MONITORING SYSTEM FOR ACCURACY AND RELIABILITY CHARACTERISTICS OF STANDARD TEMPERATURE MEASUREMENTS IN VVER-440 REACTORS

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Abstract

Description of a monitoring system for accuracy and reliability characteristics of standard temperature measurements in VVER-440 reactors and benefits obtained from its use are shown in the presentation. As standard reactor temperature measurement, coolant temperature measurement at channel exits and in loops, entered into the In-Reactor Control System (SVRK), are considered. Such systems have been implemented at two V-230 reactors and are under implementation at other four V-213 reactors.

Introduction

Accuracy and reliability of standard temperature measurement in VVER-440 reactors is very much important with regard to safe and economical operation of plants with these reactors. The levels of accuracy and reliability of the standard temperature measurement in VVER-440 reactors have been continually enhanced during the history of their use. The history of improvements in their levels in the former Czechoslovakia is shown in a presentation at a symposium on temperature reconstruction at Bohunice.

The enhanced level has been reflected in an enhanced accuracy and reliability of the standard reactor temperature measurement. The implementation of the monitoring system for accuracy and reliability characteristics (SPAS) is a significant element in their enhanced level.

In the presentation it is also shown:

- what the SPAS system deals with and what is its function
- description of the SPAS system and of its outputs
- what benefits provides the SPAS system in its use
- what is the status in the implementation of the SPAS systems in Slovak reactors.

1. What the SPAS system deals with and what is its function

- The system deals with the temperature measurement of reactor coolant both at the exits of fuel assemblies and at reactor inlet and outlet (temperature in loops).
- The system performs the following functions:
  - calibration of standard temperature measurement during quasi-isothermal conditions
  - control of accuracy of standard temperature measurement of reactor coolant during power conditions in each measurement cycle (accuracy characteristics)
  - control loop and isolation resistance of temperature sensors during power conditions in individual intervals (reliability characteristics)
  - database of accuracy and reliability characteristics
  - dialogue for the purpose of analysis of accuracy and reliability characteristics.

2. Description of the SPAS system, its most important outputs

The monitoring of accuracy characteristics of standard reactor temperature measurement is based on the use of reactor temperature etalon [1]. By means of the reactor temperature etalon, standard reactor temperature measurements during quasi-isothermal conditions can be calibrated and their accuracy during power conditions can be controlled.

The reactor temperature etalon controls automatically in each measurement cycle the accuracy of measurement. Its temperature sensors are metrologically related to temperature etalons of higher orders by means of standards [2,3,4]. Combined temperature sensors of the reactor temperature etalon measurement instrumentation are the measurement devices specified in [5,6].

The monitoring of reliability characteristics of the standard reactor temperature measurement is based on the monitoring of the loop and isolation resistances of their complete measurement circuits. The principles for monitoring the reliability measurement from temperature measurement circuits by means of measurements of the loop and isolation resistances and suitable methods of measurement are shown in [7] and [8].

The SPAS system uses measured data both from the SVRK system and from the reactor temperature etalon for the monitoring of accuracy and reliability characteristics. In principle, the SPAS system can be then implemented by the following software:

A) directly in SVRK – as already implemented at the V-230 reactors in Bohunice

B) with reactor temperature etalon – as already implemented at Mochovce reactors. In this variant, merging of the reactor temperature etalon and the SPAS system was done by means of the Control System of Reactor Temperature Measurement (KSMTR). The function of determining corrective constants during calibration is carried out by software-hardware complex for operational control (PTK OK) by means of a supporting temperature found by the reactor temperature etalon. Assessment of quality level of the correction constants is done in KSMTR.

C) in other computer system.

Schematic outline of relations between the SAS system and reactor temperature measurements is shown in Fig. 1. Links between the temperature measurements and the SPAS system are shown for the case that the reactor temperature etalon and the SPAS system are merged into the KSMTR that stands outside the SVRK system which is the case B shown. The same links between the temperature measurements and the SPAS system as valid for the case B, are in effect also for cases A a C.

The most significant outputs of the SPAS system are as follows:

- Accuracy characteristics of the reactor temperature etalon obtained during each measurement cycle. In Fig. 2, three parameters of the accuracy of the reactor temperature etalon at Mochovce unit 1 during the whole fuel cycle are shown.
- Corrective constants in the standard reactor temperature measurement are obtained during quasi-isothermal conditions, including evaluation of their quality.
- Accuracy characteristics of the standard temperature measurement obtained during power conditions in each measurement cycle:
  - Temperatures at exits from fuel assemblies (TVPK). A parameter containing systematic error and a parameter containing random error in the set [9] for Bohunice-1 is shown in Fig. 3
  - Temperatures in loops. Systematic error in temperatures in hot legs from PTK OK1 during a fuel cycle at Mochovce-1 is shown in Fig. 4
  - Reactor coolant temperature difference. The systematic error of measurement vs. the temperature difference from HINDUKUSH during a fuel cycle at Bohunice-3 is shown in Fig. 5. The history of systematic errors of HINDUKUSH systems at Bohunice and Dukovany is shown in Fig. 6.
- Reliability characteristics. The history of the average value of isolation resistance of thermocouples at fuel assembly exits at Bohunice-2 during fuel cycle is shown in Fig. 7. The time history of the amount of measurement circuits with failures and with evolving failures prior to and during the first fuel cycle at Bohunice-2 is shown in Fig. 8. (From the magnitude of step changes in resistance, it is possible to rate the thermocouple circuits as circuits with failures, with evolving failures and without failures [7]).

