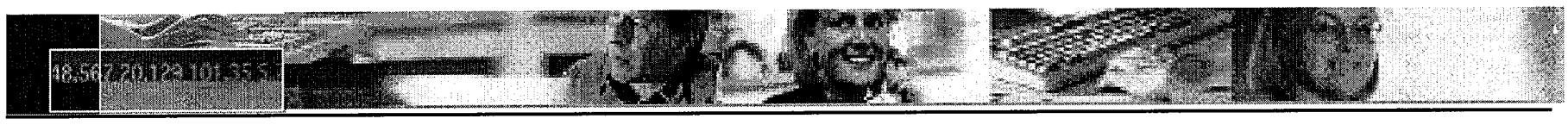

Process Data Reconciliation Software VALI III - Possible use for the Measurement uncertainty recapture power uprate in Nuclear Power Plants

Public NRC-Review
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BTB JANSKY GMBH

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CONTENT

- Why do you need and what are the benefits of process data reconciliation ?
- Some general remarks about the process data reconciliation with VALI III
- Use of VALI III in nuclear power plants in Germany and Switzerland
- Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) - modelling, execution and results
- Process data reconciliation in a 3-Loop PWR (920 MW) - results

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CONTENT (cont'd)

- Use of VALI III for special acceptance tests, maintenance activities and for component diagnosis
- Possible use of VALI III for the Measurement uncertainty recapture power uprate
- Conclusions

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Why do you need process data reconciliation ?

All results of measurements are erroneus (DIN 1319)

result of measurement = measurement + uncertainties

uncertainties = random and systematical errors

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Why do you need process data reconciliation ? (cont'd)

With incorrect measurements the conservation laws

- mass balance
- energy balance and
- material balances

cannot be fulfilled.

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What are the benefits of process data reconciliation system VALI III?

You get

- reconciled values which fulfill the
  - mass balance
  - energy balance and
  - material balances
- reduced uncertainties of the reconciled values
- the clues, where the suspected tags in your process are (ERROR-DETECOR)

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General Remarks

VALI III works with an **overdetermined system of equations**. (**IMPORTANT:** VALI III is not a simulation program!!!)

The **overdetermined system of equations,** that results when

- all available redundancies and
- secondary conditions (conservation laws mass-, energy- and material balances)

are taken into account, is resolved with the aid of the Gaussian correction principle.

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General Remarks (cont'd)

- The theoretical basis of Process Data Reconciliation with VALI III is described in the VDI 2048 guideline (VDI - society of german engineers)
- VALI III get the final certificate of the VDI 2048 commitee at October/11/2002
- VALI III was aknowledged by TÜV-southwest nuclear section as a support system for the calibration of the feedwater-mass flow measurements (official paper from August/16/2002)

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Use of VALI III in Nuclear Power Plants

- Determine all measurements more accurately (that's important for example for the mean coolant temperature or the thermal reactor power)
- Error detection system for the measuring devices (for example to get an early hint of drifting measuring devices)
- Perform acceptance tests more accurateley
- Evaluate maintenance activities more precise
- Use the reconciliation results as calibration standard
- Reduce the cost of calibrating measuring devices

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Model

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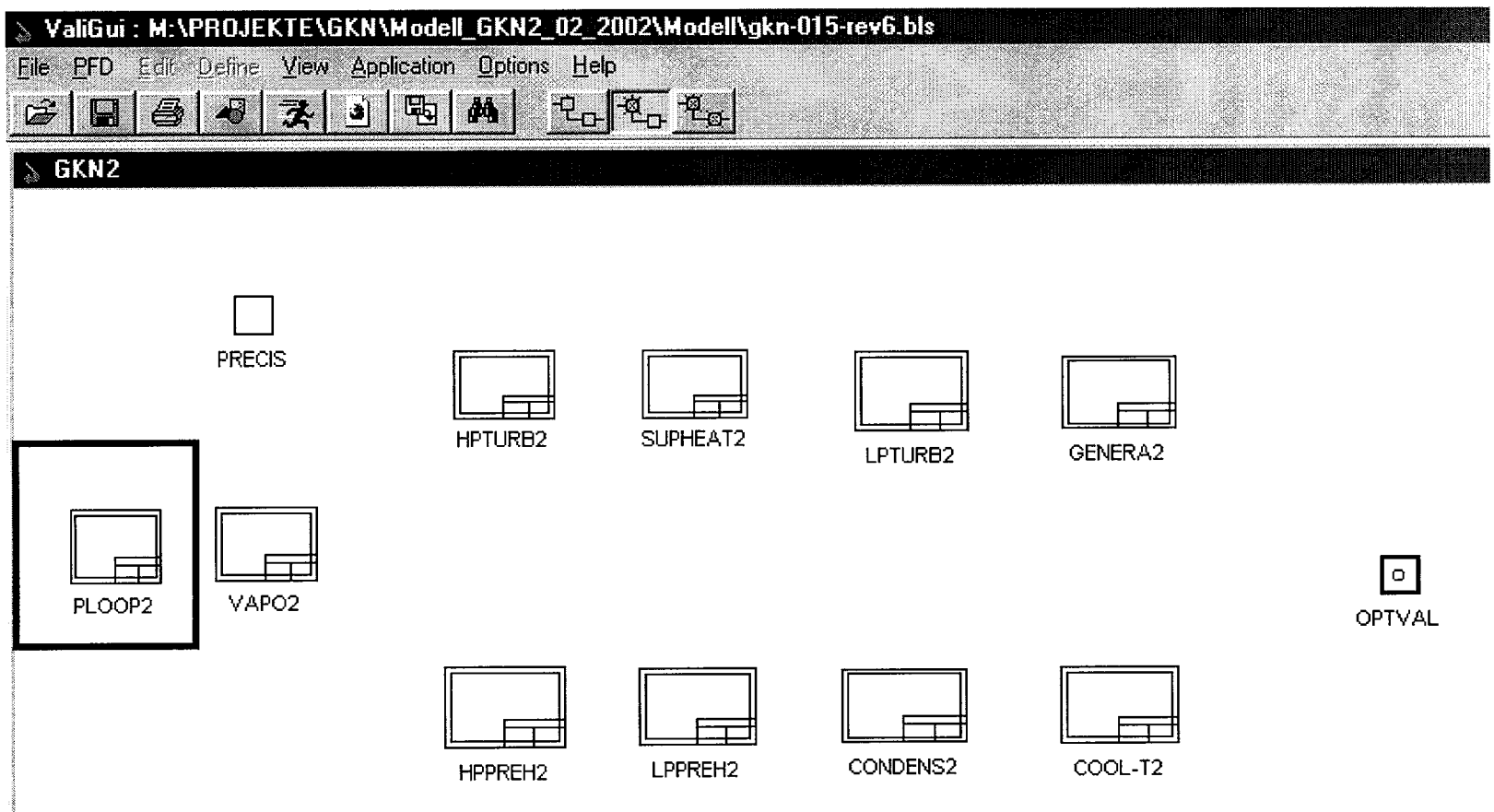
Graphical User Interface (GUI) model of the 4-LOOP PWR



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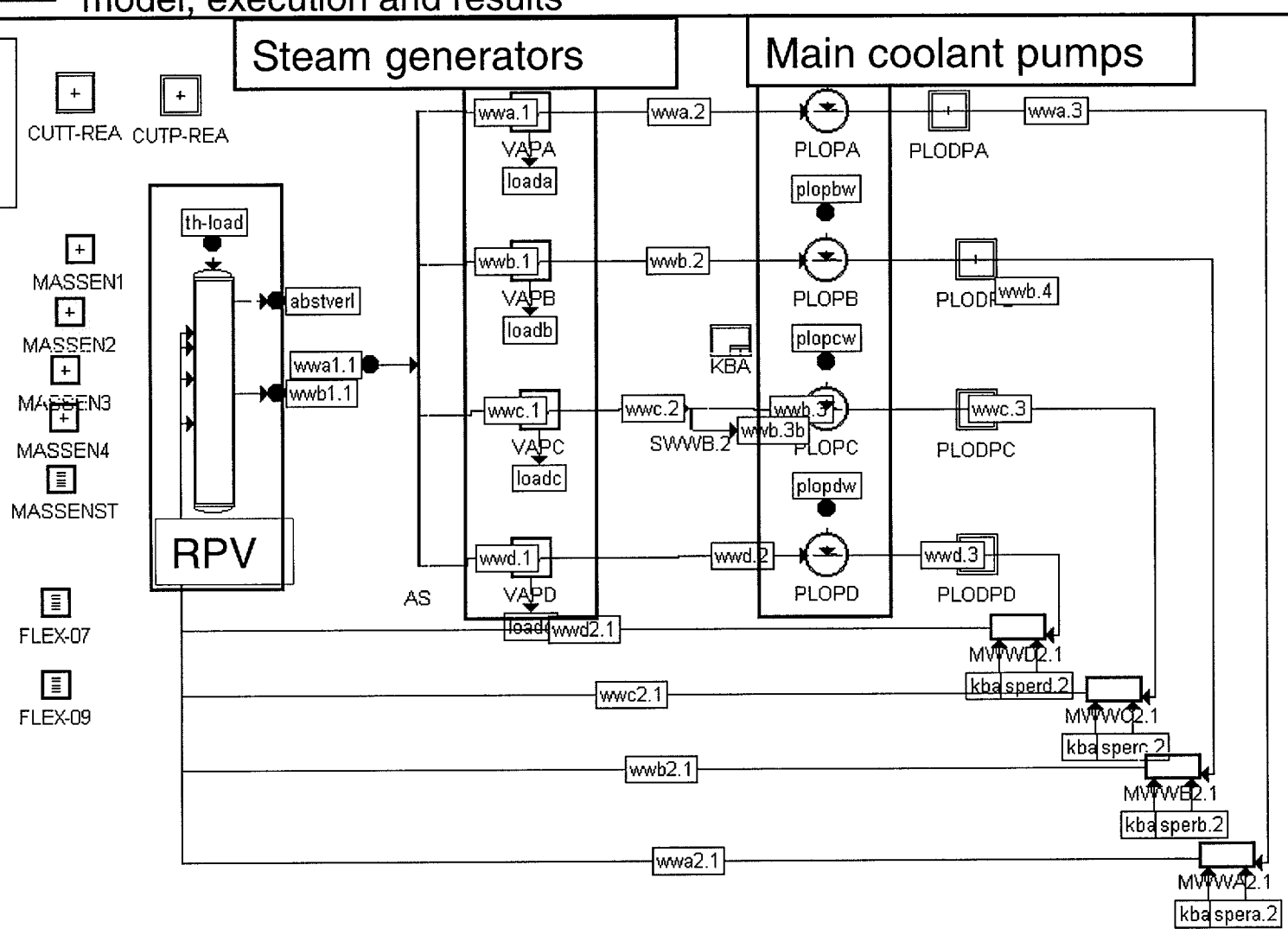
Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) - model, execution and results

