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Core Monitoring Applications in the Simulator Control Room

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ABSTRACT

Almost all boiling water reactors and many pressurized water reactors use a core monitoring system in the plant control room. These core monitor systems combine measured data and physics calculations monitor the compliance of fuel thermal limits according to the plant's Technical Specification requirements. For a variety of reasons, these systems are frequently not available in the simulated control room, or are available only via a simplified emulation. This paper presents a product which allows rigorous core monitoring to be present in the control room. Further, this paper discusses the additional instructional capabilities offered by the usage of software of this nature.

1. CORE MONITORING OVERVIEW

There are several types of core monitoring systems, but they are all conceptually very similar. All core monitoring start at the process computer, which collects measured plants signals. These signals include but are not limited to:

- State point conditions: core thermal power, coolant inlet enthalpy, core coolant flow rate, control rod positions and reactor pressure.
- Fixed incore flux detectors
- Movable incore flux detectors
- Excore flux instruments
- Thermocouples
- Pressure taps
- Flow Meters
- Pump speed indicators

These signals are then exported to a signal handling device. These signals then become the input, or boundary conditions, to a reactor physics computational module. The signals are translated into a text of a predetermined format which is readable by the physics software. Some of these signals are command boundary conditions, such as rod positions, flows, or thermodynamic state. Other signals are measured instruments which can be use to adapt to computed power to match the plant more closely. The physics model can be invoked periodically on a fixed interval, automatically in response to a change in plant condition, or manually via a request from the GUI.

2. MODERN CORE MONITORING BENEFITS

Modern core monitoring systems extends the amount of core information available to the operators and reactor engineers. The Core Monitoring System acquires measured data from the plant computer and uses that data as inputs for core analysis software. The core analysis software provides 3D and scalar computed results as printed text or via a GUI. Examples of these extensions beyond the pure surveillance of Technical Specification limits include:

- 3D Distributions (anything you want and more than you know what to do with)
- Margin to Limits (Power Distribution, Fuel Mechanical)
- Heat Balance
- Reactivity Balance

3. CORE MONITORING ON THE TRAINING SIMULATOR

Licensing authorities in many countries are requesting fidelity between the full scope training simulator control room and the actual control room. This demand may necessitate an equivalent core monitoring system in the simulator control room. Traditional core monitoring systems often have some barriers to entry in the simulator control room. Some barriers include:

- The core monitoring system relies on expensive and/or exotic hardware systems that are difficult to maintain.
- The cost of the software itself is too expensive.
- The network communication uses idiosyncratic, one-of-kind cabling.
- The core monitoring system is not properly configured to act with the simulator executive and instructor. The executive and the instructor station, among other things, allow for the saving of plant snapshots and backup-and-repeat in time, which are not normally available in the physical plants.
- Simulator core models generated inaccurate “Measured Data.”

The importance of this last point and an accurate, three-dimensional, cycle specific core model should not be understated. A core that uses representative data and few spatial will result in negative training even if the core monitoring system is used in the simulator.

The instrument responses will be in significant error and any adaptions performed would be meaningless.

4. SIGNIFICANT FEATURES OF S3R

Training simulators of the previous generation tended to use relatively simple core models as a result hardware limitations at the time of their development. Several of the simplifying assumptions include:

- transient simulation is performed the axial direction only,
- azimuthal effects are treated synthetically via externally determined tilting functions, and
- thermal hydraulic feedback is treated through the lumping of coolant channels into representative sub-regions in the core.

An additional limitation of these cores models is their ability to represent accurately the core as designed. One reason is the numerical models in the simulator are not as advanced as those in the core design tools. Another reason is that the basic nuclear data used in generic simulator core models does not accurately represent the behavior of modern lattice designs and reload strategies. As a result the static and dynamic characteristics of the training simulator may not represent those of the actual core. One possible approach to this problem is for the core physics group to make parametric adjustments to the nuclear data and external functions in the simulator, such that the simulator core is tuned to the core design. The limitations of this approach are:

- the tuning process must be performed every cycle,
- the process is labor intensive, and
- the result typically can be validated only with steady-state calculations.

