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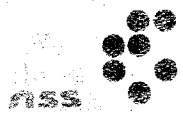

Recent Improvements to the GNOMER Code for Reactor Calculations

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ABSTRACT: The GNOMER was used for many years within the CORD-2 package for design calculations of Pressurised Water Reactors. Recently, many enhancements to the code were made which increase the accuracy of the results with thermohydraulic feedbacks, allow burnup gradients across fuel assemblies, pin power reconstruction and Xenon transients. The improvements were tested against real operation data of the Krško Nuclear Power Plant. A few examples are presented.

1. Introduction

The GNOMER code /1/ is one of the two main reactor physics codes for design calculations of PWR-type reactors with the CORD-2 package /2/, which includes WIMSD-5A /3/ for lattice transport calculations, while GNOMER is used for homogenisation of fuel assembly cross sections, as well as for the whole core multiplication factor and power distribution calculations. It contains a thermal hydraulics module so that temperature and moderator density distributions can also be calculated.

The GNOMER code was developed at the Institute "Jožef Stefan" (IJS) and is distributed by the NEA-Data Bank in Paris under the label IAEA1271.03 and also by RSICC at Oak Ridge under the label CCC-625/GNOMER. Validation of the neutron diffusion module with respect to accuracy and computational efficiency is evident from the test cases, supplied with the code. The test cases include many of the internationally defined benchmarks /4/, accumulated over the years for code validation purposes.

The main algorithm for solving the neutron diffusion equation is based on the Green's function nodal method /6/, which proved to be robust with respect to numerical stability, accurate and highly efficient. The thermal hydraulics module is relatively simple, based on the assumption of an average channel within a fuel assembly, allowing for a certain degree of coolant mixing between fuel assemblies. Effective fuel temperature is defined through an empirical correlation between the power and the surrounding coolant properties.

The source code on which the current set of updates is made was frozen in 1995. Code maintenance is done strictly by Update commands and the UPD code /5/, which is an emulator of the CDC Update system. Code maintenance through Update commands allows to keep a concise, clear and exact record of all changes in the source code, which is important for Quality Assurance (QA) purposes. The updates are available over the Internet at "http://www2.ijs.si/~trkov/" and include the following:

- Fine mesh flux and power distribution reconstruction so that fuel pin power and peaking factors can be calculated.
- Linearly varying cross sections across otherwise homogeneous nodes can be defined. This is adequate for treating effects such as burnup gradients across fuel assemblies.
- Improved cross section adjustment methods to account for thermohydraulic feedbacks.
- New criticality search options are available. Apart from the critical buckling, albedo and Boron concentration, the criticality search was extended to the search for a critical control rod position.
- Axial power offset can be defined from input. Control rod position search is performed to match the requested axial offset at critical Boron concentration.
- A new module is added to calculate the relative Xenon and Iodine concentration variation with time, so that Xenon transients can be modelled in full three-dimensional geometry.

In addition, several minor improvements and new options were added to edit and format the output parameters.

The new features are described in internal notes, before complete new documentation for the code is released. However, the user instructions are included as comments in the Fortran source and are maintained in parallel with any upgrades of the code, so they are always up to date.

Improvements in the reactivity coefficient method for fine tuning of the cross sections to account for thermohydraulic feedbacks is presented separately /7/. In the present paper a few examples are shown to demonstrate the use of the new calculational features for design calculations and transient analysis of the Krško NPP.

2. Fine mesh flux and power reconstruction

Generally, nodal methods calculate the average power and neutron flux over relatively large homogenised nodes, for which average cross sections are required. A special feature, which is available through GNOMER in CORD-2 is the ability to account for pin-by-pin burnup. In principle, every pin in an assembly has a different burnup. This would require a large number of cell calculations with the lattice code. GNOMER allows that only cross sections at the assembly average burnup, the minimum and the maximum burnup are specified. Giving the relative burnup of different pins, the cross sections corresponding to different pin burnups are obtained by interpolation. In an assembly, more than one type of cell can be burnup dependent.

With the pin burnups being accounted for, GNOMER can also homogenise cross sections to produce node average cross sections with P1 components. In this way, burnup gradients can be treated at least approximately in the whole core calculation while retaining the advantage of the "one node per assembly" coarse spatial discretization. Further accuracy is gained by the explicit treatment of the radial leakage in the fuel assembly calculation and by the EDH method /8/ for homogenising the cross sections, which guarantees the conservation of the partial currents on the node boundary at least on average.

