TOPRE & HOTPOINT IN-CORE MONITORING SYSTEMS FOR WWER-440 NUCLEAR POWER PLANTS

T. Polák
Nuclear Power Plants Research Institute
Okružná 5, 918 64 Trnava (Slovak Republic)

O. Erben
Nuclear Research Institute Řež, plc
250 68 Řež (Czech Republic)

Abstract

TOPRE/PC is a modernised core surveillance, monitoring, analysis, and prediction tool for the understanding and planning of core operations. HOTPOINT/PC is a modern software tool, which extends the TOPRE/PC system by providing the ability for power distribution reconstruction on a pin basis, and by the thermohydraulical analysis, and for data for the departure to nucleate boiling ratio (DNBR) margin and saturation temperature criteria. In the paper, these systems are described. Examples of results of verification and validation of the TOPRE/PC system as well as some results of its further application for the tests and analysis of new fuel assemblies with zirconium spacer grids, and of reactor bypass flow rate measuring by the method of the loop disconnection are presented.

Background

Two units of the WWER-440 type 230 (the power of each unit is of 440 MWe) nuclear power plant were put into operation at Jaslovské Bohunice in Slovak Republic in 1979-80. Two units of the WWER-440 type 213 nuclear power plant were put into operation in 1984-87 at Jaslovské Bohunice and four units in Dukovany in the Czech Republic. Other units of this type are under construction in Mochovce in the Slovak Republic.

For WWER-440 type 230 nuclear power plants, the in-core monitoring system HINDUKUS was supplied. This system includes, amongst other functions, 210 outlet coolant temperature measurements and 36 axial neutron flux distribution measurements. Each neutron measurement channel includes seven self-powered neutron detectors and one background detector. Figure 1 illustrates the location of the in-core sensors. Basic measuring and evaluation apparatus ensures data collection and processing so that the reactor operators have basic information regarding the reactor core parameters. Later on, the system was supplemented with equipment based on a minicomputer SM-2. Mathematical software, named VMPO SKR, of this minicomputer provides more detailed information on the state of the plant, mainly of the reactor core. It provides conversion of SPND signal values to the linear power rate values of the assemblies, 3D coarse mesh power distribution reconstruction, and power peaking factor and margins to conservative limit calculations. The software includes also functions for the diagnosis of the sensor signals credibility, e.g. comparison of measured signal values and their rates of change with limiting values, determination of SPND insulation resistance values, and comparison of reconstructed linear power rates with values calculated by simple diffusion methods.

In the early nineties, the modernisation of the instrumentation and control systems of nuclear power plants in Jaslovské Bohunice has been started and new software has been gradually developed and introduced. Some features of this modernisation are described in [1,2]. Due to increasing maintenance difficulties related to the ageing hardware and software of the HINDUKUS intelligent data acquisition system and in-core surveillance system VMPO SKR, a decision has been made to replace it with a new modern PEEKEL DATALOGGER SYSTEM (product of the PEEKEL company, Rotterdam, Holland), based on UNILOG 2500 and AUTOLOG 502 input units. The system PEEKEL reads and logs temperature sensors signals, analog signals, SPNDs signals and discrete signals with a period of about five seconds. Measurement control, pre-processing and monitoring is performed by the real-time control software system RealFlex (BJ Software System Texas, USA) operated under the QNX 2.21 operating system on an integrated PC/AT COMPAQ 486/33E network. The system RealFlex consists of an on-line, interactive set of tools for application, control and monitoring. The neutron-physics system for 3D coarse mesh power distribution reconstruction, named TOPRE/PC, is installed on a separate node (PC 486/66E) – the 1st physical node. Information exchange between systems RealFlex and TOPRE/PC is performed by means of message passing. The system for 3D power distribution reconstruction on a pin basis and the hot spot monitoring, named HOTPOINT/PC, is installed on the 2nd physical node (PC 486/66E). These systems (TOPRE & HOTPOINT) represent the physical part of the modernised in-core surveillance system.