GUI-model of primary loop



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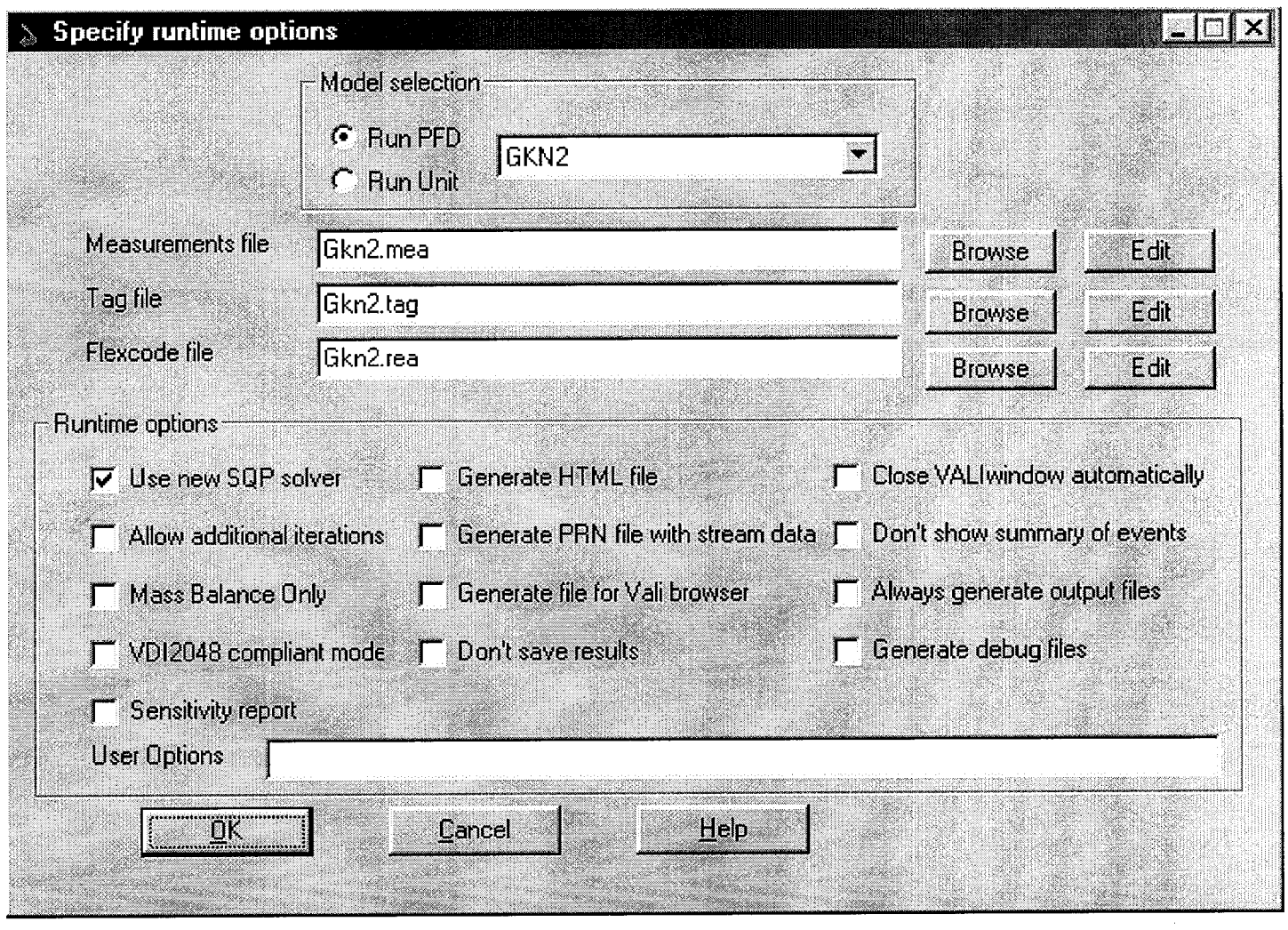
Execution, spezify runtime options



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Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) - model, execution and results

Execution

VALI - [III /10.08 License : 116 B.T.B. JANSKY #2]

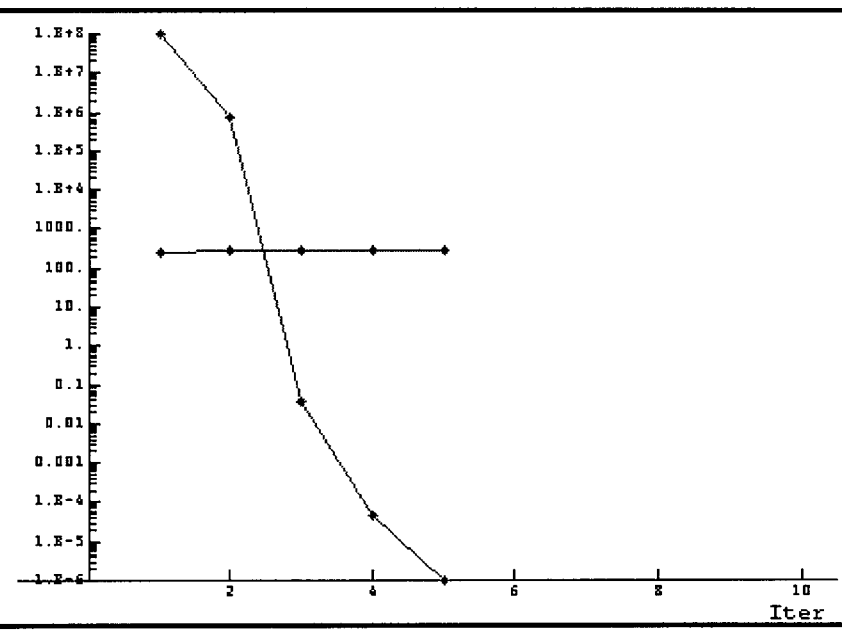
File Execution Help

Settings	
File Name	gkn-015-rev6.bls
Model	GKN2
Version	6.0
Mea File	Gkn2.mea
Tag File	Gkn2.tag
Flex File	Gkn2.rea
Options	-sqp

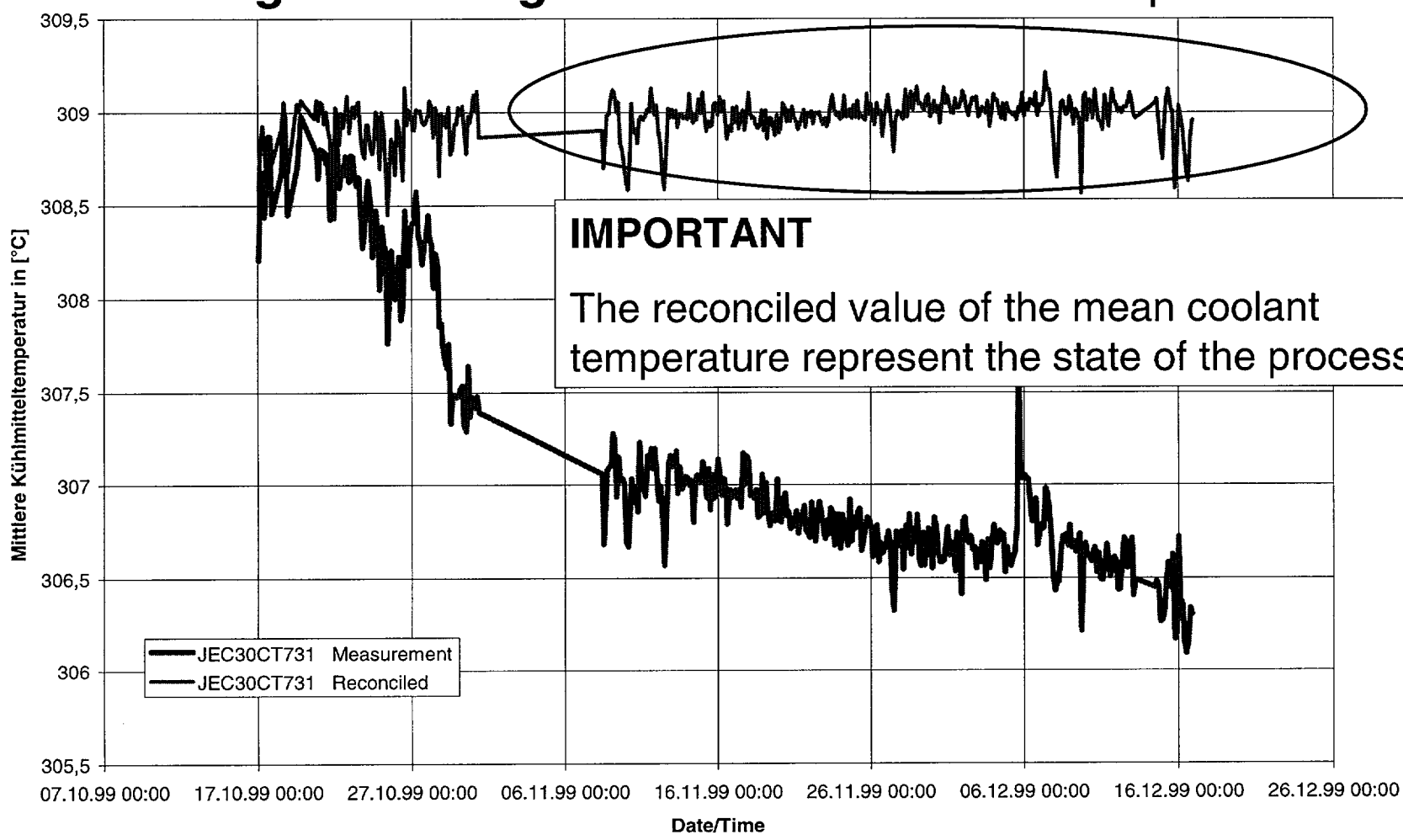
Phase	INF	WRN	ERR	ERS	ERF	CPU
TAG Reading	2	0	0	0	0	0.710
Verification	6	0	0	0	0	2.800
Analysis	610	14	0	0	0	6.210
Resolution	1	0	0	0	0	7.960
Report	0	0	0	0	0	8.190
Output	43	0	2	1	0	8.680

Analysis	
Number of equations	629
Number of unmeasured variables	506
Number of measured variables	273
Number of constants	100
Obvious number of redundancies	123
Total number of redundancies	189
Number of trivial redundancies	0

Resolution	
Iteration	5 / 100
Sum of square residues	0.42008E-06
Objective Function	274.91
Chi-square	222.08
Number of active bounds	0
Flagged tags	0



Drifting measuring device - mean coolant temperature



IMPORTANT

The reconciled value of the mean coolant temperature represent the state of the process !!!!

