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RMR: A New Portable Reactivity Measuring System Installed at NPP Paks

Tamás Czibók, Csaba Horváth, Péter Bara, Zoltán Dezső, József Láz, János Végh
KFKI Atomic Energy Research Institute
H-1525 Budapest 114, P. O. Box 49, Hungary
czibok@sunserv.kfki.hu, hcs@sunserv.kfki.hu, pbara@sunserv.kfki.hu,
dezso@sunserv.kfki.hu, laz@sunserv.kfki.hu, vej@sunserv.kfki.hu

István Pós
Paks Nuclear Power Plant Ltd.
H-7031 Paks, P.O.Box 71, Hungary
pos@npp.hu

ABSTRACT

The Hungarian Paks NPP is conducting a two year project for upgrading the reactivity measuring system applied during reactor startup experiments. The NPP has decided to replace almost all components of the previous system, only ionisation chambers remain unaltered. Devices for measuring neutron flux by means of ionisation chambers, for data acquisition and for measurement evaluation were completely renewed: new hardware-software components were introduced. Autonomous, high-precision current measuring systems (picoampere meters) are applied at each reactor unit, the converted picoampere signals are handled by a portable processing unit. The portable unit – based on a notebook PC – handles measured signals by using a high-precision A/D converter card, the scan time is 0.10 sec. In addition to handling three ionisation chamber signals the portable unit collects control rod position measurements through a serial line. The portable unit is able to receive additional measured data (e.g. core inlet temperature and boron concentration) from the process computer via local area network. Archiving of all measured and calculated data is performed in a redundant manner: data are stored locally and in the process computer, as well.

The new system applies an accurate on-line reactivity calculation algorithm based on the point-kinetic model with 6 delayed neutron groups. Input data (effective delayed neutron fraction and other delayed neutron parameters) to the on-line calculation are taken from the off-line core design calculation. Detailed evaluation and analysis of startup measurements can be performed also on the portable unit.

The user interface of the system is tailored to support various startup measurement tasks effectively: measured and calculated data are displayed on trends and on dedicated pictures. A user-friendly trending and listing graphic tool facilitates visualisation of archived data.

The paper describes the architecture, data acquisition modules, algorithms and man-machine interface of the RMR. System functions and results are illustrated with measured data recorded during the last startup of Unit 3. In 2002 the first version of RMR was installed and tested at Unit 3, in 2003 the final version was installed at all Paks NPP units.

Keywords: reactivity measuring system, reactor startup measurements

1 INTRODUCTION

1.1 Motivation

The old measuring system – called RPM, Reactivity Parameter Monitoring system – was constructed by using the technology available in the mid eighties. Until recently it worked satisfactorily, but maintenance problems started to emerge and the replacement of its components was almost impossible. In addition, the installation of the system prior to the reactor startup was a quite complicated task, a dedicated expert was needed for handling the RPM system. Replacement of the original nuclear instrumentation was also needed, because it had quite a few maintenance and reliability problems. In 2002 the Paks NPP made a decision to replace the old system with a modern, portable system called RMR (abbreviation of "Reactivity Monitoring System" in Hungarian).

The new system has significantly higher measurement and evaluation accuracy: the technology of RMR allows more precise measurement and it uses a more precise on-line reactivity calculation algorithm. The plant staff needed a more comfortable user interface, therefore one of the main tasks of the project was to develop a user-friendly man-machine interface. The design of the MMI was carried out in a close co-operation with the future users of the system. Another important task was to connect the new system to the computer network of the plant, in order to make bidirectional data transfer possible. The new system is connected to the process computer: it receives some important process data and it sends all measured and calculated RMR signals to the process computer for archiving. Establishment of a direct connection to the fine (i.e. accurate) control rod position measuring equipment was also required, to make the off-line evaluation of reactivity measurements more accurate.