S3R (Reference 1) is the training simulator core model in the Studsvik software system. The premise of the S3R product is to enable cycle specific core modeling on the training simulator in an easy-to-use, easy-to-update manner. The S3R product is designed to conform to several performance expectations, including those specified in ANSI 3.5, INPO SOER 96/02, and 10 CFR 55.46.

S3R achieves its performance goals for several reasons:

- S3R uses the same numerical methods as the core design code SIMULATE-3.
- S3R acquires all the data needed for the simulator directly from the output of SIMULATE-3, with no intermediate steps or linking tools.
- S3R can model any point in cycle operation.

- S3R models each fuel assembly and each instrument explicitly, just like in core design.

The S3R advantages are three-fold:

- The requirements of the simulator do not significantly increase the workload on the core analysis (or fuels) organization. The simulator is using the output of calculations already performed.
- Because the numerical method is the same in both places, differences in methods do not degrade the fidelity of the simulator model to the core design model.
- The real-time options in S3R can be assessed directly, offline, without consuming panel time.

For the purposes of training, S3R can replicate the performance of the reference plant with the standards set forth in the ANSI 3.5 standard, such that operators can reasonably expect to take credit for reactivity manipulations on the simulator instead of the plant, per the terms of 10 CFR 55.46. However, this high degree of fidelity to the plant provides added benefit in the simulation of core monitoring. The simulated "measured data" is sufficiently accurate that the core monitoring software can adapt to it as it would at the plant. Therefore, the reports of plant staff and safety margins are similar accurate to those at the plant. Inaccurate core models or core models which do not model the current reload are effectively unusable for core monitoring on the training simulator.

5. GARDEL-SIM SOLUTION WITH S3R

The Studsvik product GARDEL is a full scope core monitoring system. GARDEL is a modular system of several executables, each performing specific tasks. These programs are written in standard programming language of FORTRAN, C and Tcl/Tk making them highly portable to UNIX and PC computing systems. Files generated by the GARDEL system are written specifically to be binary compatible. This allows the system to be distributed on heterogeneous networks of PC and UNIX workstations. The capabilities of GARDEL are discussed in References 2 and 3.

GARDEL-SIM uses the same software structure as GARDEL, but configured to function with the training simulator. GARDEL-SIM executes on its own PC on the simulator network. The training simulator communicates with GARDEL-SIM via standard sockets using either an IP address or hostname. The interface allows GARDEL-SIM to stop, start, save data and/or backup under the direction of the training instructor. The GARDEL data packet of measurements is extracted from the plant computer at the plant. However, in the simulator environment, all the measured data is in fact already available in digital form, being simulated by software. Therefore the data packet is written directly from the simulator database.

The configurations of GARDEL at the plant and GARDEL-SIM in the training simulator are compared in Figure 1. GARDEL-SIM is triggered in batch mode evaluation with an evaluation taking around 30 sec as in the plant. It executes on its own PC on the

