The SCORPIO-VVER Core monitoring and Surveillance system with Enhanced Capabilities

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The Developers

The original version of the SCORPIO system was developed for the western type of PWR reactors.

- long history, starting from 1987,
- more than 9 PWR units (Sweden, UK, USA).

The first version of the SCORPIO-VVER Core Monitoring System for Dukovany NPP (VVER-440 type of reactor, Czech Republic) was developed in 1998 in co-operation between:

- IFE Halden, Norway,
- ÚJV Řež, a.s., Czech Republic,
- Škoda JS a.s., Czech Republic,
- Chemcomex Praha a.s., Czech Republic.

For SCORPIO-VVER implementation at Bohunice NPP in Slovakia (2001) the system was enhanced with startup module KRITEX in co-operation with:

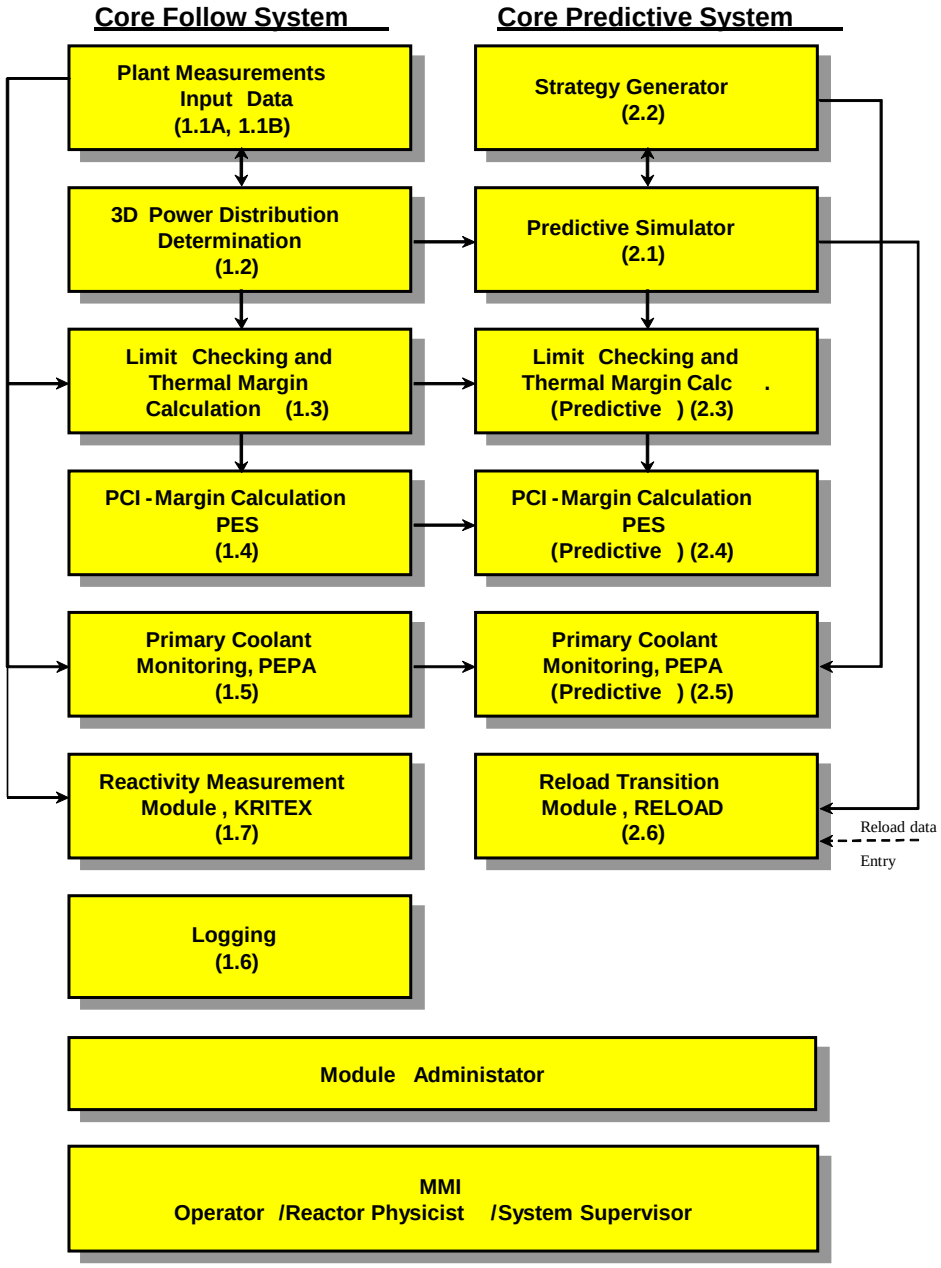
- VUJE a.s., Slovak Republic.