TOPRE/PC system

TOPRE/PC is a modernised core surveillance, monitoring, analysis, and prediction tool for the understanding and planning of core operations. It supports control room operators and reactor engineers in the complicated tasks of keeping strict safety limits and optimal operation of the nuclear power plant. TOPRE/PC reconstructs coarse mesh 3D core power distributions on-line, using in-core measurements, advanced reconstruction algorithms and methods, and the advanced core model-3D simulator MOBY-DICK. (MOBY DICK is a two groups diffusion coarse mesh macro code [3] which is standardised for the WWER-440 reactors core load). This core model is always in agreement with the current operation, because it is continuously updated with input data obtained from the plant instrumentation measurements. TOPRE/PC operates in an on-line regime with a period of 6 seconds. The assessment process performed by the system includes the following main features:

- Tests of credibility of thermocouple and SPNDs signals;
- Assemblywise power, power peaking factor and outlet temperature distribution reconstruction taking into account measured thermocouple signals, core load symmetry and MOBY DICK calculation results for non-instrumented assemblies;
- 3-D linear power rate distribution reconstruction in 36 fuel assemblies instrumented with SPNDs taking into account SPNDs signals;
- Assemblywise axial power distribution reconstruction taking into account the results from the preceding step;
- 3-D power peaking distribution reconstruction;
- 3-D fuel burn up distribution reconstruction;
- Tests of differences between the reconstructed and with the MOBY DICK calculated radial and axial distribution;
- Graphical window based dialogue;
- Numerical output in the printing form;
- Data storage.

Verification and validation tests were performed both with the use of the results of the off-line MOBY DICK calculation and with the use of data from the reactor standard VMPO SKR in-core monitoring system both for the normal performance as well as for states with simulated break down of some in-core sensors signals. As an example of test, the comparison with the results of MOBY DICK calculation is presented in Figure 2, the comparison with data from VMPO SKR system is presented in Figure 3. Some other examples of tests are presented in [4].

TOPRE/PC was also adapted and successfully used for the tests and analysis of new fuel assemblies with zirconium spacer grids [5], and of reactor bypass flow rate measuring by the method of the loop disconnection [6]. As an example, the differences between the temperature heat-up during the reactor start up are presented in Figure 4, these values for the beginning days of operation are presented in Figure 5. The dependence of the virtual temperature heat up on the reactor bypass flow rate is presented in Figure 6. It was found that the temperature rise on assemblies with zirconium spacer grids is about 1.0°C lower (relative flow rate is by about 3.0% higher) than on assemblies with steel spacer grids. It was also found that reactor bypass flow rate for the core loaded with Zr spacer grid assemblies is about 8%, while this one for the core loaded with steel spacer grid assemblies is about 10%.

HOTPOINT/PC System

HOTPOINT/PC is a modern software tool, which extends the TOPRE/PC system by providing the ability for power distribution reconstruction on a pin basis, and by the thermohydraulical analysis, and for data for the departure to nucleate boiling ratio (DNBR) margin and saturation temperature criteria. HOTPOINT/PC operates in a quasi on-line regime with a period of about 1.5 minutes. The assessment process performed by the system includes the following main features:

- Results of the coarse mesh reconstruction by the TOPRE/PC system as an input data;
- Assessment of the 12 maximum loaded fuel assemblies taking into account the MOBY DICK calculation results;
- Power load reconstruction in the 12 maximum loaded assembly by finite element method on the pin basis;
- load factor calculation of central fuel pins for fuel assemblies instrumented with SPNDs
- Tests of differences between the reconstructed and with the MOBY DICK calculated values;
- Thermohydraulical calculation of DNBR and saturation temperature criteria;
- Graphical window based dialogue;
- Numerical output in the printing form;
- Data storage.

