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by

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Abstract:

This report is the result of the KfK part of a joint study of KfK and INTERATOM. The aim of this study is to explore the advantages of microprocessors and microelectronics for a more sophisticated core surveillance, which is based on the integration of separate surveillance techniques.

After a description of the experimental results gained with the different surveillance techniques so far, it is shown which kinds of correlation can be done using the evaluation results obtained from the single surveillance systems.

The main part of this report contains the systems analysis of a microcomputer-based system integrating the different surveillance methods. After an analysis of the hardware requirements a hardware structure for the integrated system is proposed. The software structure is then described for the subsystems performing the different surveillance algorithms as well as for the system which does the correlation thus deriving additional information from the single results.

Ein integriertes, mikroprozessorgesteuertes System zur Kernüberwachung bei schnellen Brutreaktoren.

Zusammenfassung:

Dieser Bericht beschreibt den KfK-Teil einer gemeinsamen Studie von KfK und INTERATOM. Ziel dieser Studie ist es, den Vorteil der Mikroprozessortechnologie für eine fortgeschrittene Kernüberwachung aufzuzeigen, die auf der Integration verschiedener Überwachungstechniken basiert.

Nach einer Beschreibung der bisher erlangten Ergebnisse mit den unterschiedlichen Überwachungsmethoden wird aufgezeigt, wie die Verarbeitungsergebnisse der einzelnen Verfahren miteinander korreliert werden können.

Der Hauptteil dieses Berichts enthält eine Systemanalyse für ein auf Mikrorechnern basierendes System, das die verschiedenen Überwachungsmethoden integriert. Nach einer Analyse der Hardware-Anforderungen wird eine Struktur für das integrierte System vorgeschlagen. Danach erfolgt eine Beschreibung der Software-Struktur sowohl für die einzelnen Überwachungs-Subsysteme als auch für das System, das durch Korrelation der Einzelergebnisse zusätzliche Information gewinnt.

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I. Preface

In future fast breeder design the concept of preventive actions will be attached particular importance; besides the concepts

- operational and adminstrative measures,
- demonstration of inherent safety features of the core and subassemblies,
- scram by a DND system in case of rapid progression of damage,

priority is attributed to the early recognition of defects.

The goal consists in identifying anomalous conditions of operation in the early phase of their development before the normal surveillance instrumentation responds of limit values are attained, respectively. In general, a subsequent damage analysis reveals that already in the early phase of appearence of the anomaly minor indications can be found in the measured values which, however, are initially not noticed because of their insignificance.

In Part I of this study /GME 84/ various measuring techniques were presented which had been applied both to out-of-pile rigs and to the KNK reactor. The interrelationship existing between the initially largely independent individual techniques was described by fault propagation diagram (cf. Fig. 1.1). This diagram describes the phenomenological sequence of measurement which can become effective in each particular case.

Besides - based on the individual techniques - a coarse concept was elaborated for a microprocessor-based integrated surveillance system (cf. Fig. 1.2).

This report describes part II of the joint KfK and INTERATOM-study. The study is subdivided in 2 main parts:

- The KfK-part is concerned with a detailed system analysis as well as the development of correlation algorithms.

  The system analysis as one subpart will clarify the detailed requirements for the proposed microcomputer system with respect to computation speed, capacity, redundancy, diversity, reliability, and the use of busses as a communication medium.

As an other essential subpart the correlation algorithms are developed starting from the cause consequence diagram for disturbances (Fig. 1.1). Based on this diagram, appropriate algorithms aimed at combining the results of separate core surveillance techniques are suggested. By means of correlation of results additional information can be derived which is useful for a more sensitive and an earlier failure detection.

- The INTERATOM-part introduces the concept of an LMFBR diagnostic system based on artificial intelligence techniques.

  As a subpart the construction of a knowledge base is demonstrated by means of a real life example, the sodium-level-control-system.

  The other subpart deals with the manipulation and utilization of knowledge, which is imprecise, uncertain, or probabilistic in nature. The handling of such 'fuzzy' sets is as well visualized by means of the sodium-level-control-system example.