Surveillance of reactor CORe by Picture On-line display

- **The SCORPIO-VVER Core Surveillance and Operation Support System is:**
  - software based system,
  - implemented on the robust mission critical hardware platform.

Surveillance of reactor CORe by Picture On-line display

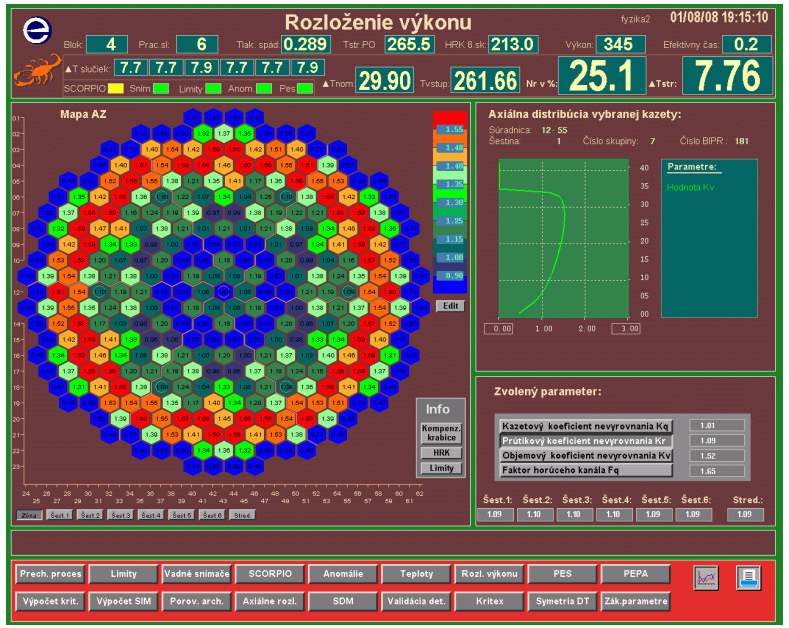
- **The SCORPIO-VVER core monitoring system:**
  - consists of autonomous SW modules,
  - for communications the Software Bus communication package is used,
  - the MMI is developed using the ProcSee GUI Management System,
  - support different user logins with difference rights and presented information details,
  - uses the plant's own in-core and ex-core measurements,
  - servers with more then 70 thousand parameters on the system output (results of nodal calculations, ...).



Surveillance of reactor CORe by Picture On-line display

The system is operate in two modes:

- **the core follow mode** - the present core state is evaluated by a method combining the instrumentation signals and the theoretical calculation. The operator obtains relevant information on core status through the MMI in the form of well arranged screens containing trend curves, core map pictures, diagrams and tables displaying relevant information on the core state including margins to Technical Specifications.



