SCORPIO - VVER CORE SURVEILLANCE SYSTEM

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ABSTRACT

The Institutt for energiteknikk has developed the core surveillance system SCORPIO, which has two parallel modes of operation: the Core Follow Mode and the Predictive Mode. The main motivation behind the development of SCORPIO is to make a practical tool for reactor operators which can increase the quality and quantity of information presented on core status and dynamic behavior. This can first of all improve plant safety, as undesired core conditions are detected and prevented. Secondly, more flexible and efficient plant operation is made possible. The system has been implemented on western PWRs, but the basic concept is applicable to a wide range of reactors including VVERs. The main differences between VVERs and typical western PWRs with respect to core surveillance requirements are outlined. The development of a VVER version of SCORPIO has been done in co-operation with the Nuclear Research Institute Rez, and industry partners in the Czech Republic. The first system is installed at Dukovany NPP, where the Site Acceptance Test was completed 6. March 1998.

1. INTRODUCTION

The SCORPIO system, Ref. 1 has been in operation at the Ringhals PWR unit 2 in Sweden since the end of 1987. In addition, the system has been installed at Nuclear Electric's Sizewell B PWR in UK and all the 7 NPPs of Duke Power Co. in USA, Ref. 2.

The SCORPIO system was designed to be modular, which is particularly important if other plant models (for instance the core simulator) are desired or one wants to connect to a specific type of core instrumentation. This is mostly the case with the core follow system because the instrumentation may vary from plant to plant, whereas it can be made more generic for the predictive system.

The development of the VVER version of SCORPIO has been carried out in co-operation with the Czech partners Nuclear Research Institute (NRI), Skoda and Chemcomex, with the NPP Dukovany as the target plant. The goal has been to adapt the functionality of SCORPIO to address the particular needs in VVERs. The project has been initiated and is partly funded by the Science and Technology Agency (STA), Japan through the OECD NEA assistance program.

The system specification is general covering all reactors of VVER type, and the target system has been prepared such that adaptation to other VVERs, including VVER-1000, can be easily achieved.

Due to our experience with the SCORPIO system for western PWR reactors it was decided that the main software framework of the PWR SCORPIO system should be used as a basis for the development of the VVER version.

Special characteristics which have been emphasized for VVERs are:

- Control of radial power distribution to minimize fluence at the vessel wall may be important in VVERs due to the small diameter of the pressure vessel. Further, it might be desirable, in certain operating regimes, to reduce the load on certain identified leaking fuel rods.
- In VVERs there are a number of fixed in-core neutron detectors and core exit thermocouples which are used for core surveillance. One problem is to validate the correctness of these measurements. In Western plants one has reported problems with effective validation of the exit thermocouples. With a detailed simulator one can use the simulator to calculate the measurements thus providing analytical redundancy. This increases the possibility of detecting sensor failures at an early stage. This has been demonstrated in PWRs and BWRs where the simulator is used to check the status of fixed in-core sensors and other measurements.
- Thermocouple measurements are more credible in a VVER reactor than in standard western plants due to the shrouds surroundings of the fuel assemblies.

The core physics simulator in the VVER version of the SCORPIO system had to be changed to one appropriate for VVER core calculations. The simulator must be capable of handling hexagonal fuel assemblies. The VVER-440 reactors have shrouds surrounding the fuel assemblies and the height of the active core is only 2.42 meter. This means that axial xenon oscillations do not play the same important role as in larger Western PWRs. The VVER 1000 reactors have no shrouds surrounding the fuel assemblies, and the active core height is increased (~3.5 m). This means that axial power distribution variations are more important, and the core dynamics are more similar to the Western reactors.

In addition to the change in the core physics simulator in the VVER version of SCORPIO, new modules have been developed to support VVER operation. The major new features of the SCORPIO-VVER core surveillance system compared to existing VVER core monitor systems can be summarized as follows

- Improved limit checking and thermal margin calculation.
- On-line 3D power distribution calculation based on the same physics model as used for core design and safety analysis.
- Improved validation of plant measurements and identification of sensor failures by utilizing the core simulator as an independent means for calculation of 3D power distribution.
- Optimum combination of measurements and calculations to obtain more precise values of critical parameters.
- Predictive capabilities and strategy planning, offering the possibility to check the consequences of operational maneuvers in advance, prediction of critical parameters, etc.
- Provide interfaces to off-line analysis codes for core loading pattern design, neutron fluence calculations at the reactor vessel wall, etc.
- Integration of modules for monitoring fuel performance and coolant activity as a means for detection and identification of fuel failures.
- Improved man-machine interface for operators and reactor physicists.
- Improved HW/SW reliability, by introduction of a new computer system.