Besides the most significant outputs mentioned above, there is a lot of other partial outputs that may be obtained from the SPAS system for the need of analyses of the measured data [10].

3. What benefits provides the SPAS system in its use

- It rovides metrology links.
- It provides automatic monitoring of accuracy and reliability of measurement circuits during fuel cycle.
- It makes possible to clarify anomalous conditions occurring during reactor fuel cycle.
- It makes possible to monitor long-term changes (within a few years) of the characteristics of sensors and measurement circuits.

3.1 Metrology relations

Metrology relations of the standard reactor temperature measurement in VVER-440 are shown in Fig. 9. It can be seen from the lower part of Fig. 9, that temperatures from resistance sensors and temperatures from thermoelectric sensors (both in loops and assemblies) are related metrologically in real conditions at reactor during quasi-isothermal conditions prior to each plant restart following refueling to combined sensors of temperature (of reactor temperature etalon) which are the measurement devices specified in [5,6]. It is obvious that during each calibration in the course of quasi-isothermal conditions (KIS), the measurement devices specified – the combined sensors of temperature – have to have calibration sheets. The combined sensors can obtain valid calibration sheets in two ways. Either by their calibration under laboratory conditions according to [4], res. by extending the validity of laboratory calibration constants under real conditions in reactor according to [3]. Such extension of validity can be done subsequently following laboratory calibration only two times [6].

In reality during KIS calibration, not only resistance temperature sensors and thermoelectric temperature sensors are calibrated by the combined sensors, but also complete measurement circuits of temperature resistance sensors and of temperature thermoelectric sensors are calibrated by the reactor temperature etalon. This thus means that the reactor temperature etalon has to have a valid calibration sheet.

For the reactor temperature etalon to have a valid calibration sheet, also the combined temperature sensor [3,4], the normal resistance and the analog-digital transducer have to have calibration sheets based on accuracy analysis of the temperature etalon [11]. A material about the results of regular checks of components of the temperature etalon – combined temperature sensors, normal resistance and analog-digital transducer [12] – is thus developed prior to each plant restart after refueling.

For the calibration procedure of the standard reactor temperature measurement by means of the temperature etalon during KIS, a methodology [13] was developed. The calibration procedure is done according to the methodology shown in the following steps:

- parameters of initial plant conditions during KIS
- sequence of operations at plant to achieve KIS
- quality control of KIS
- control of KSMTR during KIS
- procedure for the calibration of SVRK measurement circuits, corrective constants obtained
- entering the corrective constants and control of their correctness (under the condition of KIS quality control).

Current conditions at VVER-440 reactors are such that most of them has no reactor temperature etalon. How to check the accuracy of measurements at these reactors?

During KIS (temperature inhomogeneity in reactor is not known during KIS), the average temperature from standard measurements is calculated, it is taken as a reference value and individual corrections are calculated in relation to this average value. It is clear that even such a procedure could have a positive impact the measurement accuracy, however, it is not a correct one from the metrology point of view. In such a procedure, the technology is first used for the measurement of calibration, and then the measurement are used for the control of technology. The major weakness in this procedure is that coolant temperature inhomogeniety during quasi-isothermal conditions is not known. In the course of temperature measurement in loops during quasi-isothermal conditions, when the measured temperatures differ usually by a few tenths of degree only (but may differ also more), it is not possible to state explicitly what is the cause of the difference, whether the technology, res. accuracy of the measurement. Measurements focussed on revealing the magnitude of this inhomogeneity at the units in Bohunice and Dukovany by means of the reactor temperature etalon show [14] that temperature differences exceed even 0,5°C.

Operational safety of VER-440 reactors requires metrology relations. In 1989 within a former COMECON topic 10.06.52 – Metrology assurance of NPP operation – a technical standard document „Methodology for metrology certification and verification of circuits for coolant temperature measurement in in-reactor control system" was developed. Because of break of COMECON, the document has never been brought into practice.

3.2 Automatic quality monitoring of measurement circuits during fuel cycle

Such monitoring has major benefits mainly for I&C personnel. Specifically:

- Information on the conditions of measurement systems are obtain in real time (measurement personnel obtain free information about the measurement conditions which they could in the other case to obtain only by other supporting measurements, res. by comparing various measurement).
- Immediate finding of errors makes it possible to respond immediately with repair (if repair is possible).
- Knowledge of error history in measurement circuits during fuel cycle makes it possible to prepare a correct restoration during unit outage.