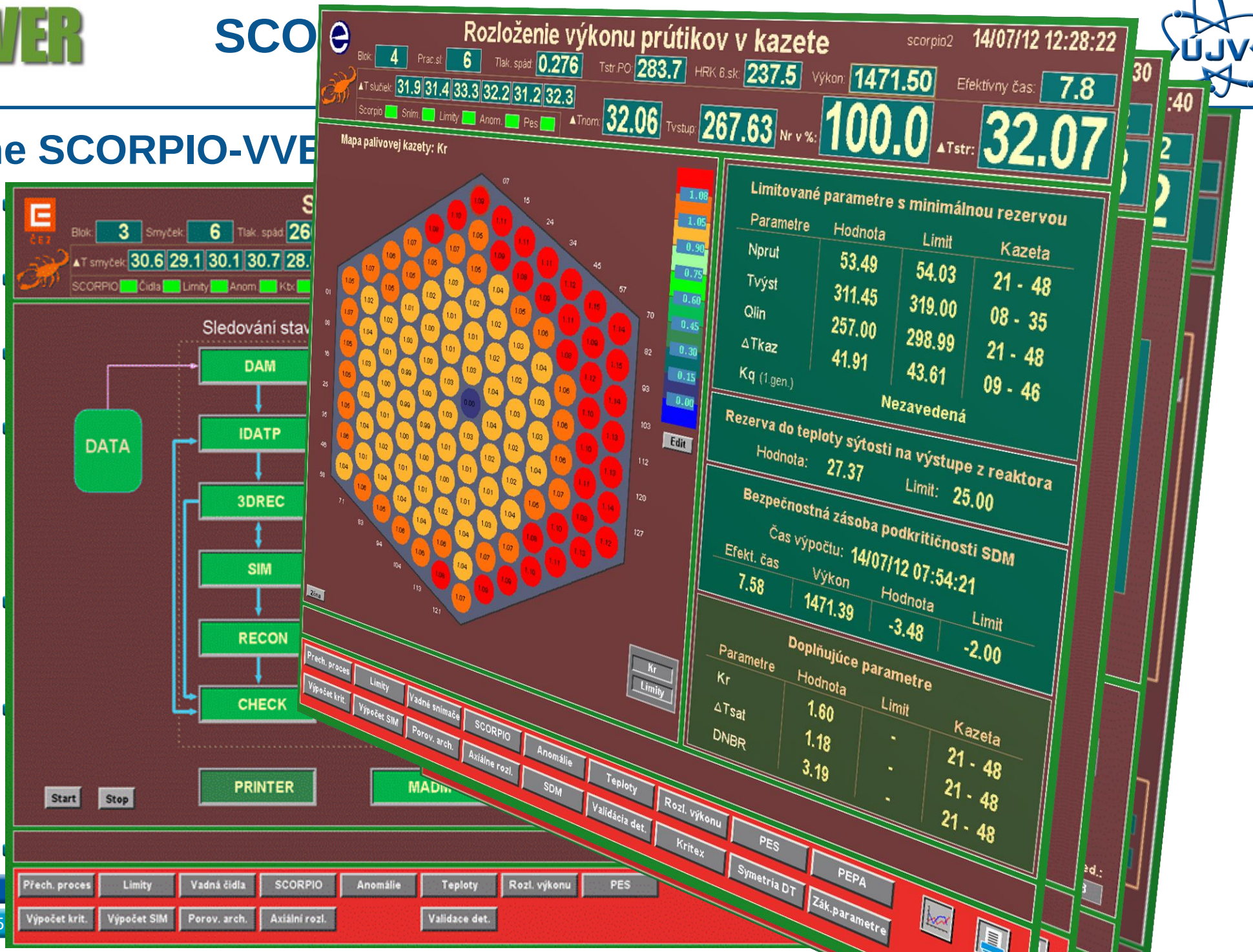
- **the predictive mode** - the operator can visualize the core characteristics during the transients forecasted for coming hours or days. Quick forecasts realized by the strategy generator could be deeply analyzed by the predictive simulator. Similarly as in the core follow mode, characteristics of the evaluated states can be compared against Technical Specifications, and the predicted behavior of the core can be analyzed through the number of dedicated screens.