As a consequence of these requirements it was decided that the SCORPIO-VVER version should use the core simulator MOBY-DICK. It was also decided to continue using the PICASSO system as the MMI part of SCORPIO-VVER. The old Picasso-2 system was replaced by Picasso3, see Ref. 3. This because the latter system includes much more functionalities than Picasso-2. In addition two new modules, a new PCI model PES, see Ref. 6, and a primary coolant monitoring system PEPA, see Ref. 7, were to be integrated with the basic SCORPIO system.

The SCORPIO-VVER system was to be implemented on workstations running in UNIX environment with the X Window System and communication based on the TCP/IP protocol. More specific Hewlett Packard was chosen as the hardware platform. Implementation languages for the different modules in the system were to be a mixture of C, C++ and FORTRAN. As far as possible the system should be made configurable to allow easy extensions/modifications of system parameters.

2. IMPLEMENTATION

The SCORPIO-VVER system consists of autonomous modules which communicate through the communication package Software Bus, see Ref. 4. Basically the modules are divided into two blocks defining the two operation modes, namely the core follow mode and the predictive mode. Roughly speaking, the main modules in SCORPIO are identified in the block diagram shown in Figure 1. A short description of each module is given in the following sections.

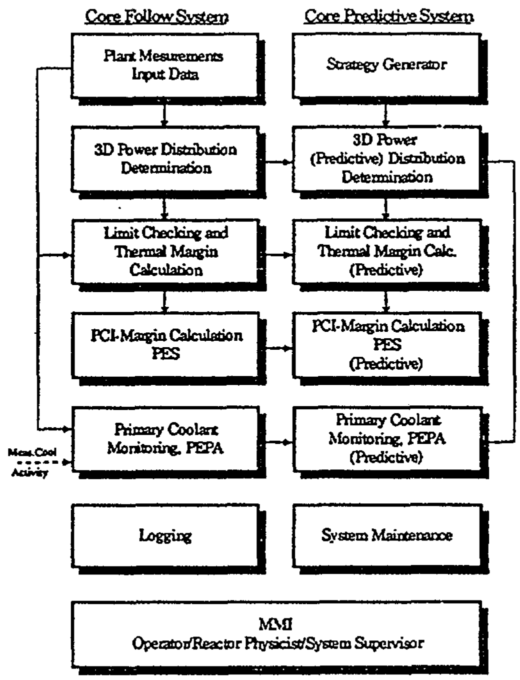

Figure 1 Main Modules of the SCORPIO-VVER system

2.1 Core Follow Mode

In the core follow mode, the present core state is calculated based on a combination of instrument signals and a theoretical calculation of the core power distribution. An automatic limit check against the core state is performed on these data. The operator obtains relevant information on core status through the Man-Machine Interface. This information is presented on color CRTs in the form of trend curves, core map pictures and diagrams displaying margins to operational limits. The primary coolant monitoring is an extension of the core follow mode functionality.

2.1.1 Plant Measurements Input Data

This task is taken care of by the two modules, the Data Acquisition Module (DAM) and the Input Data Processing Module (IDATP).

Data Acquisition Module (DAM)

Basic functions :

- Accepting of multiple client connections.
- Data messages receiving from multiple clients of two types (Hindukus and TMBS).
- Decoding of client messages of both types.
- Preparation of data structures with Hindukus and TMBS signals.
- Confirmation of data transfer by special messages.
- Periodic updates of communication status information.
- Software Bus interface to other modules for transfer of data and status information.

Technical properties

- Non-blocking communication, safe in the case of client or connection malfunction.
- Immediate processing of the message is not blocked by other processing (e.g. output).
- A complete message with the Hindukus data is processed in less than 100 milliseconds.

The input part of module works as TCP/IP server with ability to serve several connections simultaneously. When a client working at some peripheral data acquisition system asks for connection using standard TCP/IP protocol routines the connection is accepted and the communication channel (socket) is monitored until the connection is shutted down by client or interrupted due to any hardware or system error. Sockets are created as non-blocking.

