ARGOS - IMPLEMENTATION OF FRAMATOME'S CORE MONITORING SYSTEM ON THE EUROPEAN MARKET

TOM KRIEGER, TOBIAS PAUL
Framatome GmbH, Paul-Gossen-Strasse 100, 91052 Erlangen (Germany)

STEPHAN MERK
Framatome Inc, 3315 Old Forest Road OF-12 Lynchburg, Va. 24501 (USA)

LUKAS MEYER
Kernkraftwerk Gösgen-Däniken AG, Kraftwerkstrasse CH-4658 Däniken (Switzerland)

ABSTRACT

ARGOS is Framatome's new state-of-the art core monitoring system which offers highly accurate power distribution monitoring and Technical Specifications surveillance for all types of commercial light water reactors. As a completely modular universal platform implementing consistently modern open software standards, ARGOS can utilize different neutronic simulators and a variety of proven and innovative power reconstruction and adaption methodologies. Besides supporting general operator assistance and a wide set of specific functions, ARGOS features a highly flexible and powerful prediction module assisting in precise planning of projected power manoeuvres. By earning the privilege to be Gösgen's choice for renewing its core monitoring system, ARGOS enters now the final phase of commercial market implementation: ARGOS was installed on-site in spring 2017 and has been operating successfully in parallel with the legacy system; it is planned to replace it during the operational cycle 2018/2019 at the end of 2018. ARCADIA, ARGOS, ARTEMIS and POWERTRAX are trademarks or registered trademarks of Framatome or its affiliates in the USA or other countries.

1. Introduction

Framatome has developed ARGOS as a universal core monitoring system to support all types of commercial light water reactors. The development has been performed by an international team consisting of nuclear physicists, nuclear engineers, and software experts from 5 countries. The chosen software architecture is completely modular and is based consistently on state-of-the-art open software standards. This architectural design leads naturally to a high level of flexibility and customization offered through a very efficient and user-friendly Graphical User Interface (GUI). Furthermore the modular structure of ARGOS demonstrates its versatility through the implemented coupling with Framatome's core simulators PRISM (1) and ARTEMIS (2) and a wide selection of supported power reconstruction and adaptation methodologies like MEDIAN (3), INPAX (4), and SUPR-FMTS (5). ARGOS offers a complete set of functionalities to support power distribution monitoring, Technical Specifications surveillance, general analysis of both steady-state reactor periods and transient events, as well as a powerful prediction module to plan and assist in the execution of projected load follow manoeuvres. With the scheduled commissioning of ARGOS at the Swiss power plant Gösgen the rollout of Framatome's state-of-the-art

universal core monitoring system has begun.

2. Software Architecture

ARGOS has been designed from scratch as a completely modular system. All components use consistently robust and proven cross-platform software standard packages. The GUI is programmed in C++. It interacts with a Qt library and data processing engine modules written in Python. For binary files the HDF5 format was chosen and internal and external interface files are all in XML. The data backbone of the system is a PostgreSQL database.
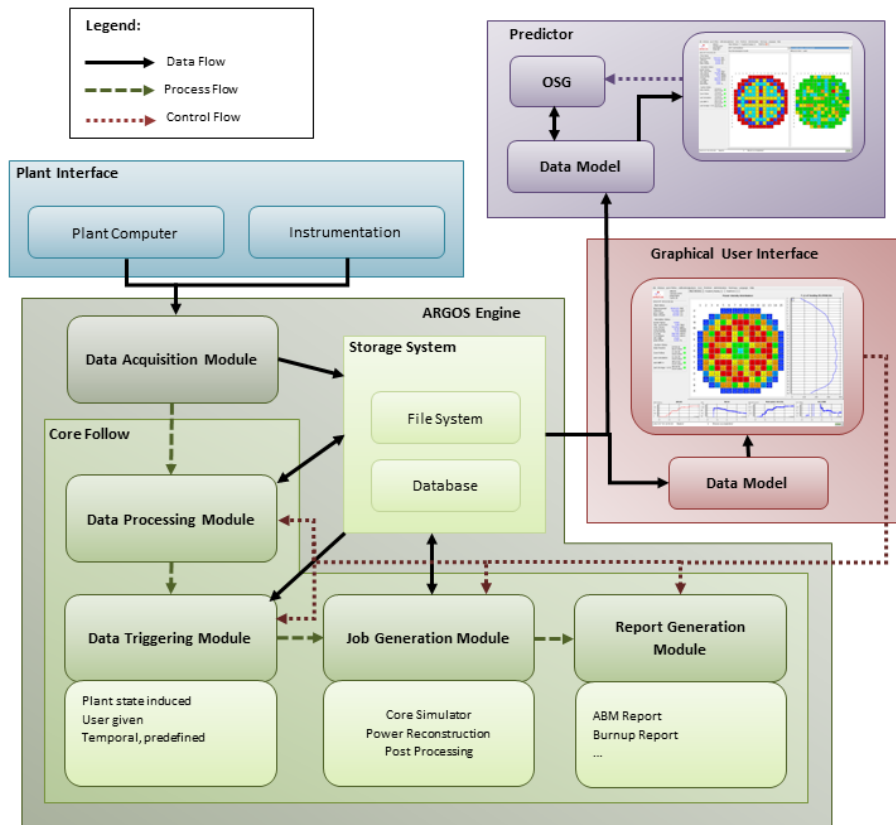

