Advances in Nuclear Fuel Management IV (ANFM 2009)
Hilton Head Island, South Carolina, USA, April 12-15, 2009, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2009)

ADVANCES IN CORE MONITORING AT STUDSVIK SCANDPOWER

Alejandro Noël, Gerd Anton
Studsvik Scandpower
Hertensteinstrasse 35, CH-5415 Nussbaumen AG, Switzerland
alejandro.noel@studsvik.com, gerd.anton@studsvik.com

Claudio Oña, Néstor Patiño
Studsvik Scandpower
P.O.box 15 NO-2027 Kjeller, Norway
claudio.ona@studsvik.com, nestor.patino@studsvik.com

Keywords: **Core Monitoring, PWR, BWR, core analysis, operational support**

ABSTRACT

Studsvik Scandpower has established its core monitoring system GARDEL as an advanced and reliable solution for PWR and BWR plants of different designs seeking high accuracy, availability, simplicity and powerful core analysis and operational support tools.

This paper provides an overview of the most recent GARDEL implementations and of GARDEL's functionality beyond that of traditional Core Monitoring Systems.

1. INTRODUCTION

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 within the GARDEL system are written specifically to be binary compatible. This allows GARDEL to be installed on heterogeneous networks of PC and Linux/UNIX computers. GARDEL's computational engine is Studsvik's advanced core simulator SIMULATE[1].

A typical configuration is to have the GARDEL data collection processes and core tracking calculations executing on two redundant servers. GARDEL users sharing this network would run the GARDEL graphical user interface locally on their own desktop, to see the current core state, make trend plots, generate reports, perform support or reactivity management calculations, etc.

It is important to note that GARDEL does not run on the plant's process computer and therefore no modifications are required in it to install GARDEL. A simple query to the plant computer data archive is conducted periodically (typically every 1 minute) to pass process data to the GARDEL server.

The process data set is a small ASCII file containing relatively few parameters such as reactor power, flow, pressure, inlet and outlet conditions, control rod positions, fixed and movable detector signals.

Cycle initialization is a simple task that requires only the SIMULATE restart file for the beginning of cycle and the associated cross-section library. A panel of the graphical user interface within GARDEL guides the authorized system administrator to setup the new cycle. Authorization rights for individual users are also controlled through a panel of the system administrator's graphical user interface.

The GARDEL-GUI, named Atlas, provides full insight into the current core conditions as well as into past or postulated core conditions. Furthermore, GARDEL users may simulate and evaluate through Atlas any core conditions or planned maneuvers.

2. FUNCTIONALITY BEYOND TRADITIONAL CORE MONITORING

The basic mission of core monitoring systems is to perform a continuous surveillance of some key reactor core parameters that shall satisfy the requirements in the particular plant's Technical Specifications. Those parameters are presented to the control room personnel, in a convenient way to help a smooth operation without violating fuel thermal limits. The methods to calculate the limiting parameters typically consist on the simulation of the core power distribution by means of a core simulator and/or adaptive methods that force the computed power distribution to match the readings from in and ex-core instrumentation. The limiting parameters are then derived from the resulting power distribution.

2.1 Enhanced core monitoring

The typical core monitoring functions, aimed mainly to assist the operations personnel, have been enhanced in GARDEL in a number of ways:

- Authorized users have full control of the signals fed to GARDEL, and a detailed insight, via customized mimic displays, c.f. Figure 1.

- In addition to the standard, default monitors (like power-flow or delta-I maps), GARDEL is delivered to the users with customized monitors and displays, to accommodate the monitoring practices particular to each organization, c.f. Figure 2.

- New upcoming issues like the current "Zero-Ten" industry initiative (zero fuel failures by year 2010) are evaluated by Studsvik and appropriate measures are taken in GARDEL to address any new needs.

- GARDEL is configured to present all graphical data and reports in the plant's language and units. Currently supported languages are English, German and Japanese, as well as SI and British Units. Customer specific "dialects" are supported as well.