Two types of clients (data sources) are defined in module configuration : clients sending data structures with Hindukus signals and clients sending data from temperature measurements backup system (TMBS). The module allows several simultaneous connections of each type to support special hardware configurations with doubled communication channels, more peripheral connection hardware interfaces etc. Support of hardware interfaces is assured by the workstation operating system (HP-UX) functions.

Data set received from any client is stored in temporary buffer and following characteristics are checked :

- Size of data structure corresponds with predefined data format for this type of client.
- Signal identifiers are in appropriate positions in the structure according to predefined data format.
- Data are readable and has an appropriate format of numbers and arrays.

After the verification data sets are stored in output structures and released for transfer to other modules.

Input Data Processing (IDATP)

Basic functions :

- Identification of Operational Regime (operational states with different number of loops in operation, shutdown states, stuck rods, etc.)
- Signal conditioning, stabilization and signal quality checking.
- Signal validation.
- Signal transformation to physical units.
- Calculation of primary/secondary circuit parameters including reactor power.
- Determination of thermocouple corrections from isothermal reactor states, including supervision of temperature stabilization process.

Input sources used by the module :

- Plant measurement data collected by Data Acquisition Module.
- Parameters specified by operator using MMI.
- Constant parameters for measured data processing configurable in initialization file.
- Temperature sensors correction factors and other configurable constants transferred during initialization call.
- Transformation coefficients for SP detectors signals interpretation from CHECK Module.
- Calculated 3D power distribution Core-Follow Simulator (SIM) for input data validation.
- Parameters used for temperature sensors calibration entered interactively from MMI.

Discrete signals from SVRK Hindukus and analog signals from both SVRK and TMBS are processed and results are used for additional calculations. Most important outputs are temperature and pressure values in all measured locations, linear powers by SP detectors, state of primary circuit loops, control assemblies positions, boron acid concentration, mean reactor inlet and outlet temperatures, temperature rises, coolant flow rate and reactor thermal power.

Input data validation is performed in two steps. Primary signal checking is based on comparison of values from signal interpretation and maximal reasonable limits. Faulty sensors are excluded in this step. Advanced method of signal validation is applied to thermocouple measurements of outlet coolant temperatures at fuel assemblies and to SP detector measurements. Credibility factor is assigned to each measurement using statistical evaluation of measured and calculated values.

For thermocouples and resistance thermometers calibration before the reactor start-up a special procedure is performed to monitor the temperature stabilization process and calculate individual correction coefficients for sensors.

Output quantities may be sorted into following parts :

- Results of discrete signal processing - description of the state of reactor and important parts of primary and secondary circuit, information about data acquisition system state.
- Results of analogue signals processing - physical interpretation of all temperature, frequency, pressure, ionization chambers and SPND measurements etc.

- Additional values obtained by analogue signals evaluation - mean and maximal values of selected parameters, maximal permissible values of temperatures, peaking factors etc.
- Integral characteristics of primary circuit - reactor inlet and outlet mean temperatures, reactor thermal power, effective time etc.
- Results of input data validation - description of faulty measurements, thermocouple and SPND measurements credibility factors, sensors long-term stability factors etc.

2.1.2 3D Power Distribution Determination

The main task of this functionality is to supervise calculations of 3D power distribution and critical boron concentration performed by the core simulator MOBY-DICK on the nodal level. A solution using two modules to perform these tasks has been chosen. The 3D Power Reconstruction (3DREC) is activated each basic system cycle (15 sec) and The Simulator (SIM) which is activated on request from the 3DREC module, usually each 15 min.

3D Power Reconstruction (3DREC)

Basic functions :

- Calculation of the reconstructed 3D power distribution using calculated distribution from the Simulator and measurements interpretation (in-core thermocouples and SPNDs) from Input Data Processing. Two methods are implemented : "Traditional" and "Advanced".
- Triggering of Simulator calculations - sending of the new calculation request in dependence on changes in the reactor state.
- Triggering of the Simulator adaptation in dependency on reactor state and user requests.

The main task of 3DREC is to provide representative 3D **nodal** power distributions in the core, using three sources of information :

- validated FA outlet temperature thermocouple measurements (transferred from the IDATP Module)
- validated SPND measurements (transferred from the IDATP Module)
- results of Simulator calculation

Two alternative methods of power reconstruction are implemented in 3DREC :

- "Traditional" method similar to the one applied in the VK3 monitoring system, using "local" interpretation of validated in-core measurements.
- "Advanced" method oriented more on "global" interpretation of both measurement types and using the Simulator results with higher priority. This method is able to reach acceptable results with significantly less number of valid in-core sensors.