The common topic of these two approaches is the usage of modern software techniques, especially artificial intelligence.
The INTERATOM-approach favours a complete expert system for LMFBR diagnostics, whereas the KfK-approach is a mixture of conventional techniques (microprocessor-based individual process control system) and pattern recognition based problem solving. In the KfK-part the application of pattern recognition techniques - a subdiscipline of artificial intelligence - mainly concentrated on the software within the decision making level (cf. Fig. 1.2) and in the acoustic noise subsystem.

/GME 84/ Gmeiner, L. (Editor): Microprocessor-Based Integrated LMFBR Core Surveillance, KfK 3749, Juni 1984

II. KfK-Part:

1. Introduction

Part I of this study was concerned with existing separate core surveillance techniques. Starting from the analysis of these techniques, a rough concept (cp. Preface, Fig. 1.1) for an integrated microprocessor-based core surveillance system was given.

The central point of this concept was the so-called decision-making-level (DML). The newly introduced DML is interfaced to all units in the separate-evaluation-level (SEL). The elements of the SEL are the separate individual core surveillance techniques.
Chapter 2 summarizes shortly the results of and the experiences with the currently existing separate systems.
Unfortunately, the current form of processing and the outputs are not always appropriate for usage together with the proposed DML. As a consequence, some modifications are necessary in the separate systems. This modification mainly concentrates on the identification and isolation of common subparts in the data acquisition area. The system analysis showed that primarily the acquisition of fuel element outlet temperatures is a promising candidate for common preprocessing. Furthermore, some modifications were necessary to define a unique interface to the DML. The results of these modifications are described in more detail in chapters 4.1 and 4.2

Chapter 3 is concerned with the refinement of the DML. For that reason it introduces a correlation method, which combines and correlates the outputs of each individual system. Based on some realistic examples the methodology is explained and the rough data structure for an information flow between SEL and DML are considered.

Chapter 4 describes the systems analysis for the total, integrated system. As mentioned before, the modules appropriate for common preprocessing are identified. This preprocessing and other aspects are the basis for a refinement of the system concept (cp. Fig. 1.2).
Furthermore, the hardware and software requirements for the complete system are investigated. The main effort hereby concentrates on the software aspect (cp. chapter 4.4.).

Chapter 5 describes an implementation plan for a stepwise realization of this concept starting from existing subsystems.

Chapter 6 draws some conclusions and points to the main aspects of future work.