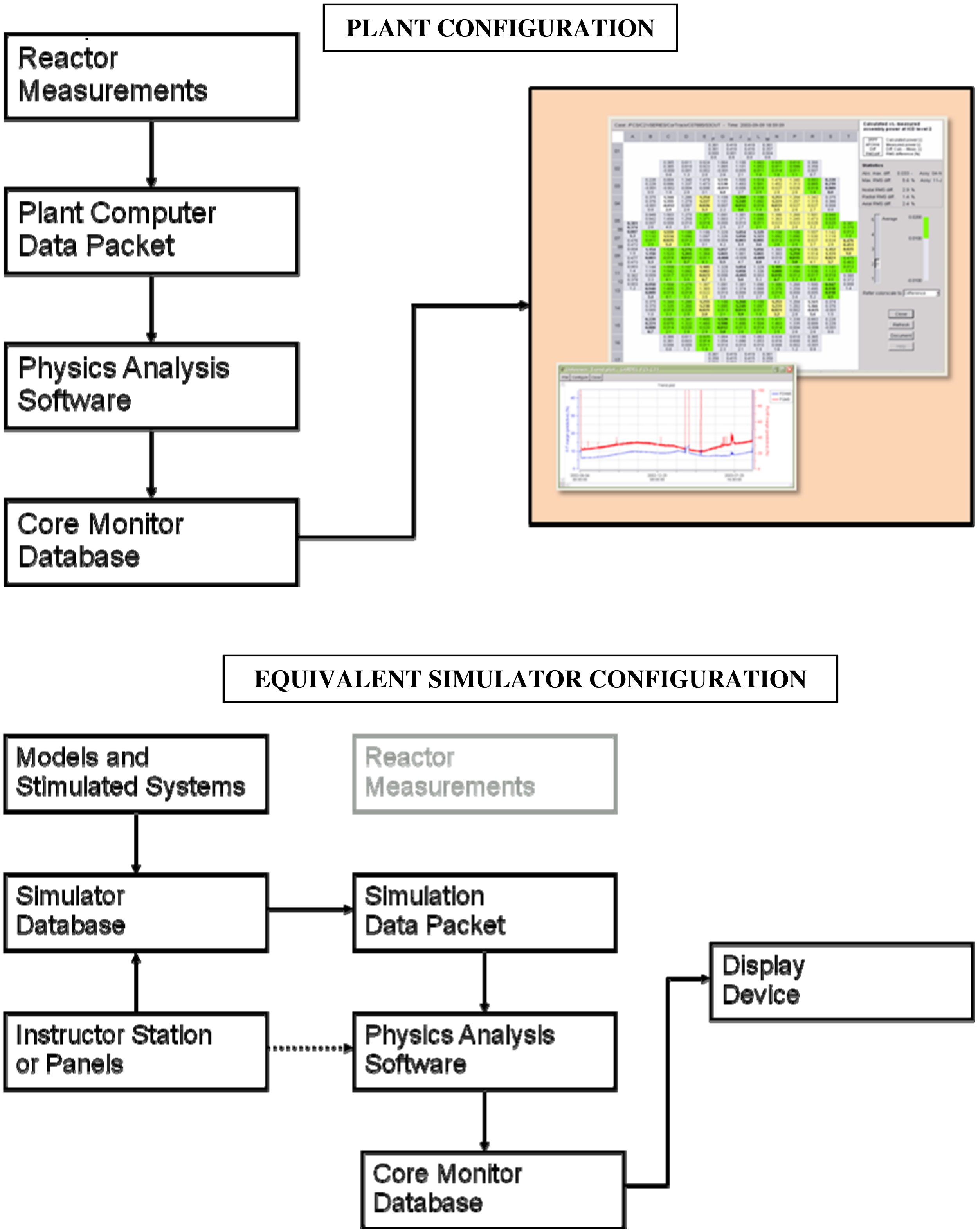

Fig. 1 GARDEL and GARDEL-SIM Configurations

same network as the simulator PC and maintains its own ICs and backtracks. Simulator commands are transmitted via sockets. A simple ASCII file is used as data packet to exchange information is exchanged between GARDEL-SIM PC and simulator PC.

Because of the simulator core is modeled in S3R, the measured responses exhibit very high fidelity (Figures 2, 3, 4). The combination of GARDEL-SIM and S3R results in several new capabilities with the training simulator:

- The simulator control room has increased fidelity with respect to the plant control room.
- Malfunctions on core instruments are reflected on margin to limits. These include training on violations of PCI, MCPR and other limits pertaining to licensing and the integrity of the fuel.
- The GARDEL-SIM database is an effective way to store 3D data that is changing too quickly during real-time training. This data may be archived for offline and classroom analysis after the fact.
- The results presented by GARDEL-SIM are suitable for reactor physics training in a classroom setting.

