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HANDOUT

NRC Review of VALI III

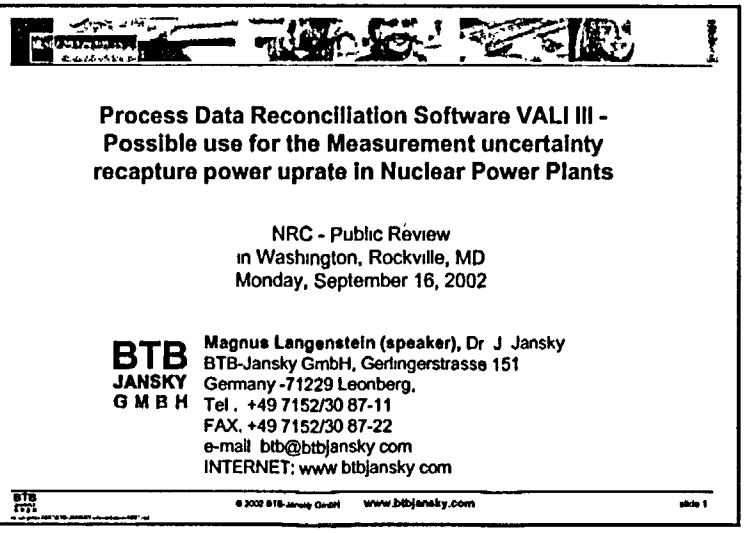
9/16/2002

AGENDA

1. Introduction of BTB-Jansky and the goal of the review (5 minutes) see **APPENDIX A**
2. Presentation of the functionality of VALI III (45 minutes), see **APPENDIX A**
3. discussion

Documents

- TÜV-southwest germany review of VALI III (translated form in english), see **APPENDIX B**
- Preliminary certification from the VDI 2048 committee (in german) **APPENDIX C**
- Manual of the VALI III-program (in english)
- Official VDI 2048 guideline (in german and english)



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

NRC - Public Review
in Washington, Rockville, MD
Monday, September 16, 2002

BTB JANSKY G M B H

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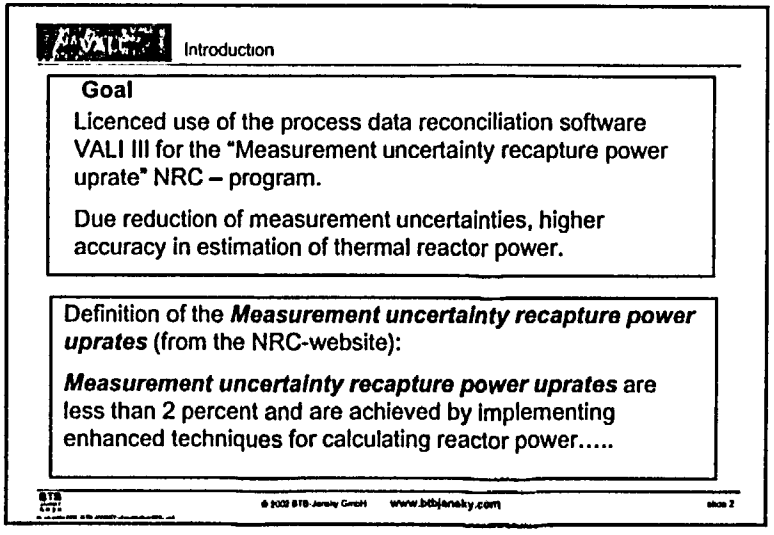


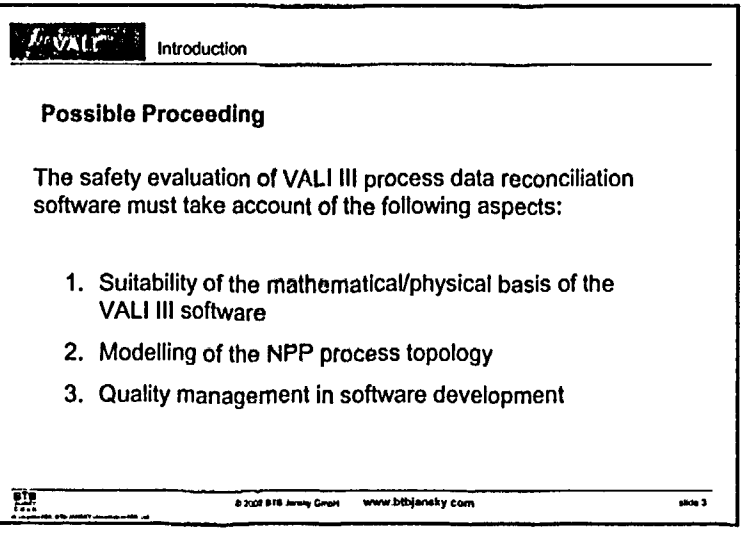
Goal

Licenced use of the process data reconciliation software VALI III for the "Measurement uncertainty recapture power uprate" NRC – program.

Due reduction of measurement uncertainties, higher accuracy in estimation of thermal reactor power.

Definition of the ***Measurement uncertainty recapture power uprates*** (from the NRC-website):

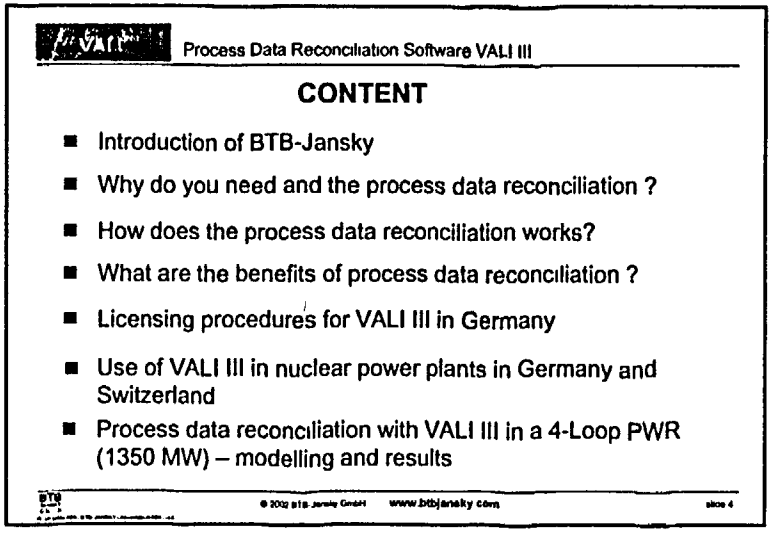
Measurement uncertainty recapture power uprates are less than 2 percent and are achieved by implementing enhanced techniques for calculating reactor power.....