1.2 Project milestones

The reconstruction project is carried out in a rather short time interval to ensure that by the end of 2003 all Paks units will have the new system operating. KFKI AEKI was selected as main contractor, its main responsibility was project management, software development, system integration and V&V testing. The new nuclear instrumentation was designed and manufactured by KFKI Regtron Ltd., while EuroCom Ltd. developed some communication software modules. Experts from the Paks NPP participated in the specification, data delivery and testing activities. The System Design Document was approved in August 2002, the first – pilot – installation of the system took place at Unit 3. in September 2003. The final version was installed and commissioned at Unit 3. in January 2003, then the remaining three units followed. As a result of the RMR project, the four Paks units now have uniform startup reactivity measuring systems.

2 SYSTEM ARCHITECTURE AND MAIN FUNCTIONS

The scheme of the RMR system architecture is shown on Figure 1. Some components of RMR are located in the primary circuit, the rest is installed in the unit control room.

The system processes signals originating from 3 intermediate range ionisation chambers measuring the neutron flux during the startup measurements. Ionisation chamber signals are processed by 3 autonomous picoampere meters (type RNL-03.02) transmitting data to the interface unit of the measuring computer via a common communication module (type NFL-03.02) as analogue current signals. Signals are transformed to voltage signals in the interface unit. The neutron flux signals are measured by a portable (notebook) computer called RMRPC. The RMRPC collects other process data, too. Signals corresponding to fine control rod positions are transferred via a serial connection. Other data like moderator temperature, boron concentration and reactor power come from the process computer through the network.

