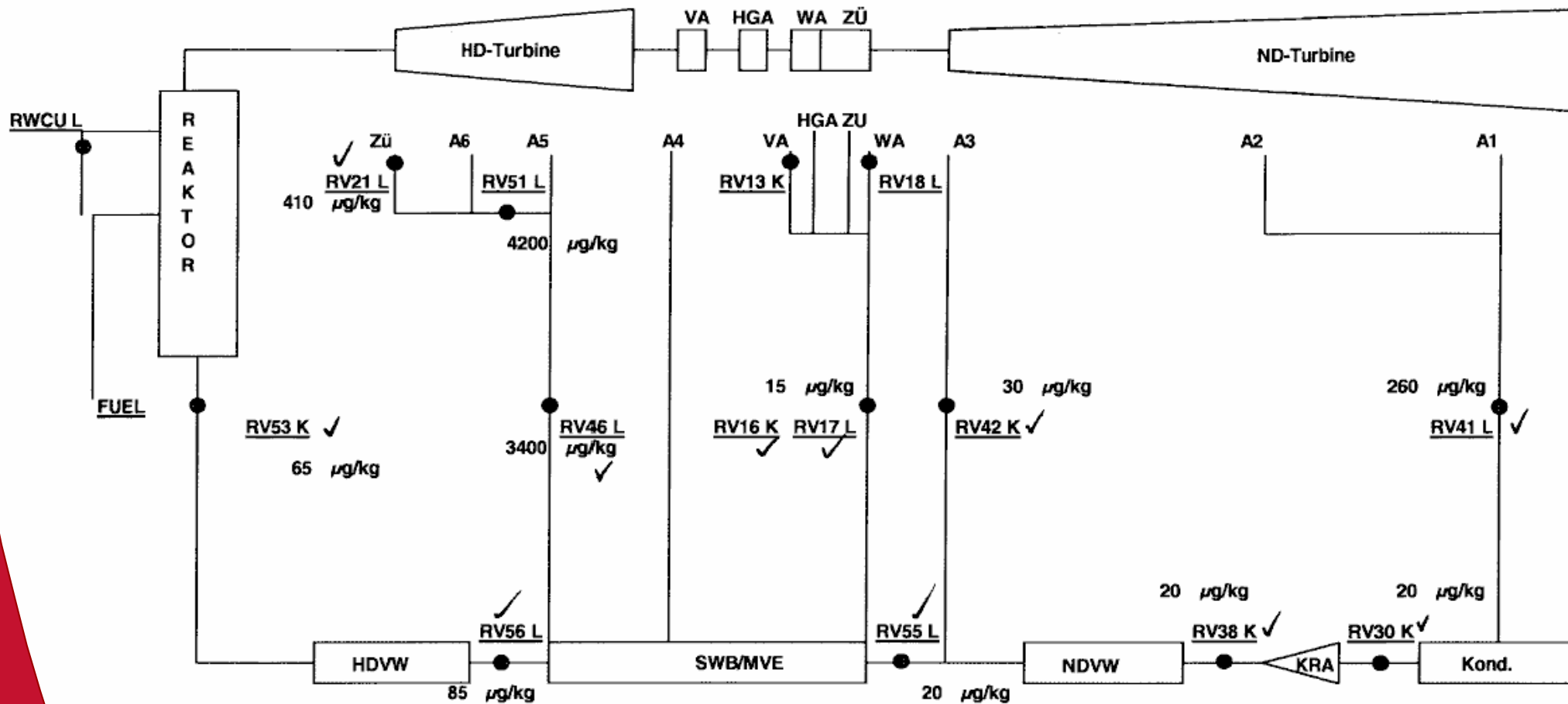
- > Oxygen concentrations below 50ppb allow for the occurrence of FAC
- > In two-phase flow the oxygen concentration is influenced by the temperature-dependent distribution coefficient of the oxygen