SCORPIO VVER Project

SCO

ÚJV

The SCORPIO-VVE



SCORPIO-VVER Predictive Mode

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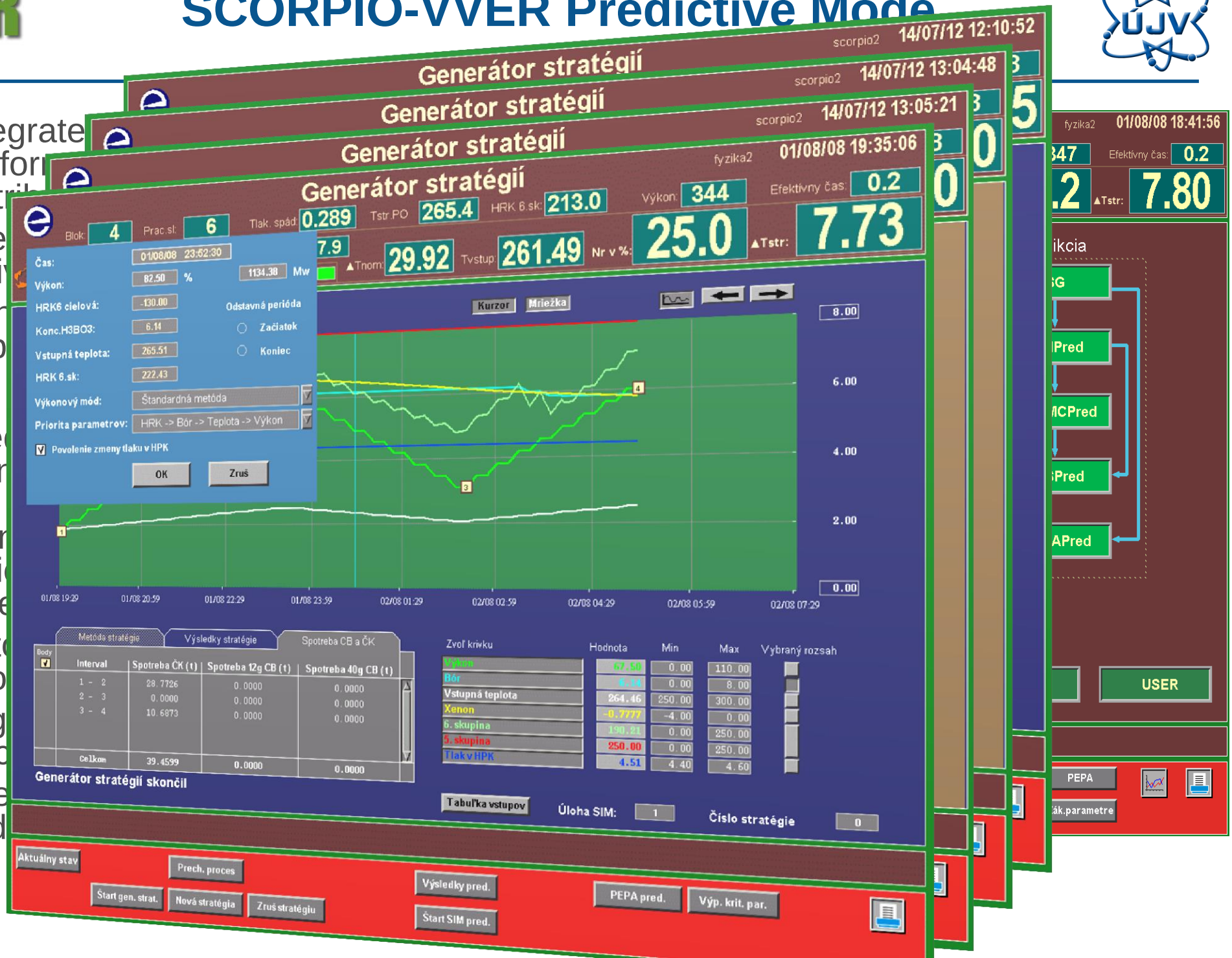


Implementation and upgrade history in CZ

First implementation at Dukovany NPP in Czech Republic:

- completed in 1998, migrated to all 4 units.