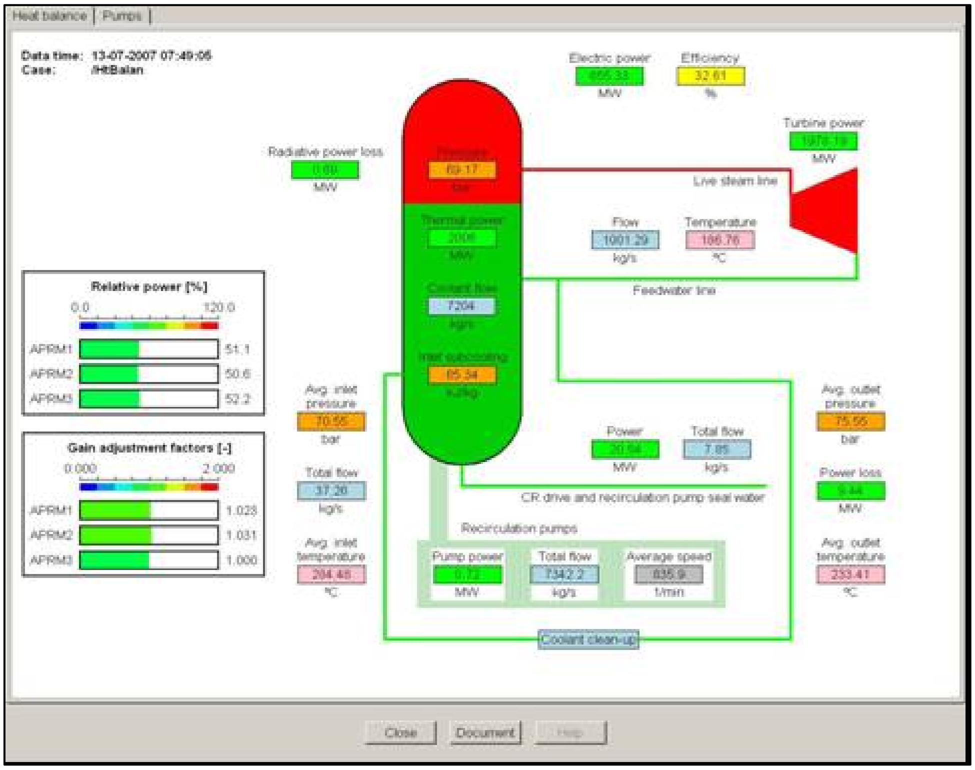

Fig. 1 Example of BWR heat balance mimic display.

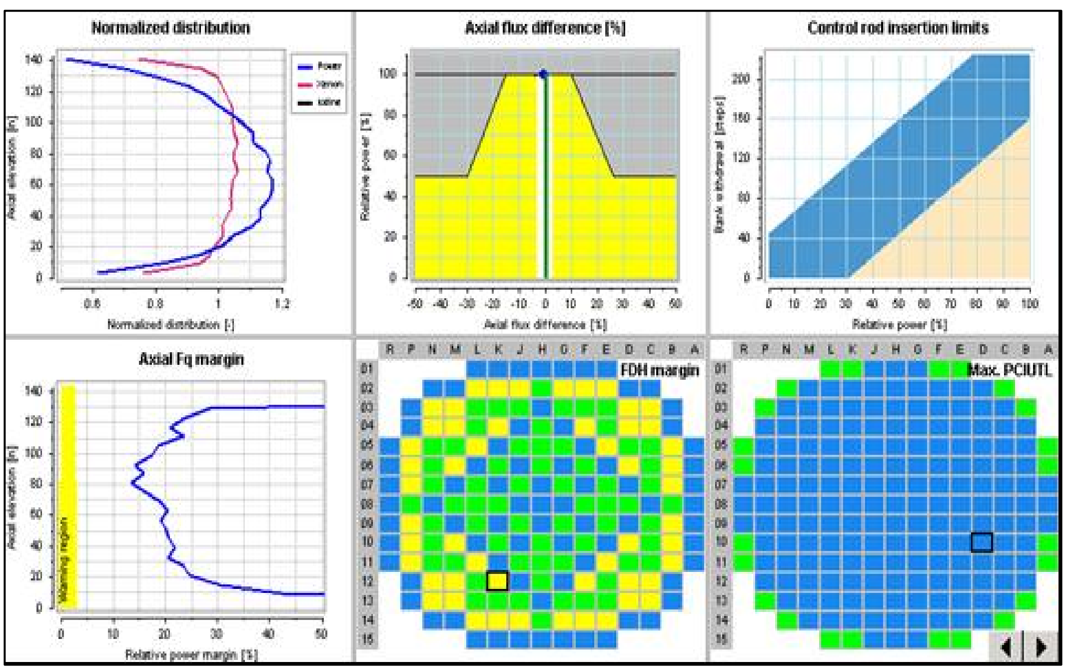

Fig. 2 Example of PWR on-line monitors

2.2 Beyond core monitoring

GARDEL's purely core monitoring duties are complemented with numerous functions to provide assistance to the plant personnel in several other areas.