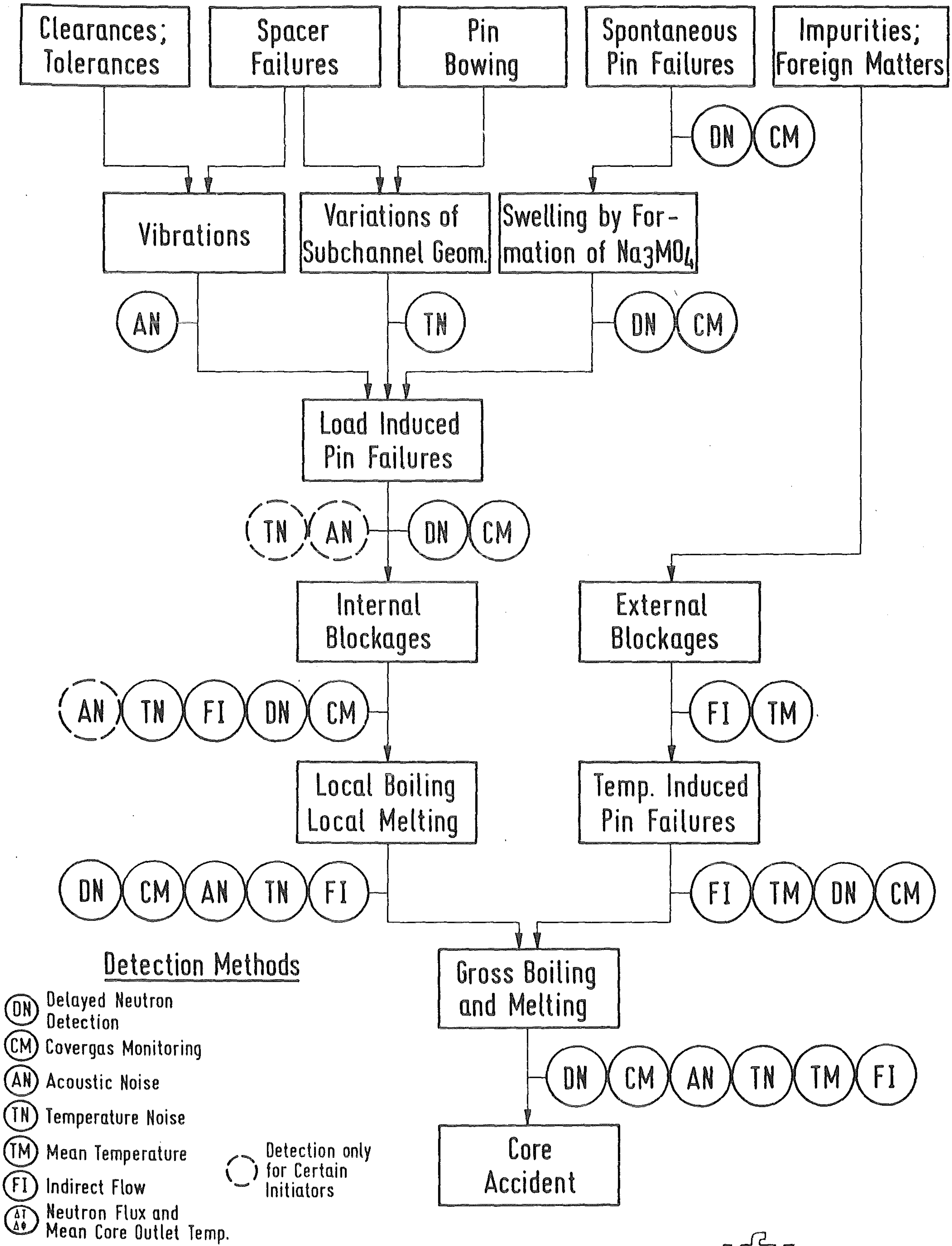

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Fig. 1-1 Local Fault Propagation and Related Detection Possibilities