3.3 Clarification of anomalous conditions during reactor fuel cycle

By anomalous conditions such conditions are understood in which the data measured do not comply (in certain boundaries) with the data calculated, res. expected.

Among the most typical anomalous conditions the following below:

- non compliance in reactor core power distribution (a number of such events are known, reactor power level has to be limited frequently)
- non expected values of core bypass flow rates
- non compliance in the maintained and actual reactor thermal output
- non expected values temperature values obtained from thermocouples during transient conditions.

The above mentioned anomalous conditions occur frequently during operation. In such cases it is not easy to find answer on the question whether the anomaly was caused by technology, or by inaccuracy in measurement.

3.4 Monitoring of long term changes in characteristics of sensors and routes

The monitoring of long term changes (of the order of years and tens years) in characteristics of sensors, res. of complete measurement circuits is important very much mainly for the measurement of temperatures at assembly exits. In such measurements, thermocouples are exposed to severe conditions, mainly with regard to reactor radiation. Opinions on the magnitude of such changes of thermocouple characteristics by irradiation may be different. A set of non-uniform references as regards the magnitude of this effect is shown in [15] and [16]. One of the reasons for the non-uniformity of opinions on the magnitude of the effect of radiation on thermocouple characteristics is the absence of metrology relations at the reactors observed.

The understanding of long-term changes in thermocouple characteristics is one of important parameters for the assessment of the life of thermocouples used at assembly exits.

4. Status in implementation of SPAS systems and in their use at Slovak reactors

SPAS systems have been implemented at two V-230 reactors in Bohunice during the reconstruction of standard reactor temperature measurements at assembly exits [9]. It has been also implemented partially at four V-213 reactors, two of them at Mochovce [17] and two at Bohunice. The level of these systems at the particular reactors has been and will be different. The difference is given mainly by different SVRK systems (HINDUKUSH, PEEKEL, PTK) and by different temperature sensors.

The results from the use of the implemented and partially implemented SPAS systems obtained up to now are positive. These systems make it possible to obtain maximum parameters of accuracy and reliability at real standard reactor temperature measurements, to monitor and record these measurements in real time during fuel cycle, they help to clarify anomalous conditions occurring at plants [18, 19, 20].

Conclusions

The implemented and partially implemented systems for the monitoring of accuracy and reliability characteristics at V-230 and V-213 reactors proved beneficial as a useful helper at individual nuclear power plants. For I&C personnel the systems are helpers for continual quality monitoring of standard temperature measurements, for physicians and technologists they are helpers in clarifying anomalous conditions at plants.

The described systems were designed and implemented in close cooperation with I&C personnel and physicians at the particular plants.

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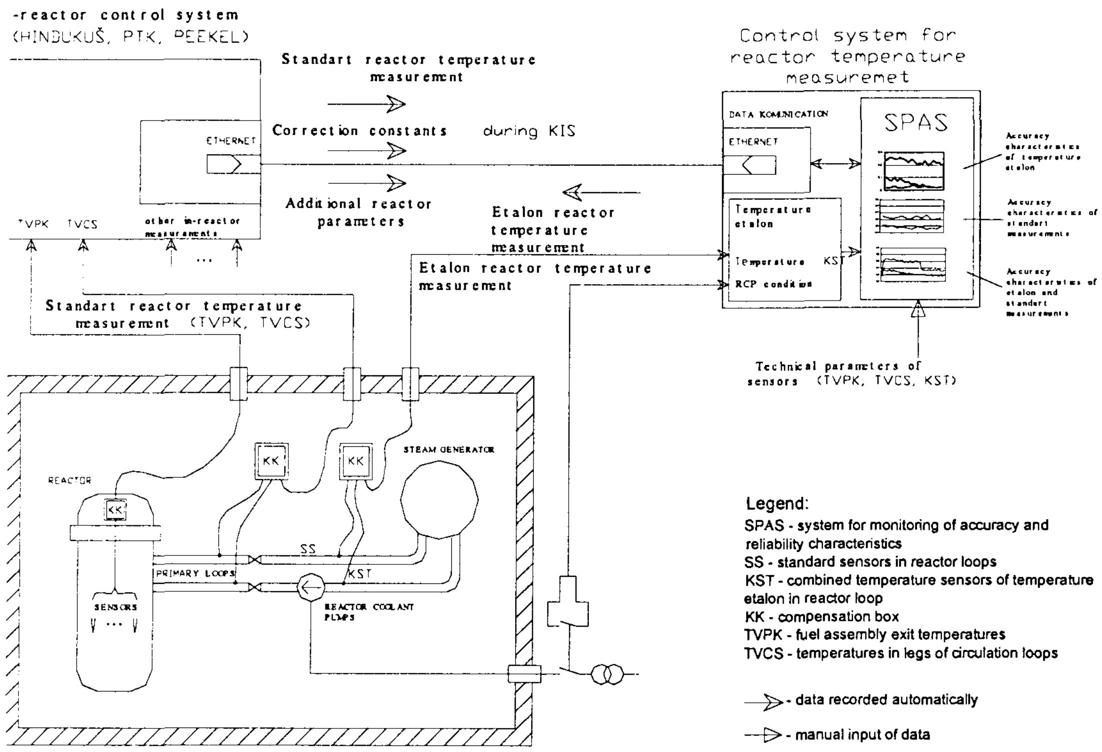