Dukovany's short upgrade history:

- **2000, Upgrade-1**, system maintenance and system tuning.
- **2003, Upgrade-2**, adjusting the physical modules to EDU's requirements.
- **2004, Upgrade-3**, adaptation to use the Gd2 fuel type, moving to 42 axial layers.
- **2005, Upgrade-4**, system adaptation to work with the upgraded I&C plant system.
- **2007- 12/2009, Upgrade-5**, improvements in operation support tools, implementation of SPNDs to the 3D Power Reconstruction, support of new GD2+ and Gd2M fuel, support the up-rated reactor thermal power.

Implementation and upgrade history in SK

First implementation at Bohunice NPP V2 in Slovak Republic:

- completed in 2001, migrated to 3. and 4. unit.

Bohunice's short upgrade history:

- **2006, Upgrade-1**, adaptation to use the Gd2 fuel type, moving to 42 axial layers, improvements in SG, implementation of online shape function generation.
- **2008 - 2009, Upgrade-2**, adaptation to the new I&C, improvements in limit checking (online SDM calculation) and 3D Power Reconstruction method, improvements in Strategy Generator, support the up-rated reactor thermal power.
- **2011 – 12/2012, Upgrade 3,** system update for support of the new fuel type with enrichment 4,87% of U235 (libraries, uncertainty factors, etc …)
  - Leaving the old scheme of limit checking (groups, categories), moving to full core margins checking – individual margins for all fuel assemblies
  - Introducing new input parameters, new high accuracy circuits for pressure and temperature measurements were included,
  - Enhancement in Strategy Generator, Management and service tools.

Thanks to the SCORPIO-VVER system all EBO units with the 4,87% type of fuel could reach their 100% of nominal power (1471 MWt).

Implementation into the Full-Scale Reactor Training Simulator

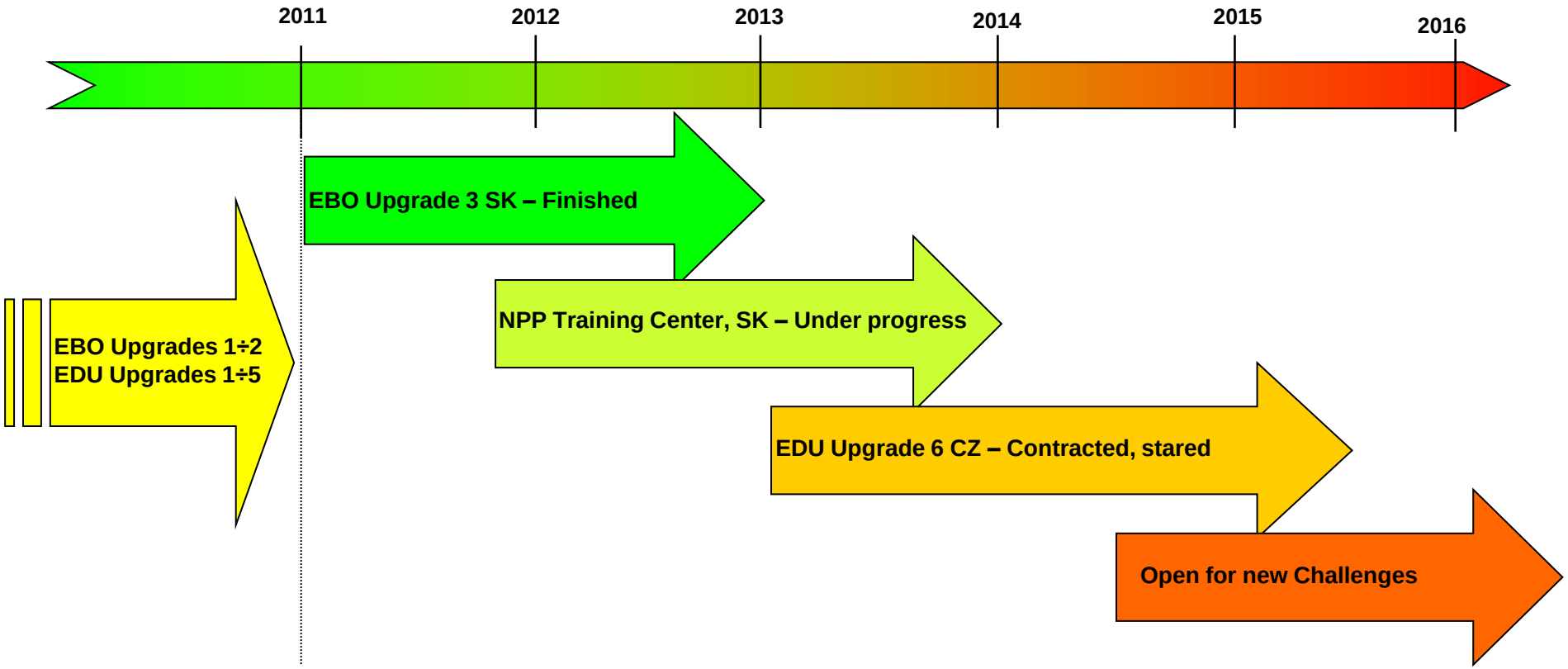
SCORPIO-VVER for training purposes of EBO V2 (SK)