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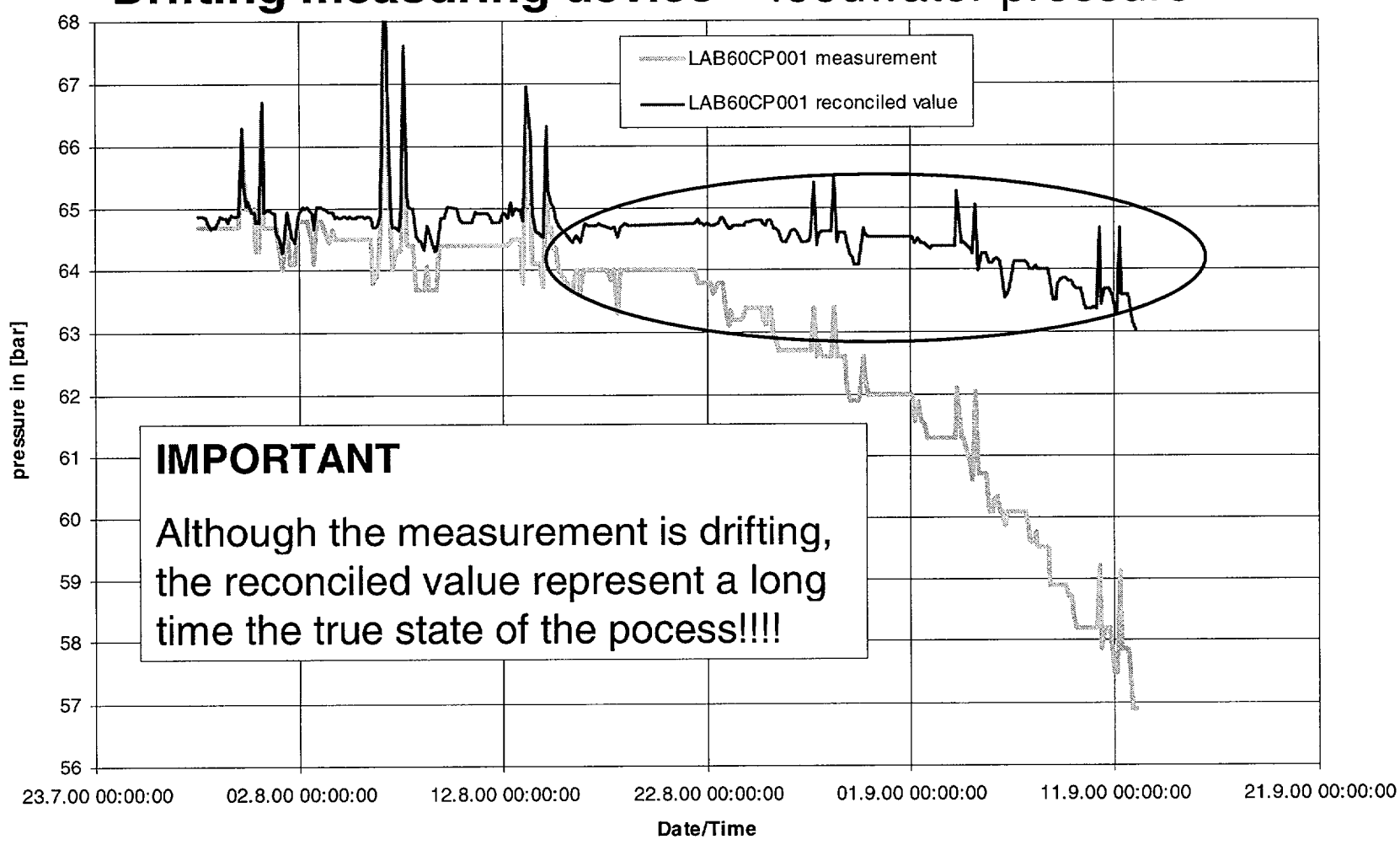
Drifting measuring device – feedwater pressure



IMPORTANT

Although the measurement is drifting, the reconciled value represent a long time the true state of the pocess!!!!

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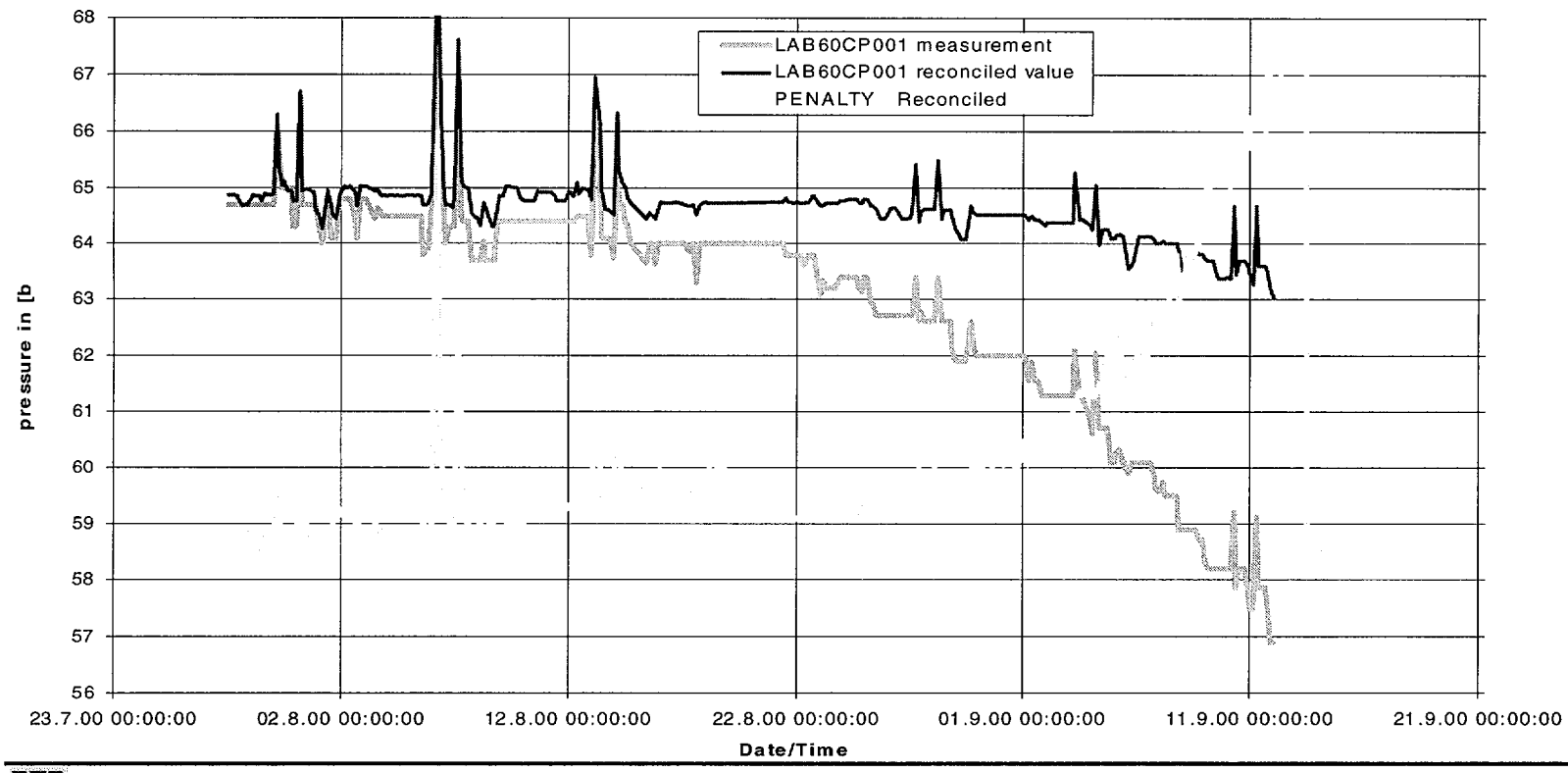
PENALTY (OBJECTIVE)-function; The Error-indicator in VALI

$$\textbf{PENALTY (whole process)} = \sum \left(\frac{\text{reconciled value} - \text{measured value}}{\text{standard deviation of the measured value}} \right)^2$$