- All information fed to GARDEL since beginning of its operation is stored in the database and is available for analysis and inspection. The database is designed for storage of key output parameters that allow for later reconstruction with full detail of any past core conditions.

- While performing its core monitoring duties, GARDEL automatically creates and stores in the database a comprehensive set of PDF reports, which are readily available to the user. In addition, a number of on-the-fly reports are available on demand. GARDEL is delivered with pre-defined contents for these reports, but they can also be easily customized to the plant's needs and practices.

- Analysis of past conditions. It is often necessary to extract data out of the core monitoring system to perform varoius kinds of analyses like validation of past calculations against other methods, tracking of specific fuel assemblies or fuel pins performance, tracking of individual in-core detectors, detailed analysis of past maneuvers, etcetera. GARDEL's user interface provides automated tools to regenerate core monitoring results in full detail for any operation period of interest. The regenerated data may later be exported in a format suitable for use by external applications.

- Operation planning. An accurate planning of power maneuvers will help maximizing the power output while ensuring compliance with Technical Specification limits. GARDEL's GUI, combined with SIMULATE, generates accurate predictions of any scenario proposed by the user, assisting them in the planning and optimization of future operation. Figure 3 shows examples of the operation planning tools available for these purposes.

- GARDEL offers a host of analysis tools, like core and pin maps, trends, tables, database searches, etc. The same functions are applied to analyze the current conditions, past operation and future maneuvers. Figure 4 shows examples of those analysis tools.

- Fast verification of core performance. Tedious and error-prone evaluations of reactor physics measurements during start-ups are streamlined.

- A replica of the GARDEL system can be implemented in the plant's training simulator, providing 100% fidelity to the core monitoring and core analysis functions available in the control room. Thus, GARDEL also becomes a powerful reactor physics training tool.