- The **SCORPIO-VVER** Core Surveillance and Core Monitoring System as become a part of the **Reactor Training Simulator** (full-scope simulator) for reactor physicist and reactor operators.
- From the “one way” online core monitoring system become a externally driven Start-Stop-Jump system.
- New special function will be implemented as are:
  - **FREEZ** – freezing all calculations and trending,
  - **TIME JUMP** – based on the requirements the system should jump and start from the required core state and time,
  - **SNAPSHOT** – based on the requirements the system should make a snapshot of the actual core state to be able to start from it in the future.

The planned end of the SCORPIO-VVER implementation is 12/2013.

SCORPIO-VVER Future Upgrades and Plans

THE ROADMAP



Dukovany's Upgrade 6 (CZ)

The Dukovany's Upgrade 6 presents the most advanced upgrade in the system's history.

- **The Upgrade 6 goals are:**
  - to solve the HW life cycle end,
  - to increase the efficiency of the fuel cycle with effective control of core technical specifications and margins.

- **The SCORPIO-VVER system will be completely renewed with:**
  - re-hosting to the new high computational performance hardware,
  - removing the historical limitation based on the system design,
  - implementation the latest advanced codes with enhanced accuracy:
    - Implementation of full core pin-wise calculation into the system with the latest Moby-Dick code,
    - Enhancement of the thermo-hydraulic part of the system (calculations will be performed by the sub-channel codes TH-BLOK code supported CALOPEA).

Dukovany's Upgrade 6 goals realization

Solving of the HW life cycle end:

- The system will be rehosted / ported to the new hardware:
  - **Mission Critical Servers** with manufacturers guarantee of support were selected
  - Configuration was focused to reliability, redundancy and high computational power
  - Official letter from the HW manufacturer confirming the valid roadmap and the **support of the HW platform for the upcoming next 10 years**.

Increasing the efficiency of the fuel cycle:

- with achieving of more effective core technical specification and margin control with **system functions upgrade**:
  - getting higher accuracy of the computed results,
  - decreasing the uncertainties,
  - obtaining more reliable information about the reactor core using the latest advanced neutronic and thermo-hydraulic codes,
  - using tuned offline methods and algorithms.

The system functions upgrade based on the 3 key functions, all other modifications are triggered/enabled by them.

Dukovany's Upgrade 6
System function upgrade (1)

Key function No.1

Implementation of full core pin-wise calculation into the system

- The old SIMULATOR module of the system will be replaced with the latest version of MOBY-DICK code.
- All the calculations within the system will be done in 3D pinwise mode.
- All pinwise reconstructions (used before) will be removed.
- The method of 3D Power Reconstruction will be revised.
- Pinwise calculations will allow more detailed thermo-hydraulic analysis.

- The Moby-Dick macrocode is primarily based on the finite difference approximation to the few-group (2 to 10 energy groups) diffusion equation. It employs the Borresen's modification of the finite difference scheme. The code works with two mesh types:
  - with triangular mesh for the coarse mesh core calculation,
  - with hexagonal mesh for the pin-wise calculations.