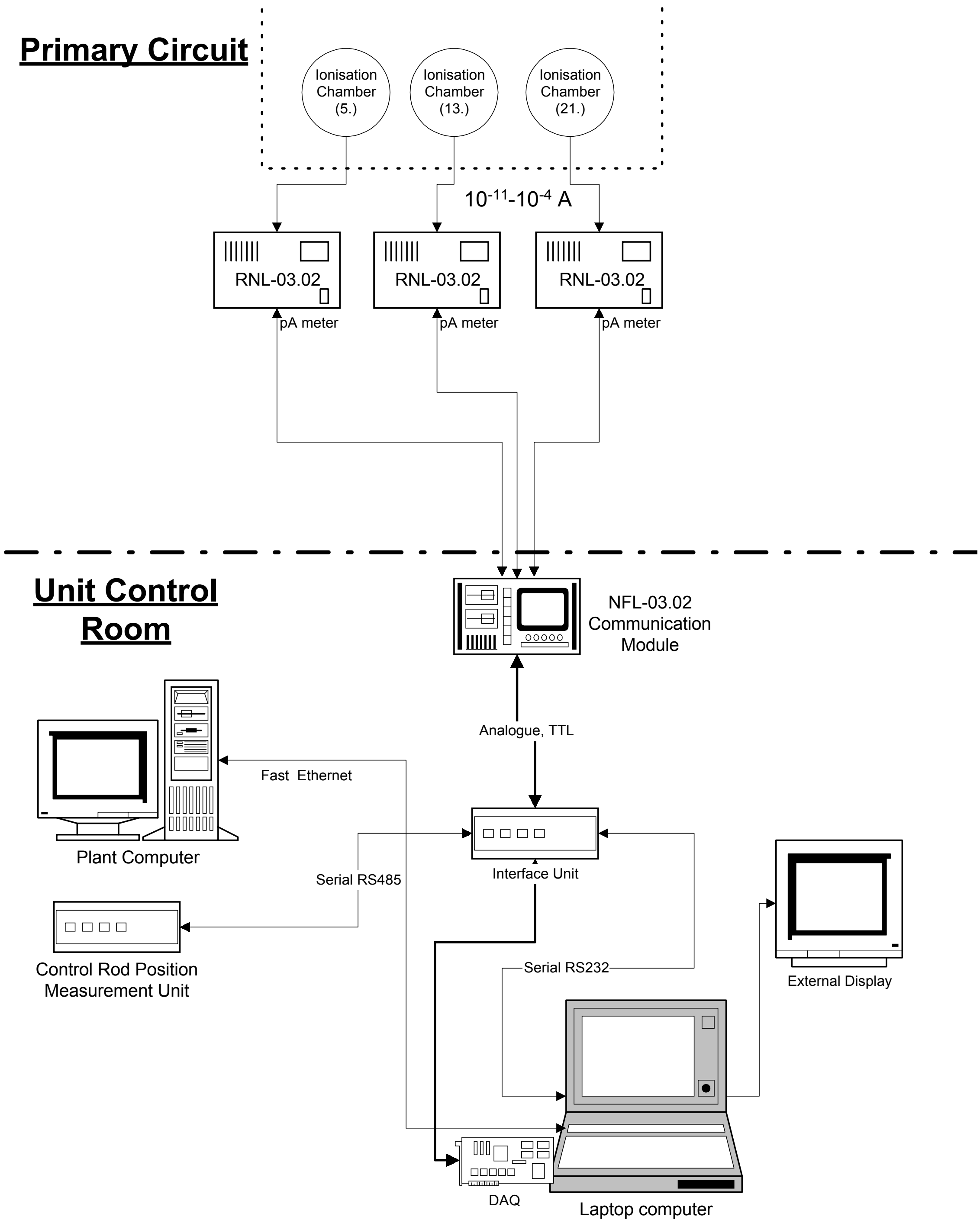

Figure 1: Logical scheme of the RMR system architecture

The central unit of the RMR is RMRPC: it collects data and measures neutron signals, calculates reactivity and other parameters, stores data on disk and transmits data to the plant computer. It also provides the man-machine interface for measurement control and display. The components of the RMR can be divided into two sets, a mobile (portable) set and a permanently installed set at each unit. RMRPC with its accessories forms the mobile set. It is used at each unit and it is connected to the cabling during the startup measurements only. Permanently installed sets are identical at all four units.

2.1 Ionisation Chambers and Picoampere meters

The RMR uses ionisation chambers of the type originally installed for measuring the so called intermediate neuton flux range. The neutron detectors are of standard KNK-4 type ionisation chambers (^{3}He + ^{4}He filled, BDPNZ-16 type mounting and γ-compensation). The chambers are placed at the ex-core positions of No. 5, No. 13 and No. 21 (these positions are 120° symmetrical).

Signals of the ionisation chambers are processed by RNL-02.03 autonomous picoampere meters. The pA meters work in ranges from 10^{-11}A to 10^{-3}A, their accuracy is ± 0.2% above 10^{-8}A. A picoampere meter converts its input signal to two analogue current signals. One signal carries the measurement range information (in a coded form) and the other carries the volume information within the actual range. The latter signal can be produced with or without digital filtering. There is a built-in 500 nA test signal generator in each picoampere meter unit. A pA meter is able to receive the following three digital control signals: (1) set direct/digitally filtered mode, (2) set autorange/inhibited mode and (3) turn-off/turn-on of the built-in 500 nA test generator.

The NFL-03.02 communication module regenerates the control signals coming from the RMRPC computer and it can also generate control signals for picoampere meters. The analogue signals pass unchanged through the communication module, but by means of serially connected resistors and with isolated coupling the chamber currents can be measured and displayed by the communication module.

2.2 RMRPC: components and functions

The RMRPC is a notebook computer of type Compaq EVO N600c (1.2 GHz Pentium III processor, 256 MB RAM, 30 GB hard disk, 15” TFT monitor). The operating system is Windows-NT 4.0, the 100 Mbps network communication is based on the TCP/IP protocol. The PC provides an external display connector to couple the screen of the reactor operator (this connection is used when reaching criticality). Application software was developed by using Borland C++ Builder 5.0 and Microsoft Visual C++ V6.0. Main functions of the software system running in the RMRPC are as follows:

- handling the data acquisition card,
- communication with the fine control rod position meter,
- communication with the process computer (bidirectional),
- synchronisation of the RMRPC to the central clock of the plant,
- local storage of all measured and calculated signals,
- detailed off-line evaluation of measurements (calculation of rod worths, etc.),
- displaying task-oriented pictures and ensuring a convenient man-machine interface.