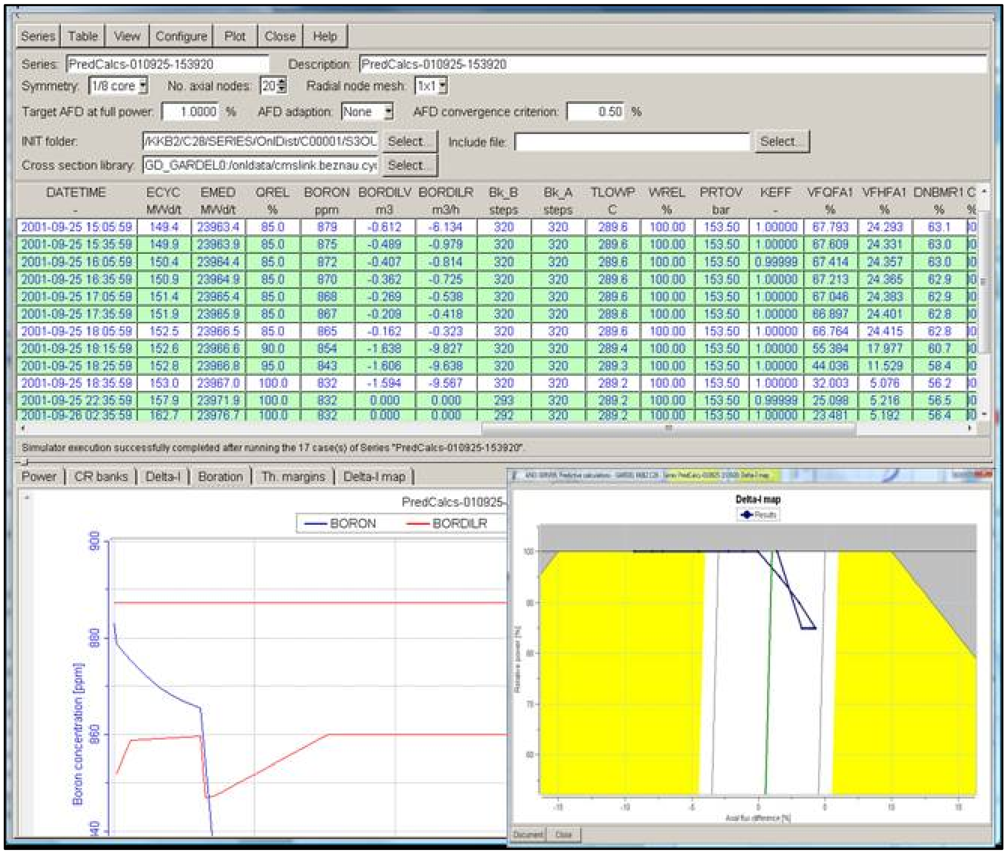

Fig. 3 Example of operation planning tools

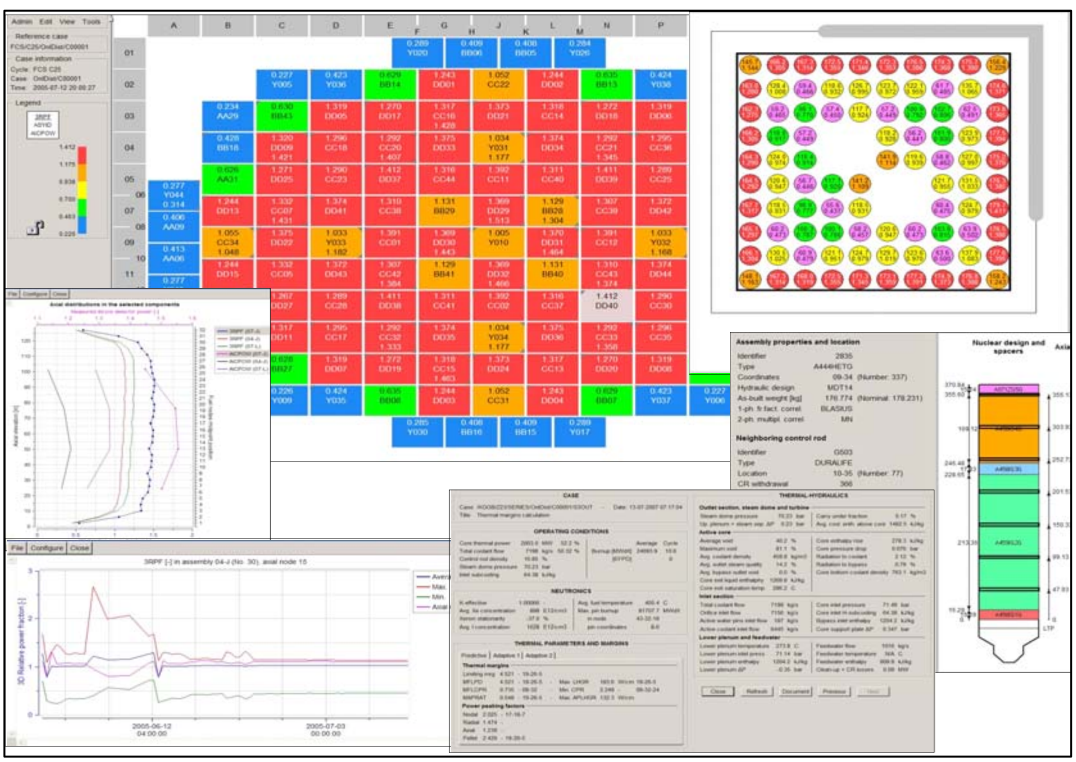

Fig. 4 Examples of core analysis tools

2.3 Access to external applications

Being a modular system, GARDEL integrates in a natural way other applications that may be of interest for some plants. Examples of such applications are:

- Decay heat, radiation source and spent nuclear materials calculations for the whole core and individual fuel assemblies -in the core and/or in the pool- by means of Studsvik's Spent Nuclear Fuel (SNF[2]) program.

- BWR stability verifications of current or postulated conditions by means of Studsvik's dynamic core simulator S3K[3]. Stability verifications can be performed for both global and regional oscillations.

- Customer-specific plug-ins. Some customers developed own methods to solve some particular problems that due to proprietary restriction cannot be distributed to other GARDEL users. The customer may integrate its own methods into GARDEL following instructions provided by Studsvik.

3. OPERATIONAL EXPERIENCE WITH GARDEL

GARDEL is currently operating or being implemented in 25 LWR units, of which 18 are PWRs and 7 BWRs. Those reactor units are located in the United States, Germany[4], Japan, Sweden, and Switzerland[5]. GARDEL has been licensed for on-line core monitoring by the regulators in all those countries; a total of 5 BWR and 11 PWR installations out of the 25 installations have already been licensed for on-line core monitoring.

The reactor units for which GARDEL is applied correspond to a variety of designs as listed in Table 1.

