LOAD FOLLOW SOFTWARE DEVLOPMENT FOR THE KRŠKO NPP PROCESS COMPUTER

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ABSTRACT

The LOADF program package is designed for the Process Information system of the Krško Nuclear Power Plant, with the objective to simulate by calculations in real time the operation of the reactor, in order to provide to the operators the additional information, which can not be measured directly. A three-dimensional reactor core model is selected. The power distribution is calculated by solving the diffusion equation, allowing for thermohydraulic feedback effects on the cross sections. The essential input parameter is the power level. For criticality search three options are available in order of preference: axial flux difference, control rod position or boron concentration. Prediction mode calculations can be executed with the same software on remote computers. On-line calculations on the process computer are repeated at fifteen-minute intervals. The operating experience of the software is very good so far, considering the computational efficiency, numerical stability and good agreement between the calculated and the measured parameters.

1. INTRODUCTION

Accurate information on the state of the reactor core can contribute to a safe, economic and reliable operation of a nuclear power plant. There are parameters that describe the reactor core, which are not directly measurable and available from the control instrumentation, but can help the operators to optimise the operation of the plant on economic terms. Examples of such parameters are the relative xenon concentration and its axial distribution, which are relevant for quenching xenon oscillations (when present) and for minimising the radioactive waste production due to reactivity control through changing the boron concentration in the coolant primary circuit. In addition, an accurate estimate of the xenon concentration level can improve the estimate of the shutdown margin. The Krško Nuclear Power Plant (NEK) ordered the LOADF software to provide at least the following additional information:

- Relative concentration and axial distribution of xenon and iodine.
- Reactivity hold-up by xenon.

- Shutdown margin in various modes of operation.
- Minimum boron concentrations to meet the shutdown margin requirements in various modes of operation.
- Expected critical boron concentration for a given control rod configuration at criticality after a trip.

Although there are commercial packages available, which can provide the required quantities, the specific requirement of the NEK was that the software should be incorporated into the Process Information System (PIS-NEK) on the process computer under the Afora Process Management System.

2. LOADF PACKAGE DEVELOPMENT

2.1 AVAILABLE RESOURCES

The PIS-NEK system runs on two Digital VAX-4200 machines, which by today's standards provide a relatively modest resource of computational power. The PIS-NEK database contains detailed information on many measured parameters, which describe the reactor core. The parameters are available as current values, one-minute average values, ten-minute and one-hour average values. The reliability and accuracy of the entries in the database as input to the calculations needed to be ascertained.

The standard computational tool for design calculations at the “Jožef Stefan” Institute (IJS) is the CORD-2 package[1], which is well tested for pressurised water type reactors. It is verified by design calculations of all cycles of the Krško NPP. It includes the GNOMER code[2] to calculate the whole-core power and temperature distributions, including thermohydraulic feedbacks. The general features and the ability of GNOMER to predict core behaviour during slow reactivity transients have already been discussed[3]. With only trivial modifications this code was incorporated as a computational module into the LOADF program. The input cross sections for the calculations are generated according to the standard design procedures with CORD-2. The LOADF package provides an interface between the database of the PIS-NEK system and the GNOMER module, to retrieve the required information about the core operating parameters and to enter the calculated results back into the database.

2.2 IMPLEMENTATION

Considering the modest computational power of the PIS-NEK computers, a one-dimensional model of the reactor core would seem appropriate. However, such a model would inevitably introduce approximations at various stages of the calculations, to force agreement between measurements and calculations. On the other hand it has been demonstrated by design calculations at the IJS that good results can be obtained from first principles, when a three-dimensional model is used. Furthermore, the computers of the PIS-NEK system are likely to be replaced with similar but more powerful machines. The high efficiency of the computational methods in GNOMER make the implementation of a three-dimensional model for the calculations feasible even on the existing PIS-NEK machines, therefore this model was selected for the LOADF package. The additional advantage of such an approach is the flexibility for possible future extensions, when more computational power becomes available.

Due to the computational constraints, prediction mode calculations can not be executed in parallel with normal program operation on the process computer at present. Provision is made to run the same software on remote computers. VAX/VMS or PC/DOS platforms are supported. By transferring the LOADF dump-file from PIS-NEK to the remote computer, calculations simulating various operation scenarios can be initiated with starting conditions identical to the real situation, as it appears on the PIS-NEK system.

The geometrical representation of the reactor core consists of assembly-sized nodes for a core octant in the radial direction and ten core slices in the axial direction. Real-time operation is possible without overloading the system when the calculations are repeated at fifteen-minute intervals. This is adequate to follow any xenon transients with sufficient accuracy.