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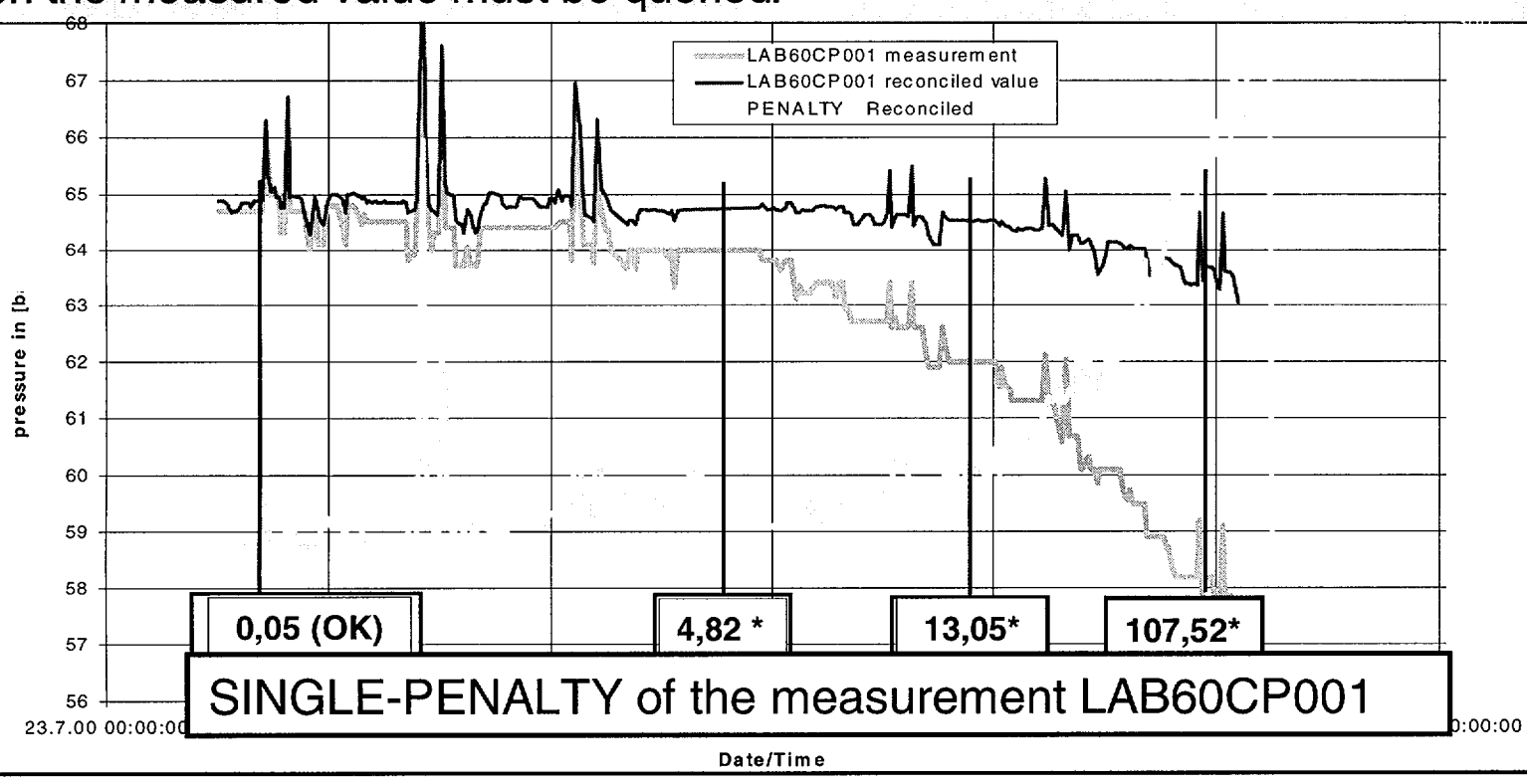
Single-PENALTY; The Error- detector in VALI

If the Single - PENALTY $= \left(\frac{\text{reconciled value} - \text{measured value}}{\text{standard deviation of the measured value}} \right)^2 > 1{,}96^2 (= 3{,}84)$

then the measured value must be queried.



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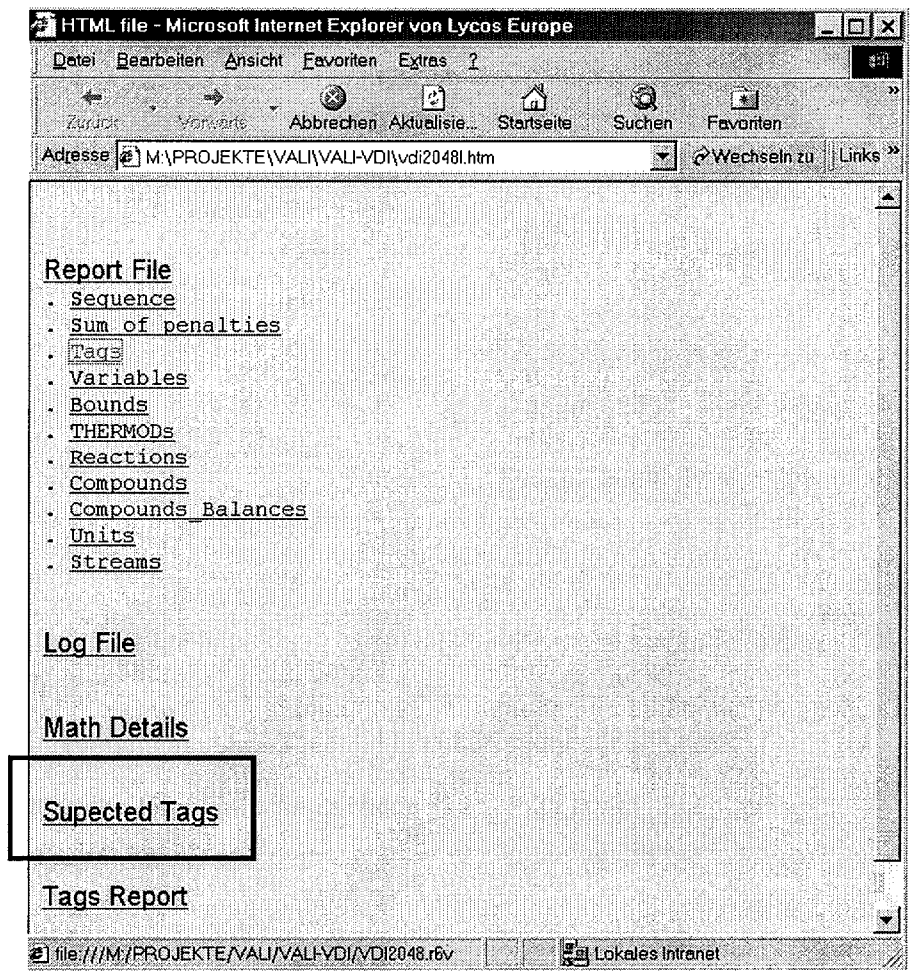
Results


HTML file - Microsoft Internet Explorer von Lycos Europe
Datei Bearbeiten Ansicht Favoriten Extras ?
Zurück Vorwärts Abbrechen Aktualisie... Startseite Suchen Favoriten
Adresse M:\PROJEKTE\VALI\VALI-VDI\vdi2048l.htm
Wechseln zu Links
Report File
. Sequence
. Sum of penalties
. Tags
. Variables
. Bounds
. THERMODs
. Reactions
. Compounds
. Compounds_Balances
. Units
. Streams
Log File
Math Details
Supected Tags
Tags Report
file:///M:/PROJEKTE/VALI/VALI-VDI/VDI2048.r6v
Lokales Intranet

Single-PENALTY; The Error- detector in VALI

If the Single - PENALTY $= \left(\frac{\text{reconciled value} - \text{measured value}}{\text{standard deviation of the measured value}} \right)^2 > 1{,}96^2 (= 3{,}84)$

then the measured value must be queried.

TAG NAME	MEA.VAL.	MEA.ACC.	REC.VAL.	REC.ACC.	Single PENALTY	P.U.
* MAC10CT071A	45.938	1.50	43.107	0.725	17.86	C
* JEC20CP007	158.36	0.500	157.42	0.169	15.25	barg
* JEC20CT003A	323.94	1.00	325.61	0.370	12.53	C
* MAA50CP001	58.991	0.500	58.195	0.337	17.82	barg
* LBA60CP001	62.185	0.500	62.972	0.111	10.02	barg
* LBA60CP004	62.188	0.500	62.972	0.111	9.95	barg
* LBA20CT001	278.25	1.00	279.80	0.115	9.36	C
* LBA10CT001	278.25	1.00	279.80	0.115	9.36	C

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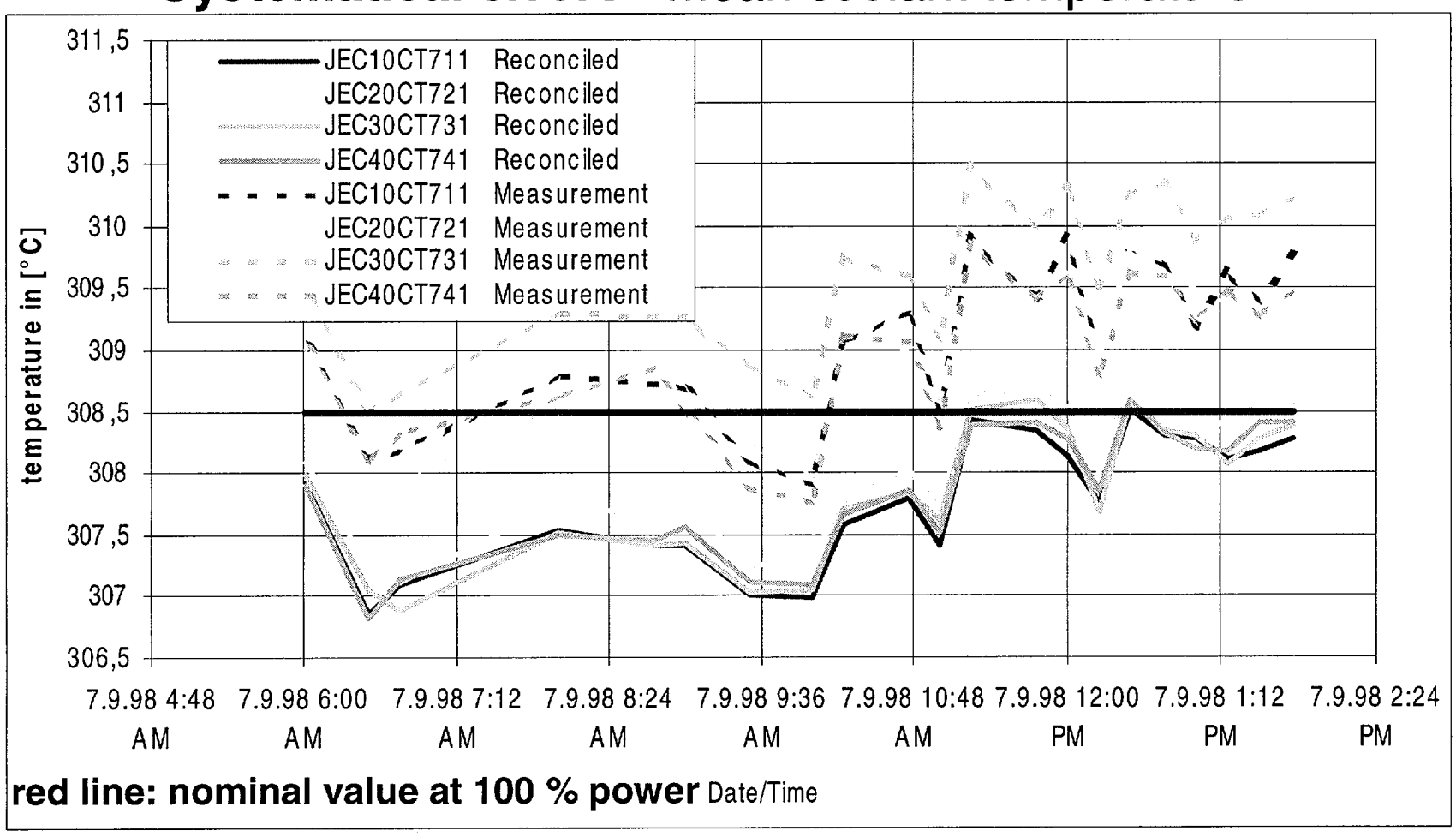
Systematical errors - mean coolant temperature



