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A NEW METHOD FOR EVALUATION AND CORRECTION OF THERMAL REACTOR POWER AND PRESENT OPERATIONAL APPLICATIONS

Dr. Siegfried Streit
Sebastianplatz 7, 1030 Wien, Austria
e-mail: streitsiegfried@surfeu.at, Tel.:+43 1 7133442

Dr. Magnus Langenstein, Dr. Bernd Laipple
BTB-Jansky GmbH, Gerlingerstrasse 151, D-71229 Leonberg, Germany
e-mail: btb@btbjansky.com, Tel.:+49 7152 30870

Dipl.-Ing. Horst Eitschberger/NPP Leibstadt (KKL),
CH-5325 Leibstadt, Switzerland
e-mail: horst.eitschberger@kkl.ch, Tel.: +41 56 267 7633

ABSTRACT

The determination of the thermal reactor power is traditionally be done by heat balance

- for a boiling water reactor (BWR) at the interface of reactor control volume and heat cycle
- for a pressurised-water reactor (PWR) at the interface of the steam generator control volume and turbine island on the secondary side

The uncertainty of these traditional methods is not easy to determine and can be in the range of several percent. Technical and legal regulations (e.g. 10CFR50) cover an estimated error of instrumentation up to 2% by increasing the design thermal reactor power for emergency analysis to 102 % of the licensed thermal reactor power.

Basically the licensee has the duty to warrant at any time operation inside the analyzed region for thermal reactor power. This is normally done by keeping the indicated reactor power at the licensed 100% value. The better way is to use a method which allows a continuous warranty evaluation. The quantification of the level of fulfilment of this warranty is only achievable by a method which

- is independent of single measurements accuracies
- results in a certified quality of single process values and for the total heat cycle analysis
- leads to complete results including 2-sigma deviation especially for thermal reactor power

Here this method, which is called 'process data reconciliation based on VDI 2048 guideline', is presented [1, 2].
This method allows to determine the true process parameters with a statistical probability of 95%, by considering closed material, mass- and energy balances following the Gaussian correction principle. The amount of redundant process information and complexity of the process improves the final results. This represents the most probable state of the process with minimized uncertainty according to VDI 2048.

Hence, calibration and control of the thermal reactor power are possible with low effort but high accuracy and independent of single measurement accuracies. Further more, VDI 2048 describes the quality control of important process parameter. Applied to the thermal reactor power, the statistical certainty of warranting the allowable value can be quantified. This quantification allows keeping a safety margin in agreement with the authority.

This paper presents the operational application of this method at an operating plant and describes the additional use of process data reconciliation for acceptance tests, system and component diagnosis.

INTRODUCTION

The determination of thermal reactor power is traditionally be done by heat balance. The uncertainty can be in the range of several percent caused by instrumentation errors. Technical and legal regulations (e.g. 10CFR50) cover an estimated error up to 2% by increasing the analyzed area for emergency cooling analysis to 102 % of the licensed thermal reactor power, see Figure 1.

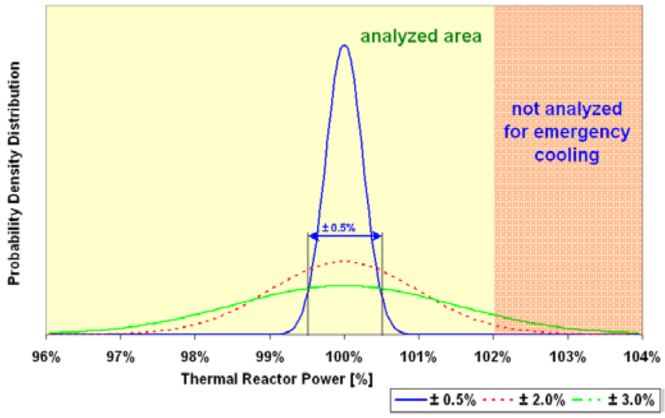


Figure 1: Probability Density Distribution for different uncertainties

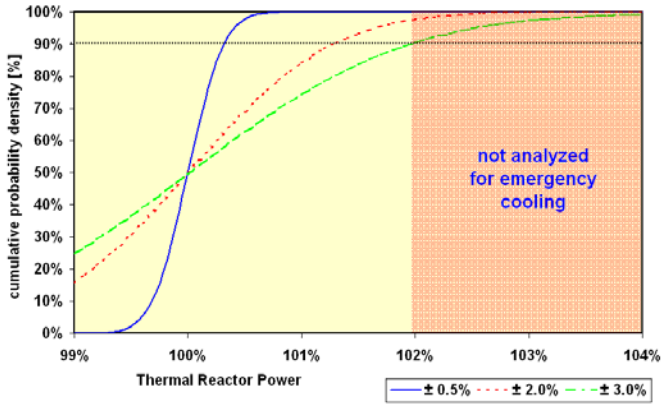


Figure 2: Cumulative Probability Density Distribution

Figure 2 shows that an uncertainty (2σ) of ± 2% leads to a probability of 97.5% that the thermal reactor power is inside the analyzed area. It is easy to show that larger uncertainties always fail to a higher degree the warranty to be inside the analyzed area. For an uncertainty of 3% there is only 90% warranty for being inside the analyzed area.

Until today the common strategy of determination of thermal reactor power is based on single parameter measurements with an as high as possible (but not known) accuracy. This can be achieved by state of the art calibration of flow nozzles including tracer measurements for total feed water mass flow or implementation of ultrasonic measurement devices with a sophisticated software evaluation. The disadvantage of all these methods is the unknown absolute accuracy of the field measurement and the unknown development of the accuracy of measurement devices including sensor characteristics, amplifier, cable links, digitizing circuits and so on.

The here described method is independent of all of these unknown and not controllable influences. The heat balance is done by use of multi redundant information of operational measurement devices. The fulfillment of energy- and mass-balance includes a quality control of the results. Thus a contradiction free heat balance is warranted with an continuous accuracy of about ± 0.5% for thermal reactor power.

Proposal for application of new method

The authors propose a license method for evaluation of thermal reactor power based on data reconciliation according to VDI 2048 by which the operator has to demonstrate to what amount he is outside the not analyzed area. It is according to present praxis when the operator can prove any time, that he is with a probability of greater than 97.5 % outside the not analyzed area (compare **APPENDIX 1 + 2**).

The authors understand the evaluation of thermal reactor power by process data reconciliation as a continuous warranty measurement with a quantified high accuracy which could be easily controlled by the authorities.

Benefits for the Authorities

A continuously quantified margin to the operational limits of thermal reactor power is easier to control and provides clear criterias for inspections.

Benefits for the Operators

The smaller the uncertainty of thermal reactor power is, the more margin he can use for operating at a higher reactor power level at the same level of safety.

This method pays for itself and assures a high level of safety.