Table 1 Reactor designs currently using GARDEL

Reactor type	Designed by	In-core instrumentation
PWR	Westinghouse	Movable fission chambers
PWR	Westinghouse	Movable fission chambers and gamma thermometers
PWR	Combustion Engineering	Fixed rhodium detectors
BWR	General Electric	Fixed fission chambers
		Movable fission chambers or gamma detectors
BWR	ASEA	Fixed fission chambers
		Movable gamma detectors
BWR	Kraftwerk Union (Siemens)	Fixed fission chambers
		Movable gamma detectors

4. RECENT ADVANCES IN CORE MONITORING

The latest GARDEL developments are aimed to leverage the capabilities offered by modern computer hardware. Recent development has been focused on:

- Hosted solutions. Each installation "hosted" by Studsvik is a replica of the on-line system at the plant, running in parallel. The objective is to provide customers access to GARDEL from outside the plant.

- Client/server configuration. All calculations, data base access and administration is centralized in a server cluster, while the GUI is deployed as a thin client.

- Migration to 64 bit data architecture, providing virtually unlimited data storage capabilities

- Analysis clusters. Core monitoring functions are performed in two servers, while all core analysis and operational support functions are performed in an expandable cluster of computers.

Figure 5 below shows the newly recommended GARDEL configuration.

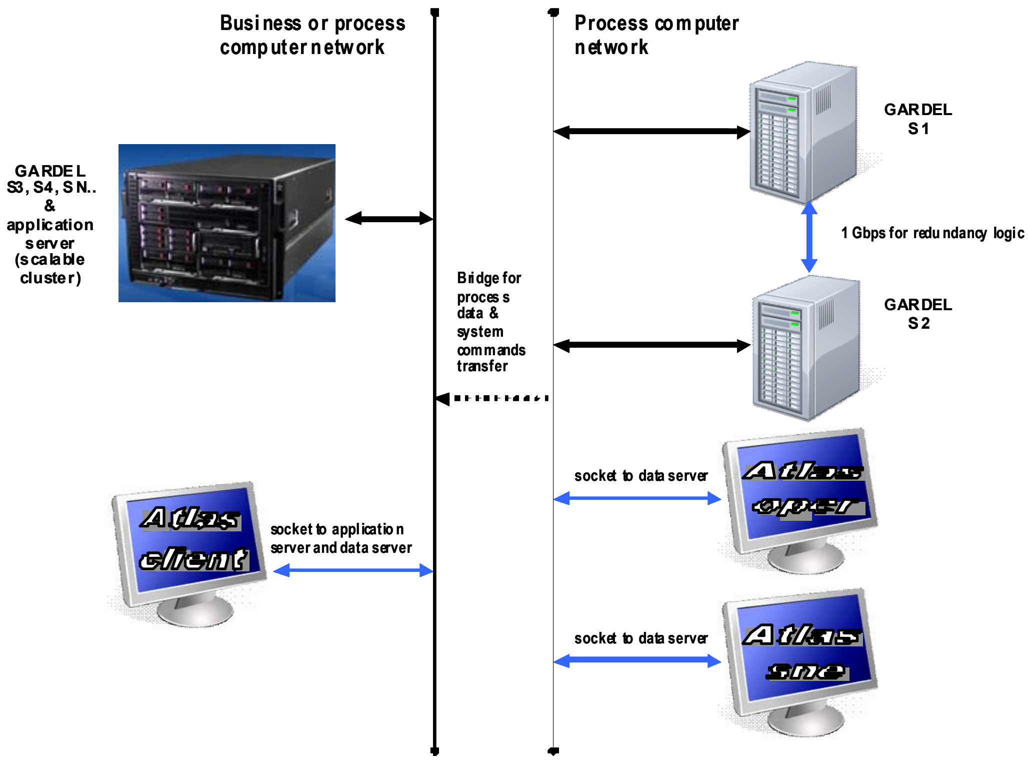

Fig. 5 Recommended GARDEL configuration

4.1 Client-server configuration

Several client computers run the Atlas graphics program to provide the control room personnel information about the current core conditions as well as to support the reactor engineering personnel's core analysis and operational support activities.

The graphic software establishes a connection to an application and data server resident in the computing servers and presents the data graphically as well as the available system reports. User calculations take place in the analysis cluster.

Atlas does not require pre-installing any particular software on the client computers. The first time GARDEL is accessed from a client computer, the system will automatically install the GARDEL-GUI on it.