red line: nominal value at 100 % power

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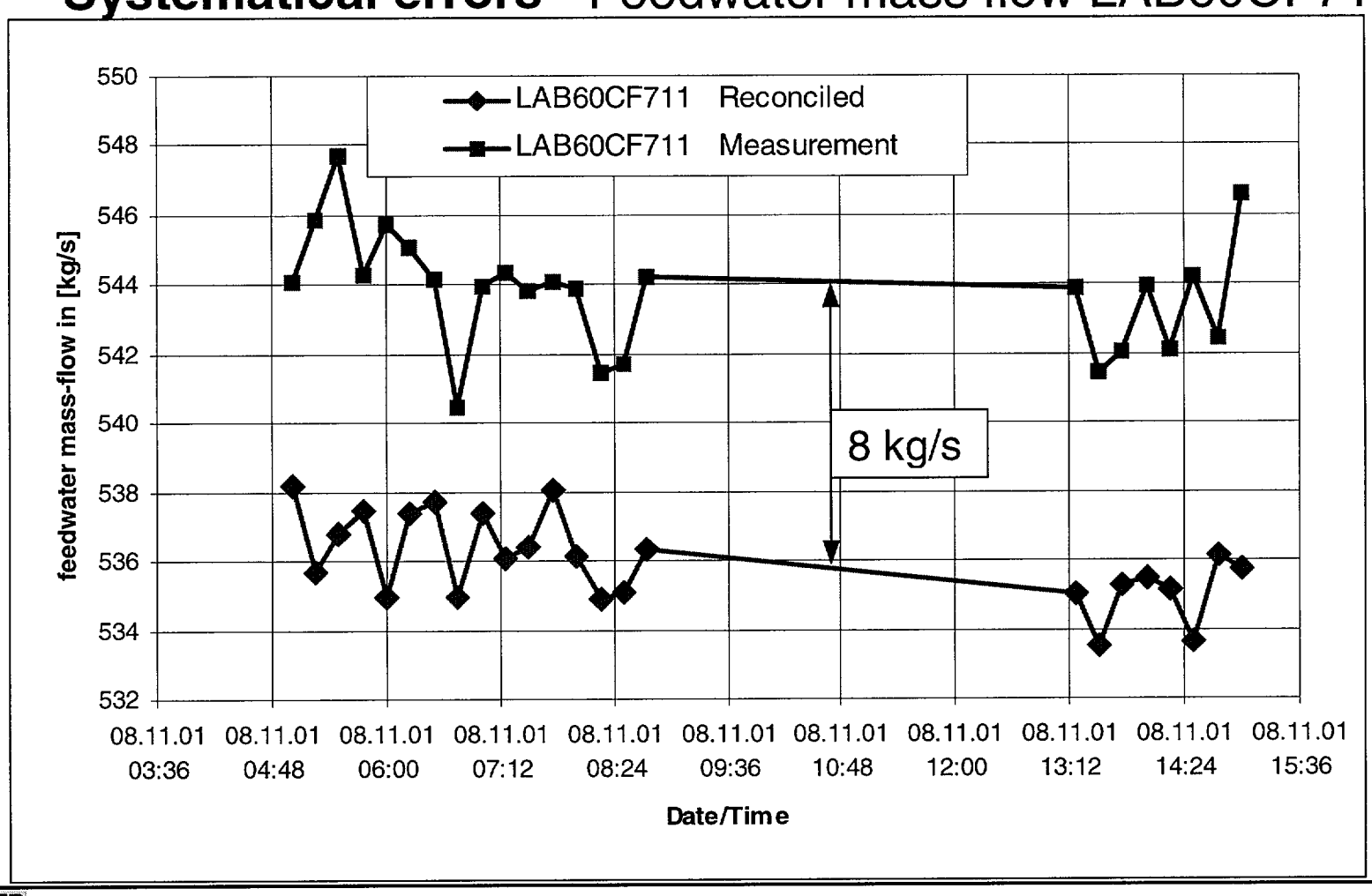
Systematical errors - Feedwater mass flow LAB60CF711



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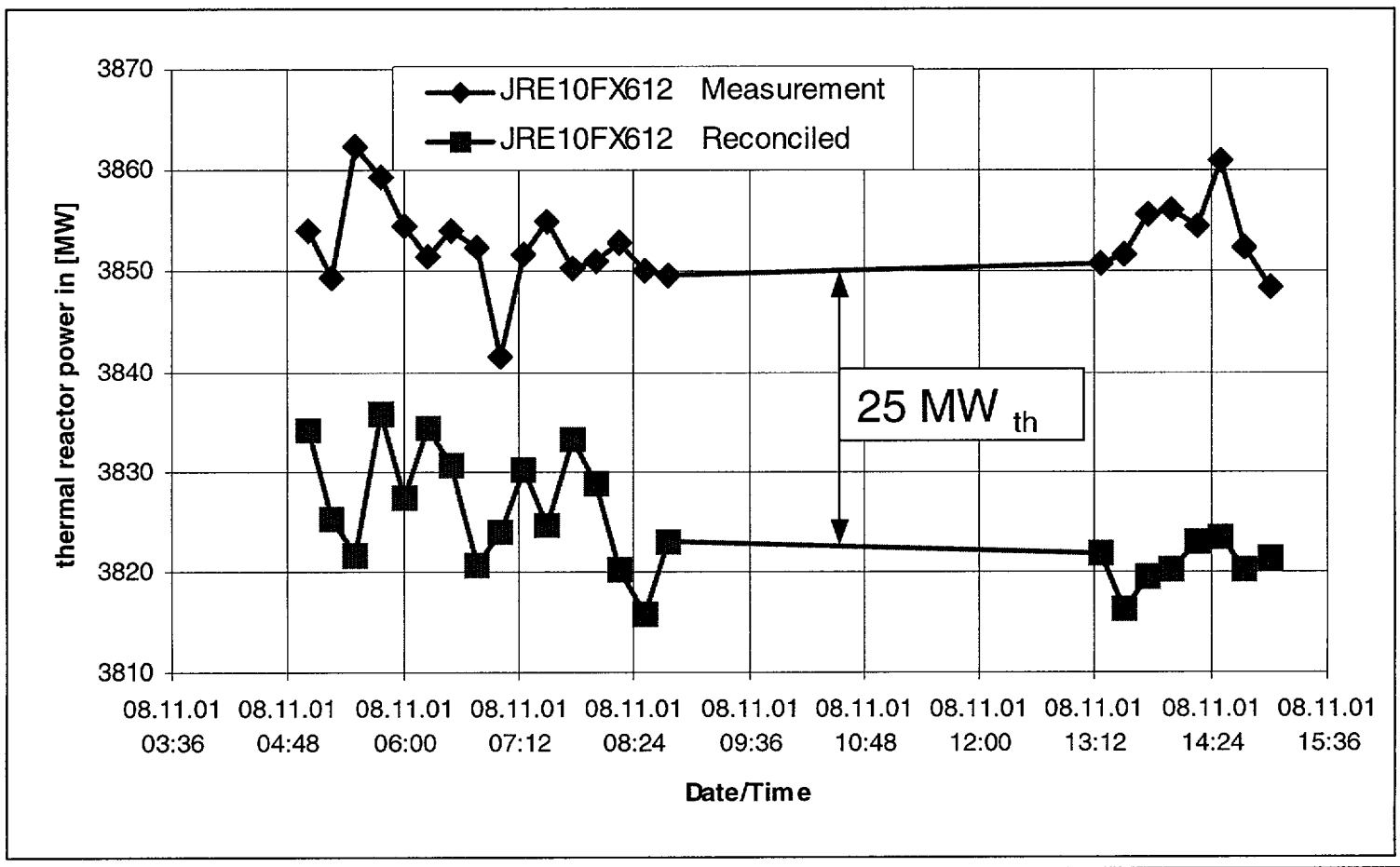
Systematical errors - Measured and reconciled thermal reactor power