There is no longer a need for expensive calibration procedures or other expensive and dose rate related tests.

THEORETICAL BASIS

Gaussian correction principle

The advantages of using the correction calculation are:

- quality control
- detection of serious errors
- the result confidence interval is the lowest possible and independent of the calculation method

(compare **APPENDIX 3**)

As described in [1] corrections $\mathbf{v}$ are made to the measured values $\mathbf{x}$ according to equation (1), in order to obtain estimated values (reconciled values) $\bar{\mathbf{x}}$.

$$\bar{\mathbf{x}} = \mathbf{x} + \mathbf{v} \qquad (1)$$

The corrections **v** must be determined such that the quadratic error form

$$\xi_0 = \mathbf{v}^{\mathrm{T}} \cdot \mathbf{S}_{\mathbf{X}}^{-1} \cdot \mathbf{v} \Rightarrow \min \tag{2}$$

becomes a minimum and the *r* implicit auxiliary conditions

$$\mathbf{f}(\mathbf{x}+\mathbf{v}) = \mathbf{f}(\overline{\mathbf{x}}) = \mathbf{0} \tag{3}$$

are fulfilled with the reconciled values. These *r* auxiliary conditions are simple laws of physics, like the principles of the conservation of mass or energy or simple relationships from chemistry, e.g. the laws of stoichiometry. The measured values **x** will not satisfy these *r* auxiliary conditions but, as a result of the inevitable random measurement deviations, lead to contradictions. Since the true values satisfy the auxiliary conditions, this is also demanded of the estimated values (reconciled values) $\overline{\mathbf{x}}$.

The instructions for calculating the vector of the non-contradictory estimated values (reconciled values) $\overline{\mathbf{x}}$ from the vector of the measured values **x**. can be formulated as follows

$$\begin{aligned} \overline{\mathbf{x}} &= \mathbf{x} + \mathbf{v} \\ &= \mathbf{x} - \mathbf{S}_{\mathbf{X}} \cdot \mathbf{F}^{\mathrm{T}} \cdot (\mathbf{F} \cdot \mathbf{S}_{\mathbf{X}} \cdot \mathbf{F}^{\mathrm{T}})^{-1} \cdot \mathbf{f}(\mathbf{x}) \end{aligned} \tag{4}$$

$\mathbf{S}_{\mathbf{X}}$ empirical covariance matrix of measured values **x**

$\mathbf{F} = \left(\dfrac{\partial \mathbf{f}}{\partial \mathbf{x}} \right)$ Functional matrix of the auxiliary conditions

$\mathbf{f}(\mathbf{x})$ Vector of contradictions of the measured values **x**

The covariance matrix $\mathbf{S}_{\mathbf{V}}$ of corrections **v** and the covariance matrix $\mathbf{S}_{\overline{\mathbf{X}}}$ of non-contradictory estimated values (reconciled values) $\overline{\mathbf{x}}$ is obtained with:

$$\begin{aligned} \mathbf{S}_{\overline{\mathbf{X}}} &= \mathbf{S}_{\mathbf{X}} - \mathbf{S}_{\mathbf{V}} \\ &= \mathbf{S}_{\mathbf{X}} - \mathbf{S}_{\mathbf{X}} \cdot \mathbf{F}^{\mathrm{T}} \cdot (\mathbf{F} \cdot \mathbf{S}_{\mathbf{X}} \cdot \mathbf{F}^{\mathrm{T}})^{-1} \cdot \mathbf{F} \cdot \mathbf{S}_{\mathbf{X}} \end{aligned} \tag{5}$$

The result variables calculated from these estimated values (reconciled values) $\overline{\mathbf{x}}$ and their covariance matrix $\mathbf{S}_{\overline{\mathbf{X}}}$ have the lowest possible measurement uncertainties, independently of the chosen calculation procedure (e.g. direct or indirect method), and this facilitates the best possible assessment of compliance with the guaranteed values

Quality control and detecting suspected tags (serious errors)

For the general assessment of the measured values **x** (acquired data) the following applies:

$$\begin{aligned} \xi_0 &= \mathbf{v}^{\mathrm{T}} \cdot \mathbf{S}_{\mathbf{X}}^{-1} \cdot \mathbf{v} \\ &= \mathbf{f}(\mathbf{x}) \cdot (\mathbf{F} \cdot \mathbf{S}_{\mathbf{X}} \cdot \mathbf{F}^{\mathrm{T}})^{-1} \cdot \mathbf{f}(\mathbf{x}) \end{aligned} \tag{6}$$

With a statistical certainty of $p = 95\%$, ξ_0 is not greater than the 95% quantile of the χ^2 distribution from the degree of freedom *r* (number of auxiliary conditions) to be found in statistical tables. If the condition

$$\xi_0 \leq \chi^2_{r,95\%} \tag{7}$$

is not satisfied, the acquired data (measured values x) must be rejected because the contradictions are too great. This generally applies if the actual deviations from the true value μ_i in the case of certain measured values x_i fall outside the given confidence ranges. These excessive deviations can therefore be suspected in cases where the correction calculation in accordance with Eq.(4) had to make improvements v_i to the measured values x_i which fall outside their confidence ranges. According to the expectation of the improvement

$$E(v_i) = 0 \tag{8}$$

the magnitude of correction v_i is with a statistical certainty of $p = 95\%$ not greater than the confidence range to be calculated from the associated element of the main diagonal of the covariance matrix $\mathbf{S}_{\mathbf{V}}$ of the improvements. The covariance matrix $\mathbf{S}_{\mathbf{V}}$ must be determined by using Eq.(5). If the condition

$$\left| \frac{v_i}{\sqrt{s_{v,ii}}} \right| \leq 1.96 \tag{9}$$

is not satisfied, the associated measured value x_i, or of the estimated value of the associated variance $s^2_{X_i}$, must be queried. In this way it is possible to obtain not only a general assessment of the acquired data, but also specific pointers to where serious errors or seriously inaccurate estimates of the measurement accuracy can be found.

To eliminate the serious error suspected in measured value x_i, it is helpful to know which measured values x_k the measured value x_i mainly conflicts with. These are the measured values of those measured variables which have become subject to a strong stochastic dependence as a result of the correction calculation. The correlation coefficient calculated from the covariance matrix $\mathbf{S}_{\mathbf{V}}$ is a measure of the stochastic dependence. According to this, it is mainly those measured values x_k which also have to be examined for which

$$\left|r_{V,ik}\right| = \left|\frac{s_{V,ik}}{\sqrt{s_{V,ii}s_{V,kk}}}\right| \approx 1 \tag{10}$$

holds, i.e. the magnitude of the empirical correlation coefficient calculated from the covariance matrix of the improvements $\mathbf{S_V}$ has a considerable value.