# *Study*

# Influence of hydrogen dosing on the FAC rate - Measurements performed (1)

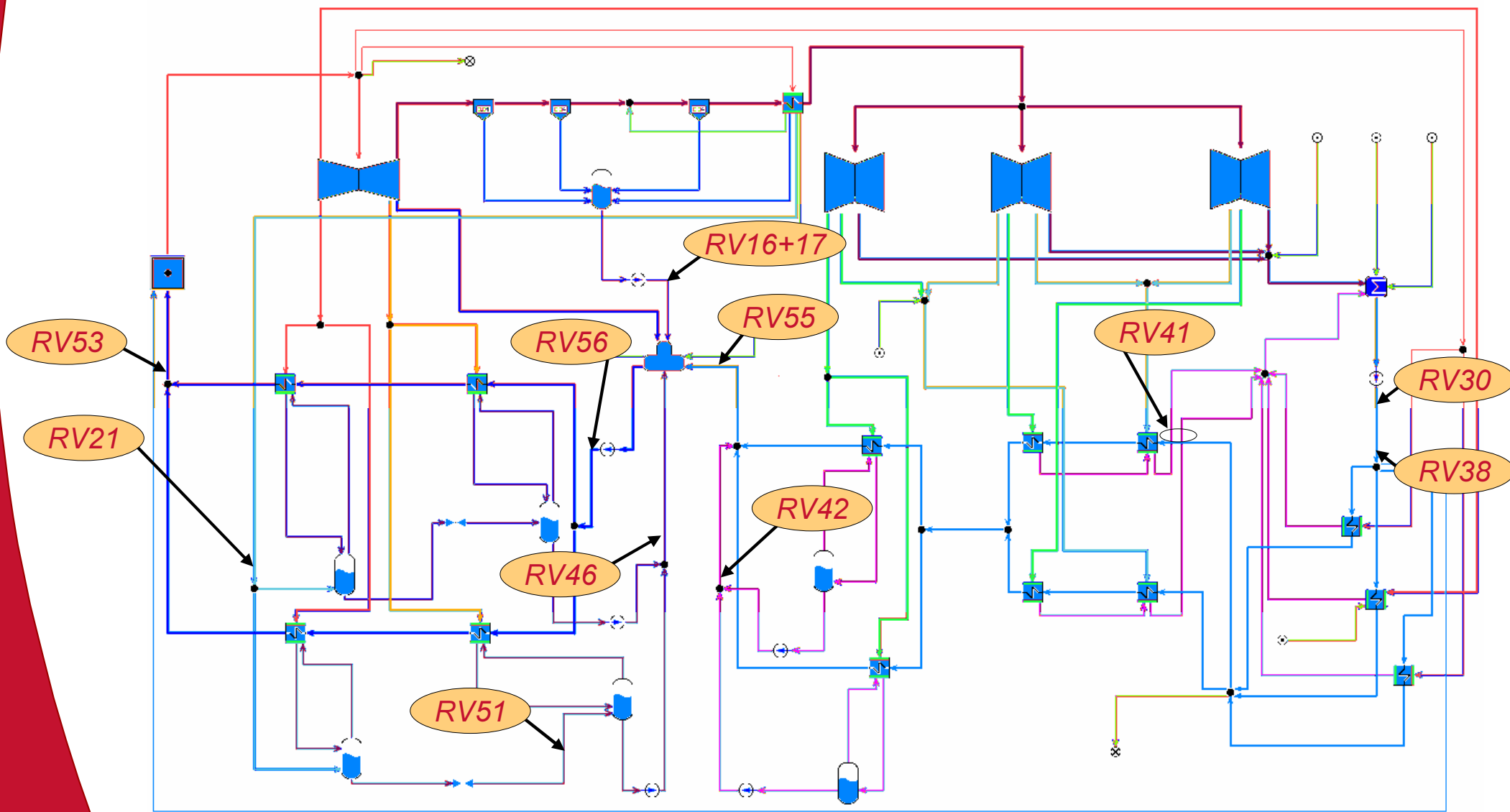
Sauerstoffmessung Juli 2004; 100 % Leistung