Criticality search options on the buckling, boron concentration, control rod position and axial flux difference (i.e. the relative difference in the power between the top and the bottom half of the core) are available. The power level and at least one additional parameter must be fixed. These are set equal to the measured values, while the dependent parameters provide an indication of the overall performance of the calculated results. The choice of the fixed parameter is determined automatically and depends on the power level, the validity of the measured data and sometimes on the actual value of the measured parameters.

The main calculated parameters are the axial power distribution and the relative concentrations and axial distributions of xenon and iodine, corresponding to core conditions, which match as closely as possible the measured values, retrieved from the PIS-NEK database. All other quantities can be derived from them and entered into the PIS-NEK database to be available to the operators, if necessary.

2.3 OPERATING EXPERIENCE

The LOADF program is operational for testing since January 1997. Due to the exceptionally good operation record of the power plant in the 1997/98 cycle there were relatively few transients that would severely test the performance of the program. The transients included power reduction to 70% during turbine valve tests, inlet temperature variation during the moderator temperature coefficient measurement and reactor coastdown at the end of cycle. In the 1998/99 cycle the data from the startup after refuelling and from a plant trip were analysed. A few minor modifications to the calculation flow logic were made, mainly connected with improvements to the logic in establishing the correct control rod position. Also, changes to some other applications were made that enter the average axial flux difference value into the database.

The algorithms of the program turned out to be very efficient and stable. No numerical instabilities were encountered, in spite of the several layers of nested iterations, which are necessary in the calculations.

To illustrate the performance of LOADF the results from the planned Y2K transient are presented. At 16:00 hours the power was gradually reduced to reach 50% at 21:00 hours. At 8:00 on the next day the power was gradually raised to reach 80% at 12:00. Finally, at 6:40 on the following day the power was increased again to reach full power at 9:00 on the same day.

The variation of power with time is shown in Figure 1. It is an input parameter to LOADF. The differences between the measured and the actually used values in LOADF are only due to the numerical roundoff error.

In Figure 2 the measured and the calculated axial flux difference are shown. Except for a rather narrow time interval with deeply inserted control rods, the axial offset was an input parameter. The differences between the measured and the actually used values in LOADF are again only due to the numerical roundoff error.

In Figure 3 the measured and the calculated control rod position are shown. Zero-steps is the fully inserted and 225 steps is the fully withdrawn position. Except when control rods are inserted deeper than 150 steps, the control rod position is a calculated quantity, determined by the required position to match the axial offset. Very good agreement between measurements and calculations is observed, except near the fully withdrawn position. In this range the differential control rod worth is very small so from a practical point of view the discrepancy is unimportant.

In Figure 4 the measured and the calculated boron concentrations are displayed. Two observations can be made:

- The measured values are obtained from chemical analysis. They are updated only periodically, therefore the trace of the measured values is discontinuous. As such it is not useful as input for any practical calculations.
- There is a systematic difference between the measured and the calculated values of about 30 *ppm*. Normally, an adjustment of the buckling for criticality is made to eliminate the discrepancy. For testing purposes deliberately no adjustments were made.

CONCLUSIONS

The numerical algorithms of LOADF proved efficient and stable. The analysis of the transients with LOADF shows that the program is very flexible and capable of reproducing the operational parameters with very good accuracy. It provides a useful analytical tool for reactor operation.

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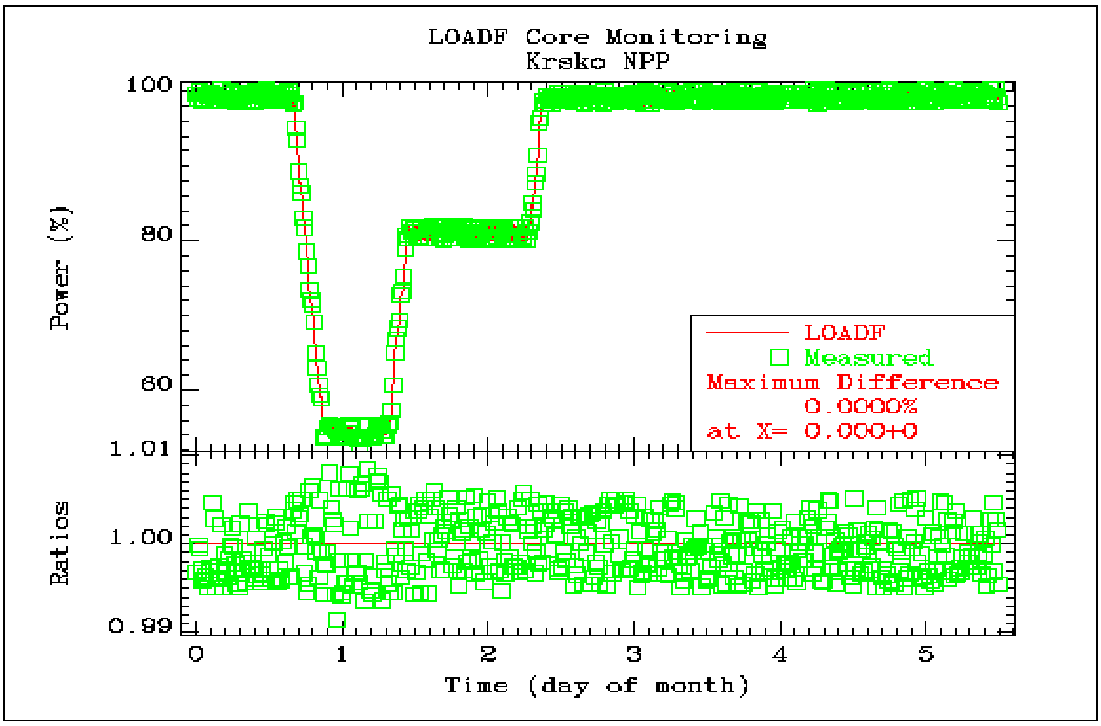