Possible Proceeding

The safety evaluation of VALI III process data reconciliation software must take account of the following aspects:

1. Suitability of the mathematical/physical basis of the VALI III software
2. Modelling of the NPP process topology
3. Quality management in software development



CONTENT

- Introduction of BTB-Jansky
- Why do you need and the process data reconciliation ?
- How does the process data reconciliation works?
- What are the benefits of process data reconciliation ?
- Licensing procedures for VALI III in Germany
- 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 and results

Process Data Reconciliation Software VALI III

CONTENT (cont'd)

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

BTB-Jansky GmbH

Technik	Management
Maintenance Concepts	Organisazional Analysis
Defect Analysis	Analysis of Business process
Process Data Reconciliation	Performance Data for Benchmarking
Vibration Measurements	
Environmental Consultancy	

Process Data Reconciliation

Partner of BTB and Software developer of VALI III®

BELSIM

The Developer of the Software VALI III is the company BELSIM in Belgium

VALI III was developed in 1970 for the chemical and petrochemical industrie

Process Data Reconciliation

Process Data Reconciliation software VALI III®

BTB JANSKY G M B H

For the data reconciliation software VALI III

- we are the reseller of the software in the U.S. and the german speaking countrys (for power plants)
- we provide the engineering service and hotline
- we supported the licensing procedure in Germany.
  - VDI 2048 – certification and
  - TÜV-southwest germany (for GKN 2)

With VALI III we have experience since 5 years

- in nuclear power plants in Germany and Switzerland (BWR and PWR)
- in coal and gas-fired plants and
- in CCGT.

VALI Why do you need the process data reconciliation ?

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

VALI Why do you need the process data reconciliation ?

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

With incorrect measurements the conservation laws

- mass balance
- energy balance and
- atomic balances

cannot be fulfilled.

VALI How works the process data reconciliation with VALI

How does VALI III works ?

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 atomic balances)

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

VALI What are the benefits of process data reconciliation ?

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

You get

➨ reconciled values which fulfill the

- mass balance
- energy balance and
- atomic balances

➨ reduced uncertainties of the reconciled values

➨ the clues, where the suspected tags in your process are (ERROR-DETECOR)

Licensing procedures for VALI III in Germany

Licensing procedures for VALI III in Germany

The mathematical/physical basis of Process Data Reconciliation with VALI III is described in the VDI 2048 guideline (VDI - society of german engineers)

ICS 17.020; 27.010 VDI RICHTLINIEN Oktober 2000 / October 2000

VEREIN DEUTSCHER INGENIEURE

Messunsicherheiten bei Abnahmemessungen an energie- und kraftwerkstechnischen Anlagen Grundlagen

Uncertainties of measurement during acceptance tests on energy-conversion and power plants Fundamentals

VDI 2048

Blatt 1 / Part 1

Ausg. deutsch/englisch / Issue German/English

Das deutsche Version dieser Richtlinie ist verbindlich. / The guideline shall be given with respect to the English translation. The German version of this guideline shall be taken as authoritative.

Inhalt / Contents

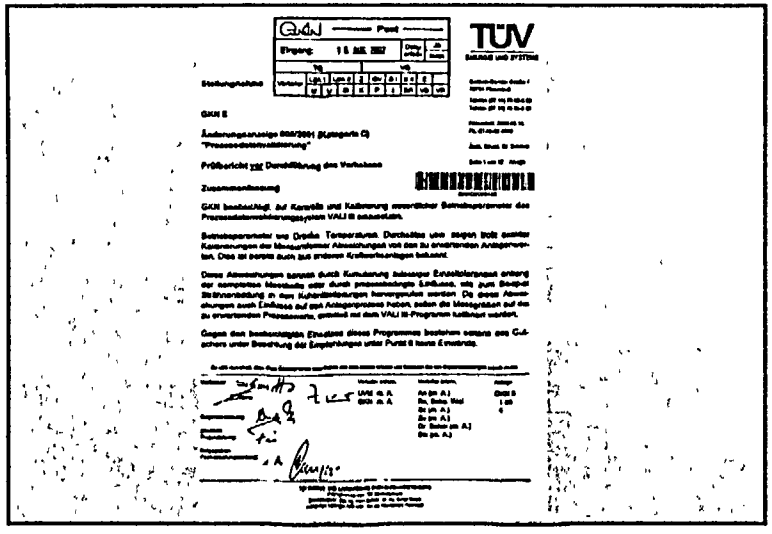
Licensing procedures for VALI III in Germany

VALI III - preliminary certificate of the VDI 2048 commitee since December/17/2001

VALI III - final certificate of the VDI 2048 commitee on October/11/2002

Licensing procedures for VALI III in Germany

VALI III was aknowledged by TÜV-southwest nuclear section as a support system for the calibration of the feedwater-mass flow measurements in GKN2 (official paper from August/16/2002), see **APPENDIX B** in the handout



TÜV

Licensing procedures for VALI III in Germany

Abstract of the TÜV test report

GKN plans to use the VALI III process data reconciliation system to monitor and calibrate key operating parameters.

Despite precisely calibrated measuring transducers, operating parameters such as pressures, temperatures, flow rates, etc exhibit deviations from the expected plant values This phenomenon is also known from other power plants.

Such deviations may be caused either by an accumulation of permissible individual tolerances along the complete measuring chain or by process-related factors, for example stratification in the coolant pipes. Since these deviations also influence the plant process, the measured variables need to be calibrated to the expected process values, as determined with the VALI III software.

No objections are raised by the examiner to the planned use of this software, provided the recommendations stated in section 6 are observed.

Licensing procedures for VALI III in Germany

Extract of the TÜV test report (full report see APPENDIX B)

.....Online reconciliation also enables measured value drift to be detected at any time during the plant cycle. Appropriate maintenance activities can thus be initiated at short notice.

.....Online reconciliation is an additional tool for assuring the quality of the relevant measured values. It facilitates optimisation of the plant.

Licensing procedures for VALI III in Germany

The TÜV had tested the following points:

1. Suitability of the mathematical/physical basis of the VALI III software

Opinion of TÜV (see also APPENDIX B)

The point is fullfilled, because the VALI III program is agree with the VDI 2048 guideline (The mathematical/physical basis of VALI III was tested from the VDI 2048 commitee; VALI III get the VDI 2048 certificate at 10/11/2002)

Licensing procedures for VALI III in Germany

The TÜV had tested the following points:

2. Modelling of the GKN II process topology

Opinion of TÜV (see also APPENDIX B)

.....The repercussions of these simplifications for the map of the real overall system are negligible in relation to the process as a whole, and their influence on the quality of the model is therefore minimal. In the examiner's opinion, the VALI III model of the technical processes and the heat flow diagrams is adequate.