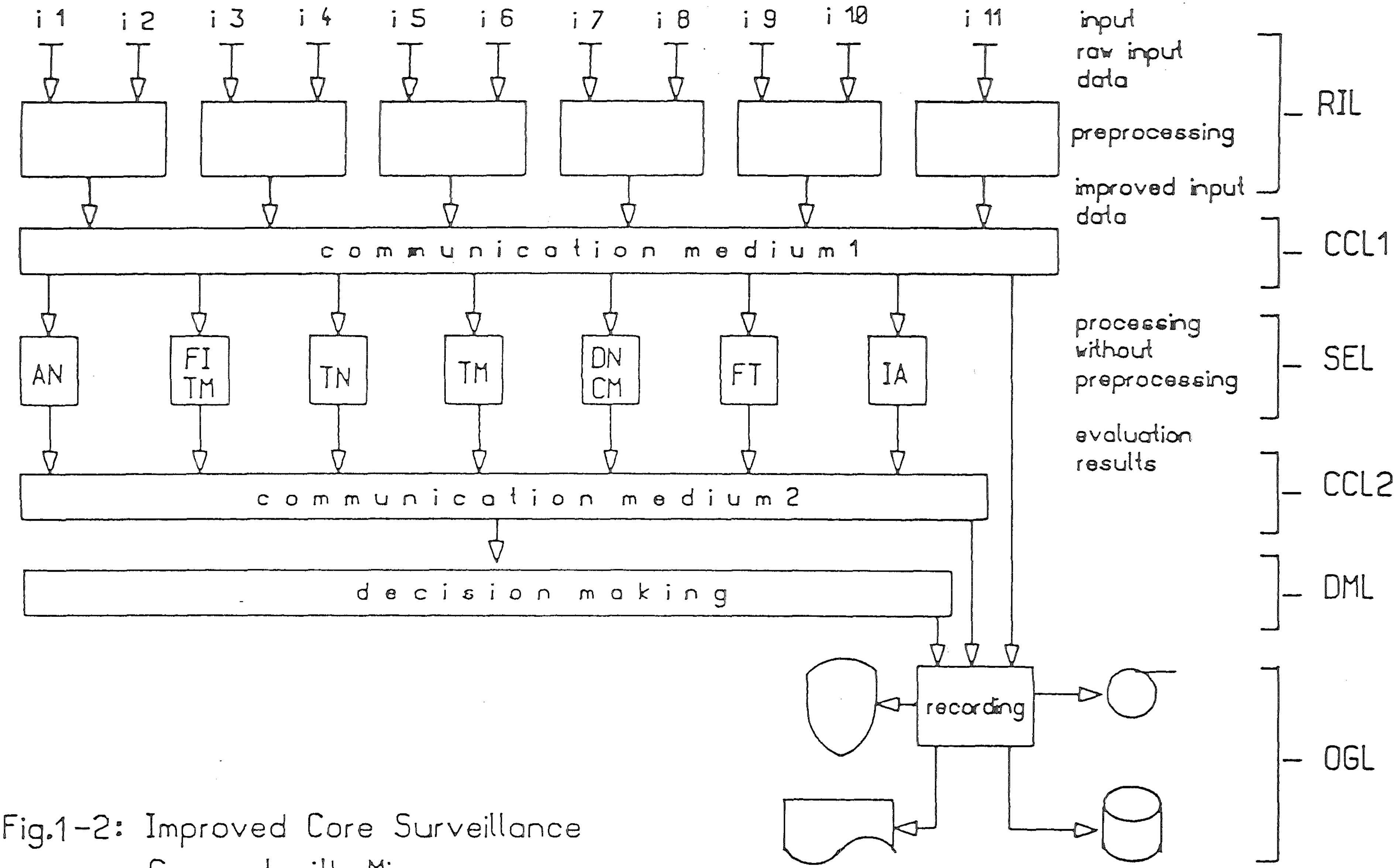

Fig.1-2: Improved Core Surveillance Concept with Microprocessors

IDT 14.07.83voges5

2. Experimental Verification of Direct and Indirect Measurements

2.1 Experience with subassembly state and performance monitoring

M. Edelmann, KfK-INR

In fast breeder reactors individual subassembly (SA) state and performance monitoring is of particular interest because single SA faults might have severe safety implications and could possibly lead to major whole-core incidents. A well-known initiating anomaly of this kind is local loss of cooling within a SA. In general, this cannot be detected by conventional SA outlet temperature monitoring even if it causes fuel failure due to overheating. Special methods of sensitive (indirect) SA coolant flow monitoring have been developed and tested, therefore. The experimental SA monitoring system KASUMOS / Edelmann 82 / was built for this and other purposes. First experience with this system obtained at the sodium cooled test reactor KNK II /Edelmann 83/ was encouraging KASUMOS performance tests under the more realistic breeder reactor conditions of the french breeder prototype Phênix. Experience obtained at this reactor is described elsewhere in some detail /Edelmann 84/.

The principle of KASUMOS SA state and performance monitoring is illustrated by the block diagram in Fig. 2.1-1. Three major functions can be distinguished:

1 - Measurement and identification of thermal-hydraulics fuel element (SA model) parameters (parameter estimator).

2 - On-line prediction of dynamic SA outlet temperature reference signals (fuel element + TC simulator).

3 - Sensitive SA coolant flow monitoring by intercomparison of measured and model-predicted outlet temperatures; monitoring of parameter estimator outputs with respect to variations in SA state (fuel-to-coolant heat transfer coefficient, SA power, fuel temperature coolant mass flow; TC response time).

Conclusions from investigations at KNK II and Phênix can be summarized as follows:

1 - The sensitivity of SA outlet temperature monitoring with respect to local loss of cooling is significantly improved by balancing-out those temperature fluctuations which are caused by operational

and stochastic variations of reactor power, primary coolant flow and inlet temperature. This is achieved by subtracting the model-predicted outlet temperatures from the actually measured ones (= "balanced outlet temperatures"). An example of this procedure is given in Fig. 2.1-2. There it is seen that during a power variation of more than 13% of nominal power the coolant outlet temperature of a SA changes by about 23K whereas the balanced outlet temperature varies by less than 1K. As a consequence, cooling disturbances of 1% in SA coolant flow become detectable by balanced outlet temperature monitoring. It is expected, that fuel failure due to local overheating can be excluded in this way.