Results of both methods can be displayed and compared through Reactor Physicist MMI, enabling to select each of them as the "primary" for use in other modules including Operator MMI.

In addition, the 3DREC monitors reactor parameters being important for power distribution development and controls „triggering" of the Simulator.

Method of reconstruction
Coolant specific enthalpy is calculated at inlet and outlet of assemblies with thermocouples and the relative power distribution for measured assemblies is produced. Results are used for modification of the calculated radial power distribution (from Simulator). Credibility factors of measurements produced by IDATP module are used as weight of corrections. For the axial power distribution corrections the actual control assemblies positions and SPND measurements are taken into account.

All radial and axial power distribution corrections are applied on the Simulator results for both methods of reconstruction. As the result the 2D and 3D arrays of the reconstructed relative power distribution are stored for each method. Reconstructed arrays of coolant temperatures at assembly outlets (for all assemblies) are calculated using the total reactor power for coolant specific enthalpy calculations.

Core-Follow Simulator (SIM)

<u>**The SIM module**</u> has been designed in accordance with the following principal requirements :

- The module is based on universal finite-difference few-group program MOBY-DICK licensed in the Czech Republic for nuclear design of VVER-440 cores, see Ref. 5. Specific measures have been implemented to assure Simulator correct and reliable operation in all normal and abnormal (even hypothetical) reactor operational conditions. A simple adaptation procedure has been added to "fit" radial and axial power shapes calculated by SIM to the actual "reconstructed" power distribution. A standard 2-group diffusion data library of off-line MOBY-DICK is utilized in SCORPIO. This library contains data for homogenized fuel assemblies (FA), prepared by internationally accepted multi-group transport program WIMS-6(E), processed to polynomial etc. form. The library is completed by gamma (albedo) matrices representing boundary conditions on absorbing parts of control fuel assemblies (CFA) and on radial/axial reflectors. Results of the Simulator (without adaptation) and the MOBY-DICK are fully identical.
- SIM performs coarse mesh (nodal) 3D analysis of actual core states. It solves either 60° core symmetry segment (standard mode) or full core (360°), if (and only if) an explicit perturbation of core symmetry exists, i.e. there is a significant asymmetry of core loading or individual CFAs are dropped or misaligned. Switching between symmetries is automatic, and return to the 60° calculation is carried out when symmetrical power distribution is restored and stabilized. Full core solution is performed with a little simplified core model (with 6 mesh points per FA cross section, instead of 24 points used at SIM symmetrical solution). For that reason the SIM is able to complete one time step (reactor state) calculation within less than 20 sec of CPU time in all expected situations.
- SIM is designed for use of standard off-line MOBY-DICK archive files as its initialization files in the BOC etc. Dump files generated periodically during SIM operation have the structure of the archives mentioned above and are applicable at off-line calculations (e.g. at loading pattern design) without need for any modification. These dumps are utilized also for PREDSIM initialization and SIM re-initialization (if needed). In the beginning of the first SIM calculation cycle following its re-initialization SIM checks the differences

between time variables associated with the most recent dump file being at disposal and actual core state. If the dump is significantly delayed against actual state, a procedure to "catch-up" the actual state is initiated.

- SIM provides calculated power, neutron flux and burn-up distributions for : 1) "reconstruction" of the representative 3D nodal power distribution (performed in 3DREC); 2) power distribution "de-homogenization" (i.e. determination of pin power peaking factors F_q and $F_{\Delta H}$, carried out in reconstruction module RECON); 3) signal validation (carried out in IDATP); 4) evaluation of probability of fuel defects caused by PCI (performed in PES module). In addition, critical boron concentration calculated by SIM (for actual insertion of CFA banks) is used to determine the boron concentration in primary circuit, and special input data are prepared for Strategy Generator (SG).

2.1.3 Limit checking and thermal margin calculation

This unit is divided into two tasks:

- The module **RECON** is called after each Simulator calculation (approx. 10 – 15 min.) and provides detailed 3D pin-wise power distribution by the fast reconstruction methodology based on modulation principle.
- The module **CHECK** called in each period of measurements (approx. 16 sec.) uses results from RECON and 3DREC for calculation and checking of both pin-wise and assembly-wise parameters.

RECON basic functions

- Determination of 3D pin-wise power distribution and pin-wise F_q and $F_{\Delta H}$.
- Transformation from 20 mesh to 7 points for FAs including SPND detectors.