To reconstruct the fine mesh (pin-by-pin) power distribution within the large, homogenised nodes, the heterogeneous solution is obtained as a superposition of the homogenised solution and the heterogeneous form factors, which are a by-product when homogenising the cross sections. The homogenised solution is reconstructed from the results of the nodal calculation by employing the principle of the flux and current continuity and a polynomial approximation for the intra-node neutron

flux distribution /9/. Although many authors argue, that polynomial approximation is inadequate, the use of polynomial coefficients which are obtained directly from the nodal solution provide additional accuracy, so that pin-wise power can be reconstructed accurately to within a few percent.. An example of the pin power distribution in the Krško NPP core at Hot-Full-Power conditions at the beginning of is shown in Figure 1.

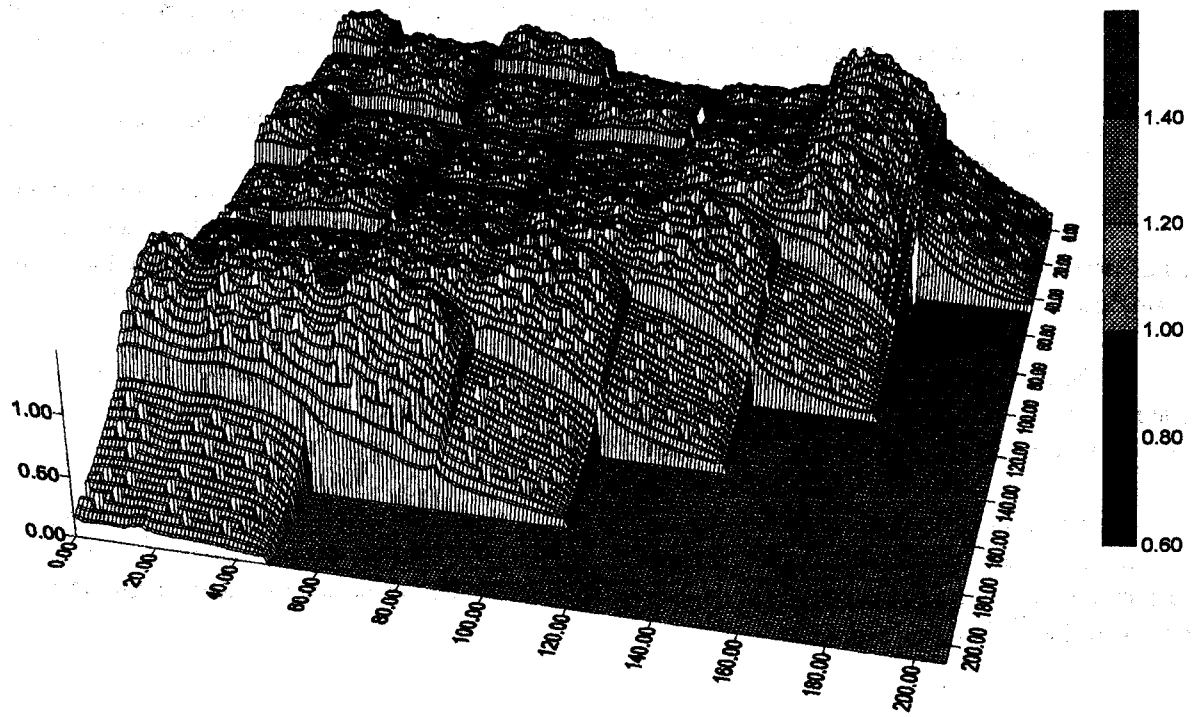

Figure 1. Pin power distribution in the Krško NPP core at BOC, HFP conditions.

3. Xenon transient analysis

Xenon is an important fission product which seriously affects many operating aspects of a power reactor. For this reason it is important to have a tool for analysing the build-up and decay of Xenon and its precursor Iodine as a function of time and position within the core.

A set of equations was derived which gives the time-evolution of the Xenon and Iodine concentration at a certain time dependent power level, relative to the equilibrium concentration at the average nominal power. Knowing the Xenon reactivity worth, fine tuning of the cross sections can be done to account for the presence of Xenon.

The Xenon module was checked to reproduce correctly the asymptotic behaviour. Its capability to model the transients was checked by simulating a real situation in which a scram occurred and the reactor was taken back to power after a few hours. In the calculations the control rods were positioned such that the axial offset matched the measured one. The Boron concentration was adjusted for criticality. The calculated and measured relative power level, Boron concentration and control rod position are shown in Figure 2. On the abscissa the time after the scram (hours) is shown. For the simulation, the operation parameters were available only as one-hour-average values, so exact simulation of the transient was not possible. Considering the uncertainties in the measured values we believe the agreement between the measurements and calculations is excellent.