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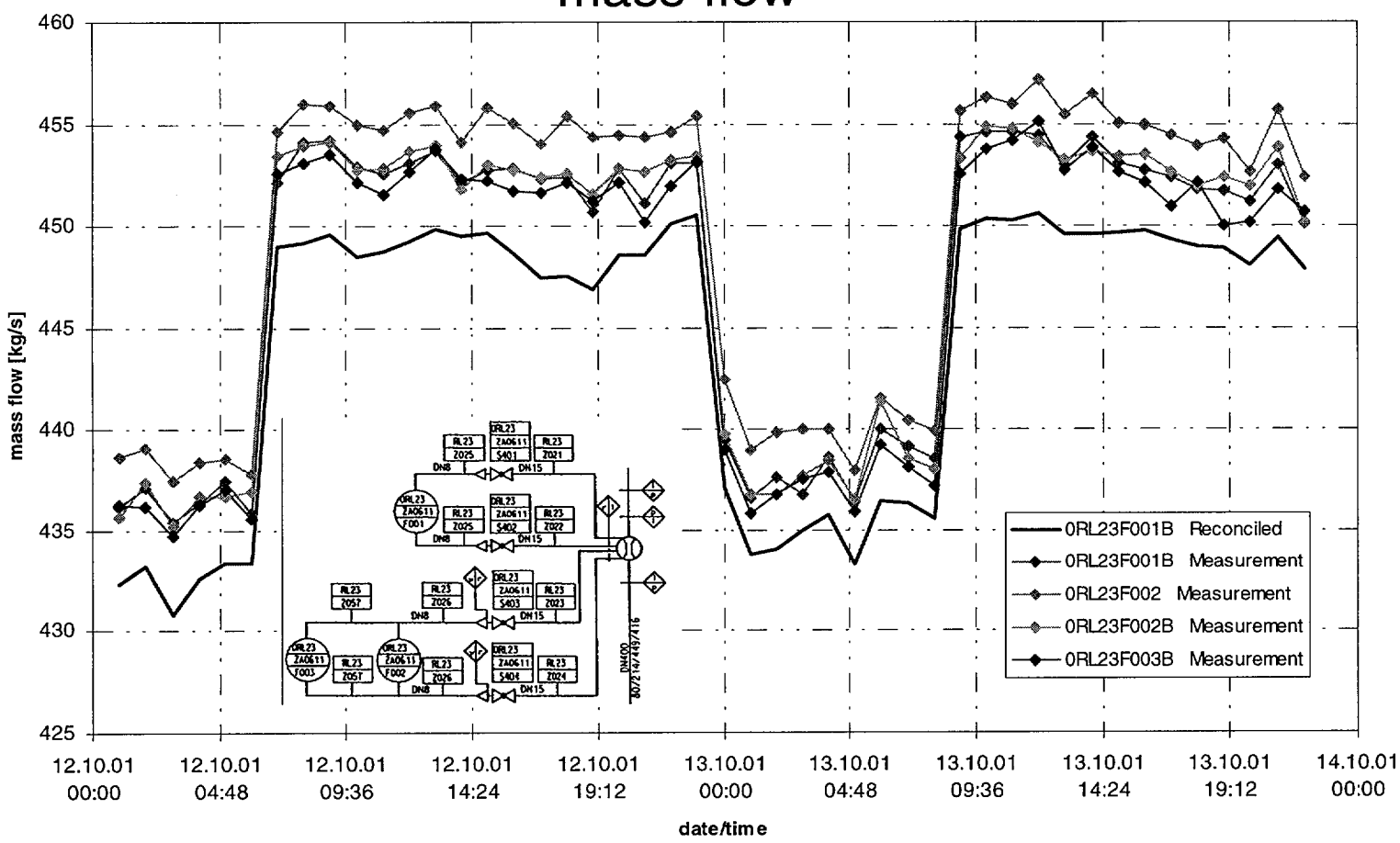
Systematical errors - Measured and reconciled feedwater mass-flow



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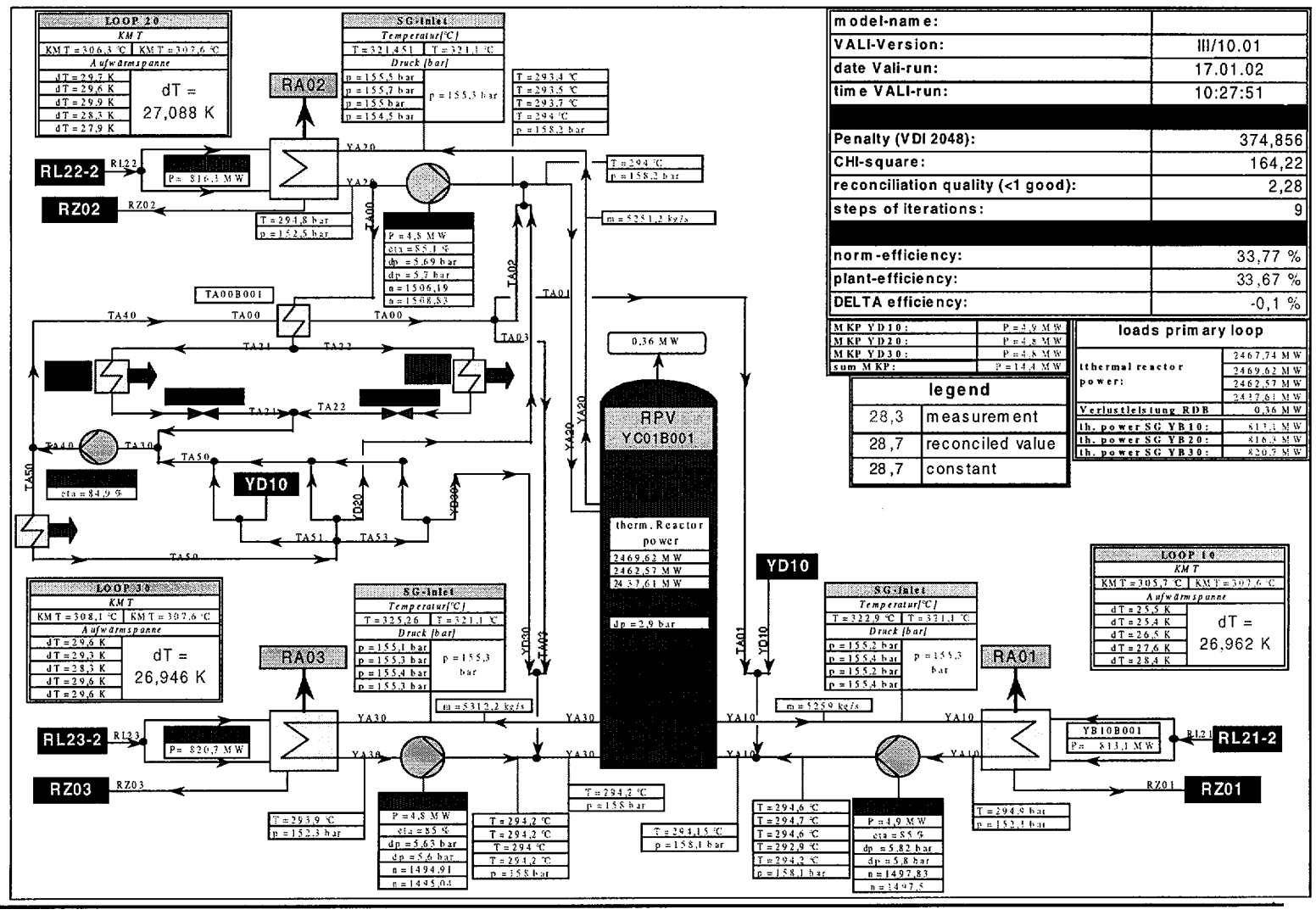
Process data reconciliation in a 3-Loop PWR (920 MW) results

PRIMARY LOOP – results in flow-sheet



Use of VALI III for special acceptance tests, maintenance activities and component diagnosis

Method: Comparison measurements for actual analysis of the process

Goal: A more precise statement as with conventional methods is possible.

This method is used for

- a more precise judgement of the replacement of turbine blades
- a more precise judgement of maintenance activities (cleaning of turbo charger)
- component diagnosis

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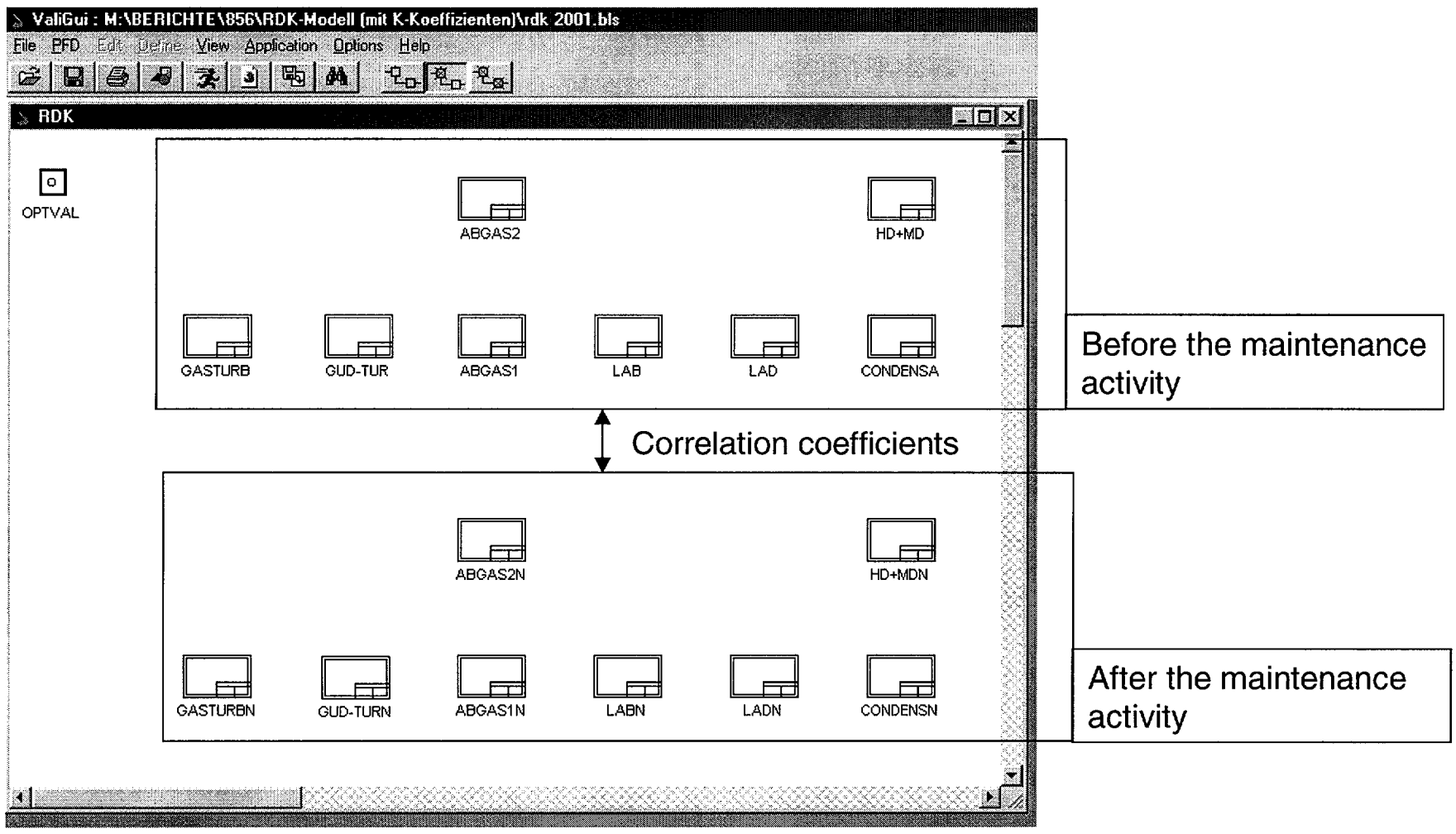
Use of VALI III for special acceptance tests, maintenance activities...