Assessment of the fulfillment of a guarantee

As described in [1] the measured variables are random variables on the principles of mathematical statistics, it is possible to conclude from their uncertainties the statistical certainty (probability) with which the guaranteed characteristics are in fact fulfilled.

Example: Guarantee of a fixed maximum value [1]

Let us assume that $g(\mathbf{x})$ is a single value of a characteristic result variable *G* (e.g. heat consumption) determined from measured values, whereby the expected value (true value) of this result μ_G is unknown. For this characteristic result variable the manufacturer promises a fixed maximum value, which means that the true value μ_{G_o} is known. With knowledge of the true values, an exact assessment of the fulfilment of the guarantee could be undertaken with

$$\mu_G \le \mu_{G_o} \tag{11}$$

which is equivalent to

$$\mu_{G_o} - \mu_G = \mu_{\Delta G} \ge 0 \tag{12}$$

The comparison function

$$\Delta g(\mathbf{x}) = \mu_{G_o} - g(\mathbf{x}) \tag{13}$$

merely calculates a single value of a random variable

$$\Delta G = \mu_{G_o} - G \tag{14}$$

whose true value $\mu_{\Delta G}$ is unknown and whose variance is defined with

$$\sigma_{\Delta G} = \sigma_G \tag{15}$$

By employing the standardized deviation from the true value

$$\frac{\Delta G - \mu_{\Delta G}}{\sigma_{\Delta G}} \tag{16}$$

it is possible to make the statement

$$P\left(\frac{\Delta G - \mu_{\Delta G}}{\sigma_{\Delta G}} \le n_p\right) = p \tag{17}$$

whereby n_p is the *p* quantile of the normal distribution. By inserting Eqs.(12),(14) and (15) and transforming the argument, one obtains

$$P\left(\mu_G \le G + n_p\sigma_G\right) = p \tag{18}$$

From this equation it is possible to derived a statement on the probability with which the guarantee is fulfilled in accordance with Eq.(11). From

$$G + n_p\sigma_G = \mu_{G_o} \tag{19}$$

follows

$$n_p = \frac{\mu_{G_o} - G}{\sigma_G} \tag{20}$$

By employing the distribution function of the normal distribution

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{x} \mathrm{e}^{-\frac{t^2}{2}}\,\mathrm{d}t \tag{21}$$

one obtains the statement

$$P\left(\mu_G \le \mu_{G_o}\right) = \Phi(n_p) = \Phi\left(\frac{\mu_{G_o} - G}{\sigma_G}\right) = p \tag{22}$$

Applied to the single value $g(\mathbf{x})$ of the random variable *G* and the estimated value for the variance obtained with

$$s_G^2 = \left(\frac{\partial g(\mathbf{x})}{\partial \mathbf{x}}\right) \cdot \mathbf{S_x} \cdot \left(\frac{\partial g(\mathbf{x})}{\partial \mathbf{x}}\right) \tag{23}$$

one obtains with

$$P\left(\mu_G \le \mu_{G_o}\right) = \Phi\left(\frac{\mu_{G_o} - g(\mathbf{x})}{s_G}\right) = p \tag{24}$$

a statement on the probability with which the guaranteed value is fulfilled. It is evident that the statement of probability becomes more precise, the greater the result of the argument in Eq.(24), i.e. the smaller the variance s_G. For the assessment of the fulfilment of a guarantee, the non-contradictory estimated values (reconciled values) $\overline{\mathbf{x}}$ and their covariance matrix $\mathbf{S}_{\overline{\mathbf{x}}}$ should be employed as these supply the smallest possible variance.

Use of the assessment for fulfillment of a guarantee on the assessment of the maximum thermal reactor power

Let us assume that $P_{\text{th}}(\mathbf{x})$ is the thermal reactor power determined from measured values, and

$$s_{P_{\text{th}}}^2 = \left(\frac{\partial P_{\text{th}}(\mathbf{x})}{\partial \mathbf{x}}\right) \cdot \mathbf{S}_{\mathbf{x}} \cdot \left(\frac{\partial P_{\text{th}}(\mathbf{x})}{\partial \mathbf{x}}\right) \tag{25}$$

the probability, that the thermal reactor power is lower than the maximum tolerable thermal reactor power P_{thmax} is given with

$$P\left(P_{\text{th}} \le P_{\text{thmax}}\right) = \Phi\left(\frac{P_{\text{thmax}} - P_{\text{th}}(\mathbf{x})}{s_{P_{\text{th}}}}\right) = p \tag{26}$$

It is evident that this statement of probability becomes more precise, the greater the result of the argument in Eq.(26), i.e. the smaller the variance $s_{P_{\text{th}}}$. For the assessment of the fulfilment of this condition, the non-contradictory estimated values (reconciled values) $\overline{\mathbf{x}}$ and their covariance matrix $\mathbf{S}_{\overline{\mathbf{x}}}$ should be employed as these supply the smallest possible variance.
With the inverse function of the distribution function of the normal distribution, one obtains from the above equation the thermal reactor power with which the condition

$$P_{\text{th}} \le P_{\text{thmax}} \tag{27}$$

with a given statistical certainty p_{given} is reached:

$$P_{\text{th}} = P_{\text{thmax}} - s_{P_{\text{th}}} \cdot \Phi^{-1}\left(p_{given}\right) \tag{28}$$

It is evident that thermal reactor power, which fulfils Eq.(27) with a given statistical certainty becomes the higher, the smaller the variance $s_{P_{\text{th}}}$ is. Therefore the non-contradictory estimated values (reconciled values) $\overline{\mathbf{x}}$ and their covariance matrix $\mathbf{S}_{\overline{\mathbf{x}}}$ should be employed as these supply the smallest possible variance.

Numerical Example

The thermal reactor power $P_{\text{th}}(\mathbf{x})$ is determined from measured values (Numbers above 200 in the circuit diagram in **APPENDIX 4**).

```
         Thermal reactor capacity [MW]
                                 Value +-Conf95%
LS after reactor Stm cmpnnt   5496.869   98.815
LS after reactor Wtr cmpnnt      1.275    0.510
Inlet reactor Wtr cleaning      22.540    0.453
Outlet reactor Wtr cleaning    -18.027    0.362
Feedwater befor reactor      -1894.999   37.790
Control rod cooling             -0.960    0.019
inner power circulating pump    -8.370    0.168
Heat loss reactor                1.100    0.550
                              --------   ------
Sum                           3599.427   66.786
```

The evaluation of Eqs.(26) and (28) yields to a probability of 98.341 % for fulfilling the upper limit of 102 %. To have a certainty of 99.0 %, that the thermal reactor power is lower than the maximum tolerable thermal reactor power, in this example the reactor should be run at 3592.72 MW which is lower than the nominal thermal capacity (compare APPENDIX 1).