HOTPOINT/PC uses a new diffusion constant library, named TOPLIB-W, generated using microcode WIMS/D-4 with the WIMKAL-88 library [7]. Pin-by-pin power distribution reconstruction in a given assembly is performed separately in regions created by the connection of centres of six neighbouring assemblies. Input data are linear power rates in all seven assemblies on a pin basis in the microsector, obtained from the 3D coarse mesh reconstruction by TOPRE/PC. Fast neutron flux distribution in this region is sufficiently smooth, therefore it is possible to perform linear interpolation in the radial direction. Diffusion of thermal neutrons in the region is calculated solving the diffusion equation by the finite element method. The region is subdivided into 331 elementary cells. In each elementary cell, diffusion constants are taken from the TOPLIB-W library and the source term is determined by the above method. The HOTPOINT/PC system also reconstructs central pin power loading coefficients for the 36 assemblies instrumented with SPNDs, the signals of which are converted to the linear power rate values in the TOPRE/PC system.

Conclusion

Several numerical and graphical outputs from the TOPRE/PC & HOTPOINT/PC system are now available for the reactor operator, e.g.:

- Coolant heat-up distribution;
- Coolant outlet temperature distribution;
- Radial power distribution;
- Radial power asymmetry distribution in microsectors;
- Radial power peaking factors distribution;
- Thermocouple signal temperatures;
- SPND signals converted to assembly linear power;
- 3D power distribution in selected sector or symmetry group;
- Monitoring of deviation between reconstructed and MOBY-DICK calculated radial and axial distributions;
- Hot-spot parameters and margins to physical limits;

Besides this information at the computer screen, results of more detailed evaluation of the reactor core are available in printed form.

Reactor engineers also utilise archived data from the data base, which can be collected with a specified period and data range. The data base structure enables the performance of off-line verification tests (e.g. tests of thermocouple and SPND signal values credibility).

At this time, the in-core surveillance systems TOPRE/PC and HOTPOINT/PC are in the process of being installed also at the WWER-440 type 230 reactors. We hope that some functions from the TOPRE/PC & HOTPOINT/PC systems will extent a new modernised system of Russian production which should be installed at the nuclear power plant Mochovce which is under construction.

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Figure 1. Location of the in-core sensors at WWER-440 type 213 reactors
(T: outlet temperature measurement, N: neutron measurement channel)

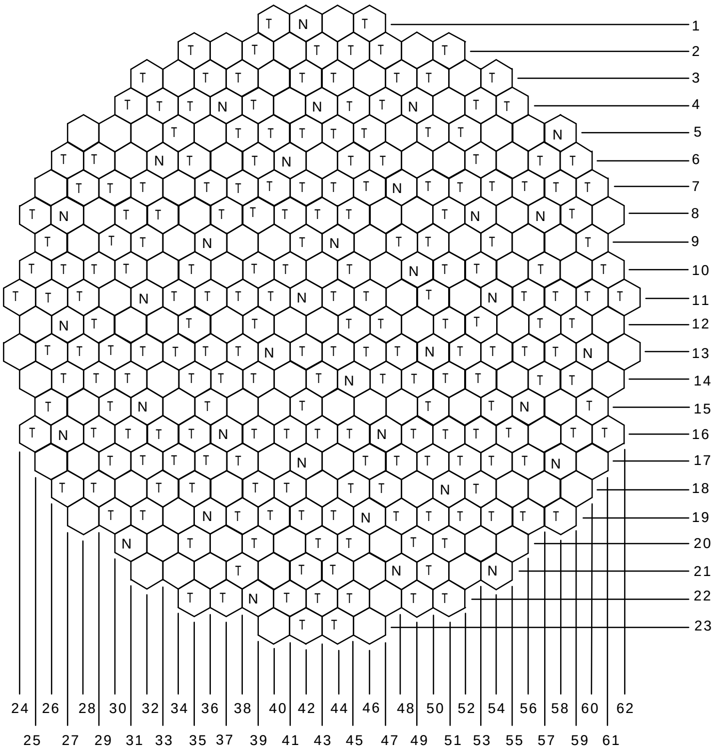

Figure 2. Comparison of relative power distribution determined with 3D simulator MOBY DICK and TOPRE/PC.