Licensing procedures for VALI III in Germany

The TÜV had tested the following points:

3. Quality management in software development

The quality management measures applied to the development and maintenance of the plant-neutral and plant-specific software were verified.

Opinion of TÜV (see also APPENDIX B)

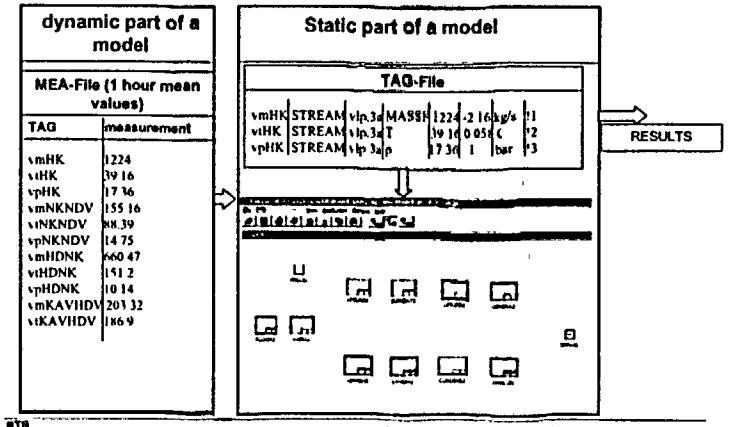
..... In the opinion of the examiner, the quality management measures defined and applied by BELSIM, the manufacturer, are adequate and in keeping with current requirements.

Use in Nuclear Power Plants

Use of VALI III in Nuclear Power Plants in Germany and Switzerland

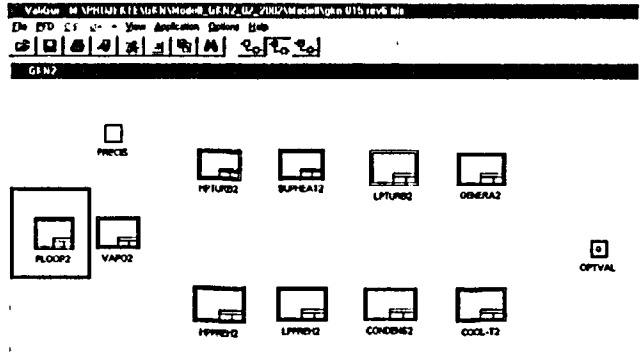
- Determine all measurements more accurately (that's important for example for the mean coolant temperature or the thermal reactor power)
- Error detection system for the measuring devices (for example to get an early hint of drifting measuring devices)
- Perform acceptance tests more accurateley
- Evaluate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

Static and dynamic part of a VALI III-model



Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

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

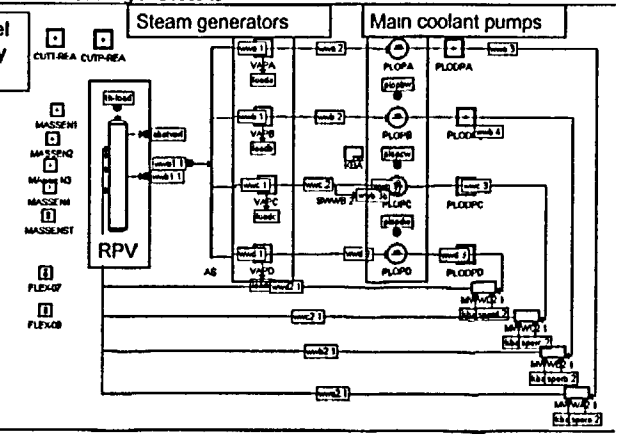


Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

GUI-model of primary loop

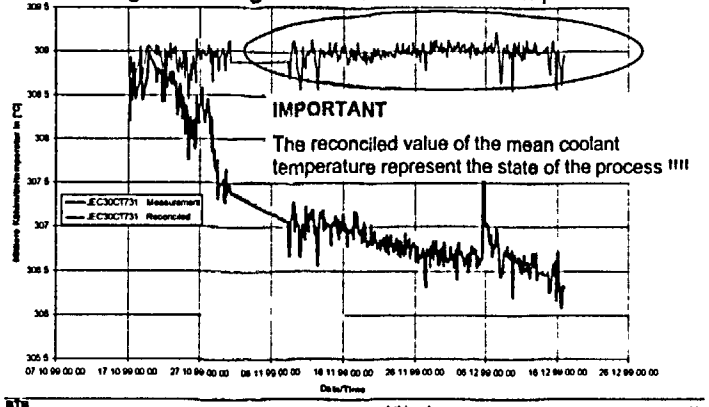
Steam generators

Main coolant pumps



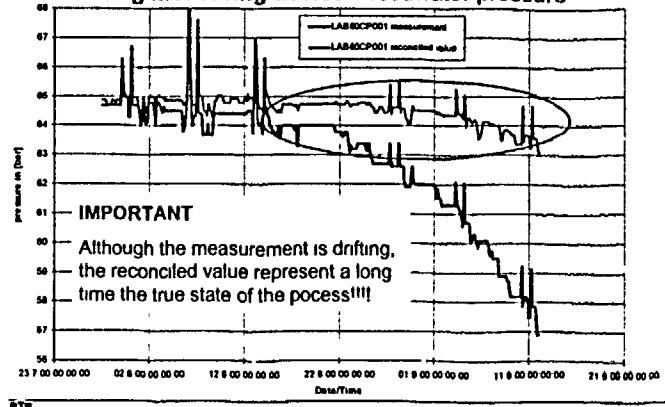
Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

Drifting measuring device - mean coolant temperature



Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

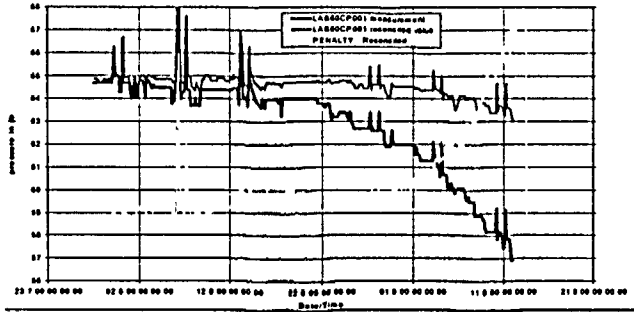
Drifting measuring device – feedwater pressure



Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

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

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

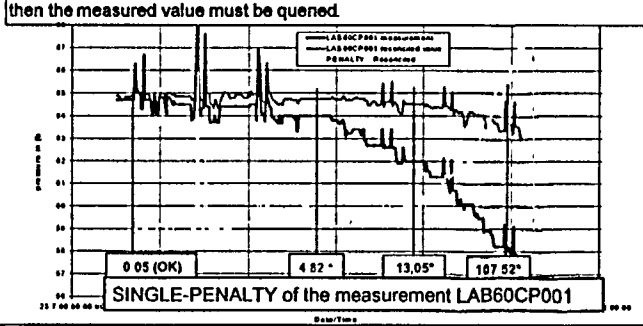


Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

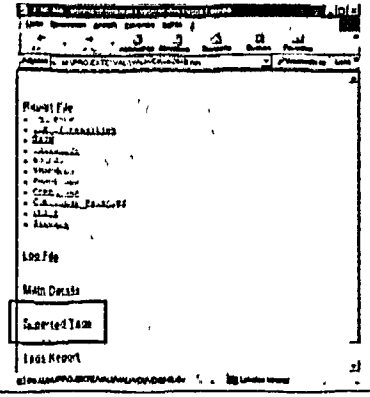
Single-PENALTY; The Error- detector in VALI

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

then the measured value must be quened.



Results



Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

Single-PENALTY; The Error- detector in VALI

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

then the measured value must be quened.

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

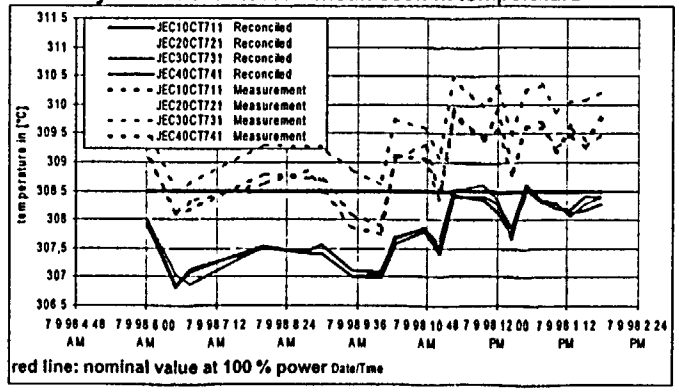
Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

Reduced uncertainties of the reconciled values

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 02	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	279.60	0.115	9.36	C
* LBA10CT001	278.25	1.00	279.80	0.115	9.36	C

Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

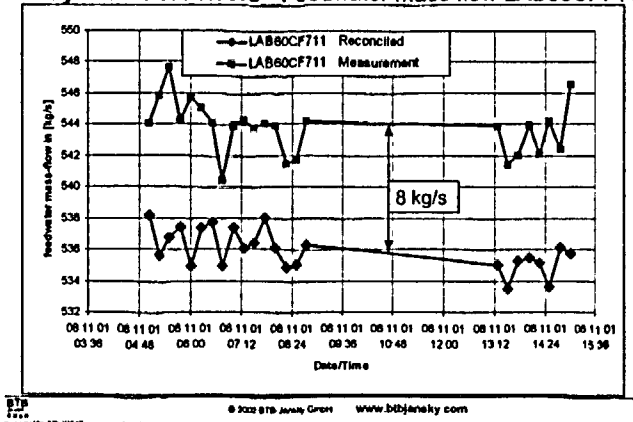
Systematical errors - mean coolant temperature



red line: nominal value at 100 % power Date/Time

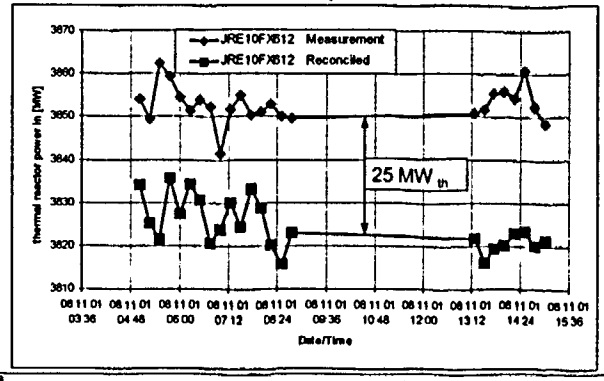
Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

Systematical errors - Feedwater mass flow LAB60CF711



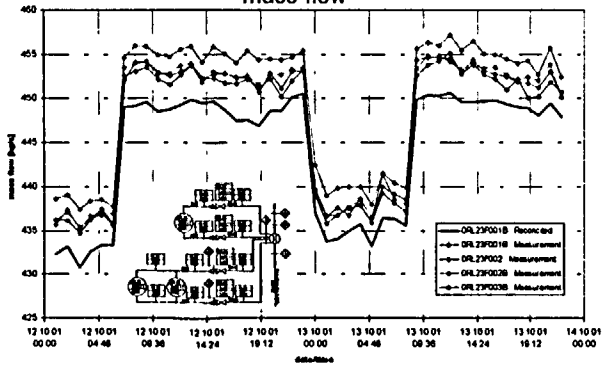
Process data reconciliation with VALI III in a 4-Loop PWR (1350 MW) – modelling and results

Systematical errors - Measured and reconciled thermal reactor power



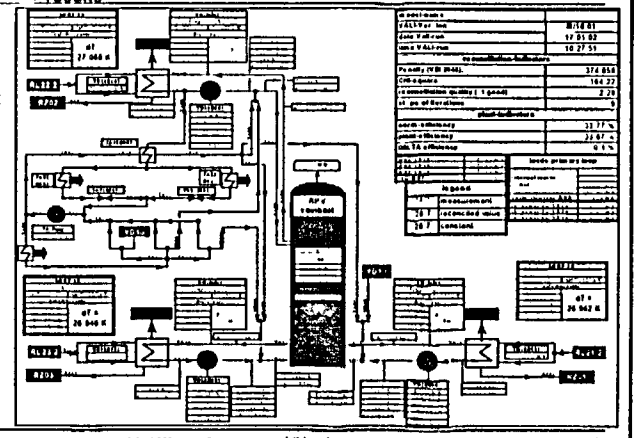
Process data reconciliation in a 3-Loop PWR (920 MW)
results