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Evaluation of a maintenance activity (Compressor cleaning in a CCGT) with and without correlation coefficients

Result of data reconciliation **without correlations** between the measurements before and after the compressor cleaning

ΔP_{EL}=3,92 MW ± 3.17 MW

ΔP_{EL}=4,02 MW ± 1.77 MW

Result of data reconciliation **with correlations** between the measurements before and after the compressor cleaning

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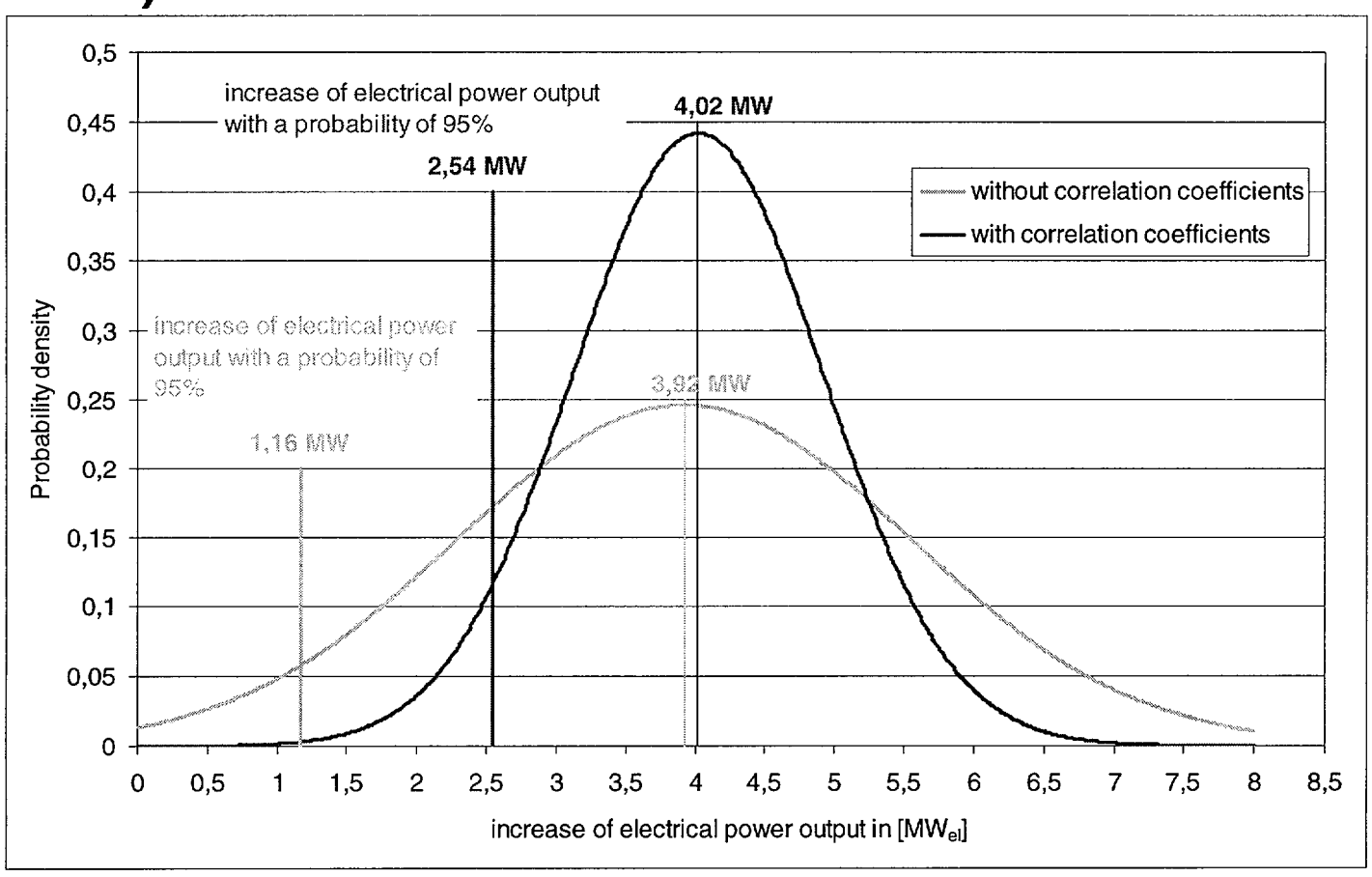
Evaluation of a maintenance activity (Compressor cleaning in a CCGT) with and without correlation coefficients



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Example: Acceptance test in a NPP

Conversion of the Low-pressure turbines

Result of a conventional acceptance test (without correlations between the measurements before and after the conversion)

ΔP_{EL}=37,88 MW ± 15.84 MW

ΔP_{EL}=38,5 MW ± 8.24 MW

Result of the acceptance test with VALI III (with correlations between the measurements before and after the conversion)

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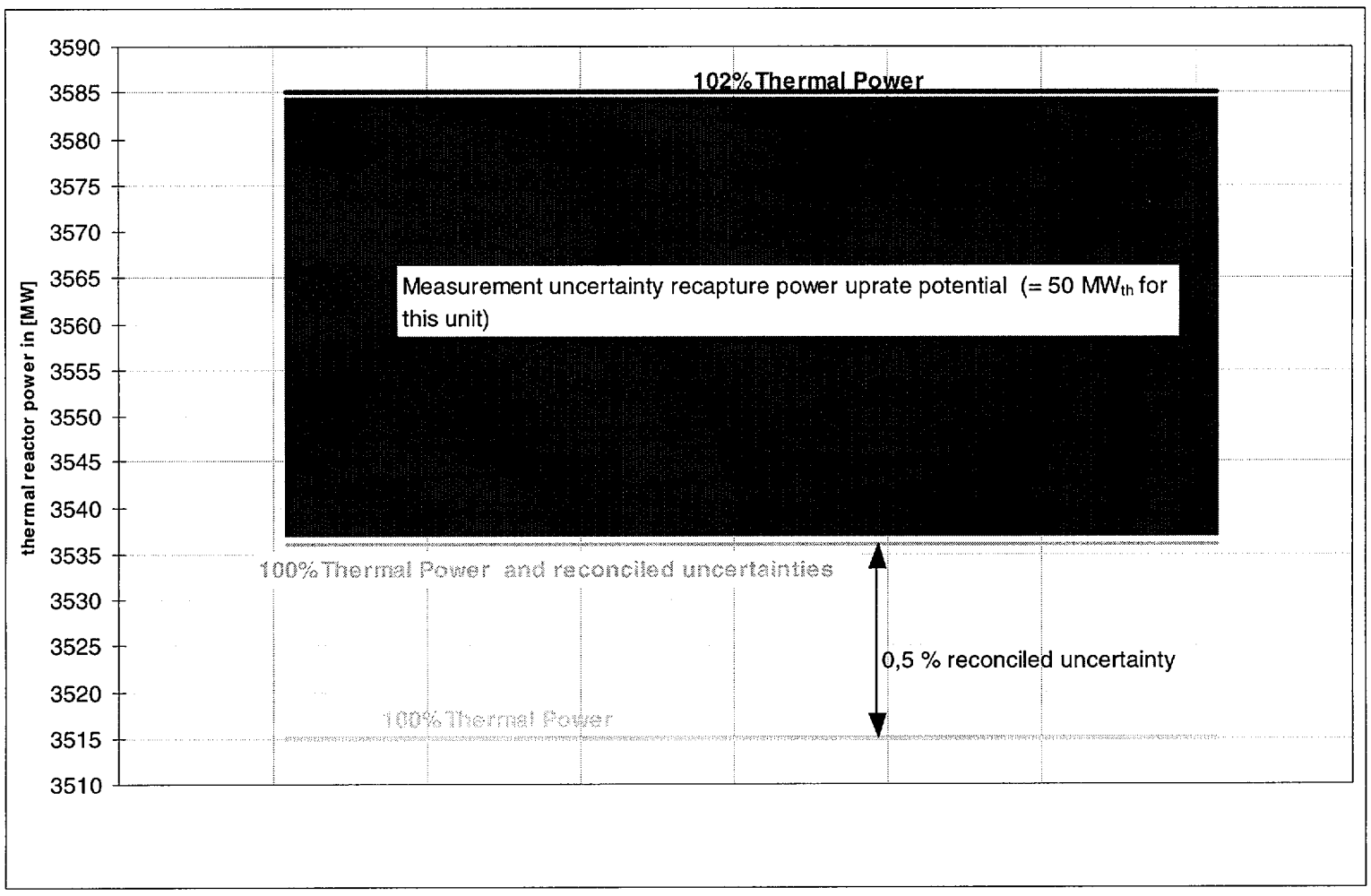
Possible Use of VALI III for the **Measurement uncertainty recapture power uprate**



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CONCLUSIONS

SLIDES for possible QUESTIONS

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Objective function < Chi-Square distribution

$$\text{Penalty (objective function)} = \sum \left(\frac{\text{measurement} - \text{reconciled value}}{\text{standard deviation}} \right)^2$$

$$<$$

$$95\% - \text{quantile of the CHI} - \text{square distribution; } \chi_{r,95\%}^{2} \text{ of freedom r}$$

If this condition is fullfill, the reconciled values represent the true state of the process.