The same software runs for all units, only databases are different. The local data storage is backed-up by the process computer: all measured and calculated signals are sent to the process computer where they are stored in the standard (SQL compatible) plant archive, as well. This function allows data analysis also on the graphic terminals connected to the process computer via the high-speed plant network.

2.3 Data Acquisition

Ionisation chamber signals are measured by a standard PCMCIA data acquisition card placed in the RMRPC. The high-precision, type II DAQCard-AI-16XE-50 card is made by National Instruments. Theoretically the sampling rate is 10 samples/sec/channel, but actually the card works with a 100-fold over-sampling rate, which makes an additional digital filtering possible. The card samples the three flux signals and the three measurement range signals, a 16 bit A/D conversion is used on each channel. Digital output channels of the card are used to send digital control signals to the picoampere meters through the NFL-03.02 module. One of the most important new data acquisition functions is the automatic handling of measurement range changes (the lack of this functionality caused a lot of problems in the old system). The "smooth" software range change is ensured by the following mechanism (see [1]).

The basic, 100 ms measurement cycle time is further divided into 1 ms intervals by an over-sampling process. This over-sampling ensures two main benefits: it makes a digital filtering possible (i.e. for noise reduction), and it reduces the length of the "lost" time interval corresponding to measurement range changes. During that very short time interval when the range is being changed it may happen that the measured current value and the analogue range-code are both invalid. The validity of these values is checked continuously by the software and they can be duly excluded from subsequent data processing if they are invalid. It has to be mentioned that after range changes the current value is not valid for a certain period. In a favourable case the total lost period is less then 100 ms, thus there will be no data loss in the series of the 100 ms data. Obviously one point will have a larger error, because it is calculated as an average from less than 100 primary (1 ms) data points.

37 control rod positions are received from an Advantech industrial PC through the standard RS-232 serial port, the communication protocol is Modbus-plus. Signal levels are converted by an RS-485/RS-232 converter in the signal interface unit. The interface unit also contains current-to-voltage analogue signal converter and DC/DC converter electronics. The RMRPC is the master unit in the protocol, it requests rod positions in groups: if all six groups are read in then the total scan time for the 37 rods is 0.60 sec. If only one group is read in then the cycle time is 0.10 sec (this mode is used during the so called rod-drop measurements, when the position of the selected rod changes quite rapidly).

The RMRPC collects additional measured signals from the process computer, as well. These signals are communicated through the 100 Mbps (Fast Ethernet) plant network using 1 sec cycle time. These signals are as follows: core inlet temperature (and its rate-of-change), primary circuit boron concentration, reactor power (as calculated by the reactor protection system). It has to be mentioned, that the RMRPC is able to receive any selected signal from the process computer, only simple software configuration modifications are required.

The software assigns time stamps to all collected signals: the time stamps are according to the central (master) clock of the plant.

2.4 On-line reactivity calculation

One of the most important functions of the RMR is the on-line calculation of reactivity. In the reactivity calculation model the inverse kinetic equation with 6 delayed neutron groups is applied (see [2]), delayed neutron constants (e.g. β_{eff}, Λ) are taken from the input file used in the off-line reactivity calculations. The algorithm of the on-line model is exactly the same as the one applied in the off-line method. The reactivity is calculated for each channel, then the three values are averaged. The software determines the reactivity drift ($d\rho/dt$), as well, it is mainly used when approaching criticality.

3 MAN-MACHINE INTERFACE

The user interface was designed to provide an efficient support during various startup measurements. Screen formats and pictures are organized according to the different startup measurement types. Screen items (e.g. pictures, trends, labels, etc.) are configurable, it makes introduction of new display formats straightforward and easy. Figure 2 illustrates the outlay of the RMR measurement support pictures.