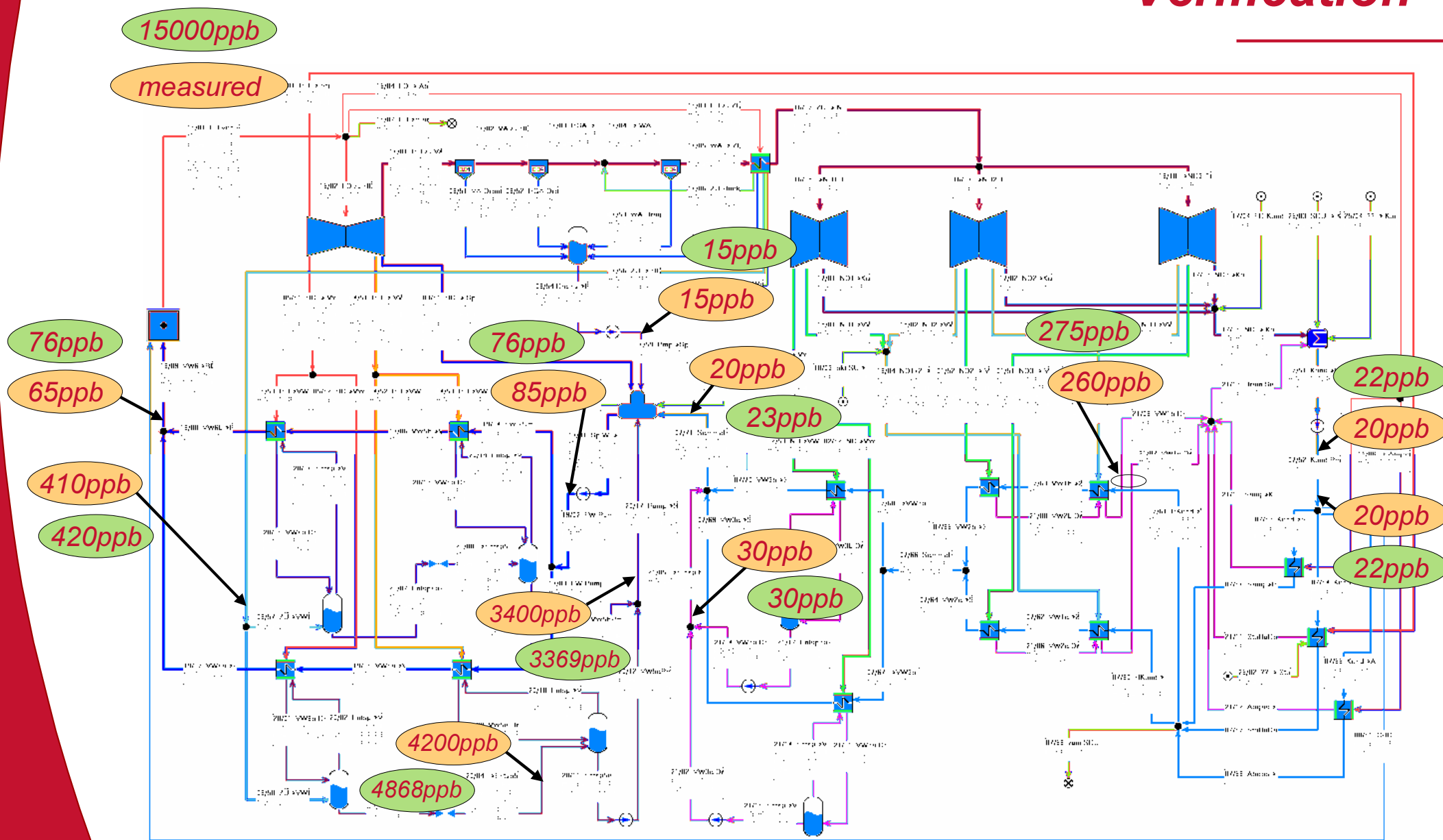
schema leer / Bilanzschema

14.07.2004 / kaw / UC