As explained in VDI 2048 the uncertainty of the measured values during measurements are based essentially on plausible assumptions about the unknown systematic deviations in measurement.(e.g. technical rules). Without additional controls, no proof of the correctness of these plausible assumptions and thus of the quality of measurements is therefore possible. .This can be done by means of correction calculation (compare APPENDIX 3).

The thermal reactor power determined from the non-contradictory estimated values (reconciled values) $\overline{\mathbf{x}}$ yields

```
         Thermal reactor capacity [MW]
                                 Value +-Conf95%
LS after reactor Stm cmpnnt   5496.137   40.924
LS after reactor Wtr cmpnnt      1.274    0.509
Inlet reactor Wtr cleaning      22.541    0.453
Outlet reactor Wtr cleaning    -18.028    0.362
Feedwater befor reactor      -1896.360   14.441
Control rod cooling             -0.960    0.019
inner power circulating pump    -8.370    0.168
Heat loss reactor                1.100    0.550
                             ---------   ------
Sum                           3597.334   27.231
```

The evaluation of Eqs.(26) and (28) with non-contradictory estimated values (reconciled values) $\overline{\mathbf{x}}$ yields to a probability of 100 % for fulfilling the upper limit of 102 %. To have a certainty of 99.0 %, that the thermal reactor power is lower than the maximum tolerable thermal reactor power, in this example the reactor can be run at 3639.67 MW which is higher than the nominal thermal capacity (compare APPENDIX 2).

PRESENT OPERATIONAL APPLICATION OF DATA RECONCILIATION FOR EVALUATION AND CORRECTION OF THERMAL REACTOR POWER

Leibstadt Nuclear Power Plant (KKL) is a BWR 6/238 Mark III with a licensed thermal reactor power of 3600 MW. Today at KKL the method of monitoring and evaluating thermal reactor power is embedded in a Total Quality Management (TQM) process with clear criteria for actions. There are two parallel and independent processes:

- The operator uses the information about the plant status by process computer, chart recorders and instruments. Because the thermal reactor power is based on a heat balance including several independent parameters, this value is digitally available. There is a display of the actual thermal reactor power and screens with additional trends of 10 min and 60 min mean values. The operator has to control the reactor power by this information which results from standard processing of heat balance parameters.

- In parallel hourly mean values of process parameters are collected and reconciled. The results of this analysis is periodically checked by a thermal performance engineer. An obvious deviation of thermal performance would be reported by operation. Deviations of the indicated reactor power and the reconciled value are analysed and found systematic deviations of instrumentation errors were corrected.

In the following a sample of the correction method is presented. **Figure 3** shows the view of operators and in parallel of thermal performance engineering. The operator keeps the indicated thermal reactor power at the "allowed" level of 3600 MW = 100%. The thermal performance engineer detects a remarkable difference between indicated and reconciled thermal reactor power of about 10 MW = 0.28 %. KKL's TQM requires action at latest at a deviation of 5 MW thermal power. In this sample the cause of the deviation is obviously an error in the feed water flow measurement and a minor deviation of feed water temperature.

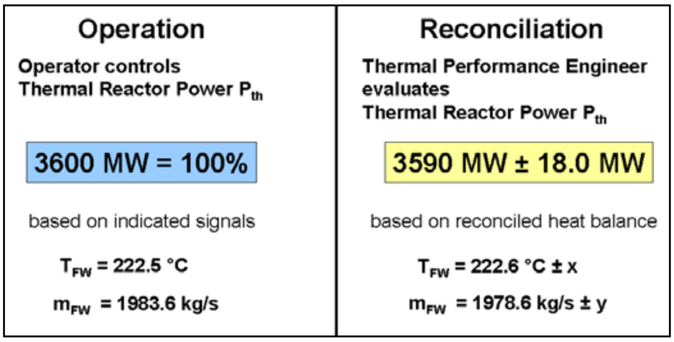


Figure 3 Process of operation and reconciliation

The decision would be made to correct the feed water flow measurement by work order and leave the temperature as is. The objective is, that indicated thermal power should be equal to reconciled thermal power. Such small changes of signals could preferably be done at the process computer with digitised values. If there is a too large deviation of instruments, first a standard hardware calibration would have been done. **Figure 4** shows the status after the correction.

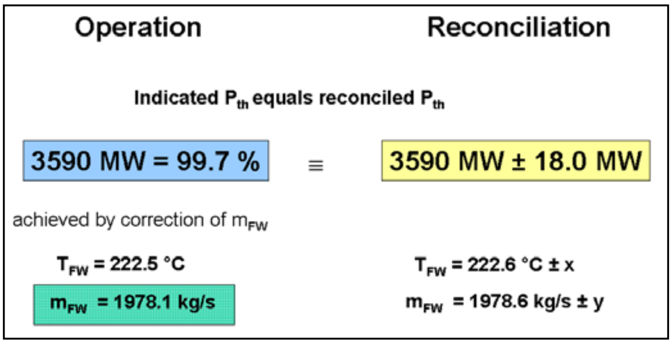


Figure 4 First corrective action

Now the operator can run the plant according to procedure and will keep 100 % power as indicated. It might be that single signals might show a difference between indicated and reconciled. That is only a minor residual error. The objective should be, that the median value of thermal power equals the indicated value. This is according to present guidelines of the authorities (see **Figure 5**).

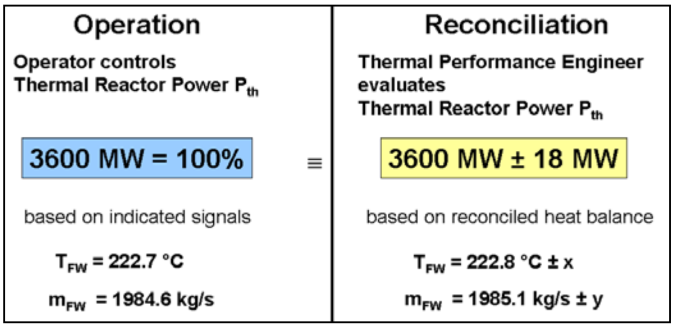


Figure 5 After corrective action

Experience at KKL

A 2σ-value of about 0.5% is standard for reconciled thermal reactor power at KKL. The margin against the non analyzed region above 102 % power can clearly be quantified.

Such corrections were done at KKL two to three times a year for minor deviations than here presented. The majority of causes for correction was erroneous instrumentation. Most of the signals are long-term stable if they are not touched.

ADDITIONAL USE OF PROCESS DATA RECONCILIATION

The process data reconciliation [3]-[9], described in VDI 2048 [1][2], is used for

- true process monitoring,
- process optimisation,
- maintenance optimisation,
- acceptance tests and
- component diagnosis.