Systematical errors - Measured and reconciled feedwater mass-flow



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

PRIMARY LOOP – results in flow-sheet



Process Data Reconciliation in Nuclear Power Plants with VALI III

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

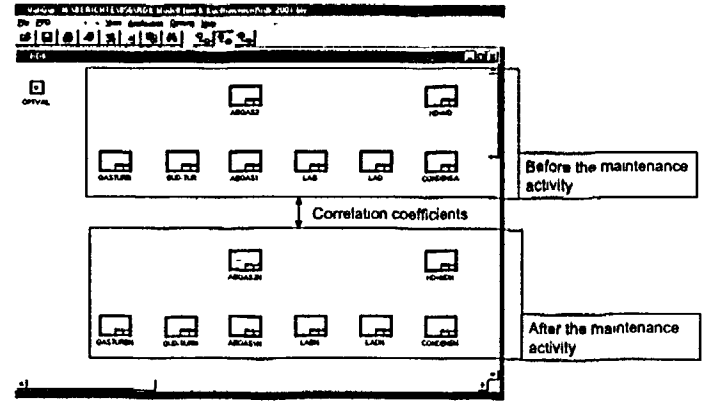
Method: Comparison measurements for actual analysis of the process

Goal: A more precise statement as using conventional methods

This method is used for

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

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



Use of VALI III for special acceptance tests, maintenance activities

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

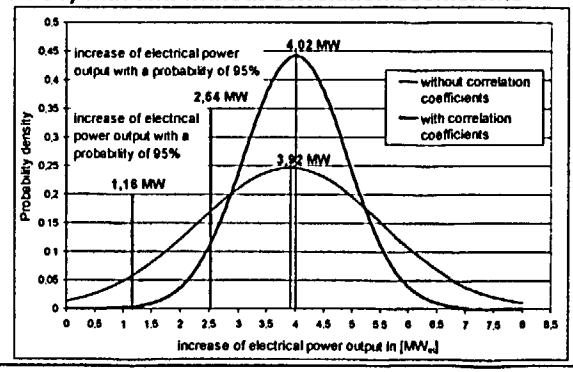
ΔP_{EL}=3,92 MW ± 3.17 MW

ΔP_{EL}=4,02 MW ± 1.77 MW

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

Use of VALI III for special acceptance tests, maintenance activities

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



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

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)

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

Reasons for the use of VALI III for the Measurement uncertainty recapture power uprate

- Process data reconciliation with VALI III has a 200 years old statistical and mathematical basis, which is described in the VDI 2048 guideline.
- If you have enough redundancies (enough measurements and enough secondary conditions), you can reduce the uncertainties of the reconciled values drastically.
- You not only reduce the uncertainties, you also get an early hince of drifting measurements.
- Although the measurement is drifting, the reconciled value represent a long time the true state of the pocess!!!!

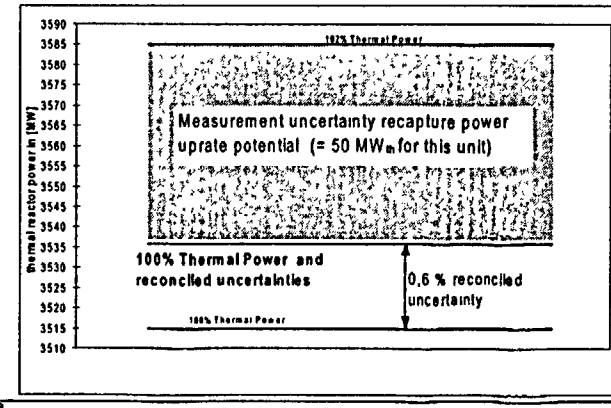
Possible Use of VALI III for the **Measurement uncertainty recapture power uprate**

Example for the **feedwater massflow measurement 10YR11F002/2 and the thermal reactor power output YC00THERMAL-LOAD**

in KKL (BWR Leibstadt, Switzerland)

Measurement	Value	95 %-confidence intervall	Reconciled value	Reconciled 95%-confidence intervall
10YR11F002/2	1937.4 kg/s	± 1.20 %	1935 8 kg/s	± 0 6 %
YC00THERMAL-LOAD	3518 0 MW	-	3517 0 MW	± 21 MW = ± 0,6 %

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



CONCLUSIONS

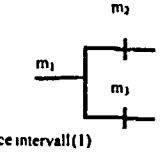
VALI III is

- Used in Switzerland
  - During an OSART mission in 1996 KKL (Switzerland) got a GOOD PRACTISE AWARD for the Use of VALI III
- Used in Germany
- Used in the U.S. ???

Our advice is, test, licence and use VALI III

Measurement values with specified standard deviations

$$m = \begin{bmatrix} m_1 = 500 \pm v_{s1} \text{ where } v_{s1} = 25\,t/h \\ m_2 = 245 \pm v_{s2} \text{ where } v_{s2} = 12{,}25\,t/h \\ m_3 = 250 \pm v_{s3} \text{ where } v_{s3} = 12{,}5\,t/h \end{bmatrix}$$



$s_m^2 = \left(\frac{v_m}{t}\right)^2$ *with* $t = 1{,}96$ *implying* a 95% confidence intervall (1)

Covariance matrix

$$S_x = \begin{bmatrix} s_{x1}^2 & s_{x1x2} & s_{x1x3} & s_{x1x4} \\ s_{x2x1} & s_{x2}^2 & s_{x2x3} & s_{x2x4} \\ s_{x3x1} & s_{x3x2} & s_{x3}^2 & s_{x3x4} \\ s_{x4x1} & s_{x4x2} & s_{x4x3} & s_{x4}^2 \end{bmatrix} (2)$$

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)

$f(\bar{x}) = f(x) + \frac{\partial f}{\partial x} v$ 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

$$v\, S_x^{-1}\, v - 2\lambda\, f(\bar{x}) = \xi_{\min} \rightarrow Min(8)$$

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

the corrective vector

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

With the values specified above it can be calculated that

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

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

As a result, the restriction fulfilling values yield

$$\bar{m} = \begin{bmatrix} \bar{m}_1 \\ \bar{m}_2 \\ \bar{m}_3 \end{bmatrix} = m + v = \begin{bmatrix} 500 \\ 245 \\ 250 \end{bmatrix} + \begin{bmatrix} -3{,}36 \\ 0{,}81 \\ 0{,}84 \end{bmatrix} = \begin{bmatrix} 496{,}64 \\ 245{,}81 \\ 250{,}84 \end{bmatrix} (13)$$

The covariance matrix of corrections can be calculated as follows

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

Implemented into the example it yields

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

and the corrected covariance matrix

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

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

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

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

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

Without data reconciliation	With data reconciliation
The mass balance is not fulfilled	The mass balance is fulfilled
$m_1 = 500 \pm 25\ t/h$	$m_{NEW1} = 496{,}64 \pm 14{,}3\ t/h$
$m_2 = 245 \pm 12{,}25\ t/h$	$m_{NEW2} = 245{,}81 \pm 11{,}2\ t/h$
$m_3 = 250 \pm 12{,}5\ t/h$	$m_{NEW3} = 250{,}84 \pm 11{,}4\ t/h$

And the uncertainties were reduced

Opinion

GKN II

Notification of change 005/2001 (Category C)
"Process Data Reconciliation"

Test report prior *to* implementation of the plan

Abstract

GKN plans to use the VALI III process data reconciliation system to monitor and calibrate key operating parameters.