Fig. 1 Schematic outline of relations between SPAS system and reactor temperature measurements

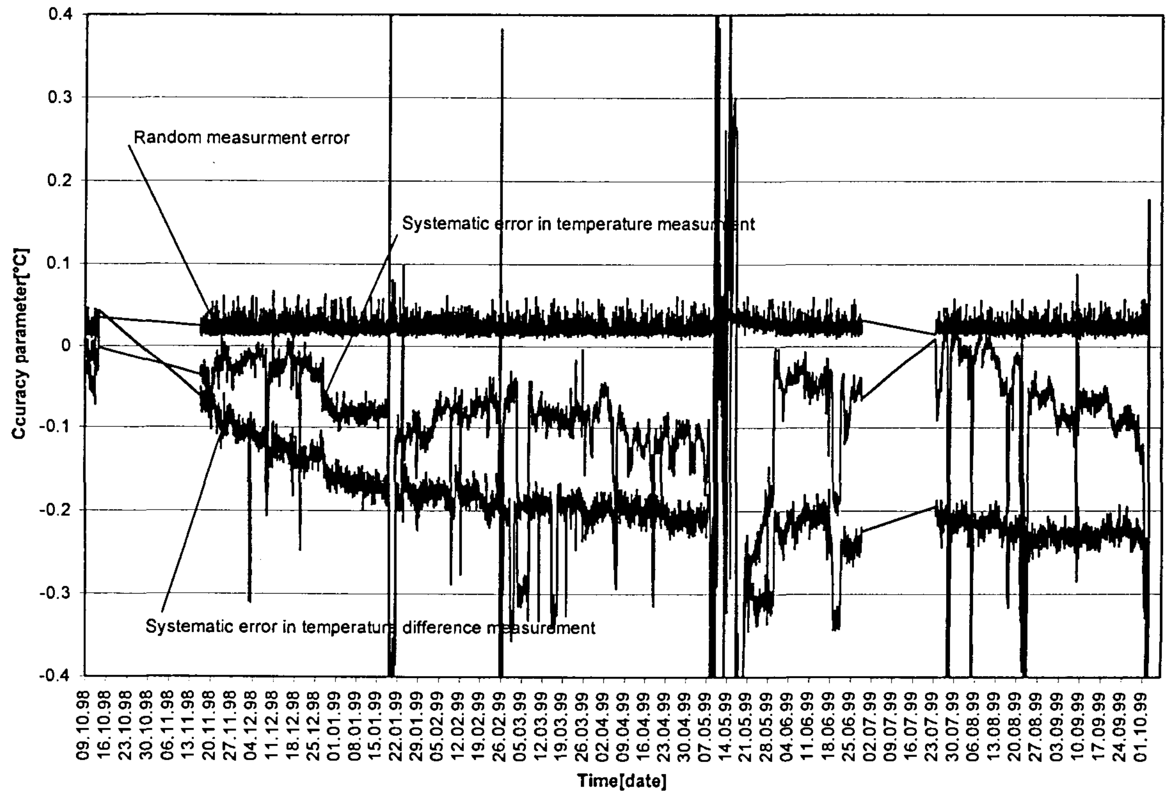

Fig. 2 Time history of accuracy parameters of KSMTR during fuel cycle 1 at Mochovce-1