CHECK basic functions

- Traditional checking of nodal power peaking factors (k_q and k_v)
- Traditional checking of coolant temperature rise in the fuel assemblies
- Assessment of the margins to the safety limits (DNBR, LOCA and sat. temperature)
- Calculation of integral data for assessment of fluence at the reactor vessel wall
- Automatic selection of limit values depending on operational mode
- Calculation of transform coefficients for SPND detectors

Detailed 3D pin-wise power distribution is produced for determination of F_q and $F_{\Delta H}$ power peaking factors and assessment of all margins to the safety limits (DNBR, LOCA and saturation temperature) on the basis of subchannel analysis and to provide information for PCI-margin calculation (PES).

Restrictions of core operation checked by CHECK module are given by

- Fuel technical specification,
- Technical specifications of NPP Dukovany for normal operation,
- Safety reports and other criteria stated by Czech NRC.

That means, by this module the following limit checking is provided :

- all FA outlet temperature
- the maximum FA outlet temperature
- the subchannel output coolant temperatures
- the total hot channel peaking factor (enthalpy rise limit)

In addition to this, following safety margins are checked on the subchannel level :

- the maximum subchannel coolant temperature shall not reach saturation temperature taking into account calculation and measurement uncertainties and manufacturing tolerances
- the Departure from Nucleate Boiling Ratio must be greater then limiting value
- the maximum linear heat rate of any fuel rod shall not exceed LOCA limit including calculation and measurements uncertainties, manufacturing tolerances and additional conservatism

2.1.4 PCI -margin calculation (PES)

The PES module is evaluating local fuel damage probabilities due to pellet cladding interaction. The model determines the maximum allowable local and global power changes.

This module has the following functions:

- Calculation of the conditioned power distribution
- Determination of limit for permitted reactor power change

2.1.5 Primary Coolant Monitoring (PEPA)

The PEPA module, based on measurements of radioactive nuclides activities in primary coolant, estimates the number of damaged fuel elements. Moreover, it enables the plant personnel to obtain information about the character of damaged fuel elements and the type of their damage.

This module determines the number and type of fuel defects based on the coolant activity analyses (i.e. identification of noble gases and fission products in the coolant)

2.1.6 Logging Unit (LOG)

The module collects output data from other modules, maintains an archive of outputs and provides output to the LAN for other systems and printed text output of selected arrays.

Basic functions

- Asynchronous data capturing from Data Acquisition, Input Data Processing, 3D Power Reconstruction, Simulator, Limit Checking and PES modules.
- Data sorting (synchronization) in accordance with time stamps in data sets.
- Temporary storage of multiple data sets in memory.
- Short term (up to 3 days) disk archivation of selected data from sets stored in memory.
- TCP/IP interface for other computers performing output of selected data arrays.
- Automatic calculations of the reactor state parameters mean values per hour and per day.
- Automatic recovery after the shutdown - reuse of backups and archive after new startup.
- Configurable print service for printing of selected arrays in specified time intervals.

Technical features

- Non-blocking communication, safe in the case of client or connection malfunction.
- Input calls are processed with a higher priority than output tasks to eliminate data loss.
- Memory and disk space requirements are controlled by configurable parameters.

The Logging Unit collects the output structures from Data Acquisition, Input Data Processing, 3D Power Distribution Determination, Simulator, CHECK and PES modules. When the structures are received a subset of arrays is stored in internal buffers. The Logging Unit checks time stamps included in structures (corresponding with the time when input signals used for calculations were received) and assembles the archive data sets.

The full set of output arrays from modules is stored in memory for approx. 30 minutes. The disk archive is updated in intervals 5 .. 20 minutes. Each archive file contains the full set of data from Data Acquisition and Input Data Processing modules and data for one selected time point from 3D Power Distribution Determination, Simulator, Limit Checking and PES (data from 3DREC may be calculated as mean values from several time points). This time point is selected with respect to data availability and validity. In most cases it corresponds with the output from Simulator. Files are kept on the disk for approx. 3 days.

Special reactor state records with basic integral parameters are extracted from input data. Mean values of variables stored in these records are calculated for each hour and each day.

The module works as a TCP/IP server for other computers in the LAN and answers to their requests for data transfer. Communication protocol is based on a set of simple text messages. Data arrays requested by the client are transferred in a text form.