Figure 1: Modular Design

The basic core monitoring cycle begins with the Data Acquisition Module retrieving data from the plant computer and periodically data from the reference measurement system (Figure 1). The original data is stored into the database and the Data Processing Module takes over performing a series of data validation checks including potential data adjustments, e.g. correcting or eliminating information, which is assessed as being obviously not correct or trustworthy. An additional task consists in the calculation of data averages. Finally all processed data is stored as a 2nd complete data set into the database. The Data Triggering Module analyses the processed data and determines when the next core calculation should be launched. The execution of the triggered core calculation, including the derivation of the measured power distribution, and all subsequent post-processing evaluations is supervised by the Job Generation Module. Again all calculated core follow data is stored into the database. Most information provided in various printable reports by the Report Generation Module is also directly retrieved from the database and the same holds true for the data being displayed in real time by the GUI. In summary, the database serves as the central and comprehensive data storage for the original plant data, the analysed and processed data, and all calculated core follow data. Naturally this paradigm is upheld for all data associated with and derived by the very versatile prediction module which

is being launched from the main core follow GUI as a completely independent process.

3.   Versatility and Configurability

The primary motivation for the development of ARGOS was to offer a universal core monitoring system covering all commercial light water reactor types. Providing the same look and feel for all targeted reactor types makes ARGOS especially attractive as a fleet solution for customers operating several reactors of different reactor types. The achieved versatility is demonstrated first by ARGOS' capability to process plant computer data from each targeted reactor type and to evaluate signals from a variety of reference measurement systems, like aeroball measurements, traveling or moving incore probes, as well as fixed incore detectors. On a second level, ARGOS can effectively be coupled with different neutronic simulators as proven by the implemented couplings to Framatome's in-house 3D simulators PRISM and ARTEMIS. The clearly defined interfaces together with the comprehensive central database would also facilitate a smooth coupling with an external neutronic engine. On a third level ARGOS shows its versatility by offering multiple power reconstruction algorithms depending on plant type and or regionally approved methodologies. At this point the following power reconstruction methodologies are supported: MEDIAN, INPAX-[CE/W], and SUPR-FMTS.