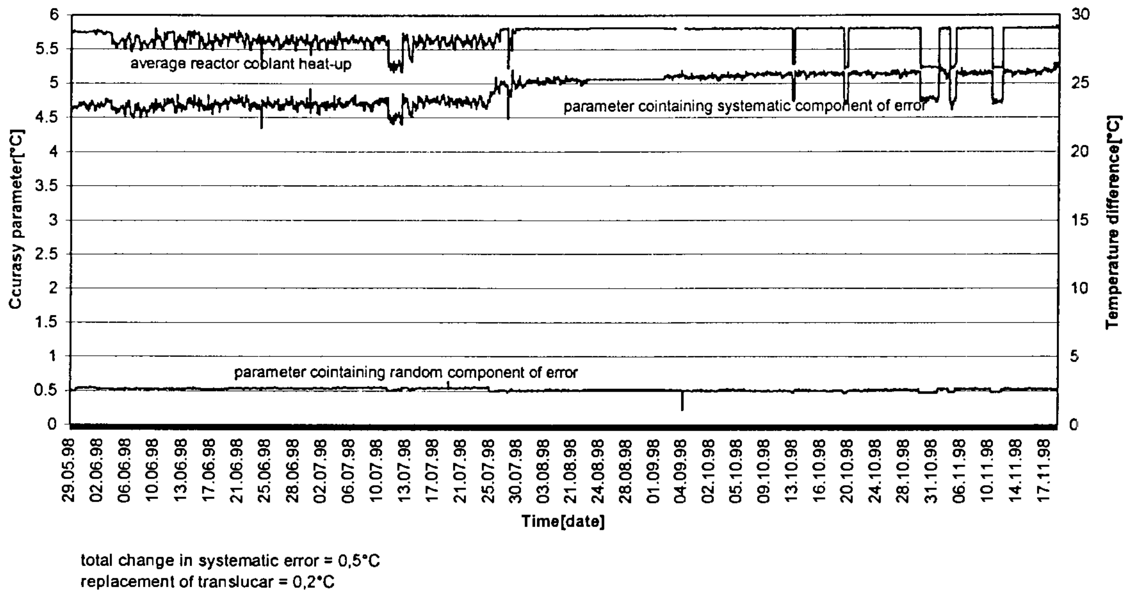

Fig. 3 Time histories of a parameter consisting of random and systematic error in TVPK and of average coolant core temperature difference from PEEKEL at Bohunice V1 unit 1

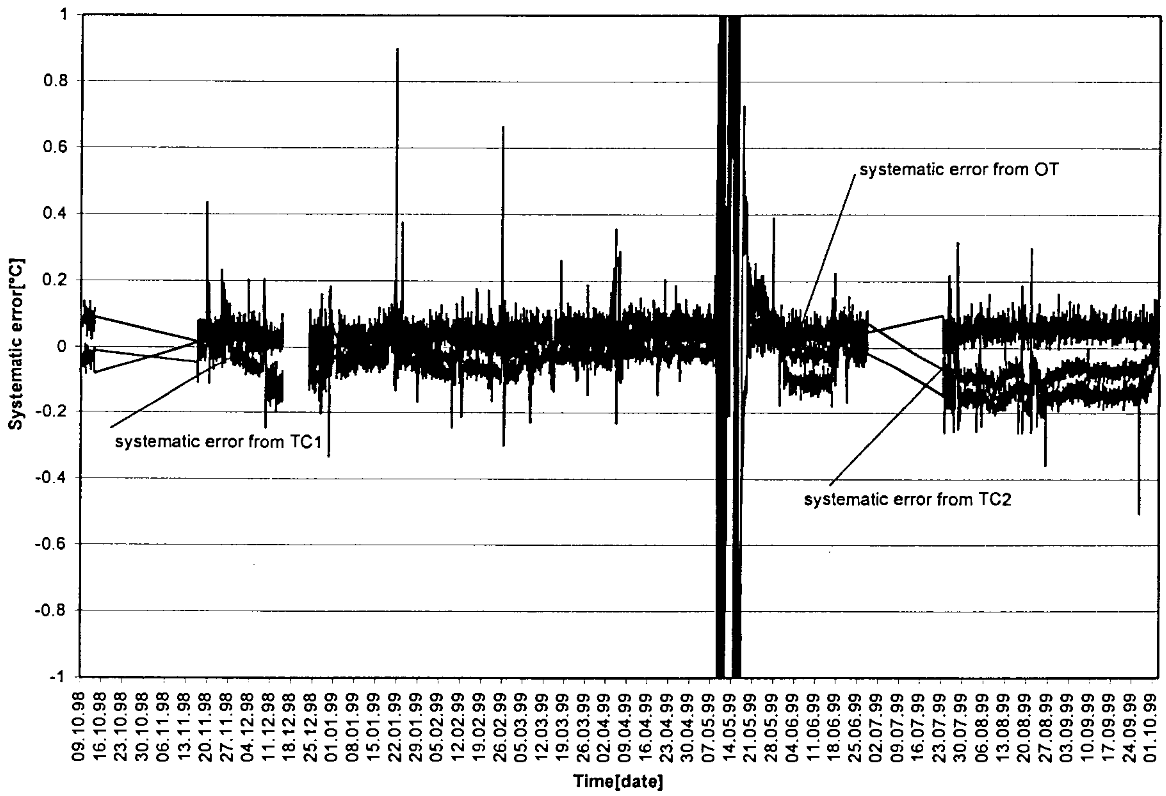

Fig. 4 Systematic error at hot legs from PTKOK1 during fuel cycle 1 at Mochovce-1