Despite precisely calibrated measuring transducers, operating parameters such as pressures, temperatures, flow rates, etc. exhibit deviations from the expected plant values. This phenomenon is also known from other power plants.

Such deviations may be caused either by an accumulation of permissible individual tolerances along the complete measuring chain or by process-related factors, for example stratification in the coolant pipes. Since these deviations also influence the plant process, the measured variables need to be calibrated to the expected process values, as determined with the VALI III software.

No objections are raised by the examiner to the planned use of this software, provided the recommendations stated in section 6 are observed.

1 Grounds for and purpose of the change, scope of the change

Despite precisely calibrated measuring transducers, operating parameters such as pressures, temperatures, flow rates, etc. exhibit deviations from the expected plant values. This phenomenon is also known from other power plants.

Such deviations may be caused either by an accumulation of permissible individual tolerances along the complete measuring chain or by process-related factors, for example stratification in the coolant pipes. Since these deviations also influence the plant process, the measured variables need to be calibrated to the expected process values, as determined with the VALI III software.

The use of the VALI III process data reconciliation software is intended to allow key operating parameters to be monitored and calibrated /U 1/. This change will affect the 'instrumentation and control' area. The monitoring and calibration procedures are specified in BAW-156 /U 2/.

2 Evaluation basis

2.1 Official requirements, instructions and rulings

None

2.2 Nuclear codes of practice, guidelines and regulations

None

2.3 Non-nuclear codes of practice, guidelines and regulations

VDI Guideline VDI 2048, Sheet 1
Uncertainties of measurements at acceptance tests for energy conversion and power plants – Fundamentals
October 2000

VDI Guideline VDI 2048, Sheet 2 (Draft)
Uncertainties of measurements at acceptance tests for energy conversion and power plants – Examples
December 2001

2.4 Specifications, design requirements, requirement levels

Not affected

3 Safety evaluation

3.1 Changes

- Statement of facts

The use of the VALI III process data reconciliation software is intended to allow operating parameters to be monitored and calibrated.

Whenever the plant is started up from the cold condition, deviations of individual measured variables from their normal values (if any) are determined by the process data reconciliation software in a steady-state plant operating mode. The divergent measured variables are then calibrated in accordance with BAW-156 /U 2/. Safety-relevant measured variables are calibrated in consultation with the examiner in accordance with the specifications set out in BAW-156 /U 2/. The limit values for the 'reactor protection' and 'confinements' safety systems are not altered.

According to BAW-156 /U 2/, when the plant is started up, the measured values for the mean coolant temperature and the feed water flow rates do not need to be determined with VALI III, and verified with regard to their process plausibility until, at the earliest, approximately 90% of the reactor output is reached in a steady-state plant mode. If it is established within the framework of the plausibility check that the reconciliation results are implausible, no parameters are allowed to be calibrated on the basis of these results. Taking the VALI results as a starting point, the process tolerances must initially be complied with insofar as they are

known; if not, the instrumentation and control tolerances must be fixed as value limits. If process plausibility is confirmed, calibrations at these measuring circuits (mean coolant temperature and feed water flow) are only ever permitted within the circuit instrumentation and control tolerances. During the operating cycle, calibrations as a result of measured value processing errors detected by VALI only take place within the fixed instrumentation and control tolerances. If measured value deviations which are not attributable to measured value processing errors occur during the course of an operating cycle, process plausibility must be verified prior to calibration.

According to BAW-156 /U 2/, corrective action taken during the operating cycle must be reset during each scheduled outage immediately after the plant is shut down, in order to ensure identical conditions when the plant is started up again. Moreover, all corrective action taken, as well as the resetting of this action, must be documented consistently, both to enable measured value drift to be detected and to allow multiple, parallel calibrations to be identified and hence prevent the specified tolerances from being exceeded.

The importance of VALI III for safety lies in the envisaged processing and/or adjustment of the measurement signals of safety-relevant systems (mean coolant temperature and feed water flow in the region of the reactor controls and confinements). The software is classified as belonging to computer group 3 (computers with relevant plant data) in accordance with operating instructions BAW 114 and is evaluated accordingly.

Online reconciliation also enables measured value drift to be detected at any time during the plant cycle. Appropriate maintenance activities can thus be initiated at short notice.

Online reconciliation is an additional tool for assuring the quality of the relevant measured values. It facilitates optimisation of the plant.

- Evaluation

The safety evaluation of the use of the VALI III process data reconciliation software must take account of the following aspects:

1. Suitability of the mathematical/physical basis of the VALI III software

2. Modelling of the GKN II process topology

3. Quality management in software development

On 1): Mathematical/physical basis

Since with all measurements both random, usually independent, influences (disturbances which vary over a period of time, ambient influences, etc.) and systematic measurement deviations (faulty equipment, installation faults, deficiencies in probe measurements or samples, etc.) are superimposed on the true value of a measured variable, it is necessary to verify the measured values within the framework of quality control, and in particular to trace and represent the influence of measured value uncertainties.

In this connection, VDI Guideline 2048 includes a detailed description – in keeping with the latest state of the art – of the theoretical and practical calculation methods employed to assure

the quality of measurements and evaluate their results, specifically in relation to acceptance tests for energy conversion and power plants.

These calculation methods are based on the propagation of measurement uncertainties and on the calculus of observations.

Measurement uncertainties are taken into account by representing material and system variables as measured variables and combining them in a measured variable vector to form an n-dimensional random variable. The population of measured variable uncertainties is combined in an empirical covariance matrix of these n-dimensional random variables. Since the expected covariance values are unknown, suitable estimated values must be carefully determined. The importance of the procedure for estimating the covariances of the measured variables, to enable their stochastic dependencies to be considered is such that it is described in detail in a separate section of VDI Guideline 2048.

Assuming they can be linearised, the uncertainties of the result variables can be determined with the help of the empirical covariance matrix of the measured variables. This linearisation is fulfilled if the vector of the first partial derivatives of the result variables remains practically unchanged after the measured values in the region of the measured variable uncertainties. Suitably precise measurements and a steady-state plant mode enable this requirement to be met.