Another highly valued feature is the free configurability of the ARGOS GUI by the plant physicist or operator. The ARGOS default GUI configuration will be determined by the customer with expert assistance offered by Framatome resulting in a complete set of ready-to-use views and tabs consisting of tables, graphs, core maps, and a wealth of predefined widgets for all monitoring and analysis needs. At any given time, the user can modify or extend the available displays at will and on the fly. Modifications can be stored as user settings per user and will be reloaded as default configuration for the next ARGOS session.
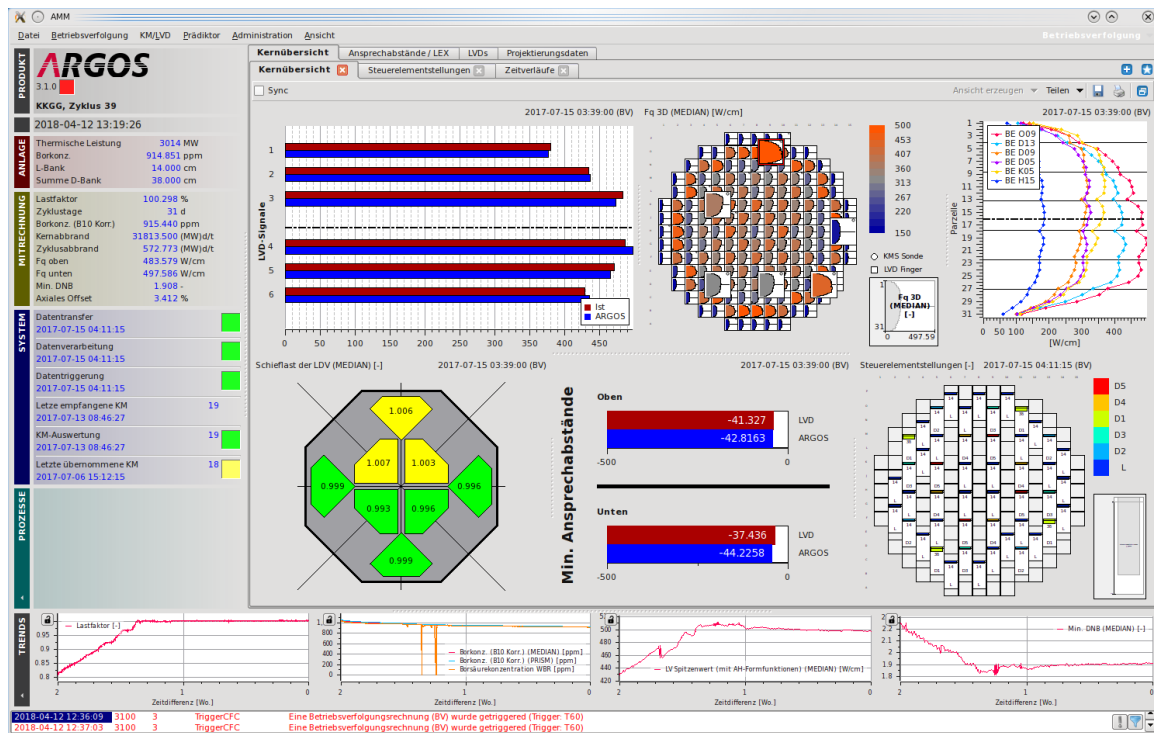
Figure 2: Core Overview

The "All-in-One Overview" includes e.g. the following main elements:
Comparison of measured and calculated incore detector signals (top left)
Corewide 3D Fq distribution per fuel assembly (top middle)
Detailed axial Fq distribution for user selected fuel assemblies (top right)
Incore power tilt (bottom left)
Measured and calculated power margins (bottom middle)

Actual control rod positions (bottom right)

Four key physics parameters are shown as time trends below the main display:
Load factor, Boron concentration, Core Fq, and Minimum DNB (from left to right)
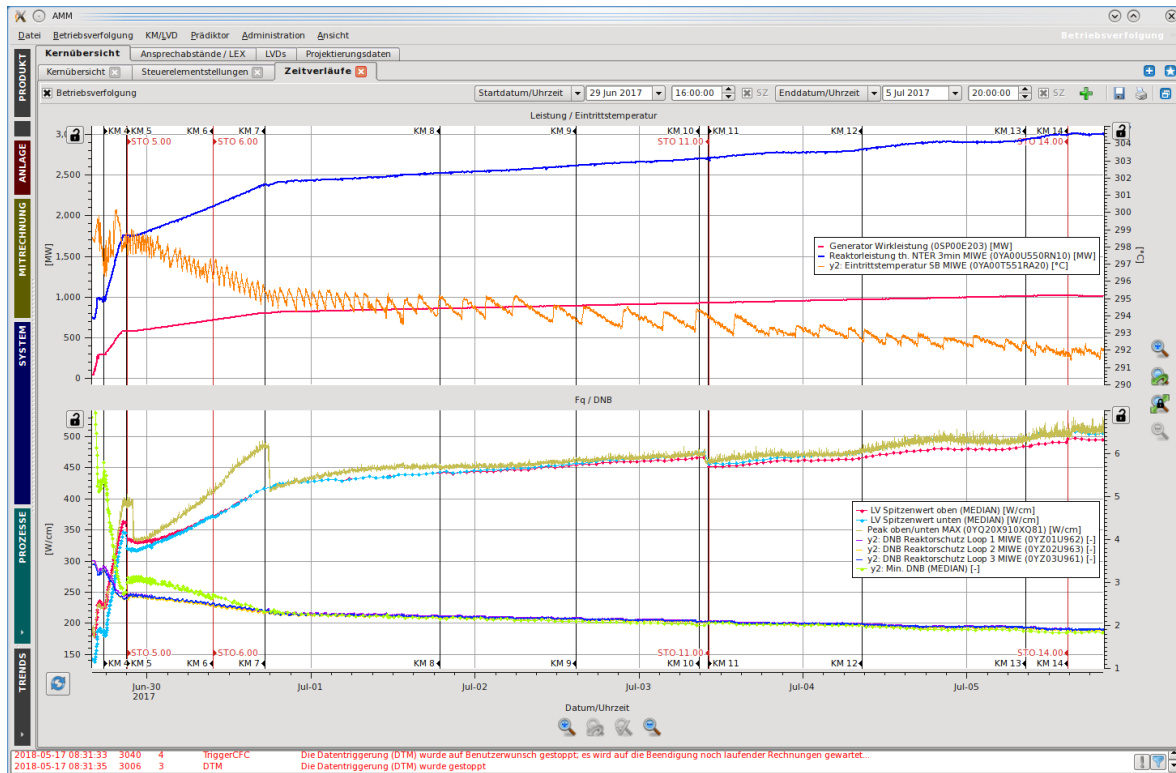