Some typical graphical and text reports prepared by GARDEL-SIM are shown in Figures 5 and 6. The reports are highly configurable and can represent nearly any pre-existing format or protocol.

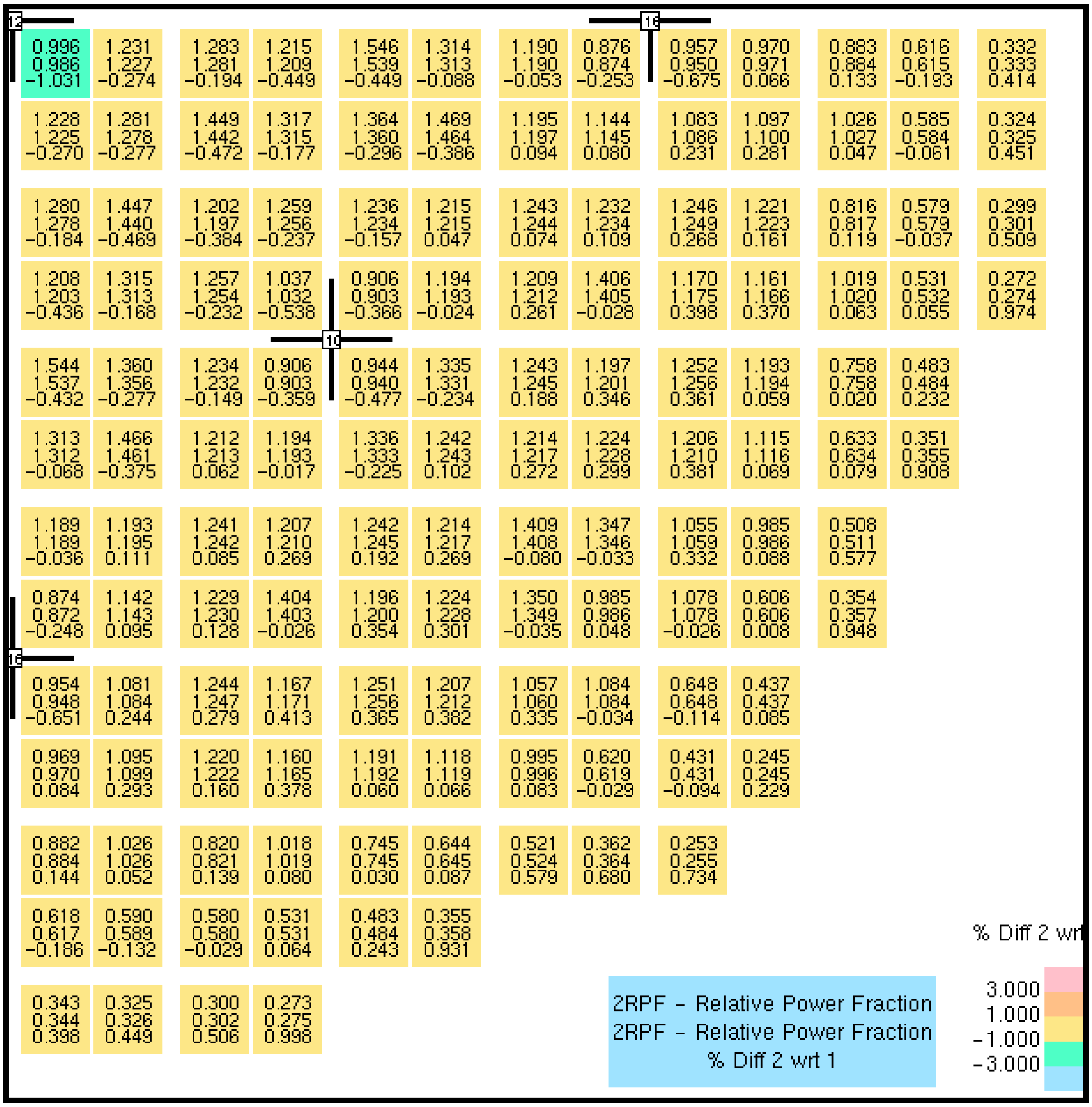

Fig. 2 S3R Real-Time Radial Power Prediction