2 - In general it is difficult to measure all of the thermal-hydraulic SA parameters with good precision. It might be that inherent power variations (power noise, power control) are insufficient and ad hoc perturbations are necessary for this purpose. However, it turned out that in this case simplified SA models can be used for outlet temperature prediction and that the corresponding reduced model parameters can be always determined from inherent power and outlet temperature fluctions. Thus, sensitive SA coolant flow monitoring would still be feasible whereas the precise measurement of thermal-hydraulic fuel parameters and TC time constants might require special power perturbations (power ramps of short rise time /Edelmann 84/).

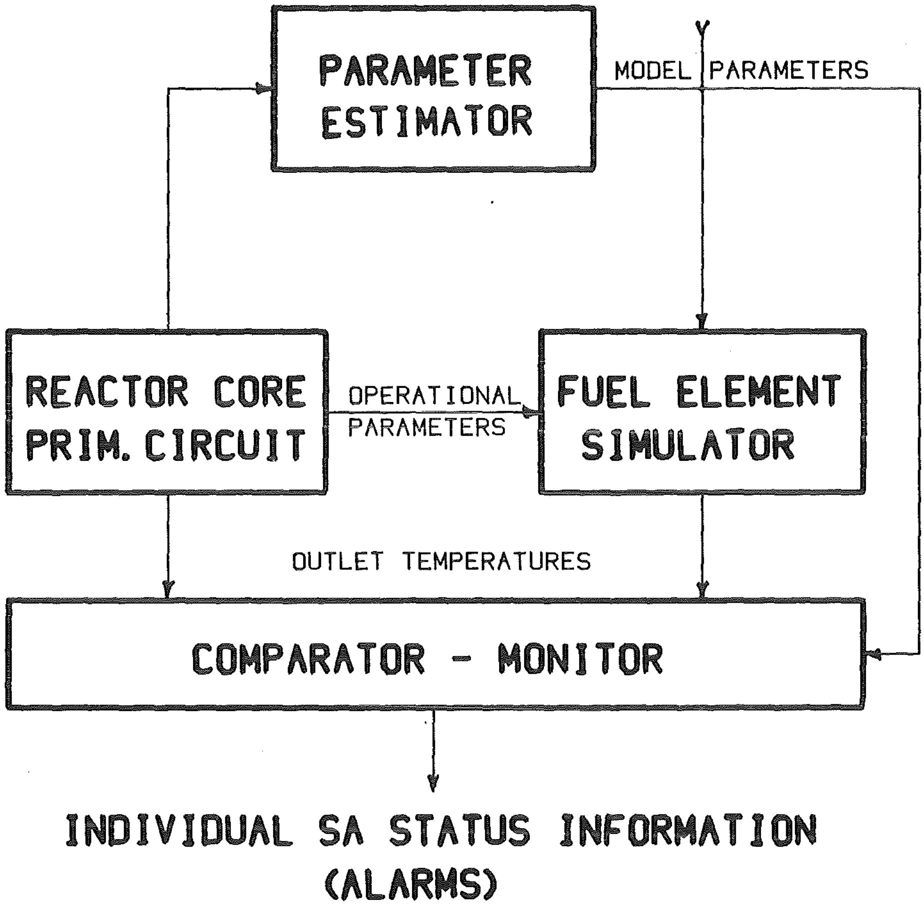

Fig. 2.1-1 SA state and performance monitoring schema

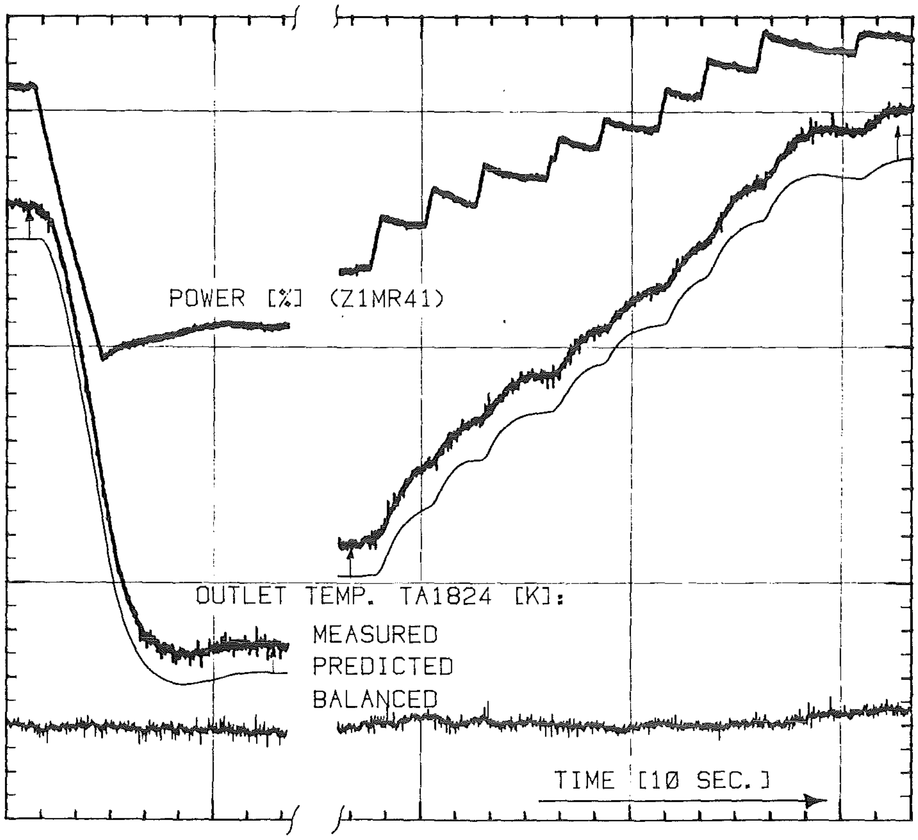

Fig. 2.1-2 Measured, predicted and balanced SA outlet temperature during power variations of the Phénix reactor

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2.2 Experience with individual fuel element temperature monitoring

U. Voges, KfK/IDT

A microprocessor based system is installed at the KNK II which monitors the individual fuel element coolant outlet temperatures. This system is in on-line open loop operation since summer 1983. The experience gained during the operatio can be summarised as follows:

1. Interface

   Some problems and failures occured with the installed separating amplifiers and the analog/digital-converters. The errors were mainly detected by Software implemented plausibility checks.

2. Microprocessors

   After preliminary testing there occured no failure in the microprocessor system. The system behaviour was quite stable. From the about 100 boards one I/O board failed, from the about 15 power supplies two failed during one year operation.

3. Fuel elements

   Concerning cooling disturbances the reactor operation was normal. Therefore no detection could be made and no experience gained.

4. Algorithms

   The implemented algorithms showed to be sensible against wrong parameters. If position dependent correction factors differed from the intended ones even less then 10%, the detection algorithms would run into alarm situations.

2.3 Experiments with temperature noise measurements

L. Krebs, G. Weinkötz

The objective of measuring and analysing temperature fluctuations in the coolant of LMFBR's is the detection of cooling disturbances within reactor subassemblies and the development and performance validation of sensitive sensors and measuring devices. Extended experimental and theoretical investigations have been performed for this purpose. The activities in temperature noise include three main parts:

- out-of-pile experiments on unblocked and blocked electrically heated rod bundles (ECN 28-rod bundle, KNS 169-rod bundle, TENOFA 61-rod bundle).

- basic research and model development of the mean and fluctuating velocity and temperature field downstream of a simulated reactor subassembly.