Figure 3: Time Trends

The first widget displays measured thermal and electric reactor power
together with the measured inlet temperature.
The second widget displays the calculated peak power in the upper and lower half of the
core
together with DNB limits and the calculated minimum DNB.

4.   Functions and Benefits
ARGOS offers a wide range of services to support the two primary purposes for a modern
state-of-the-art CMS:
a)   Core Follow Monitoring and Technical Specifications Surveillance and
b)   Prediction of future core states for optimized reactor core operation and operator
      assistance.

a) Core Follow Monitoring and Technical Specifications Surveillance
   Main functions in this category are:
   - Flux trace data processing from various measurement systems
   - Ex-core/in-core detector calibration
   - Automatic on-line core follow calculations with core parameter trending and
     monitoring of thermal limits compliance
   - Any calculation the core simulator is capable of, such as
        o Estimated critical conditions
        o Shutdown boron concentrations
        o Shut-down margin
        o Flux mapping for steady state conditions
        o Flux mapping based on accurate time and power dependent xenon

calculations for operational transients
                 o Reactivity monitoring
    - Configurable reporting for plant operators
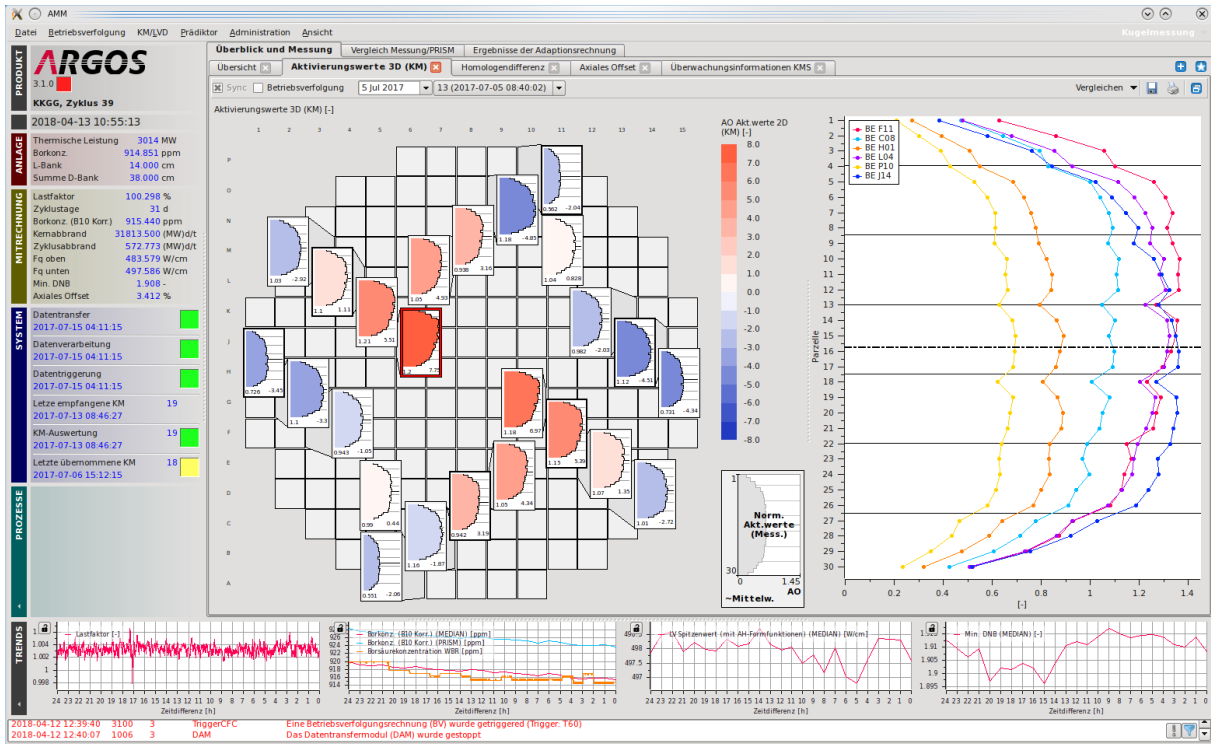   - Isotopic tracking and heavy metal mass accounting