Calculi of observations have been used in applied mathematics for around 200 years. The thinking behind the extended calculus of observations method described in VDI Guideline 2048 is that not only those measured variables which are crucial for determining the result variables should be used, but also all additionally feasible (redundant) measured variables, including their associated variances and covariances, in order to obtain additional secondary conditions that must be fulfilled by the expected measured variable values. Since the measured values do not comply with these secondary conditions in an exact manner, the resulting contradictions, on the one hand, enable an indication of the measurement quality to be derived and, on the other, provide explicit pointers to serious measurement errors. This calculus of observations permits unbiased estimated values for the measured variables to be obtained from contradictory measured values. Since, from the point of view of mathematical statistics, this method of estimation is unbiased and efficient, the result variables which are calculated from the estimated values and the covariances have the smallest measurement uncertainties that it is possible to achieve with the population of measured values.

Owing to the fact that the measured variables and the result variables determined from them (within the framework of the calculus of observations) have to be interpreted as random variables in the sense of mathematical statistics, it is possible to state the statistical certainty (probability) with which the result variables are valid, taking account of the result variable uncertainties and the assumed normal distribution based on the central limit theorem. A statistical certainty of $p = 0.95$ is taken in VDI Guideline 2048 as a measure of the confidence regions.

If additional secondary conditions are taken into consideration, the calculus of observations also generates improvements with regard to the a priori estimation of covariances, which in turn can be used to calculate further improved confidence intervals. The more secondary conditions exist, the higher the quality of the results obtained with this method.

To sum up, the following main conditions and constraints must be complied with by the calculation method:

- The sensing elements must be sufficiently precise in the sense of VDI Guideline 2048,
- The sensing elements must be sufficiently redundant (i.e. there must be a sufficient number of them) in the sense of VDI Guideline 2048,
- The plant must be in a steady-state operating mode.

Concerning the requirement for a steady-state plant operating mode, it can be ascertained that in practice it is only possible to achieve a quasi-steady-state plant operating mode when measurements are performed, and that random variations of the measured variables over time, usually of the material and energy flows (such as the mass flows, the momentum flows and the enthalpy flows), are inevitable in this condition. These temporal variations of the measured variables can be corrected by means of integration over a sufficiently long measuring period.

The operational measured values required for process data reconciliation are supplied by the process computer. An hourly mean is formed in order to reduce the volume of data per acquisition cycle of 1 s to 5 s. The formation of a mean value enables any random variations of the measured values over time to be compensated. The mean hourly values are passed on to the reconciliation routine and subjected to a reconciliation calculation. In the opinion of the examiner, this constitutes compliance with the "steady-state plant mode" cited as a condition in VDI 2048.

Owing to the higher-level nuclear requirements, the sensing elements installed in the GKN II plant and integrated in VALI III comply extremely effectively with the requirements laid down in VDI 2048 regarding measurement precision, the number of sensors and the measurement method.

As a further constraint, it must be ensured that the calculation modules for the calculi of observations and the propagation of errors by the VALI III program system planned for data reconciliation in GKN II conform to the calculation methods described in VDI Guideline 2048.

The VALI III program system is a software package manufactured by BELSIM S.A. and used for data reconciliation in the chemical industry (Belgium, France, Germany), in nuclear power plants (Switzerland, Germany) and in conventional power plants (Belgium, Germany).

As a software partner of BELSIM and a subcontractor of GKN II, BTB Jansky GmbH submitted an application for the certification of the VALI III program system to VDI-Gesellschaft Energietechnik GET.

The result of the certification of the VALI III program system was presented to the examiner as /U 3/. VDI-Gesellschaft Energietechnik GET confirms in the enclosed certificate /U 4/ that – except for the integration of thermodynamic property uncertainties – the existing version of the VALI III software (Release 2000) fulfils the requirements of VDI Guideline 2048.

BELSIM has provided VDI-Gesellschaft Energietechnik GET with a written assurance that thermodynamic property uncertainties will be included in the forthcoming version of the VALI III software (Release 2002, refer to /U 4/).

Provided that the version of the VALI III software to be used by GKN (Release 2002) takes the uncertainties of thermodynamic properties into account, the VALI III program system complies with all the criteria stated in VDI Guideline 2048, so that the certificate can then be issued by VDI-Gesellschaft Energietechnik GET /U 4/.

The examiner recommends integrating the thermodynamic property uncertainties into the version of the VALI III software that is used for process data reconciliation (**E1**).

Providing the version of the VALI III software that is used takes the uncertainties of thermodynamic properties into account (cf. (**E1**)), the examiner thus consents – with respect to the theoretical principles of data reconciliation as described in VDI Guideline 2048 – to the use of the VALI III program system for monitoring and calibrating key operating parameters in the GKN II plant.

The examiner refers in this connection to the scope of VDI Guideline 2048, and in particular to the requirements that must be fulfilled regarding the plant condition (steady-state operating mode) as well as the detection and processing of uncertainties and quality control of the measured values.

The examiner recommends that future changes to VDI Guideline 2048 (specifically to the current draft of Sheet 2) should be taken into account as appropriate within the framework of data reconciliation in GKN II (**E2**).

On 2): Process topology

In order to be able to apply the process data reconciliation method to the complete GKN II plant, a suitable model must be created. The overall system is thereby subdivided into part systems with associated plant components.

The defined components are assigned a characteristic set of secondary conditions (e.g. mass balances) and account is taken of process parameter measurements that already exist in the systems, i.e. the plant model does not simply map the components computationally but also reflects their process condition as described by physical quantities.

A model of this kind, based on the heat flow diagram, was created by the operator using the VALI III reconciliation software.

This model mapped:

The primary coolant system,

The secondary coolant system,

The volumetric control system.

Due to the complexity of the overall system, a number of simplifications were incorporated No account was taken of the gland steam system of the turbine, for instance. The

repercussions of these simplifications for the map of the real overall system are negligible in relation to the process as a whole, and their influence on the quality of the model is therefore minimal. In the examiner's opinion, the VALI III model of the technical processes and the heat flow diagrams is adequate.

On 3): Quality management in software development

a) General

The plant is modelled using prefabricated modules (pumps, heat exchangers, etc.) supplied with the BELSIM VALI III software. This software has already been employed for many years in the chemical industry and in conventional power plants. Among other things, VALI is used to analyse weak spots and verify measured values. The modules of the VALI program are the plant-neutral part of the software.

The modules are parameterised for the plant in question and linked together in a defined plant model. This plant model represents the plant-specific part of the software.