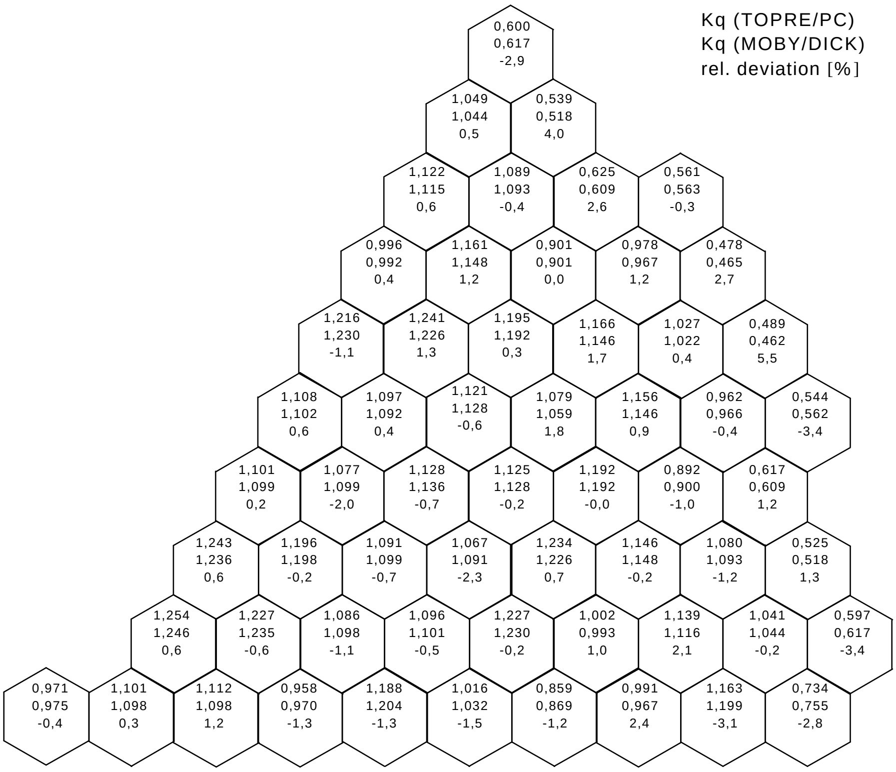

Figure 3. Comparison of relative radial power distribution reconstruction determined within-core systems TOPREC/PC and VK3.

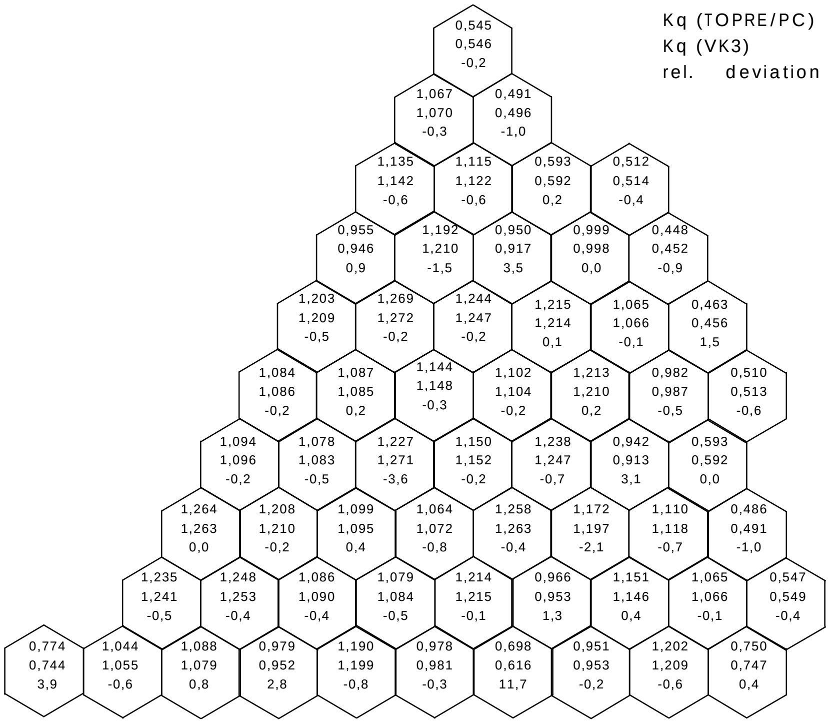

Figure 4. Average temp. rise difference of assemblies with steel spacer grid from assemblies with Zr spacer grid – dependence on reactor power level during the reactor start-up.