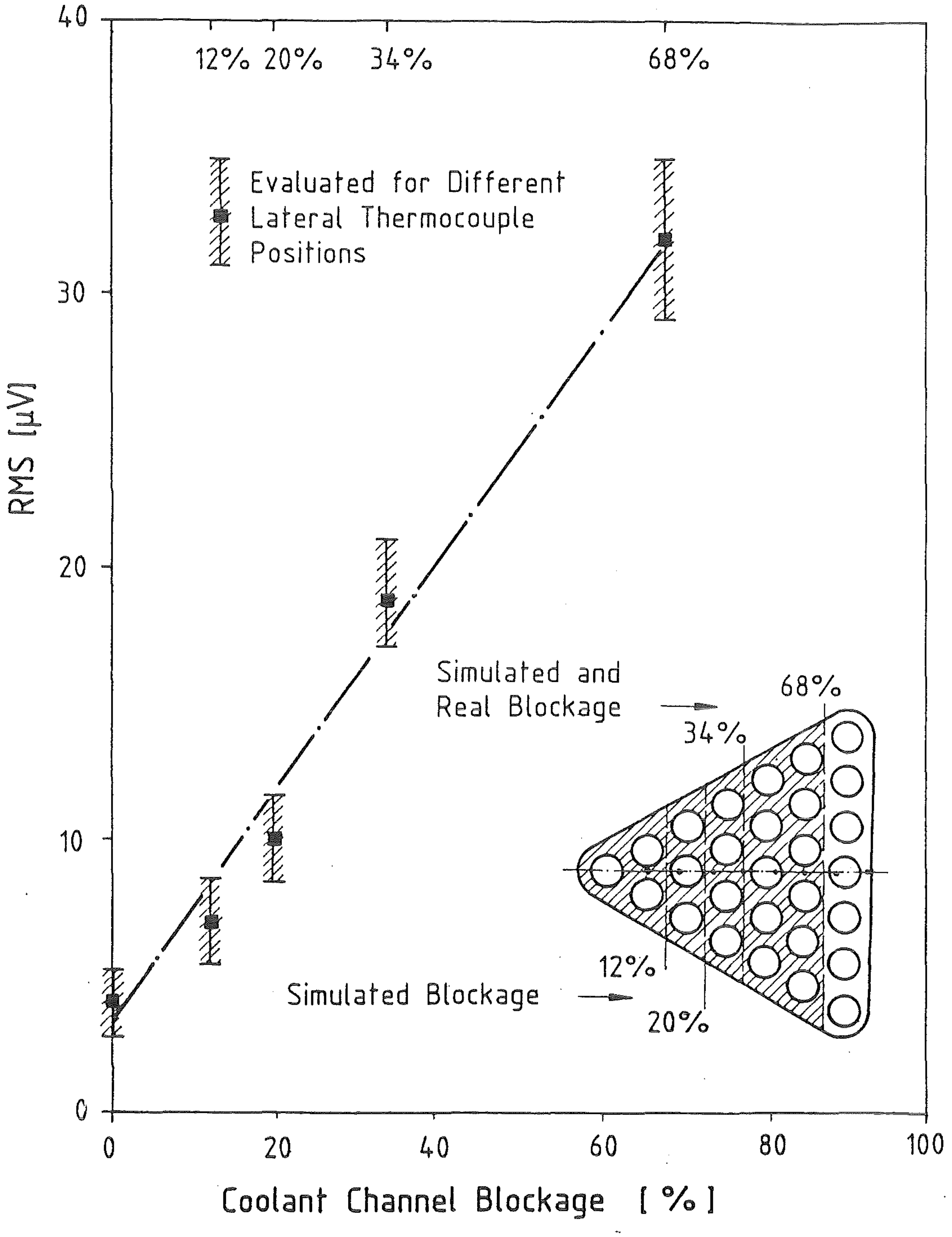
- in-pile performance tests and investigation of long term reliability of temperature noise instrumentation at KNK II and at SNR 300.

The out-of-pile experiments performed on the electrically heated rod bundles have demonstrated that the analysis of temperature fluctuations is a sensitive method to detect flow blockages. The blockages can be detected by measurements of temperature fluctuations at the outlet of the rod bundle as well as downstream of a flow mixer.

From these investigations the influence of heat flux coolant velocity and temperature rise between the inlet and the outlet of the rod bundle on the RMS-value and the PSD of temperature fluctuations was deduced.

In addition to the out-of-pile experiments with flow blockages, measurements of the temperature fluctuations have been performed on an unblocked 28-rod bundle. It was one aim of these investigations to give a comparison between the measured RMS-values of the unblocked 28-rod bundle and the RMS-values obtained by measurements with real and simulated blockages. The simulation of the blockage was performed by an increase of the rod power of those heater rods which are located in the formerly blocked cross section.

Some results of the out-of-pile experiments with the 28-rod bundle will be discussed on the following figure.



RMS-Value of Temperature Fluctuations in Dependence on the Blockage Size.