Figure 1.: Power distribution - measured and used in LOADF.

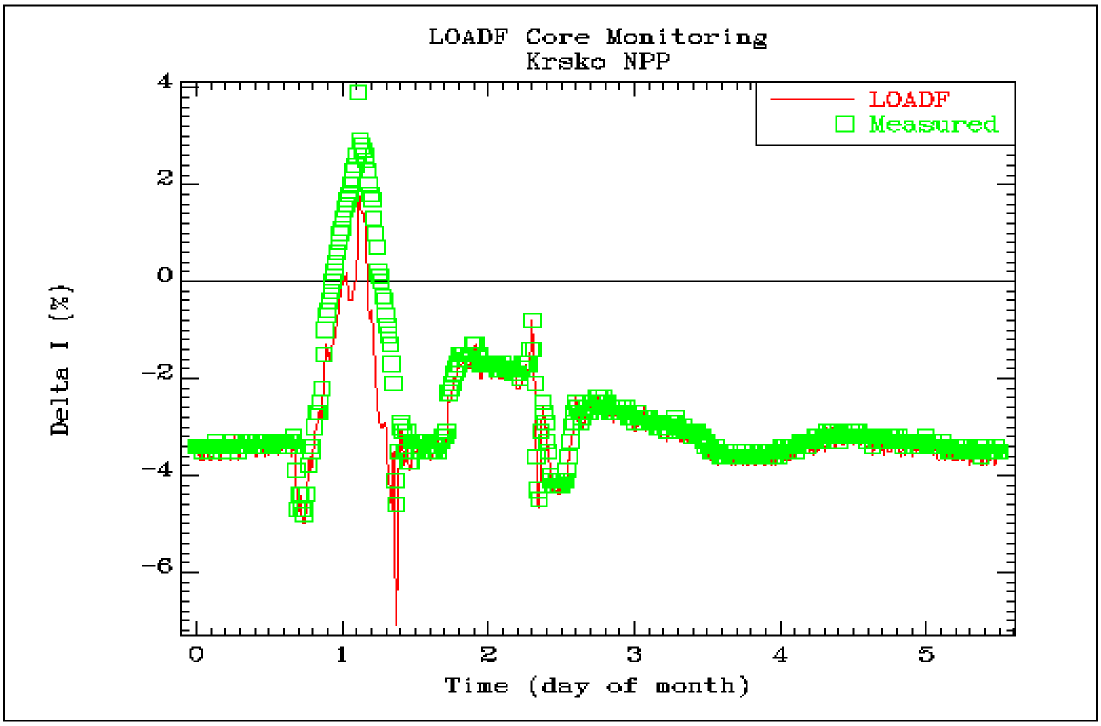

Figure 2.: Comparison of the measured and the calculated axial flux difference. This is an input quantity except in Day-1 with deeply inserted control rods (see Figure 3).