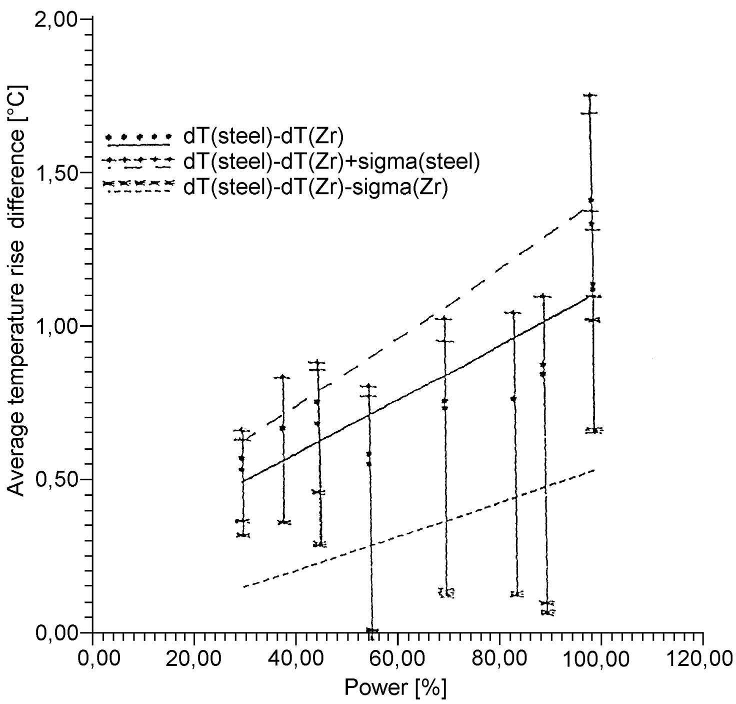

Figure 5. Average temp. rise difference of assemblies with steel spacer grid from assemblies with Zr spacer grid – dependence on effective time during the reactor operation.

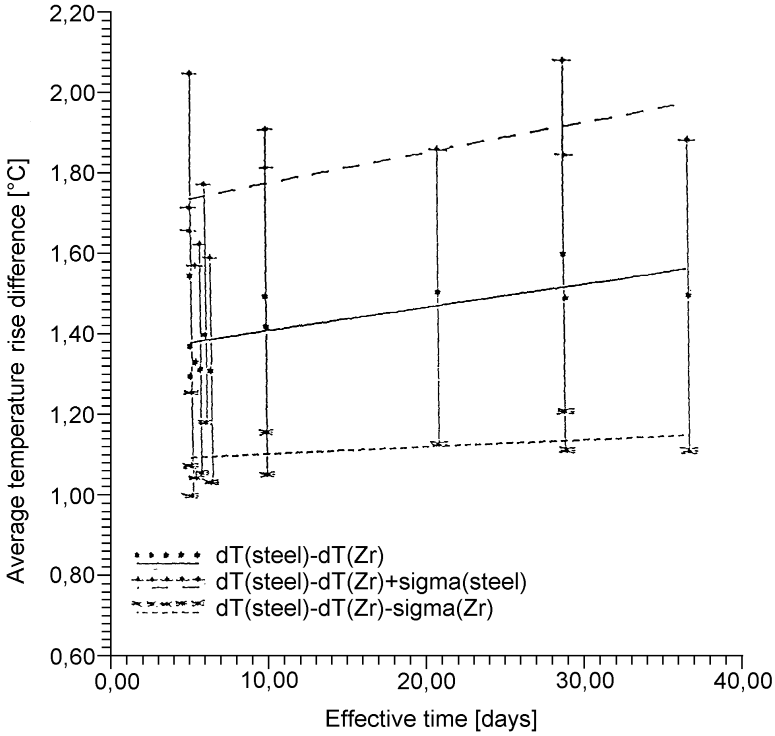

Figure 6. Virtual thermocouple temperature rise dependence on bypass value with changed number of opened circulating loops at constant reactor power 45 [%] during the reactor start-up.