Acceptance tests

The results of acceptance tests with high accurate measurements (conventional acceptance test) and with VALI 4 [10] (only operational data were used) for a low pressure turbine retrofit in the NPP Neckarwestheim is shown in **TABLE 1.**

	power uprate	uncertainty
agreed power uprate based on DIN 1942/1943	30 MW	±0,5 % of the measured generator output (ca. 7 MW)
result of the conventional acceptance test with high accurate measurement data from 13.05.2004 15:00 09.11.2004 13:00	30,86 MW	-
result of the VALI III acceptance test with operational data from 05.05.2004 09:00 10.09.2004 10:00	30,94 MW	±9,3 MW

TABLE 1 Comparison of the results of a conventional acceptance test and an acceptance test with VALI III

The VALI 4 system can also be used for the acceptance test of the cooling tower retrofit. In **APPENDIX 5** the results in the region of the cooling tower are shown. The results are based on a complete VALI 4 model for a pressurized water reactor (PWR) with primary-, secondary loop and the cooling tower.

Component diagnosis

For component diagnosis process data reconciliation is essential, because many important process data are not or not correct measured. In **Figure 6** the heat transfer coefficient k of six halfs of three condensers were displayed during a cleaning with a TAPROGGE-system and ring coated corundum balls. This values are calculated based on the heat exchanger area, the log mean temperature difference (LMTD) and the load.

The LMTD and the load itself are calculated values based on reconciled values.

$$\dot{Q} = k \cdot A \cdot \mathrm{LMTD} \qquad (29.a)$$

$$\Rightarrow \qquad k = \frac{\dot{Q}}{A \cdot \mathrm{LMTD}} \qquad (29.b)$$

k	heat transfer coefficient
$\dot{Q}$	load (based on reconciled values, fulfil energy-balance)
A	heat exchanger area (design parameter)
LMTD	log mean temperature difference (based on reconciled values)

Figure 6 reveals, that the cleaning procedure provided a heat transfer coefficient increase. This information enable to optimise the cleaning periods.

Same way is used for diagnosis of all preheaters within the process.

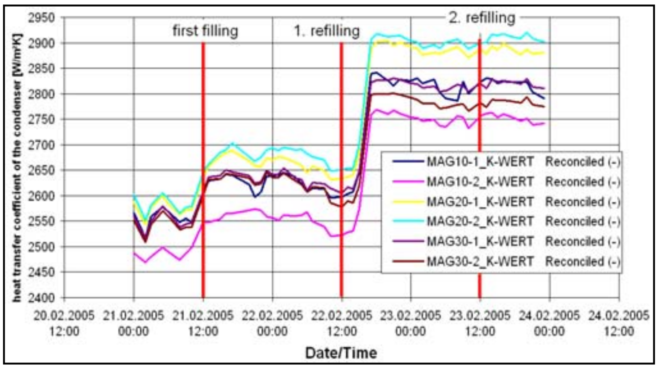


Figure 6 Heat transfer coefficients k of the condenser-halfs

The control of the cooling tower fouling is also possible. As secondary conditions the characteristics of the cooling tower is implemented into the VALI 4 model with a estimated uncertainty. If a fouling occured, the integrated quality control system in VALI 4 reveals a information which region of the cooling tower is affected.

CONCLUSION

With process data reconciliation nuclear power plants could hold the true thermal reactor power in a very narrow range. Thus avoiding production losses, detecting easily minor changes in the heat cycle and keep a quantified margin to designed safety limits. In addition, the same process data reconciliation model can be used for acceptance tests, component diagnosis and for evaluation of necessary maintenance activities.

REFERENCES

[1] VDI 2048 Part 1, “Uncertainties of measurement during acceptance tests on energy-conversion and power plants - fundamentals”, October 2000.

[2] VDI 2048 Part 2, “Uncertainties of measurement during acceptance tests on energy-conversion and power plants – Examples, especially retrofit measures”, August 2003

[3] Brockmeier U.; “Validierung von Prozeßdaten in Kraftwerken” VGB-Kraftwerkstechnik Issue 9/99 Pages 61-66.

[4] Grauf E., J. Jansky, M. Langenstein; Investigation of the real process data on basis of closed mass and energy balances in nuclear power plants (NPP); SERA-Vol. 9, Safety Engineering and Risk Analysis - 1999, Pages 23-40; edited by J.L. Boccio; ASME 1999.

[5] Grauf E., Jansky, J., Langenstein, M.: Reconciliation of process data in nuclear power plants (NPPs), 8th International Conference on Nuclear Engineering (ICONE) April 2-8, 2000 Baltimore, MD USA.

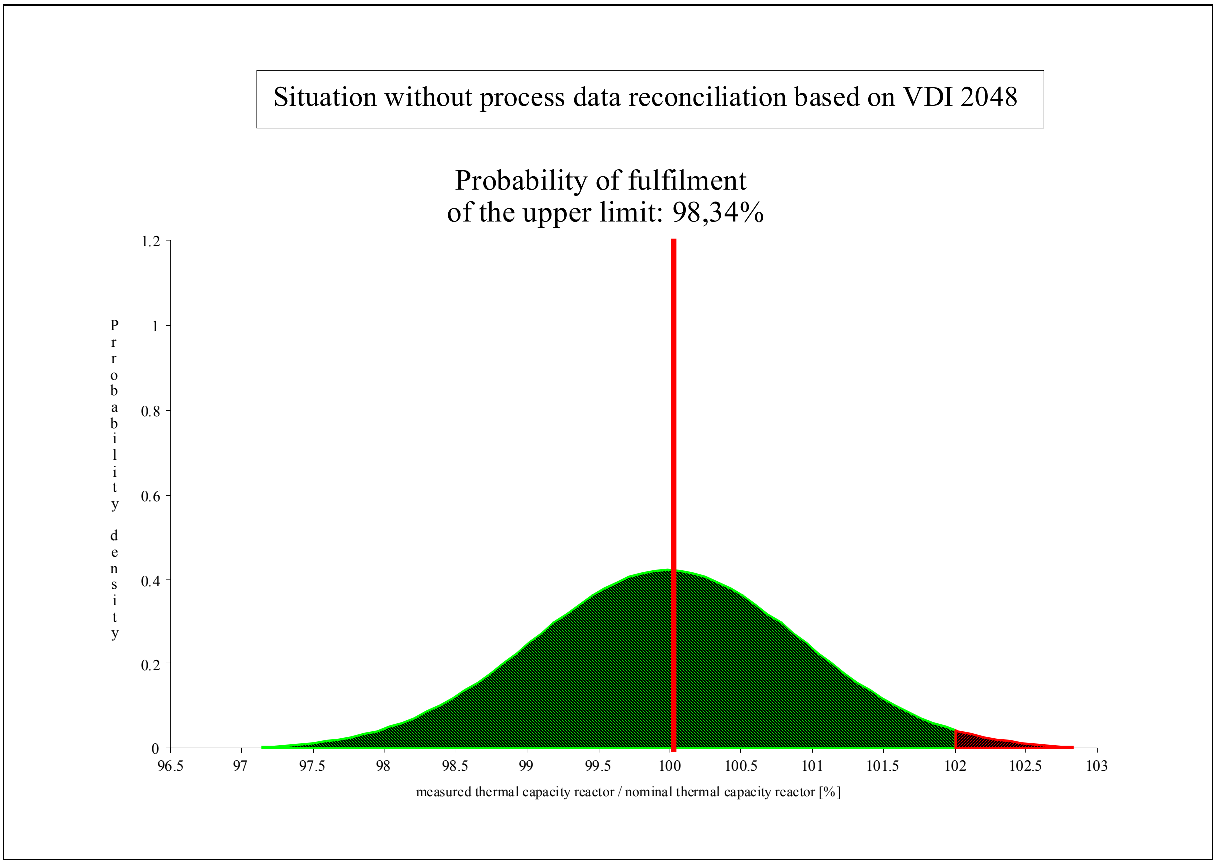
[6] Langenstein M., J. Jansky: Process data validation in CCGT and nuclear power plants, Paper # O03/2, SmiRT 16, Washington DC, August 2001.