The quality management measures applied to the development and maintenance of the plant-neutral and plant-specific software were verified. They are described and evaluated in the following.

b) Quality management for VALI modules

VALI III, the process data reconciliation software from BELSIM, is the outcome of scientific studies and has already been employed for many years in the chemical industry and in conventional power plants. The evaluation of quality management for VALI modules contained in this report is based both on practical experience with VALI III, including its ongoing development during its years in use, and on the quality management measures which have since been implemented by BELSIM in connection with the development and maintenance (if the software is modified) of the modules. The fact that the modules are programmed independently of specific plants is extremely important. They are developed, programmed, specified, tested and maintained as plant-neutral modules. They are then parameterised and linked together in a plant model on a plant-specific basis (refer also to section c) of this opinion).

Over the years, BELSIM has refined and defined the strategy and the associated quality procedures (QM). All quality management measures are combined in an application for DIN EN ISO 9000 certification planned for mid-2002.

The product-specific quality management measures are important for the present evaluation as well as for future evaluations in the event of modifications. These measures were described by BELSIM, the manufacturer, and are set out below.

Organisational procedures are described in a parent manual. They include the following:

- Responses to questions, problems and suggestions
- Change procedures
- Development of new VALI modules

- Software tests

Handling of technical documentation is described in a second manual. This includes the following procedures, which are classified by BELSIM as confidential. These documents were inspected by the examiner in relation to quality management.

- Configuration of the data records
- Definition of the modules
- Mathematical basis of VALI III
- Instructions for the development of VALI modules
- Equations generated for VALI modules
- Description of "codevali.ins"
- User problems notified via the hotline

In the opinion of the examiner, the quality management measures defined and applied by BELSIM, the manufacturer, are adequate and in keeping with current requirements.

c) Quality management for the plant model

The modules are parameterised for the plant in question and linked together in a defined plant model. This plant model represents the plant-specific part of the software (refer to section b) above).

The result of the process implementation is represented on computer graphics of the plant. The aim of process data reconciliation is to reconcile the process topology with the measured values. The procedure used to calibrate measured values as the outcome of reconciliation is described in the instrumentation and control instructions (BAW-156 /U 2/). This procedure document is classified as "subject to mandatory examination" and was given the mark of approval by the examiner following the completion of the test activities.

3.2 Influence of the plant condition while the changes are being implemented

None

3.3 Classification of the proposed change

Proposal for the licensing project:

Safety systems/radiation protection	Category C
Building legislation/civil engineering	Not affected
Fire protection affected	No
Industrial safety affected	No

Examiner's opinion:

Since, according to the operating instructions (BAW-156 /U 2/), VALI III based calibrations at the measuring circuits for the mean coolant temperature and the feed water flow are only ever permitted within the circuit instrumentation and control tolerances and since the limit values for the reactor protection and confinements systems remain unchanged, the proposed change has, in the examiner's opinion, only a minor influence on the level of plant safety.

Since, moreover, the procedure specified in the operating instructions (BAW-156 /U 2/) for documenting all corrective action taken during the operating cycle and the procedure for resetting this action each time the plant is shut down ensure that measured value drift is detected and that multiple, parallel calibrations are identified, hence preventing the tolerance ranges specified for the mean coolant temperature and the feed water flow rate from being exceeded, the classification in category C is, in the examiner's opinion, correct.

4 Quality management measures

4.1 Accompanying inspection, change testing and inspection schedule

The test steps described in the change testing and inspection schedule are adequate.

4.2 Tracking of documentation and written company provisions, documentation of the change testing and inspection list

No additional documents are required.

5 Summary evaluation

The planned use of the VALI III process data reconciliation software will enable measured values to be adjusted more precisely. Compliance with higher-level tolerances specified independently of VALI III means that the planned change will have only an insignificant influence on the level of plant safety. No objections are raised by the examiner to the implementation of this change, providing the recommendations stated in **(E1)** and **(E2)** are observed.

6 Provisos, recommendations

(E1): The examiner recommends integrating thermodynamic property uncertainties in the version of the VALI III software that is used for process data reconciliation.

(E2): The examiner recommends that future changes to VDI Guideline 2048 (specifically to the current draft of Sheet 2) should be taken into account as appropriate within the framework of data reconciliation in GKN II.

7 Other documents

/U 1/ GKN II notification of change 005/2001
with description of nuclear technology
Issued 14.06.2002

/U 2/ GKN operating instructions BAW-156
GKN II – calibration and adjustment of selected plant measuring points using reconciliation software
Issued: 11.06.2002, including pages 4, 5 and 9 dated 13.08.2002 to be inserted

/U 3/ GKN letter
GKN – change application 005/2001 "Process data reconciliation"
File no.: G2/Böger/km, 04.01.2002

/U 4/ VDI letter
Certification of the VALI III software product
VDI-Gesellschaft Energietechnik GET
Düsseldorf, 17.12.2001

8 Attachments

/U 1/

APPENDIX C

VDI-Gesellschaft
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Düsseldorf, 17.12.2001

Softwareprodukt VALI III

Sehr geehrter Herr Dr. Jansky,

geprüft wurde die prinzipielle Eignung des Softwareproduktes VALI III für die Auswertung von Abnahmemessungen an energie- und kraftwerkstechnischen Anlagen.

Das betrifft das Ablaufschema der Berechnung, die Benutzeroberfläche des Softwareprodukts und die Berechnung vorgegebener Beispiele.

Dabei wurden die folgenden Prüfkriterien herangezogen:

- Angabe der Mess- und Ergebniswerte als vollständige Ergebnisse,
- Qualitätskontrolle der Messung,
- die Untersuchung von Zusammenhängen und Fehleranalysen,
- die Darstellung der Nebenbedingungen in Bilanzform,
- die Auswertung der rohen und ausgeglichenen Daten für die Fehleranalyse,
- die Umrechnung auf Garantiebedingungen und die Ermittlung der Wahrscheinlichkeit der Erfüllung der zugesicherten Eigenschaften.

Das Programm VALI III erfüllt in der bisherigen Ausgabe alle wesentlichen Anforderungen der VDI 2048. Lediglich die Einbeziehung der Unsicherheiten der thermodynamischen Stoffdaten müsste noch aufgenommen werden. Die Erfüllung dieser Forderung im Release 2002 wurde schriftlich zugesagt. Vorbehaltlich der Erfüllung dieser Zusage erfüllt damit das Release 2002 (gültig ab 1.1.2002) alle Kriterien der Richtlinie VDI 2048, so dass das Zertifikat erteilt werden kann.

Mit freundlichen Grüßen

E.-G. Hencke

Dr.-Ing. E.-G. Hencke