Dukovany's Upgrade 6
System function upgrade (2)

Key function No.2

Enhancement of the thermo-hydraulic part of the system

- The thermo-hydraulic part of the system will be significantly improved. Thermo-hydraulic calculations will be performed by the sub-channel code TH-BLOK supported by CALOPEA code.

Key function No.3

Signal interpretation improvements

- improvements in SPND signals interpretation,
- improvements in thermocouple's signals interpretation and fuel outlet temperature evaluation,
- improvements in ionization chambers signal interpretation influenced by the control rod position during the reactor start-up period.

Dukovany's Upgrade 6
System function upgrade (3)

- **Function upgrades triggered/enabled by the key modifications**
  - Support of new FA type Gd-2M+,
  - Tuning the algorithm of fuel performance calculation, for the conditioning/deconditioning of the FA clads, support of mixed cores,
  - Implementation of the SDM calculation as a special task of the new SIMULATOR,
  - Implementation of new algorithms for TC correction calculation,
  - Implementation of TH model taking into account transversal flow and turbulent mixing in pins area,
  - Adjusting the predictive part of the system.
- **Operational and support tools**
  - New MMI Admin interfaces giving information about the validation information, given weight factors of input signals, used measurements in logics, module status,
  - New MMI Operator interfaces to give more information during reaching criticality,
  - Improvements and atomization of the isothermic state evaluation,

Project Quality Requirements

- Implementation of the new codes, functions and algorithms to the SCORPIO-VVER system and it's porting to the new hardware platforms will require to **use wide range of QA procedures** in correspondence with the local National Decrees issued by the National Authority – by the State Office for the Nuclear Safety in Czech Republic, with the international IEC standards and requirements and with IAEA guides.
- Application of all required **QA procedures**, fulfilling **IEC standards** requirements and **IAEA guides** and detailed testing are essential for the commissioning and licensing of the system for operation.

The **SCORPIO-VVER** Core Surveillance and Monitoring System at NPP Dukovany in Czech Republic in correspondence with **IEC 61226** standard is categorized as a plant equipment **Class C**.

Requirements, guides, best practices, standards

General Requirements QMS	ČSN EN ISO 9000, 9001 ČSN ISO 10006
Branch specific Nuclear industry	IAEA NS-R-1, NS-G-1.3, 50-C/SG-Q, Czech Regulation No.132
Domain specific System Engineering	ČSN ISO/IEC15288, ČSN EN 61508 ČSN IEC 61513, ČSN EN 61226 ČSN EN ISO 90003
Domain specific SW Engineering	ČSN IEC 60880, ČSN IEC 62138 ČSN EN ISO 90003 ČSN ISO/IEC12207, ČSN EN 61508

(IEC TC45 SC 45A and ISO/ IEC JTC1 SC7 standard series)

Experiences and support

More than 15 years of operation history:

- on 6 unit of VVER-440 type of reactors,
- at two different NPPs,
- in two different countries,
- with different regulatory bodies for nuclear safety,

helps to the SCORPIO-VVER developer team put the system to very high level of quality, accuracy and reliability.

Based on more than 15 years of operation experience:

- The system developer team is ready to respond to all needs of the NPP's, solve the difficulties and answer all questions **in local language of NPP** operators.
- All system documentations and user guides are maintained in 3 different languages: **English, Czech and Slovak** and the team ready to support other languages too.

Conclusions

- Since the first installation the SCORPIO-VVER system has a remarkable operating history and experience.
- The SCORPIO-VVER core monitoring system with its flexible and modular framework successfully responses to the plant operating needs and advances in nuclear fuel cycle strategies and fuel design.
- The high computation power of the robust HW platform and the modular SW framework allows for easy modifications of the system and implementation of new methods in physical modules.
- Even if the system is installed only on VVER-440 reactors, it could be adapted to the needs of other VVER type of reactors and to needs of education and training centers too.

Thank you
for your attention!

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