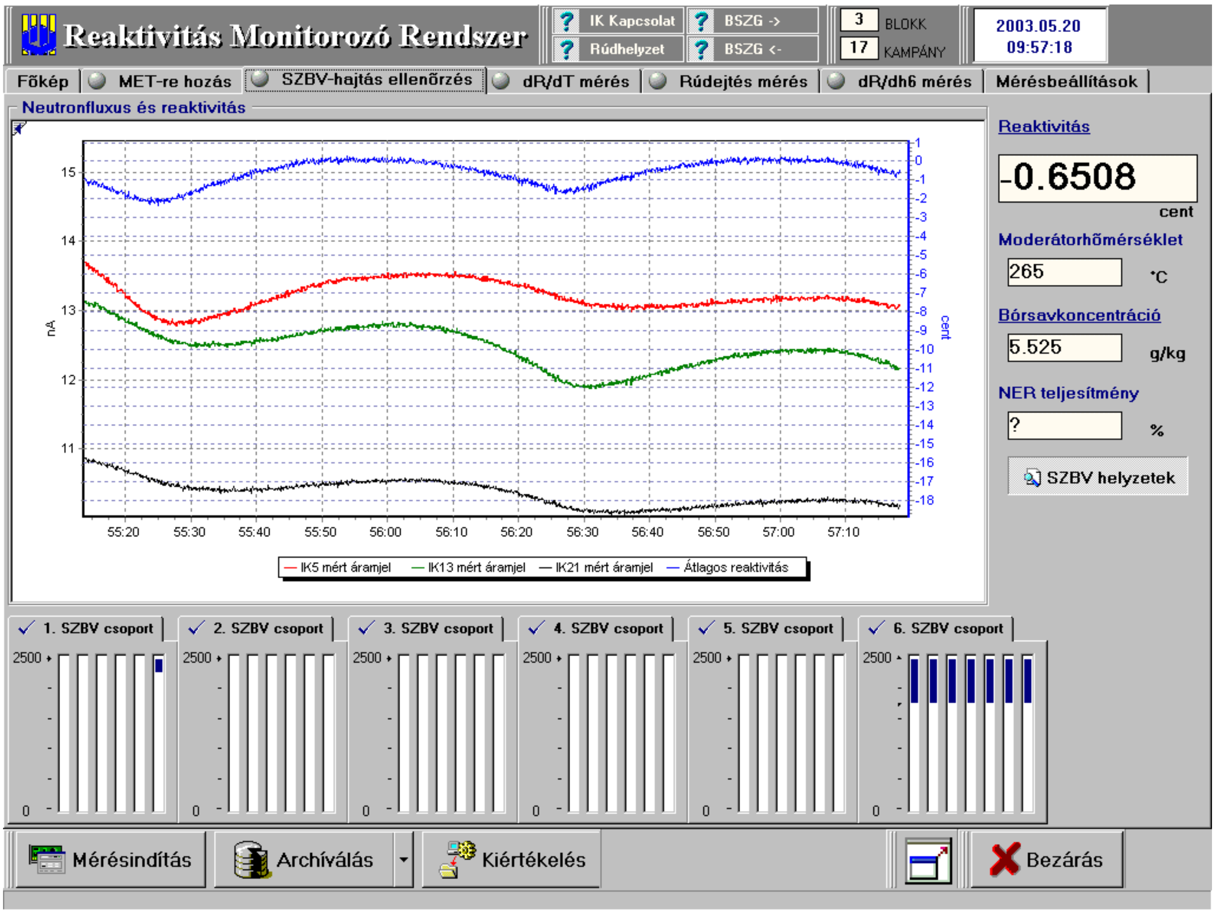

Figure 2**:** Picture for the control rod drive check measurement

The *Header* part displays symbols showing states of the data acquisition module and the communication links and also displays the switch buttons and indicator lights for the measurement pictures. The *Main picture (Főkép)* gives an overview of all measured signals, while *Measurement settings (Mérésbeállítások)* picture can be used to control picoampere meter functions. The startup measurement support picture titles and their functions are as follows:

- MET: reaching criticality (minimum controllable power)
- SZBV: checking control rod drives
- dR/dT: temperature coefficient (dρ/dT) measurement
- Rod drop: control rod drop measurement
- dR/dh6: control rod effectivity (dρ/dh6) measurement (h6: position of control rod group No. 6 which is used for reactor power regulation.)