Figure 4: Reference Measurement Evaluation

This example shows the detailed evaluation of an Aeroball Measurement.
In case of other reference measurement systems, like moveable or fixed incore detectors,
equivalent presentations will be available.

b) Prediction of future core states for optimized reactor core operation and operator
   assistance.
   A powerful prediction module has been implemented to plan future reactor manoeuvers
   both accurately and efficiently. The predictor can be launched at any time from the main
   GUI as a separate completely independent process. The prediction can be based on pure
   calculational data from the core simulator or on an adapted reactor state, e.g. through
   MEDIAN. A prediction can also be restarted from another already executed prediction.
   The input for a typical load follow manoeuver will be conveniently provided through a
   table, allowing the user to specify the envisioned power profile together with the reactivity
   control parameters of interest, like inlet temperature, boron concentration, bank positions
   etc. For each time point through the manoeuver the search parameter can be explicitly
   chosen. Once a prediction has been defined, it can be stored as a template to be
   reloaded and re-executed at any time point of the cycle. While a prediction is being
   executed the results can be monitored during run-time and the prediction can be stopped
   interactively; variation points could be interactively inserted at any time before the
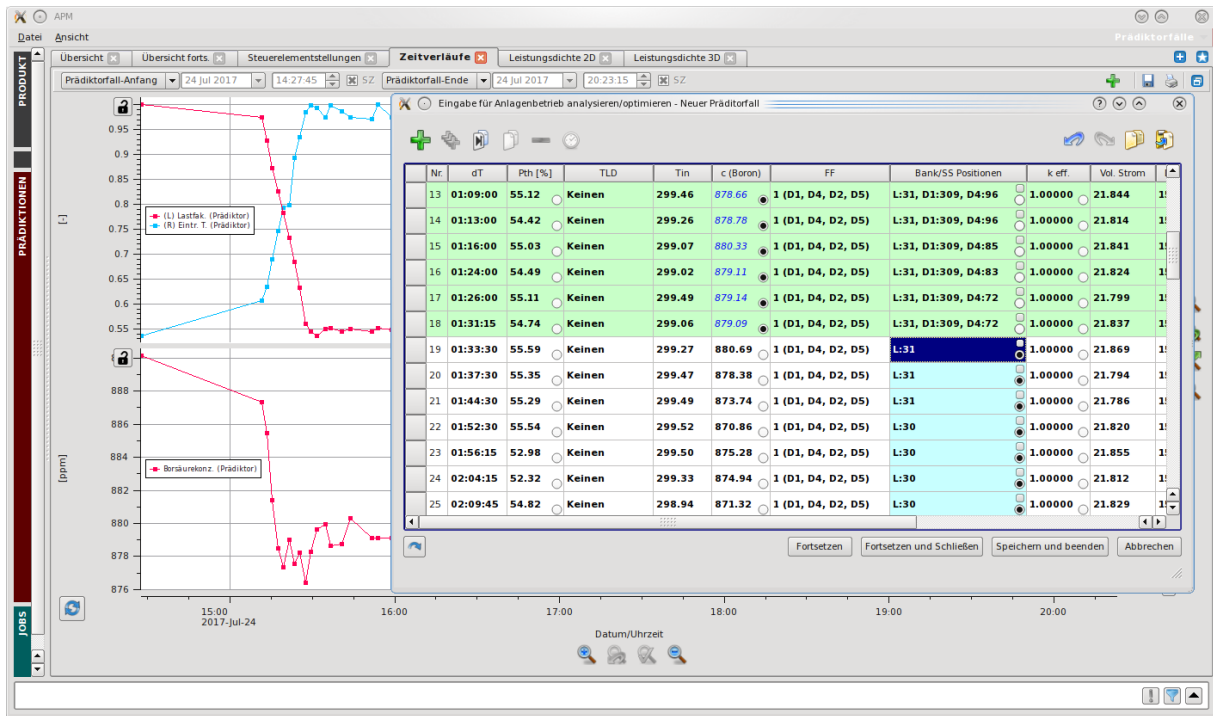   execution of the prediction would be resumed.