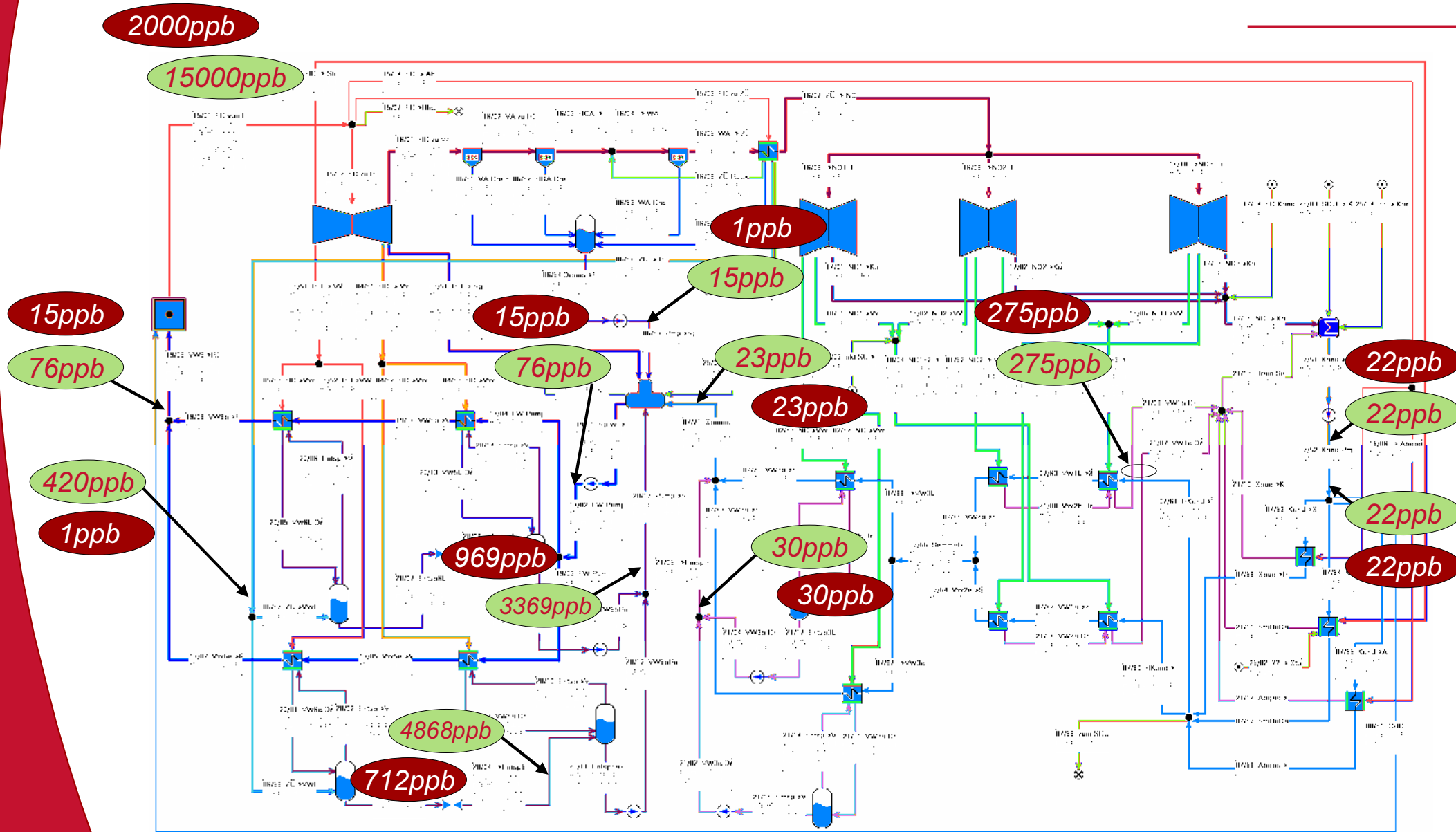
# Influence of hydrogen dosing on the FAC rate - Measurements performed (2)