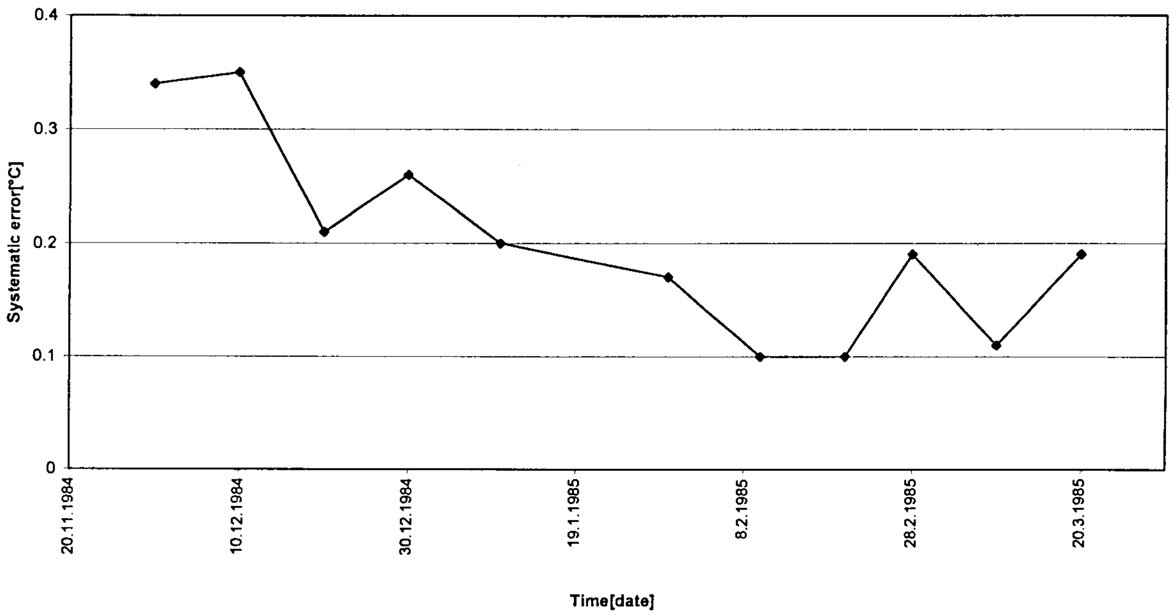

Fig. 5 Time history of systematic error in measurement of temperature difference from Hindukush at Bohunice V2 unit 1

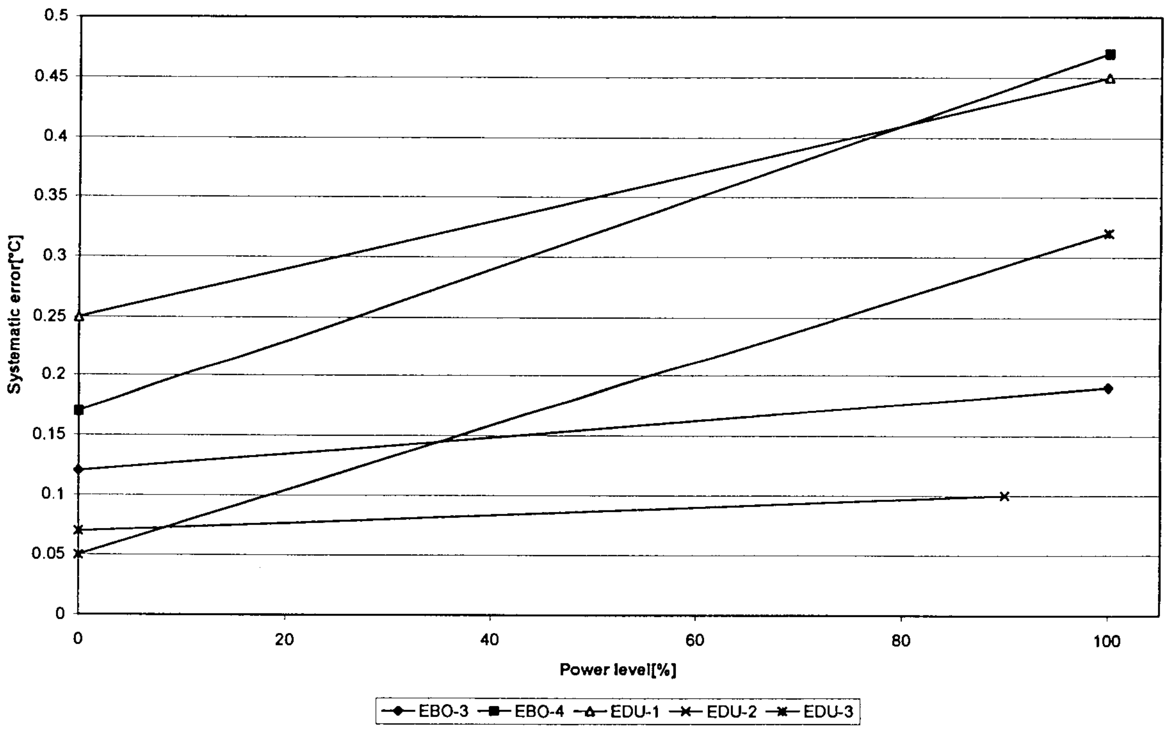

Fig. 6 Time history of systematic error in measurement of temperature difference at Hindukush at Bohunice and Dukovany