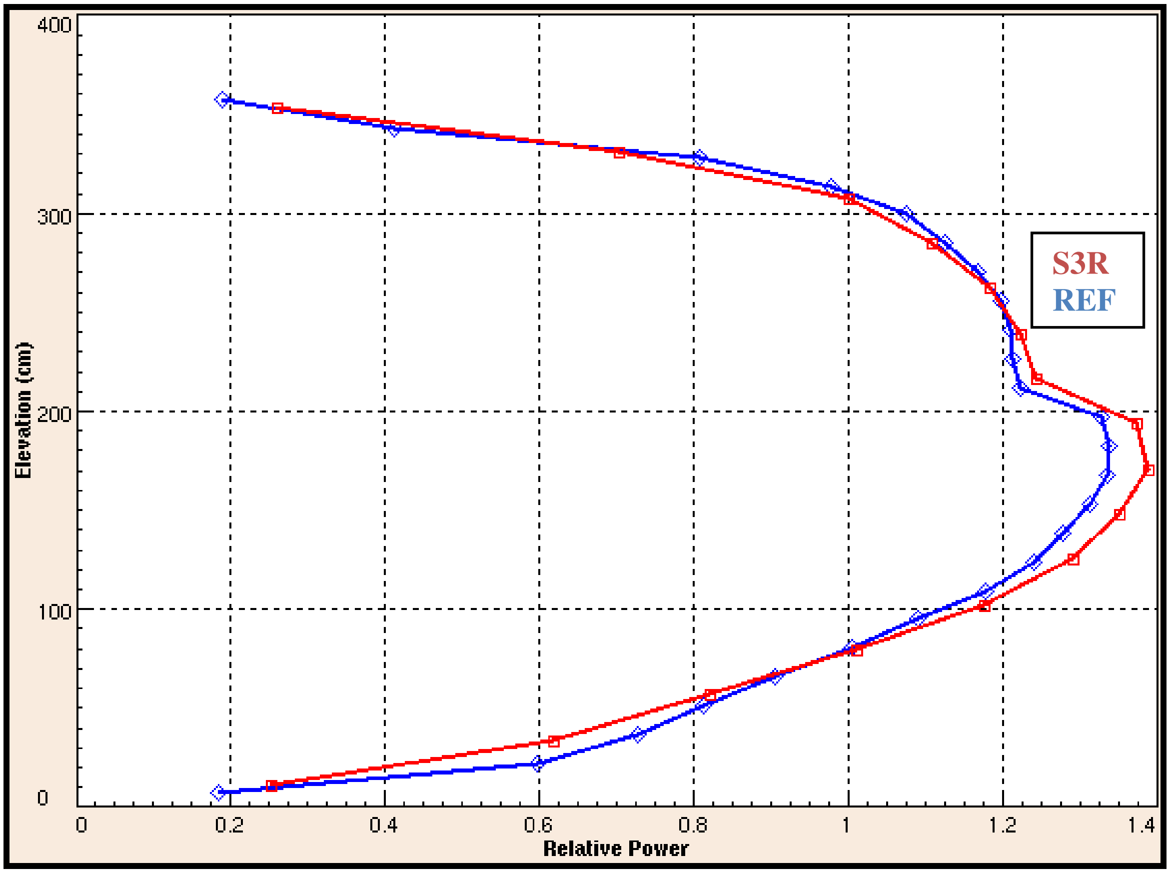

Fig. 3 S3R Real-Time Axial Power Prediction

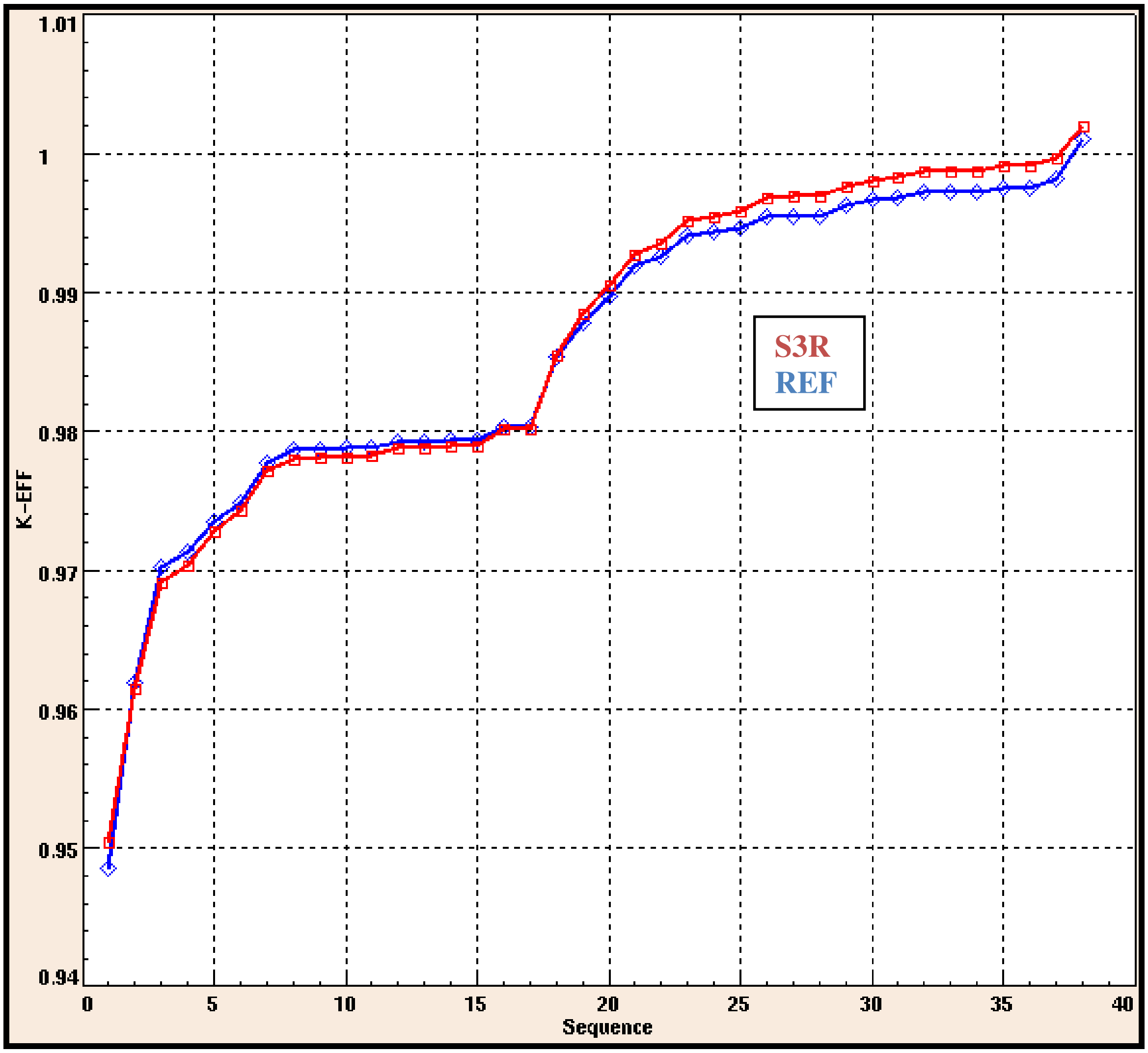

Fig. 4 S3R Real-Time Axial Power Prediction

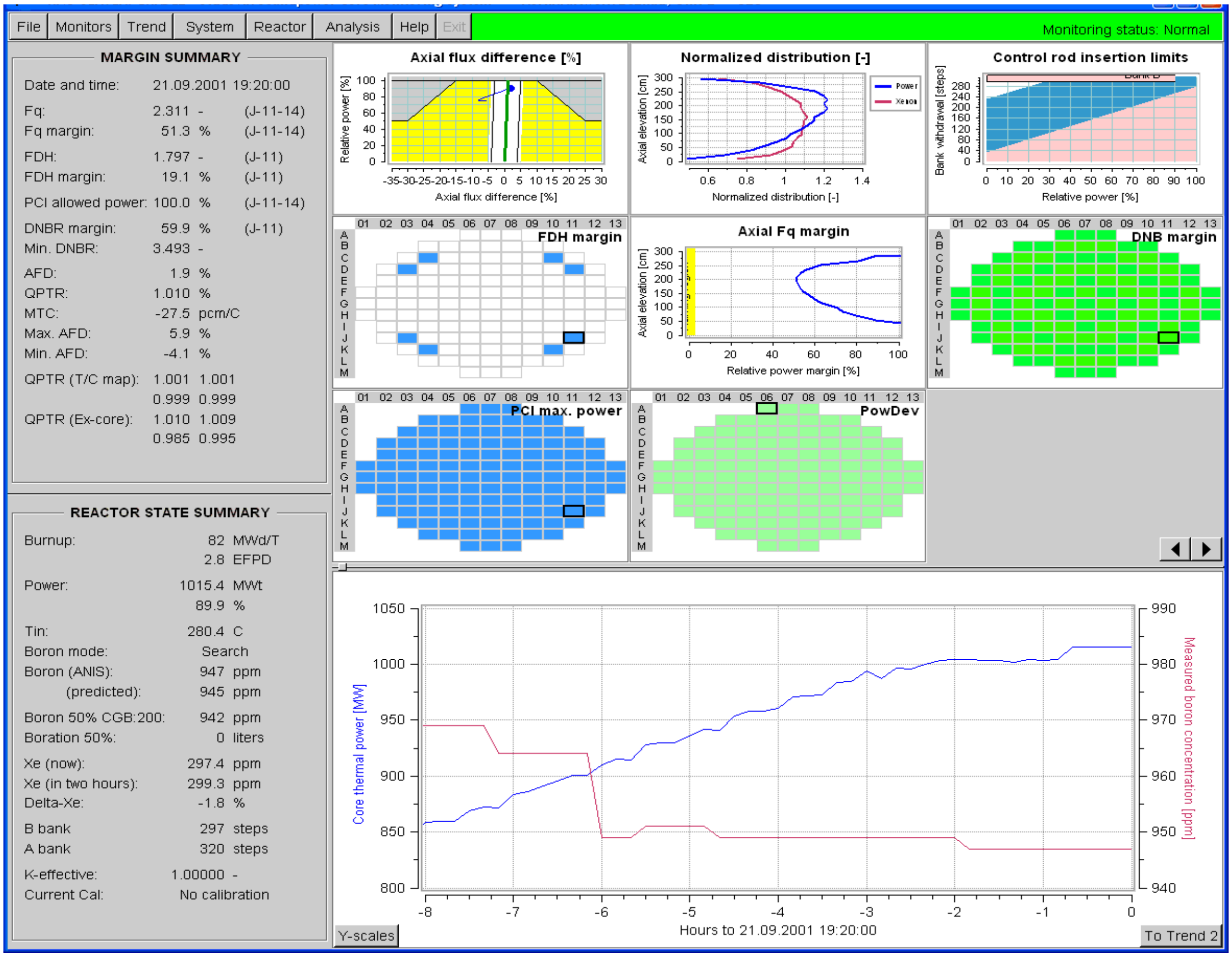

Fig. 5 Example of GARDEL-SIM PWR Graphic