# Influence of hydrogen dosing on the FAC rate - Verification



# Influence of hydrogen dosing on the FAC rate - Simulation



# *Results*

# *Influence of hydrogen dosing on the FAC rate - Results (1)*

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*> Oxygen concentrations calculated by the model match to the concentrations measured*

*→ model can be used for simulation*

*> Reduction of oxygen concentration in the main steam does not increase the existing risk potential in the*

*■ cold cross-over,*

*■ LP extractions, their condensates and*

*■ main condensate*

*also as stainless steel has been used for some areas*

*→ no further measures required*

# *Influence of hydrogen dosing on the FAC rate - Results (2)*

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- > *Reduced oxygen concentrations are to be expected in the*
  - *HP extractions and their condensates,*
  - *condensates of the moisture separator between HP and LP turbines*
  - ➔ *risk potential due to FAC is increased*
  
- > *Currently oxygen concentration in the main feedwater is too high to allow for FAC. Reduction of oxygen concentration in the main steam decreases oxygen concentration in the main feedwater significantly.*
  - ➔ *FAC may occur*

# *Influence of hydrogen dosing on the FAC rate - Summary*

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- > *Hydrogen dosing in the main feedwater influences oxygen concentrations throughout the BoP systems*
- > *The risk potential is increased in the condensates of the moisture separator between the HP and LP turbines as well as in the main feedwater*

## **Counteractions are**

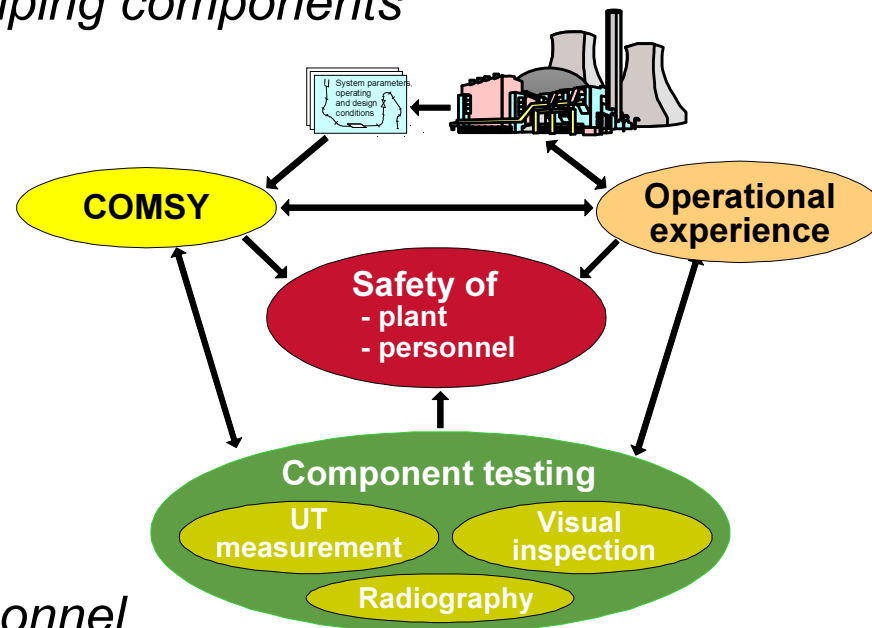
- **completion of detailed analysis with COMSY,**
- **selective inspections and**
- **countermeasures (O<sub>2</sub> dosing, less deaeration of the feedwater tank).**

> AREVA's computer program COMSY focuses

- on reliable identification of piping and piping components susceptible to FAC and
- on optimizing reduction the inspection scope and NDE efforts

> An approach was established

- to meet Swiss regulatory requirements
- to suit KKL's individual conditions
- to use the experience of operating personnel
- to minimize the resulting risk imposed on the affected piping systems



**The approach was applied with commendable success and is/will be essential part of the present/future monitoring program EROSKO at KKL**