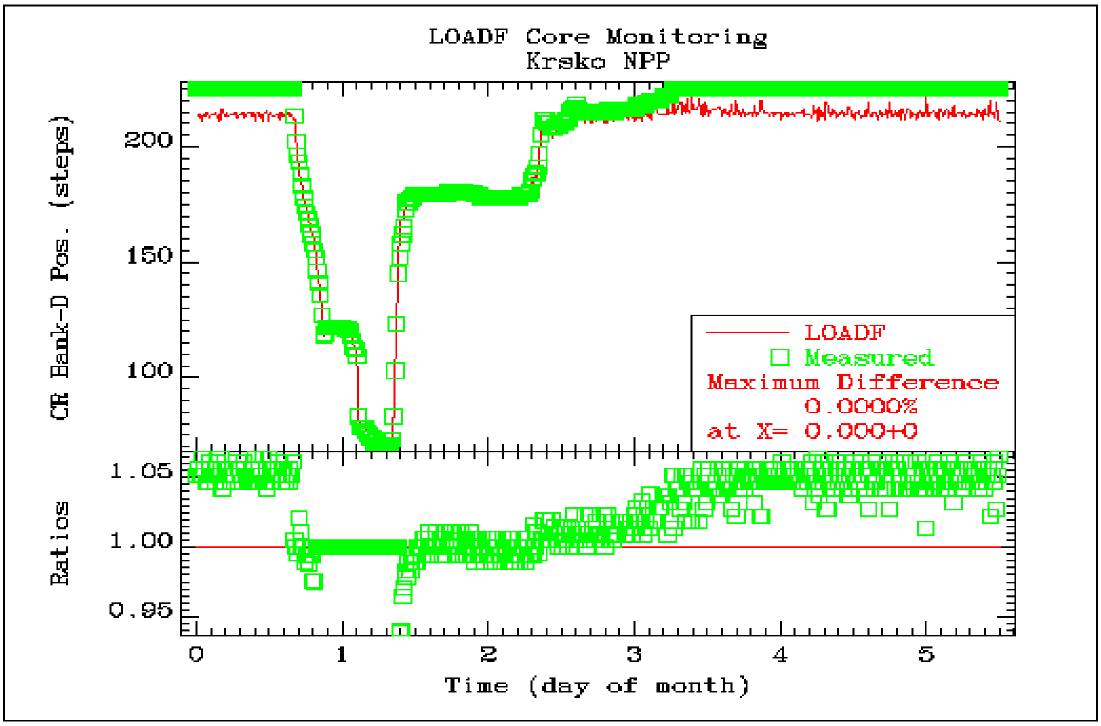

Figure 3.: Comparison of the measured and the calculated control rod position. . This is a calculated quantity except in Day-1 with control rods inserted deeper than 150 steps.

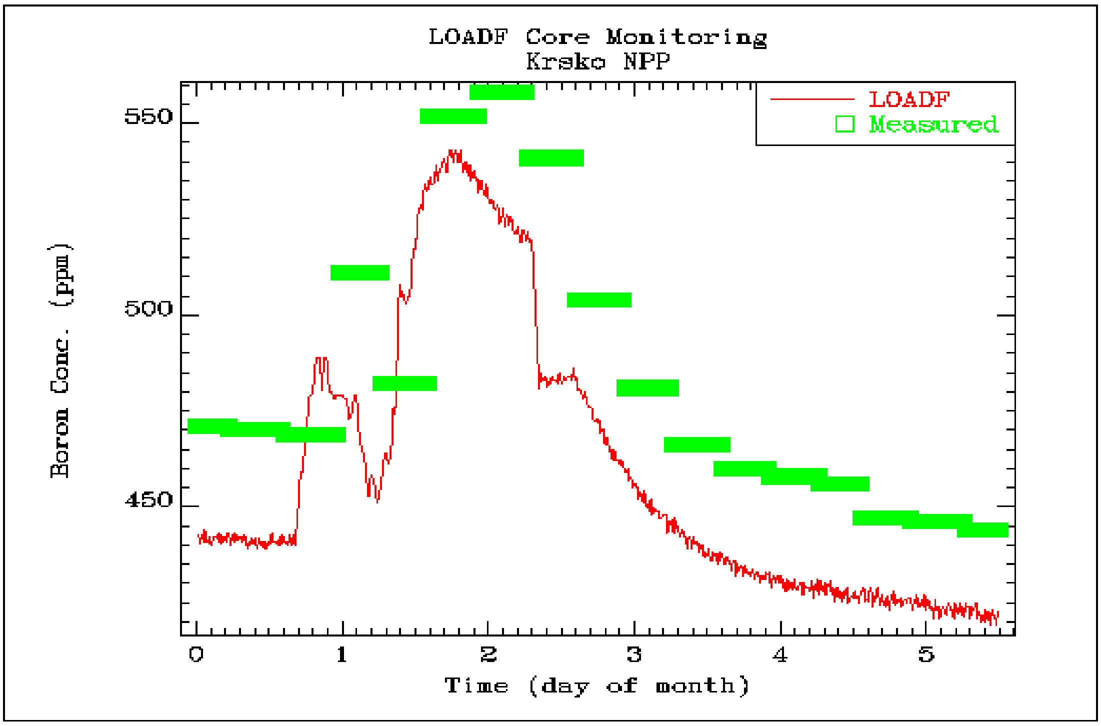

Figure 4.: Comparison of the measured and the calculated boron concentration. The measured values correspond to the results of chemical analysis and are updated only periodically.