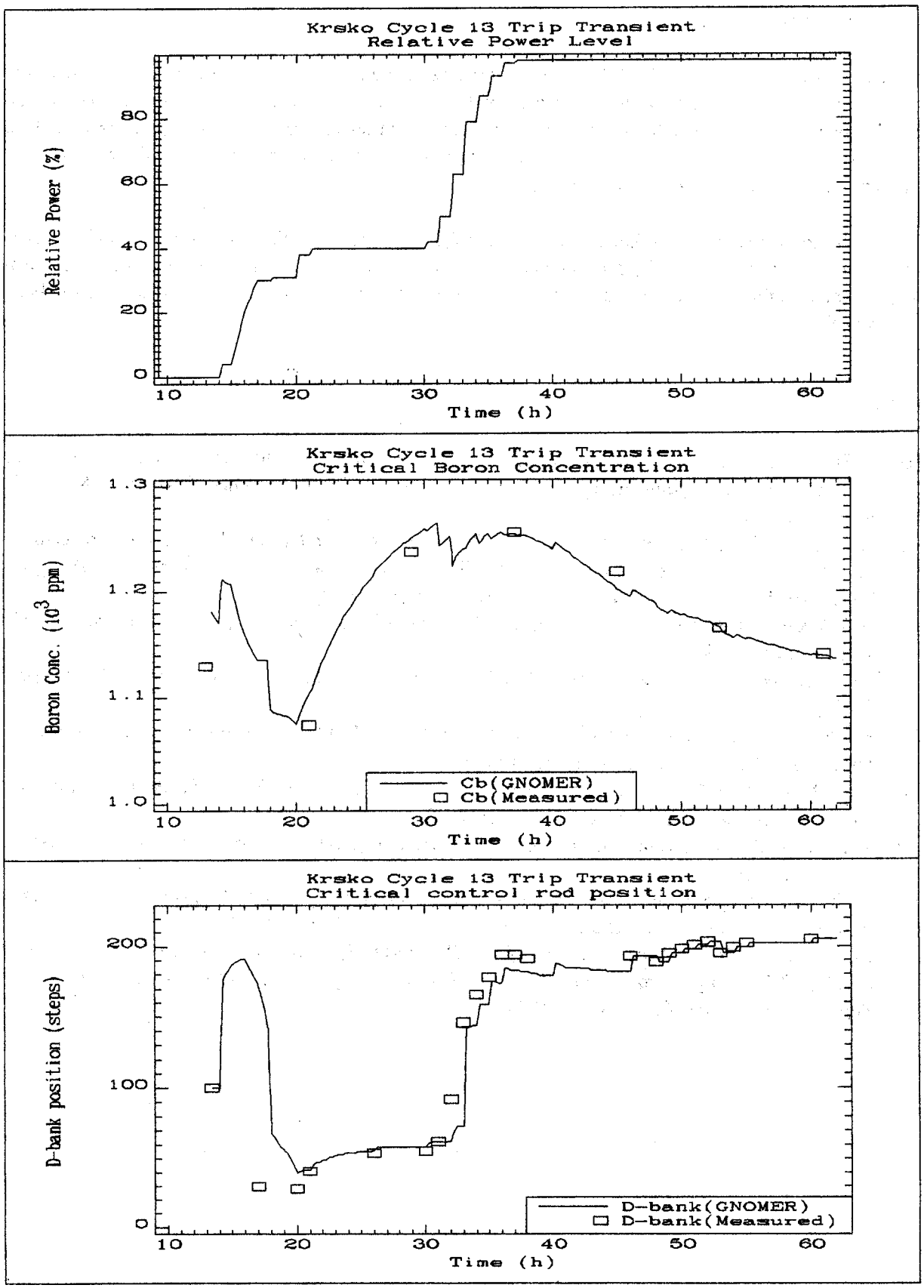

Figure 2 : Comparison between the calculated and measured core operation parameters.

4. Conclusions

Recent improvements in the GNOMER code extend its capabilities to satisfy all the requirements with regard to the options that were envisaged within the CORD-2 package. In this respect, code development work is complete and shortly, new documentation for the code will be released. Future work will be focused on improving further the computational efficiency and on more refined input error trapping, to make the code even more user friendly.

In combination with other modules of the CORD-2 package the accuracy of the GNOMER results is sufficient for the design calculations of pressurised water type reactors. This has been demonstrated in the case of the Krško nuclear power plant, for which fourteen reload cores have been analysed already.

References

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