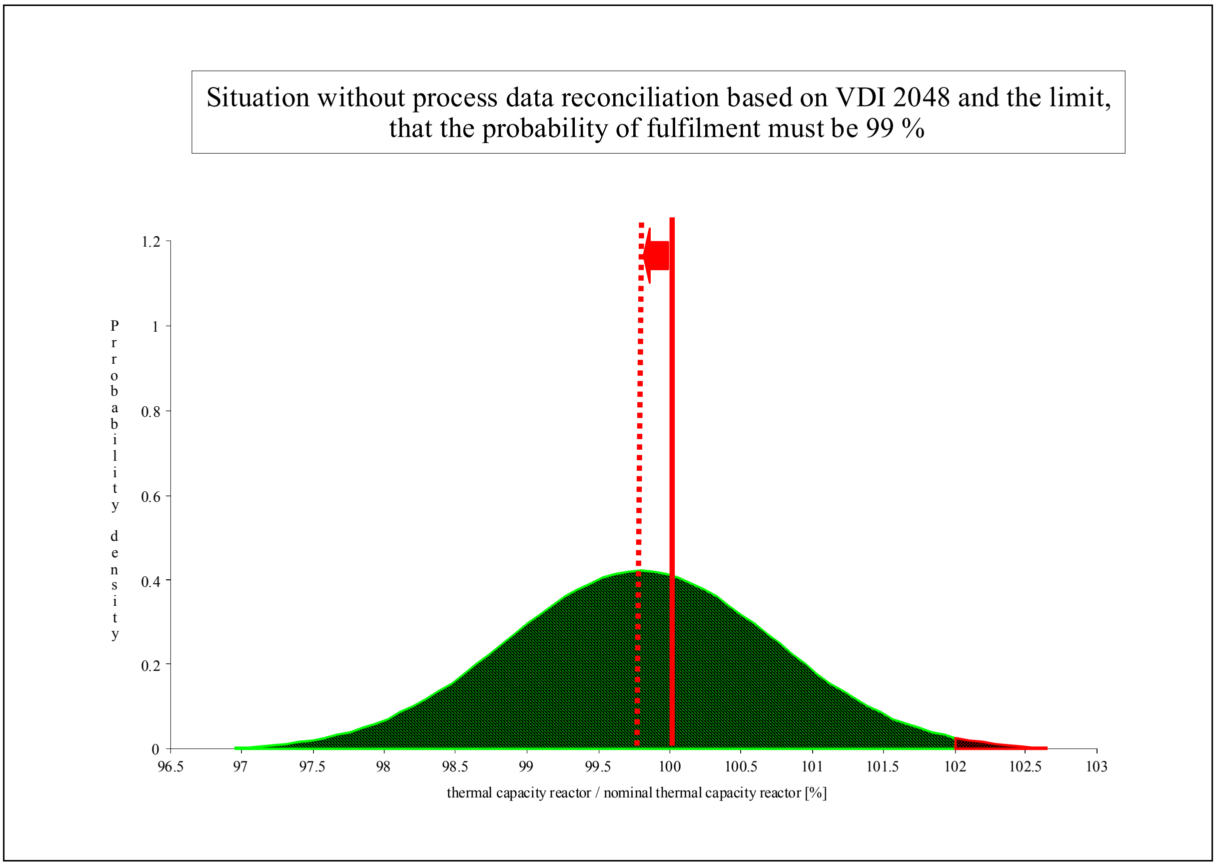
[7] Langenstein M.: Process Data Reconciliation in Nuclear Power Plants, EPRI Nuclear Power Performance Improvement Seminar, July 15-16, 2002; Saratoga Springs.

[8] H. Eitschberger, M. Neuhauser: 10 Years Experience with Process Data Reconciliation at KKL, EPRI Nuclear Power Performance Improvement Seminar, July 15-16, 2002; Saratoga Springs.

[9] Dr. Magnus Langenstein, Dr. Josef Jansky, Dr. Bernd Laipple, Dipl.-Ing. Horst Eitschberger, Dipl.-Ing. Eberhard Grauf, Dipl.-Ing. Hermann Schalk: FINDING MEGAWATTS IN NUCLEAR POWER PLANTS WITH PROCESS DATA RECONCILIATION, 12th International Conference on Nuclear Engineering (ICONE) April 25-29, 2004, Arlington, Virginia USA