The client-server paradigm maximizes the security of the computing servers: interactive GARDEL users do not logon to the computing servers but only interact with them by means of data queries for graphical presentation. Although the main objective of the client/server configuration is to minimize the data security risks, this configuration is highly efficient, allowing for many simultaneous interactive GARDEL users in networks with low band width.

4.2 Database architecture

32-bit data format files have an upper size limit of 8 Gb. Although this limit does not exist in 64-bit computers, GARDEL was extended to generate all new database files with 64 bit data format independently of the hardware platform. GARDEL recognizes the old files with 32 bit format or new 64 bit files and process them accordingly. This modification allows for virtually unlimited data storage, allowing e.g. for detailed tracking of individual fuel pins as well as the storage of complete fuel data descriptions at short intervals.

4.3 Analysis clusters

Two servers (GARDEL S1 and GARDEL S2) are responsible exclusively for the on-line core monitoring activities. Those two servers are linked to the process computer network for on-line data acquisition and, if required, export data back to the process computer.

Additional computing servers configured in a core analysis cluster (GARDEL S3, GARDEL SN…) are dedicated to core analysis and operational support activities. The core analysis cluster can be part of the process computer network or of a separate network with read-only access to the process computer network. The cluster contains a replica of the core monitoring database. The same automatic processes running on GARDEL S1 or GARDEL S2 run on the core analysis cluster in order to keep the database up-to-date. Any commands issued by an authorized user to the core monitoring servers will automatically propagate to the cluster, ensuring data consistency.

GARDEL supports a queuing system to keep track of cases being executed in different servers in the cluster. Assuming user A is running 2 SIMULATE calculations, those calculations will be directed to servers 1 and 2. If user B now wants to start another calculation, it will be directed to server 3 and so on, depending on the number of computation servers available in the cluster. Servers could be added or replaced in the cluster with minimum work effort to ensure enough computing power for the core analysis calculations.

4.4 The GARDEL Work Environment

One server in the core analysis cluster is configured as GARDEL http server and declared as the so-called primary node into which the user logs on with his internet browser.

The login page consists of snapshots of the most important up-to-date Atlas displays. A link in that page directs the user to a login page asking for the users' identification data. Upon successful login, the http server checks the user version of Atlas. If there is a newer version of Atlas available in the server, the user is offered to update its version.

Atlas client users always logon through GARDEL's http server. Direct access to the cluster's file system is not permitted. Those users interested to directly access Atlas without going through the initiation page with display snapshots only need to save a link to the login page on their desktops.

GARDEL users in the control room are configured for automatic start-up without user intervention.

5. CONCLUSIONS

Studsvik's GARDEL system is a powerful tool that, since its market introduction in 2002, has been -or is being- implemented at 25 LWRs worldwide. The strength of GARDEL's concept is the combination of a state-of-the-art computational engine with advanced graphic solutions and a sound database concept that provide accuracy, simplicity and intuitiveness while performing core monitoring, core analysis and operational support.

As a leading edge developer of software for the nuclear industry, Studsvik has combined its industry-standard physics methods with the latest computer technologies to create GARDEL, which re-defines the state-of-the-art in core monitoring systems.

REFERENCES

1. A. DIGIOVINE, et al., "Worldwide Application of Studsvik Core Management System," *ENS/ANS-Foratom Conference Transactions*, Vol. IV, p. 1964, Lyon, France (1990).

2. Børresen, S., "Spent Nuclear Fuel Analyses based on In-Core Fuel Management Calculations." *PHYSOR 2004 – The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments*, Chicago, Illinois, April 25-29, 2004

3. G. GRANDI, K. S. SMITH; "BWR Stability Analysis with SIMULATE-3K," Proceedings Int. Conf. New Frontiers of Nuclear Technology (*PHYSOR 2002*), Seoul, Korea, October 7 - 10, (2002).*)*

4. NOËL, HOLZER, ANTON, SMITH, "BWR MOX core monitoring at Kernkraftwerk Gundremmingen" *International Conference on the Physics of Reactors "Nuclear Power: A Sustainable Resource,"* Casino-Kursaal Conference Center, Interlaken, Switzerland, September 14-19, 2008*)*

5. NOËL, VIELMA, DIGIOVINE, "Modernization of Kernkraftwerk Beznau's core monitoring system with Studsvik Scandpower's GARDEL system," *Proceedings of ICAPP 2007*, Nice, France, May 13-18, 2007, Paper 7036.