Figure 5: Prediction Input Preparation

Definition of envisioned load profile
together with selection of search parameter per calculation point,
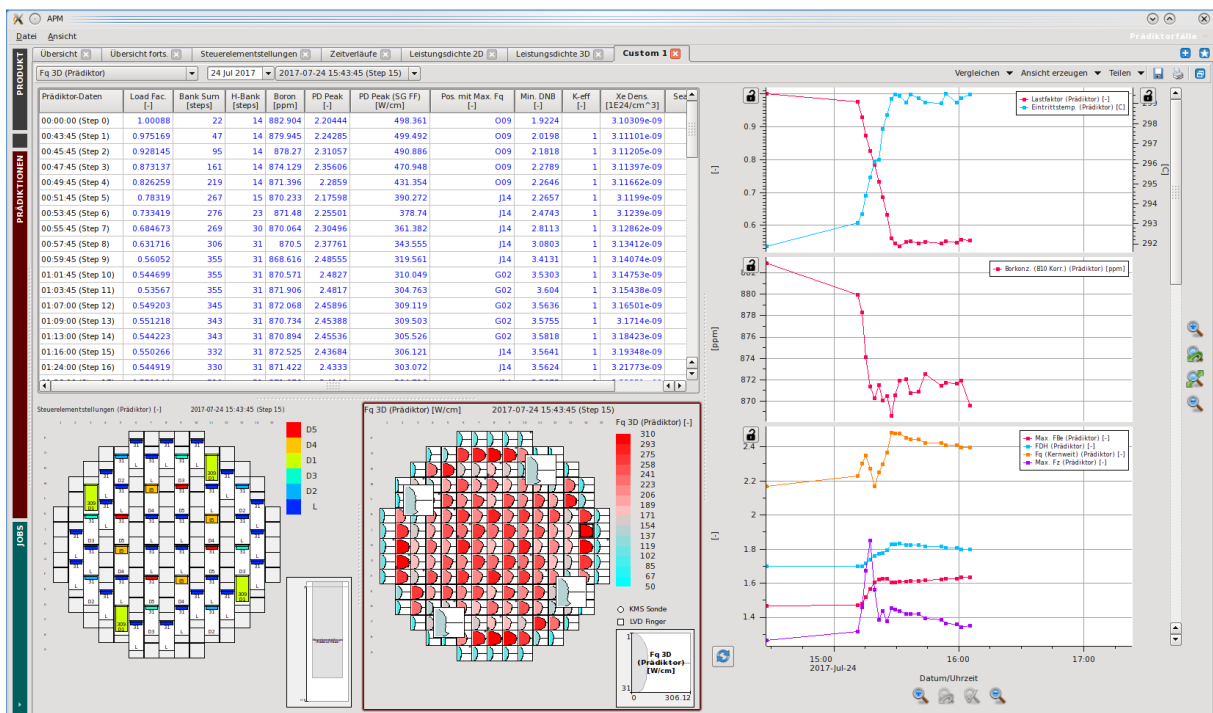for example critical boron concentration or control rod position

Figure 6: Prediction Results Presentation

Key physics parameter values in table format (top left) or
as time trend displays, e.g. load factor, boron concentration, and core Fq (right) or
as core maps, e.g. control rod positions and fuel assembly Fq distribution (bottom left)

5.   Implementation of ARGOS at Gösgen

Gösgen and Framatome share a long history of trustful commercial relationship, to which a new chapter is added by Gösgen's choice to adopt ARGOS as its new core monitoring system.