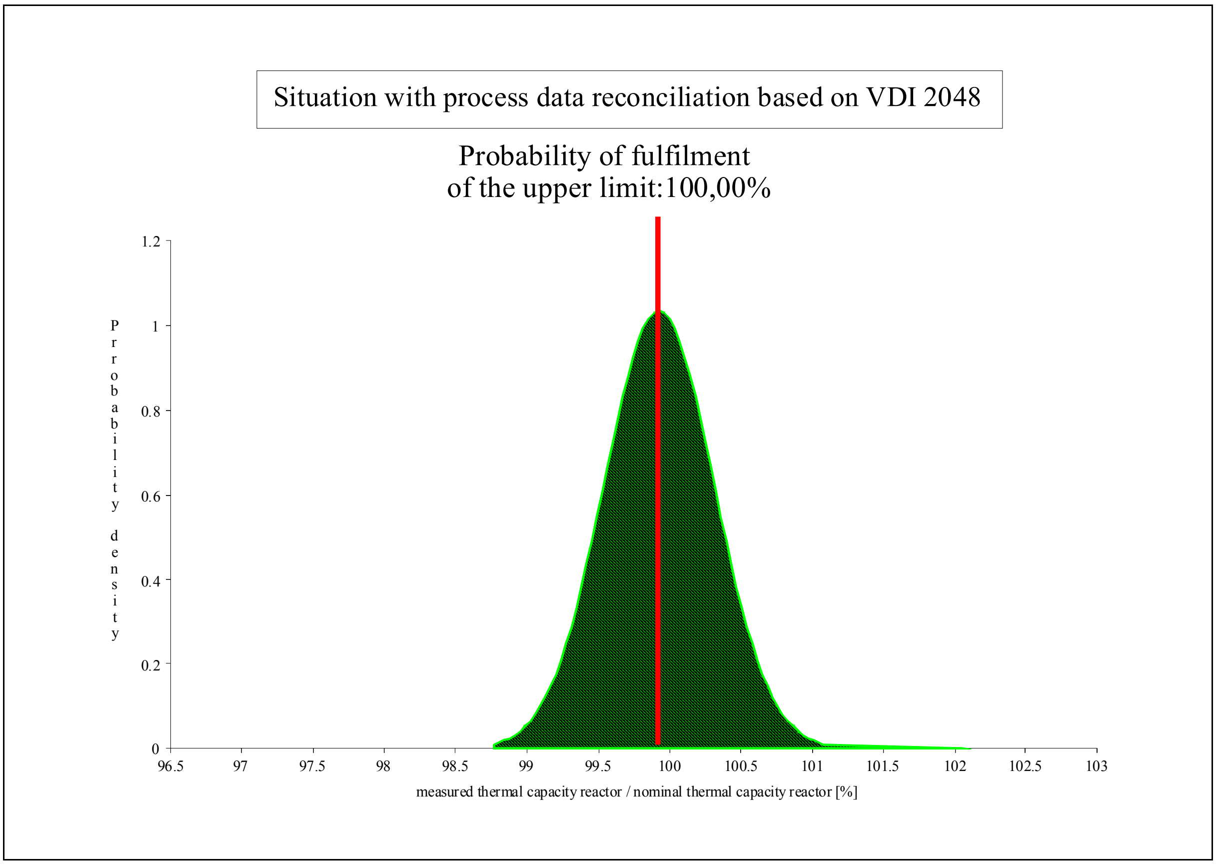
[10] VALI III USER GUIDE, BELSIM S.A., Liege, Belgium, December 2003.

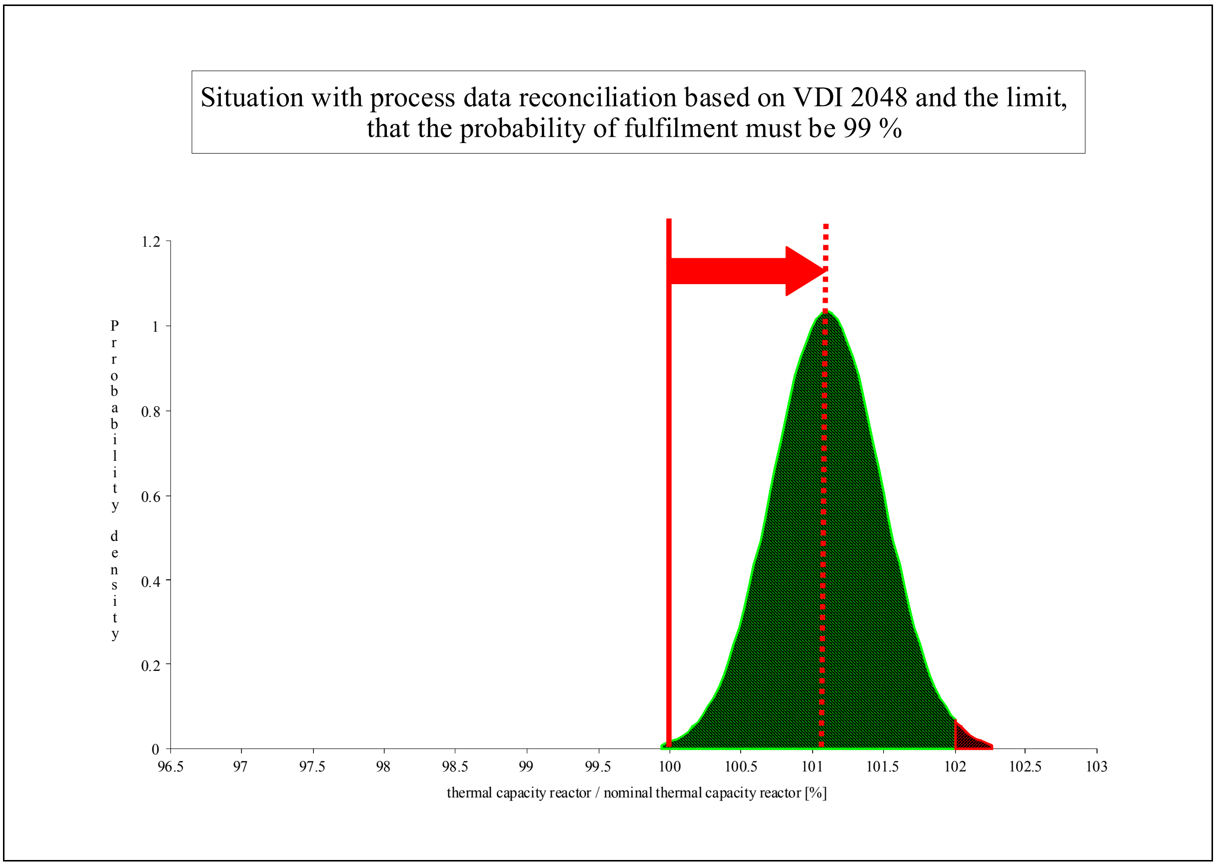




red line: 100 %
dashed red line: shift of the calculated thermal reactor power, if a 99 % probability is defined