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VALI-models				
plant	BWR Leibstadt (KKL)	CCGT-plant RDK	PWR GKN 1	PWR GKN 2
Installation ON/OFFLINE	ONLINE	OFFLINE	ONLINE	ONLINE
PENALTY	**28**	**547**	**259**	**305 ,8**
CHISQUARE	103	245	164	222 ,1
VALI-goodness	**0,27**	**2,23**	**1,58**	**1,38**

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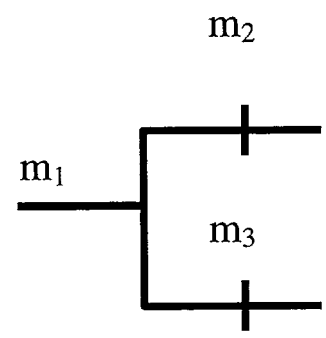
Measurement values with specified standard deviations

$$m = \begin{bmatrix} m_1 = 500 \pm v_{x1} \text{ where } v_{x1} = 25\ t/h \\ m_2 = 245 \pm v_{x2} \text{ where } v_{x2} = 12{,}25\ t/h \\ m_3 = 250 \pm v_{x3} \text{ where } v_{x3} = 12{,}5\ t/h \end{bmatrix}$$



$$s_{xi}^2 = \left(\frac{v_{xi}}{t}\right)^2 \textit{ with } t = 1{,}96 \textit{ implying } \text{a 95\% confidence intervall} (1)$$

Covariance matrix

$$S_x = \begin{bmatrix} s_{x1}^2 & s_{x1i} & s_{x1k} & s_{x1n} \\ s_{xi1} & s_{xi}^2 & s_{xik} & s_{xin} \\ s_{xk1} & s_{xki} & s_{xk}^2 & s_{xkn} \\ s_{xn1} & s_{xni} & s_{xnk} & s_{xn}^2 \end{bmatrix} (2)$$

Vector of measured values

$$\begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix} = \begin{bmatrix} 500 \\ 245 \\ 250 \end{bmatrix} (3)$$

Restrictions

$$m_1 - m_2 - m_3 = 0 (4)$$

Vector of restrictions

$$f(\bar{x}) = (m_1 - m_2 - m_3) = (0) (5)$$

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$f(\bar{x}) = f(x) + \frac{\partial f}{\partial x} v$ where f(x) – Vector of contradictions, v - Corrective vector applied to the present example

$\frac{\partial f}{\partial x} = (1 \quad -1 \quad -1)$ and $f(x) = m_1 - m_2 - m_3 = 5$ (6)

and Sx

$$S_x = \begin{bmatrix} 162{,}69 & 0 & 0 \\ 0 & 39{,}06 & 0 \\ 0 & 0 & 40{,}67 \end{bmatrix} (7)$$

The minimization problem

$$v \cdot S_x^{-1} \cdot v - 2\lambda \cdot f(\bar{x}) = \xi_0 \rightarrow Min \; (8)$$

yields, after a few adjustments and the linearization of $f(\bar{x}) = f(x) + \frac{\partial f}{\partial x} v$ (9),

the corrective vector

$$v = -\left(\frac{\partial f}{\partial x} S_x\right)^T \cdot \left(\frac{\partial f}{\partial x} S_x \cdot \left(\frac{\partial f}{\partial x}\right)^T\right)^{-1} \cdot f(x) \; (10)$$

With the values specified above it can be calculated that

$$\left(\frac{\partial f}{\partial x} S_x\right)^T \cdot \left(\frac{\partial f}{\partial x} S_x \cdot \left(\frac{\partial f}{\partial x}\right)^T\right)^{-1} = \begin{bmatrix} 0{,}673 \\ -0{,}161 \\ -0{,}168 \end{bmatrix} (11) \text{ and}$$

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$$v = -\begin{bmatrix} 0{,}673 \\ -0{,}161 \\ -0{,}168 \end{bmatrix} [5] = \begin{bmatrix} -3{,}36 \\ 0{,}81 \\ 0{,}84 \end{bmatrix} \quad (12)$$

As a result, the restriction fulfilling values yield

$$\overline{m} = \begin{bmatrix} \overline{m_1} \\ \overline{m_2} \\ \overline{m_3} \end{bmatrix} = m + v = \begin{bmatrix} 500 \\ 245 \\ 250 \end{bmatrix} + \begin{bmatrix} -3{,}36 \\ 0{,}81 \\ 0{,}84 \end{bmatrix} = \begin{bmatrix} 496{,}64 \\ 245{,}81 \\ 250{,}84 \end{bmatrix} \quad (13)$$

The covariance matrix of corrections can be calculated as follows:

$$S_v = -\left(\frac{\partial f}{\partial x} S_x\right)^T \cdot \left(\frac{\partial f}{\partial x} S_x \cdot \left(\frac{\partial f}{\partial x}\right)^T\right)^{-1} \cdot \left(\frac{\partial f}{\partial x} S_x\right) \quad (14)$$

Implemented into the example it yields

$$S_v = \begin{bmatrix} 109{,}49 & -26{,}24 & -27{,}3 \\ -26{,}2 & 6{,}28 & 6{,}54 \\ -27{,}33 & 6{,}55 & 6{,}83 \end{bmatrix} \quad (15)$$

ând the corrected covariance matrix

$$S_{\bar{x}} = S_x - S_v = \begin{bmatrix} 162{,}69 & 0 & 0 \\ 0 & 39{,}06 & 0 \\ 0 & 0 & 40{,}67 \end{bmatrix} - \begin{bmatrix} 109{,}49 & -26{,}24 & -27{,}3 \\ -26{,}2 & 6{,}28 & 6{,}54 \\ -27{,}33 & 6{,}55 & 6{,}83 \end{bmatrix} =$$

$$S_{\bar{x}} = \begin{bmatrix} 53{,}2 & 26{,}24 & 27{,}3 \\ 26{,}2 & 32{,}78 & -6{,}54 \\ 27{,}3 & -6{,}55 & 33{,}84 \end{bmatrix} \quad (16)$$

With the corrected covariance matrix and equation (1), the new corrected confidence intervals can be calculated $v_{xi} = \sqrt{s_{xi}^{\,2}} \cdot t$ *with* $t = 1{,}96$ *implying a 95% confidence interval* (17) So you get the vector m_{New} without contradiction

$$m_{NEW} = \begin{bmatrix} 496{,}64 \pm 14{,}3\ t/h \\ 245{,}81 \pm 11{,}2\ t/h \\ 250{,}84 \pm 11{,}4\ t/h \end{bmatrix} \quad (18)$$

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Mass balance: $m_1 - m_2 - m_3 = 0$

Without data reconciliation	With data reconciliation
The mass balance is not fullfilled	**The mass balance is fullfilled**
$m = \begin{bmatrix} m_1 = 500 \pm 25\ t/h \\ m_2 = 245 \pm 12{,}25\ t/h \\ m_3 = 250 \pm 12{,}5\ t/h \end{bmatrix}$	$m_{NEW} = \begin{bmatrix} 496{,}64 \pm 14{,}3\ t/h \\ 245{,}81 \pm 11{,}2\ t/h \\ 250{,}84 \pm 11{,}4\ t/h \end{bmatrix}$

And the uncertainties were reduced

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Make a model

MEA-File

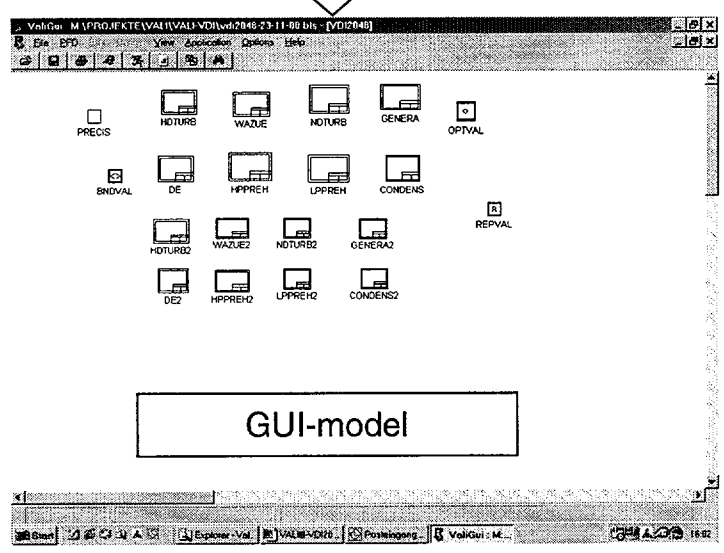
Zuordnung der Messwerte und der Korrelationen zwischen den Messwerten

```
!VORRETROFIT
vmHK        1224
vtHK        39.16
vpHK        17.36
vmNKNDV     155.16
vtNKNDV     88.39
vpNKNDV     14.75
vmHDNK      660.47
vtHDNK      151.2
vpHDNK      10.14
vmKAVHDV    203.32
vtKAVHDV    186.9

CORREL      vpAnz4 pAnz4 0.5
```

TAG-File

vmHK	STREAM	vlp.3a	MASSF	1224	-2.16	kg/s	!1
vtHK	STREAM	vlp.3a	T	39.16	0.058	C	!2
vpHK	STREAM	vlp.3a	p	17.36	–1	bar	!3



GUI-model

Resultfiles

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