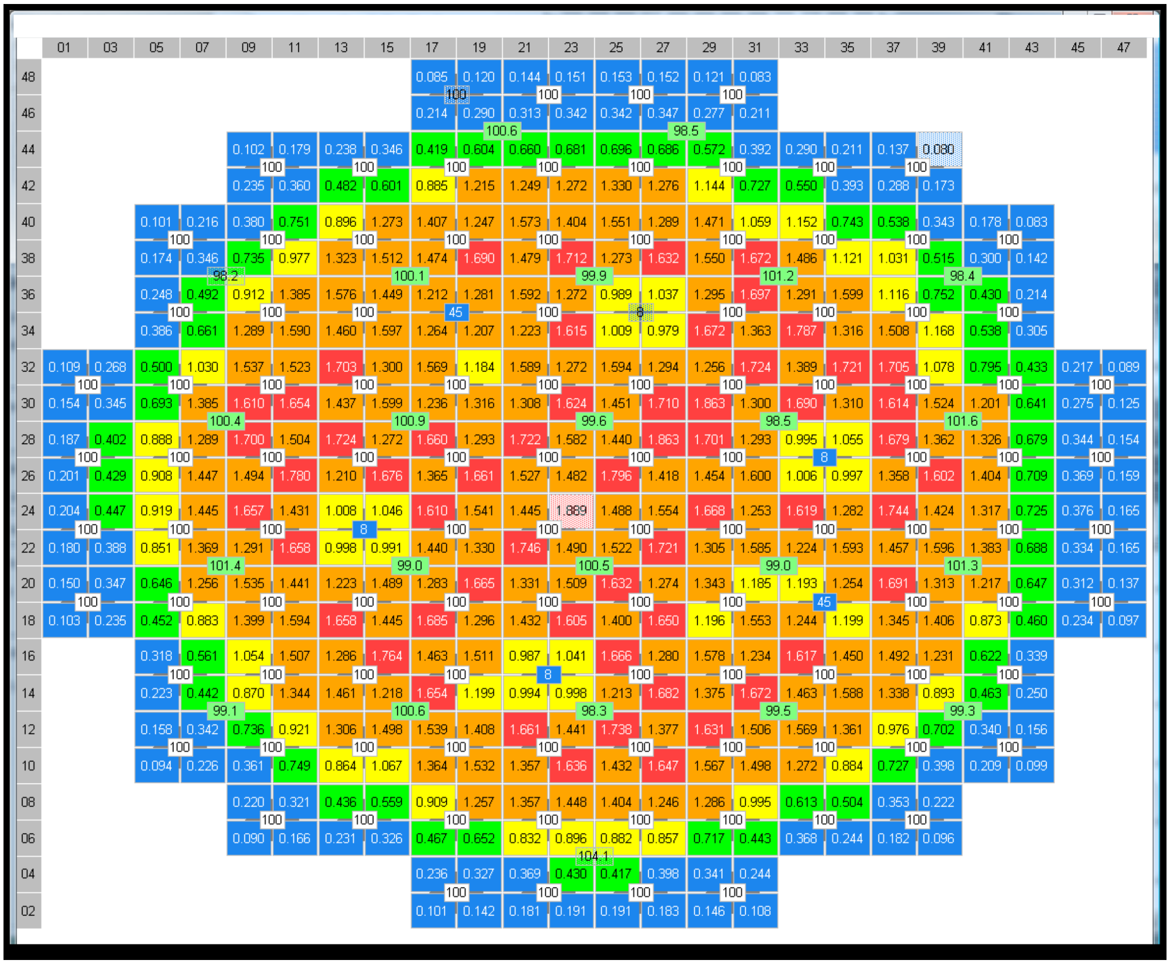

Fig. 6 Example of GARDEL-SIM BWR Graphic

6. SUMMARY

Core monitoring provides important plant information by supplementing instrumentation with calculations. Core monitoring in the simulator control room is now practical using conventional hardware, networking and software. Therefore, fidelity to the plant is increased. The same information used by the operator in the control room is now available on the simulator and used in training. Furthermore, the thermal margins displayed on the simulator are calculated using the same methods and libraries as in the plant. Core monitoring in the training simulator also generates and preserves detailed core data for study and analysis.

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