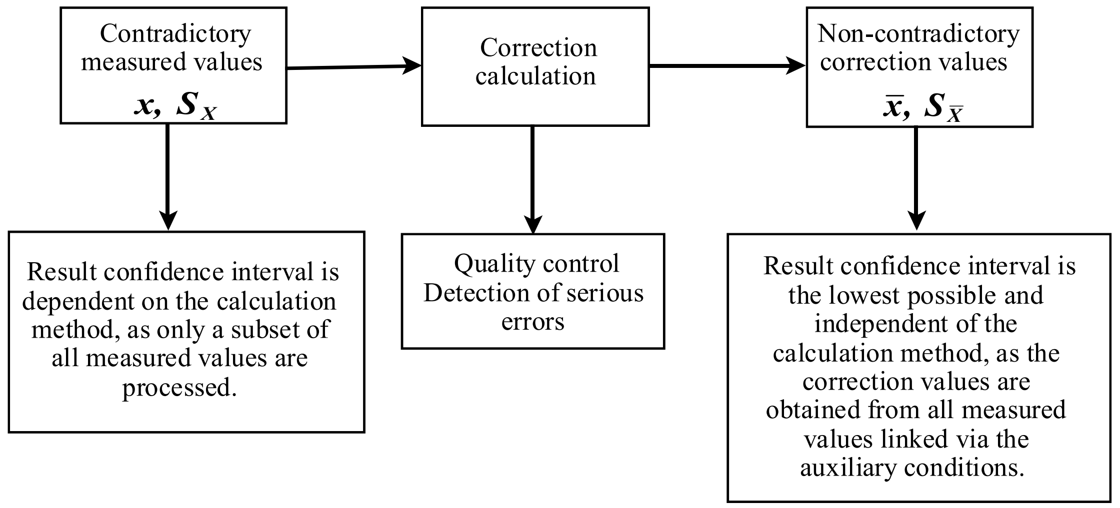
APPENDIX 1



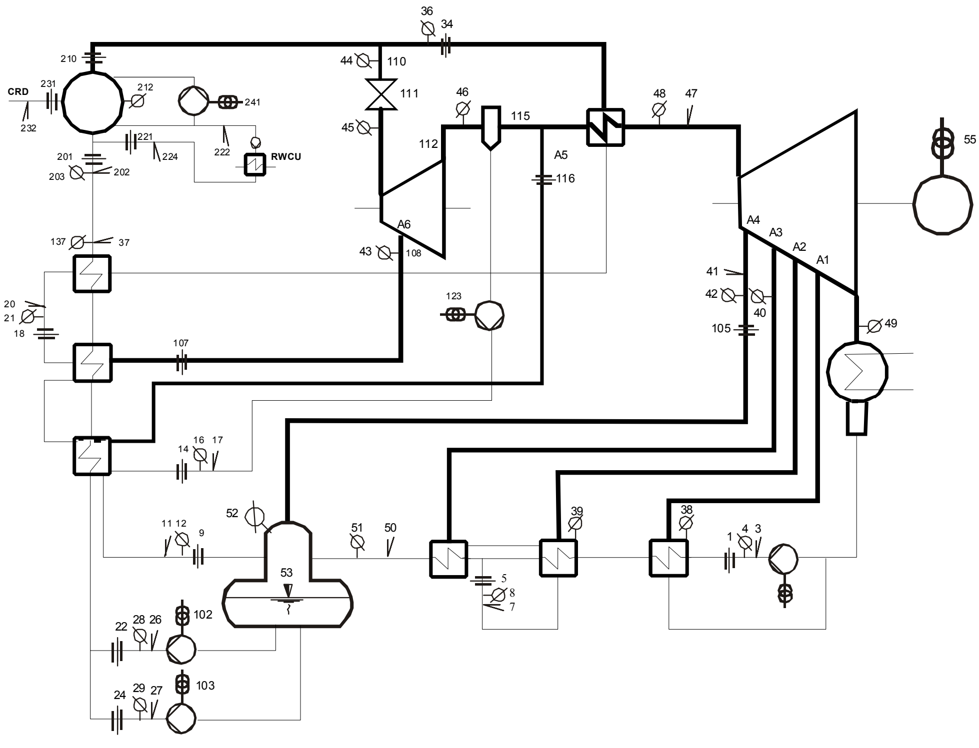


red line: 100 %
dashed red line: shift of the calculated thermal reactor power, if a 99 % probability is defined

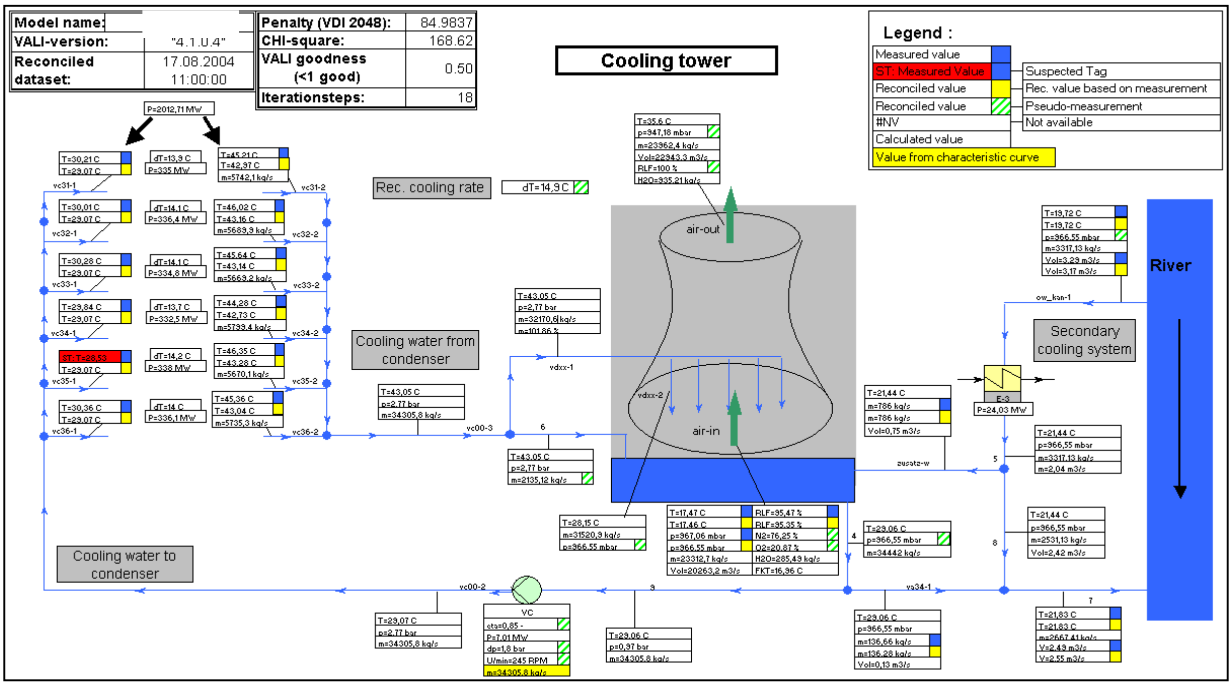
APPENDIX 2



APPENDIX 3: Advantages of using the correction calculation



APPENDIX 4: Circuit diagram



Model name:	
VALI-version:	"4.1.0.4"
Reconciled dataset:	17.08.2004 11:00:00

Penalty (VDI 2048):	84.9837
CHI-square:	168.62
VALI goodness (<1 good)	0.50
Iterationsteps:	18

Legend :

Measured value	🟦	
ST: Measured Value	🟦	Suspected Tag
Reconciled value	🟨	Rec. value based on measurement
Reconciled value	▨	Pseudo-measurement
#NV		Not available
Calculated value		
Value from characteristic curve		

APPENDIX 5: Results in the region of the cooling tower