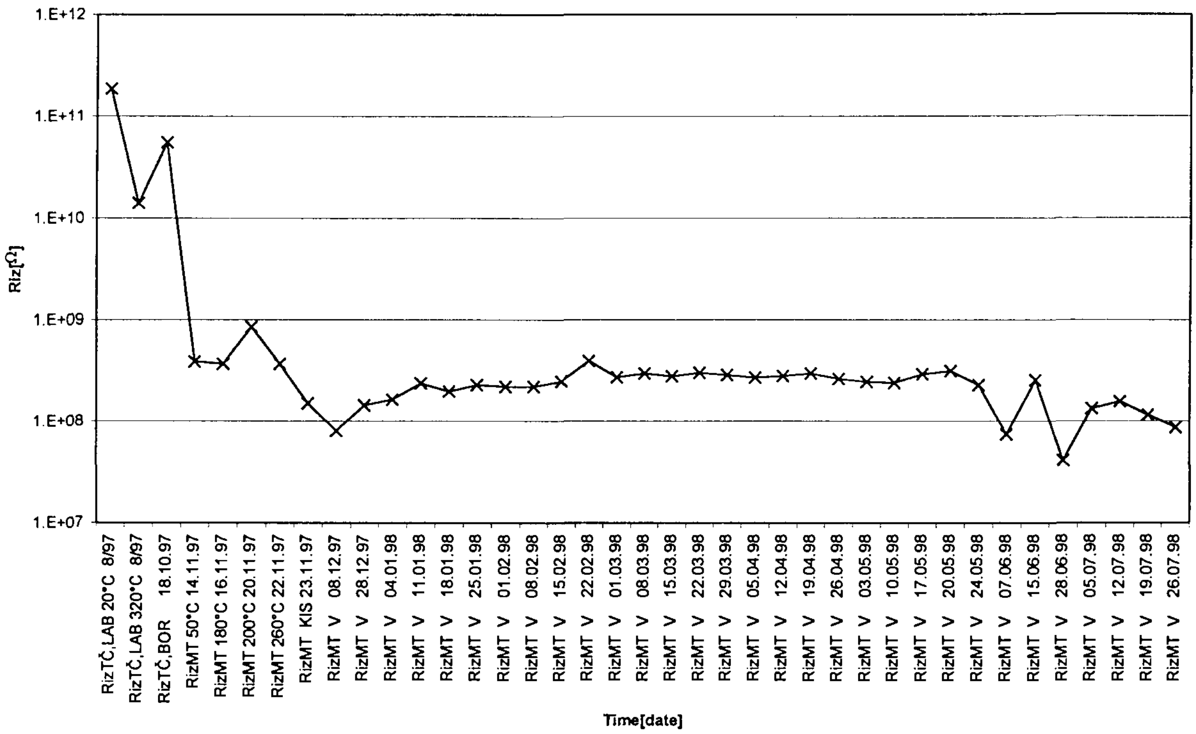

Fig. 7 Time history of average isolation resistance Riz of sensors in TVPK – Bohunice V1 unit 2, fuel cycle 18