Off-line visualisation and listing of archive data is supported by a flexible graphical tool: groups of selected signals can be listed in selected time intervals and parameter curves can be easily plotted on the screen in the form of trends. Figure 3. shows an example for this display format.

The RMR archive management system is even able to "replay" the startup experiments: in this case measured data are taken from the local archive and loaded into the RMR database cyclically. As a result measured and calculated data are displayed on the screen as they were measured on-line and the user can analyse important events in detail, if needed.

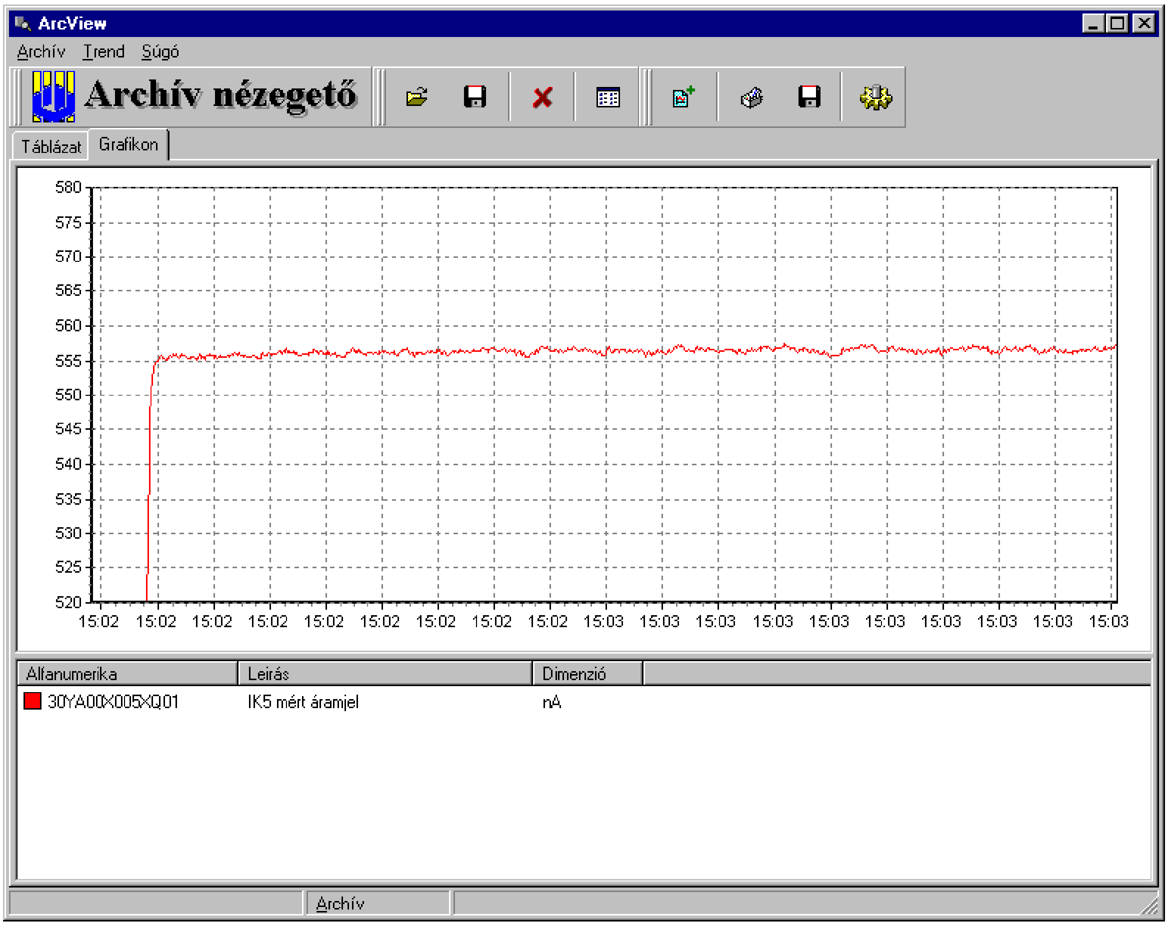

Figure 3: Measured current of neutron detector No. 5 as plotted from the local archive

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