Print service of the Logging Unit is able to print or save on the disk selected arrays in periodical intervals or after user request from MMI. Arrays may be printed in various formats and organised in predefined forms according to a specification in the configuration file.

2.2 Predictive Mode

In the predictive mode of operation, the operator can forecast the reactor behavior during the coming hours. As no detector signals are available in this case, the accuracy of the predicted core state depends heavily on the quality of the physical model in the predictive core simulator. Also in the predictive mode, results from the simulator are stored in the database. The state is checked against limits, and the predicted behavior of the core may be analyzed by the operator through a number of dedicated pictures.

2.2.1 Strategy Generator (SG)

The main task of the Strategy Generator is to assist the operators and reactor physicists to derive various operational strategies which can be verified by the predictive simulator before the actions are implemented on the reactor.

The strategy generator employs an extremely simplified core model to suggest control strategies for achieving a given power maneuver, as described in Ref. 9. Power and xenon-iodine densities are calculated for the upper and lower core halves without solving the neutronics and hydraulic equations. The calculations are therefore, in part, based on precalculated coefficients for the reactor's response to changes in the inlet temperatures, control-rod movements, and concentrations of boron and xenon. These coefficients are found by running the off-line version of the MOBY-DICK simulator, see Ref. 5, for various reactor conditions, and corresponds to multidimensional numerical expansion of reactor reactivity.

The calculated control strategies can be verified by the predictive simulator, i.e. 3D power distribution and critical parameters such as critical boron concentration, rod positions, inlet temperature in various transients like SCRAM, start-up, end of cycle, load changes, etc.)

2.2.2 Predictive simulator (PREDSIM)

As for the Simulator Module, the Predictive Simulator Module (PREDSIM) is based on the MOBY-DICK simulator, Ref. 5. This module is used for calculation of 3D power distribution and critical parameters up to 72 hours ahead of current time. The initial conditions are provided by the 3D Power Distribution Determination Module (Core Follow System). The Strategy Generator module and/or the user himself prepares the necessary input data for various types of predictive tasks.

The predictive simulator can be used to solve 5 different sorts of tasks. These are:

- Solution of load-follow transient without recalculation of critical parameters. Values produced by the Strategy Generator are used.
- Solution of a load-follow transient with recalculation of critical parameters.
- Calculation of start-up critical boron concentration and concentrations providing selected subcriticality margins for specified 3 coolant temperatures and one Rod Bank 6 insertion.

- Calculation of start-up critical Bank 6 positions and positions of Banks 4 to 6 selected subcriticality margins for specified 3 coolant temperatures and one boron concentration.
- Calculation of shutdown boron concentration at one specified coolant temperature with all Rods out of Core.

Tasks 3 and 4 can only be performed during zero power. The other tasks can be performed in the actual reactor state.

The predictive tasks can be started in 60° core symmetry only. To accelerate calculation, 6 mesh points per FA cross section are used here; no significant degradation of accuracy is caused by this provision.

The predictive simulator provides information to the PES (Predictive) module and the module for limit checking and thermal margin calculation (Predictive).

2.2.3 Limit checking and thermal margin calculation in predictive mode (LCTMCPRED)

Basic functions

- Traditional checking of coolant temperature rise in the fuel assemblies
- Determination of 3D pin-wise power distribution and pin-wise F_q and $F_{\Delta H}$
- Assessment of the margins to the safety limits (DNBR, LOCA and saturation temperature)

The Predictive Limit Checking Module is triggered by the PREDSIM. It produces detailed 3D pin-wise power distribution for determination of F_q and $F_{\Delta H}$ power peaking factors and assessment of all margins to the safety limits (DNBR, LOCA and saturation temperature) on the basis of subchannel analysis.

Detailed pin-wise power distribution is processed to provide information for PCI-margin calculation (PES).

2.2.4 PCI margin prediction (PES)

The Predictive PES module is used to find the minimum difference between limit and linear power on the detailed pin-wise level. The result is based on initial condition from the PES Core Follow Module and inputs coming from PREDSIM the predictive Limit Checking and Thermal Margin Calculation Module.

2.2.5 Primary Coolant Activity Prediction (PEPA)

The predictive PEPA module allows, based on results of the on-line module, calculation of radioactive nuclides activities in the primary coolant in transient states of the reactor. The transient is defined by using the Strategy Generator.

2.3 Man Machine Interface (MMI)

The MMI is based on the PICASSO-3 graphical system using X Window System as a platform. A set of interactive color screens is used for results presentation and system control.