Gösgen is a SIEMENS KWU 3-loop PWR with a rated core thermal power of 3002 MW and 177 Fuel Assemblies. The core instrumentation consists of 6 fixed incore detectors and an Aeroball-Measurement-System with 24 measurement positions. Up to now, Gösgen has been using Framatome's POWERTRAX/S as core monitoring system for almost 15 years. In the course of renewing IT and software infrastructure, Gösgen decided to implement the ARGOS system as a successor of POWERTRAX/S.

The utilities choice was encouraged by offering with ARGOS the right balance of proven core monitoring technology and innovative features: ARGOS encompasses all functionalities of the preceding POWERTRAX/S system, and takes core monitoring to the next level by offering unparalleled flexibility and configurability through its modular software architecture combined with a state-of-the-art GUI and a relational database as the universal data backbone for the whole system.

Furthermore ARGOS provides the choice to be coupled to different neutronic core simulators. Therefore, choosing ARGOS allows Gösgen for keeping the presently licensed Framatome core simulator PRISM; nevertheless this choice prepares in a timely manner the implementation of Framatome's comprehensive state-of-the-art code system ARCADIA with its core simulator ARTEMIS.

Indeed, flexibility and configurability have been key to fulfil the customer's request for specific adaptations to obtain a customized ARGOS configuration for Gösgen.

The following features which are of particular importance for Gösgen have been implemented, demonstrating the adaptability of ARGOS to a specific user environment:
- Versatile and easy-to-use graphical visualization of ABM results including standardized data transfer for further engineering post-processing
- Comprehensive Technical Specifications Surveillance.
- Reanalysis of Past Operational Events, recalculation of time intervals with adjusted/corrected input data at any time during the cycle.
- Comprehensive archiving functionalities for Aeroball Measurement Evaluations and Burnup Calculations; a specific interface has been created to provide optimal embedding of the ARGOS system with Gösgen's IT infrastructure (NIS-Database coupling).
- Easy creation of ABM protocols in PDF format (and data transfer functionality for further engineering post-processing) with configurable combination of core representations and relevant data tables.
- Calibration functionality in accordance to plants guidelines and creation of standardized calibration protocols.
- In addition a specific module was provided to facilitate the transfer of settings and calibration information from ARGOS to the plants I&C.

Gösgen's approach for adopting ARGOS consists of several incremental steps while simultaneously still keeping POWERTRAX/S as leading core monitoring system. This approach allows for profound testing, minimizes technical risks and simultaneously provides operational experience and sufficient time for plant physicists to obtain the required ARGOS expertise.

A first version of ARGOS with the main core monitoring capabilities and ABM evaluation functionalities was successfully installed on site in March 2017. ARGOS runs on a virtualized server which has 4 processors, 8 GB of RAM and 300GB of hard drive space assigned. The virtualization environment is VMware ESX.

This version immediately allowed to start core follow calculations with the new system and allowed for flux map evaluations. Systematic comparison of ARGOS and POWERTRAX/S results continuously assured proper functioning of the new system. Based on this first test version formats for protocols and data formats for further post-processing have been established in close collaboration between Gösgen and Framatome.

In June 2017 an updated Version of ARGOS - integrating Gösgen's first feedback and the coupling to the NIS-Database - has been activated onsite. This version was also successfully used to test the on-site initialization mechanisms for the start-up for a new cycle.

In fall 2017 then the – operationally important – coupling to the NIS-Database was officially and successfully tested, followed up by an update of ARGOS implementing some minor corrections and further feedback. In March 2018 then the latest ARGOS version was installed. It included the Prediction module and the export functionalities for calibration factors and technical settings to the I&C System, which have already been tested successfully.

After more than one year of successful parallel run of ARGOS together with the old Core Monitoring system, ARGOS is now considered as a qualified tool to replace POWERTRAX/S as the official core monitoring system at Gösgen sometime during the upcoming operational cycle 2018/2019.

6.   Conclusion

With the successful installation of ARGOS at the Swiss nuclear power plant Gösgen, the commercial rollout of Framatome's universal CMS has begun. Temporarily, the nuclear engine of ARGOS will still be the legacy 3D core simulator PRISM, which then will be replaced by Framatome's 3D neutronics and thermal-hydraulics reference code ARTEMIS which is the flagship of Framatome's comprehensive state-of-the-art code system ARCADIA.

The successful first implementation of ARGOS at Gösgen will serve as blueprint for other Siemens KWU plants and certainly also facilitate the rollout of ARGOS for different plant types.

7.   References

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