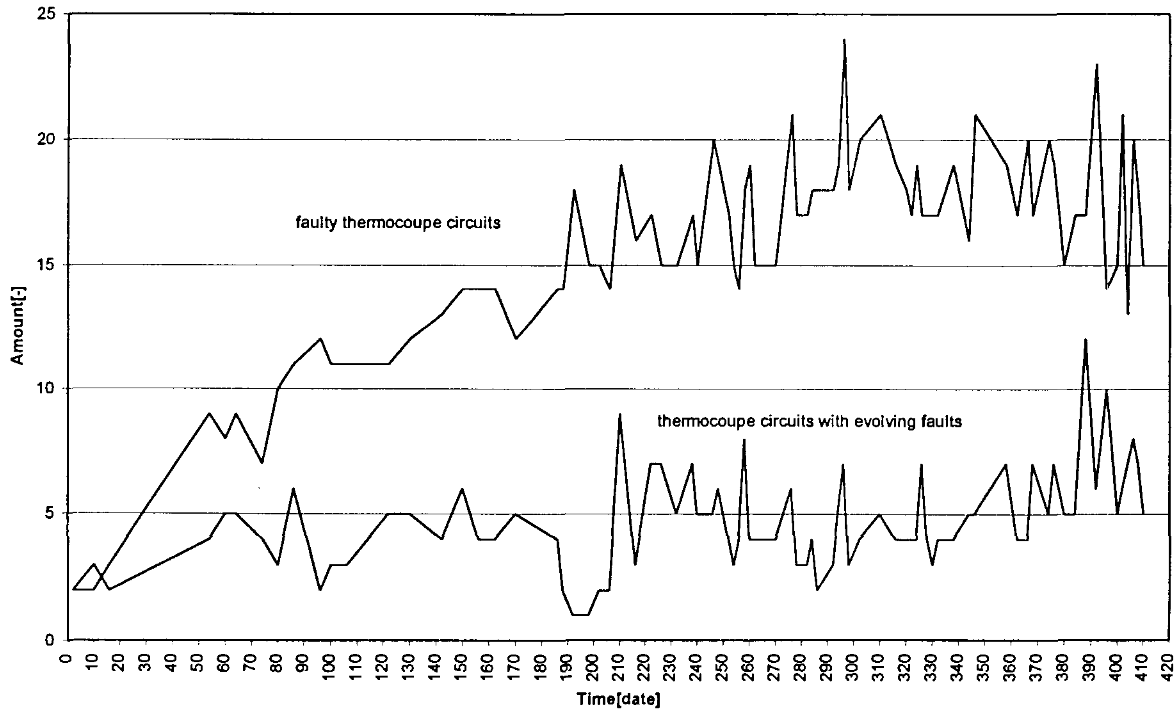

Fig. 8 Time history of the amount of failed thermocouple circuits and of thermocouple circuits with evolving failures prior to and during the first fuel cycle at Bohunice V1 unit 2

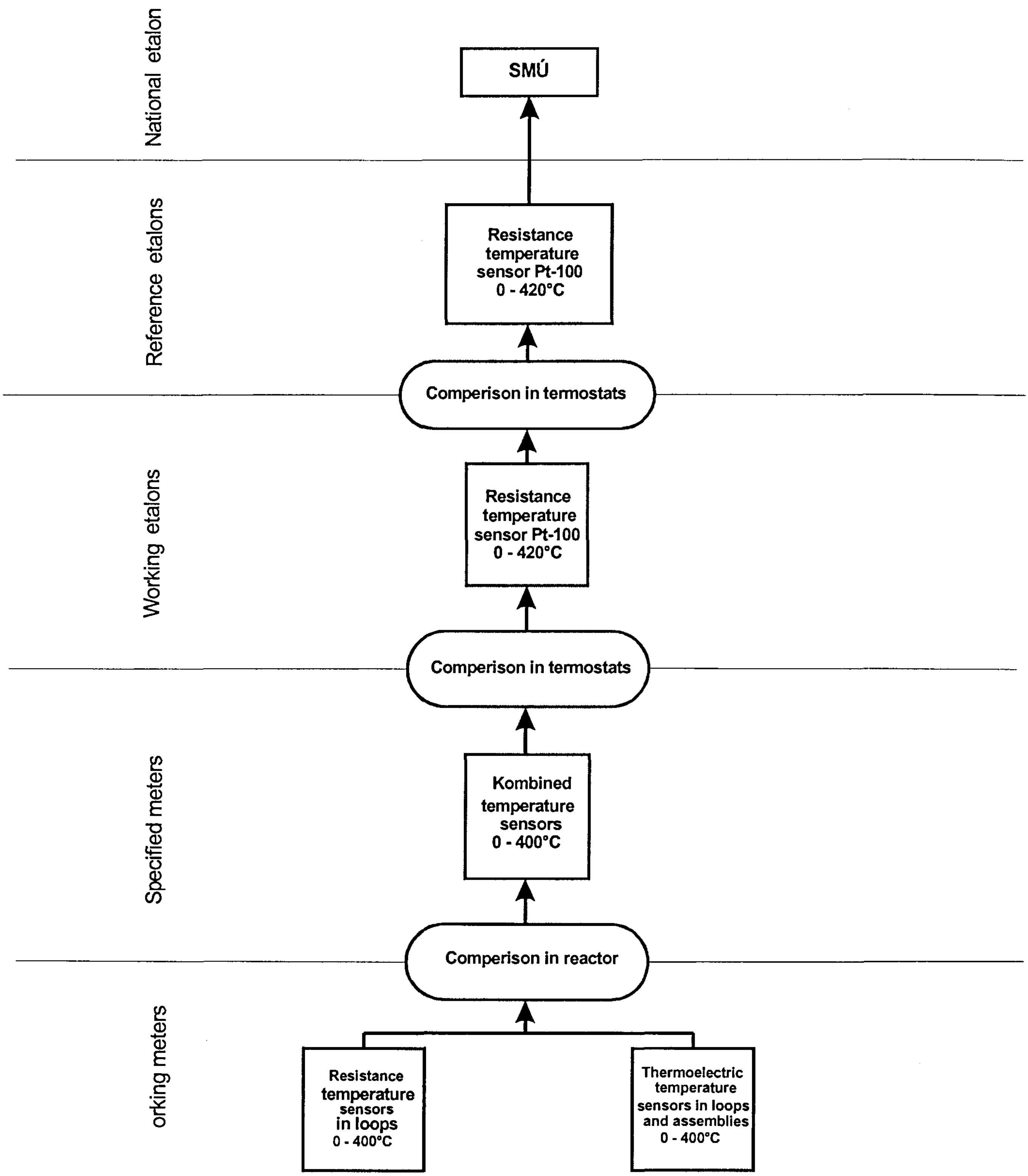

Fig. 9 Scheme of relations in standard reactor temperature measurement at VVER - 440