The input to SCORPIO is entered through a combined use of a mouse and an alphanumeric keyboard. The input to be specified by the operator is reduced to a minimum and the input procedure is made as simple as possible.

In addition, the operator is guided through a dialogue procedure with context sensitive dialogue fields and functions to be selected from menus. The dialogue is made fault tolerant. This means that feedback is obtained in form of messages if the operator tries to enter illegal data or for instance tries to start a simulation while the simulator is active etc.

The man machine interface has been designed to be used by the three different user groups·

- Reactor Operator
- Reactor Physicist
- System Supervisor.

Operator's MMI

For the operator, Overview displays cover the following information :

- Summary of key parameters related to core monitoring
- Summary of information from primary circuit
- Distinguish between validated data and bad values
- Diagnostic information on sensors and data acquisition system (Hindukus)
- Margins to limits
- 2D distribution of power, temperature rises, margins to limits
- Trends of key variables
- Summary of information from PES and PEPA
- Standard output display for key results of power transients and critical parameters, margins to limits, e.g. critical boron concentration during start-up

In addition, special displays are provided to support specification and organization of various predictive analyses, including:

- Selection of predictive tasks such as load follow, start-up boron conc. calculation etc.

- Specification of predictive tasks (e.g. power transient).
- Specification of Strategy generator objectives
- Specification of conditions for limit checking, thermal hydraulic calculations, PCI (PES) and PEPA, etc.

Reactor Physicist's MMI

All the screens used by the operator are available for the reactor physicist. Additional screens are provided with more detailed information about calculation results, Simulator adaptation, comparison of selected calculated and reconstructed power distributions etc. Several parameters for configuration of the Simulator and 3DREC functions may be specified by this user group.

System Supervisor's MMI

System supervisor has an access to all screens available for operators and reactor physicists. In addition, the supervisor may use text input fields and push buttons to perform following tasks :

- Edit configuration files with parameters for calculating modules
- Control the behavior of various functions configurable from MMI screens
- Start, stop and reconfigure any module or the whole system
- Setup limiting values for various warnings and alarms.

The functions included in the system supervisor's MMI are password protected against unauthorized use.

An example of a SCORPIO-VVER screen is shown in Figure 2. This picture shows the reconstructed outlet temperatures. The color of the assembly cells has in this case been selected to indicate the difference between measured and reconstructed temperature rise.

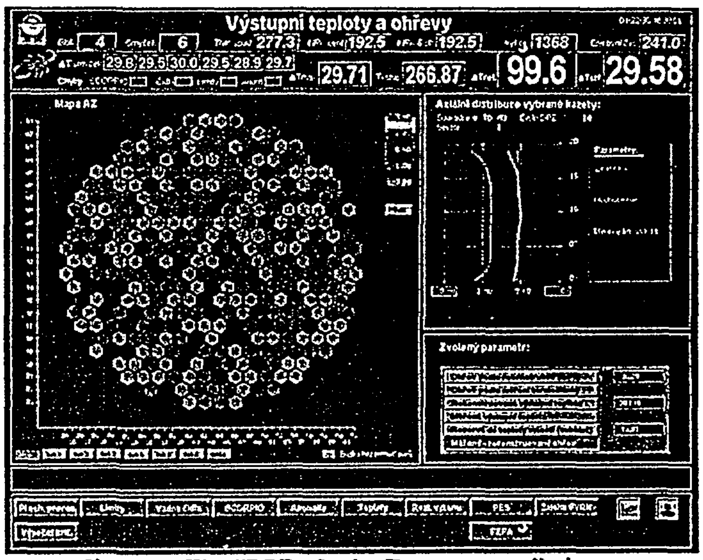

Figure 2 The "RPD, Outlet Temperatures" picture

3. CONCLUSIONS

The development of the SCORPIO-VVER system has been going on since the middle of January 1996. The development process has followed a well-defined Quality Assurance Plane. Dukovany NPP staff has taken part in the requirement specification, reviews, testing and in coupling of the system to the plant instrumentation. Factory Acceptance Test (FAT) was taking place in the first part of November 1997 and Site Acceptance Test (SAT) was successfully performed during the first week of March 1998. The system is now implemented on two of the four units at the Dukovany NPP.

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Ref. 9 *S. Hval, "A description of the two-point model used as strategy generator in the core surveillance system Scorpio", HWR-79 (1982).*Figure 3