The cross-section of the bundle is shown on the right-hand side of the figure. Real blockage experiments have been performed with partially blocked coolant sections of 34 % and 68 %. Additionally simulated blockage experiments with 12 % , 20 % , 34 % and 68 % have been excecuted. The same operation conditions have been applied to all 28-rod bundle experiments. The temperature fluctuations were measured at the bundle outlet downstream of a flow mixer. Calculating the RMS-value the temperature fluctuation signals were low-pass filtered by 5 Hz and the integration time was fixed at 30 sec.

The diagramme shows the averaged RMS-values evaluated for different lateral thermocouple positions and their associated tolerance field depending on the blockage sizes. Within the demonstrated tolerance field there is no difference between the RMS-values of simulated and real blockages. The RMS-value is about 4 to 5 μV in the case of the rod bundle without blockage. This is the background noise under the operation conditions and the adjusted parameters of RMS-value calculation. The RMS-value of a coolant channel blockage of 34 % is more than 4 times higher than that of the unblocked bundle. Therefore, it can be concluded from the experiments with the 28-rod bundle that a coolant channel blockage of 20 % and more will be detected reliable. The indication of smaller blockages depends on the temperature noise level of the background.

2.4. Experience with Acoustic Noise Measurements

H. Rohrbacher, KfK/IRE

From sodium boiling experiments performed in out-of-pile facilities (KNS, NSK) and from the Boiling-Generator Experiment in KNK II it appeared that acoustic boiling signals are detected in a broad frequency bandwidth still including energy fractions above 100 kHz. From all experiments on local boiling using a suitable acoustic instrumentation comparable results have been obtained. There are found at least two or more increases of autocorrelated power densities in a restricted number of frequency-windows. The signal density's distribution depends on the individual acoustic transfer function of each test rig as the transmission path acts as a multipolar filter with resonances and frequency-dependent attenuations.

Typical domains are found in a low frequency interval from 5 to 20 kHz followed by a high frequency window in most cases reaching from 50 to 80 kHz and even higher.

As a consequence of the always present interfering background noise from many and mostly unknown acoustic sources and from predominating electrical disturbances (mains, controlled semiconductors etc.) the measured high frequency signals are due to a significant importance. They are found in the micro-volt range and therefore, a high signal-to-noise ratio is only realistic for frequencies far above 5 kHz. In practice, the acoustic signals are preconditioned by use of front-end high-pass filters with individually selected cutoff-frequencies from 5 to 40 kHz.

During the experiment all acoustic data are enregistered on analog multi-channel tape recorders. For redundancy purposes a certain number of signals is stored simualtaneously in the FM and AM mode under different conditions with regard to the system's finite bandwidth and dynamic capabilities.

For boiling experiments an acoustic sensor system is used which consists of at least six to twenty individual microphones distributed in the detection area directly immersed in the coolant or, to some extent they are structure borne to take advantage of the waveguide effect.

The experience with acustic noise measurements turns out that the onset of boiling is detectable already at its very early beginning. Under normal conditions a maximum dead time of a few milliseconds has proven to be typical. Morover, from the boiling signal's repetition rate and time function it can be derived the boiling form, i.e. local boiling with rapidly collapsing small vapor bubbles or voiding of a large area in a subchannel and other known voiding and recondensating phenomena during the boiling phase.

In CABRI reactor the precise time of pin failures were measured by use of several microphones detecting the rupture pressure pulse and the relevant travelling time of the pulse shock-front to each of them.

It was shown from a great number of experiments that the acoustic sensors now being available meet the requirements for a reactor application under severe temperature and radiation conditions so far. The predominating task to be solved is a further improvement of the data evaluation with respect to the background noise associated by introduction of an intelligent pattern recognition technique for a learning and online operating acoustic surveillance system.

S. Jacobi

EC Study

2.5 Experience with delayed neutron detection and cover gas monitoring

by
S. Jacobi
KfK - IRE

2.5.1 Introduction

The latest summary on fission product signals and relevant experience in detection, location and characterization of failed fuel elements, prepared on an international level, are the Proceedings in [1]. According to that documentation, experience accumulated with the delayed neutron (DN) technique and cover gas monitoring have in general been good although some details are still open. On the other hand, the positive experience gathered has given rise to new problems to be treated, for example continued plant operation with failed fuel elements. As a contribution dealing with these unsettled problems, relevant KfK work carried out at KNK II from 1981 until 1984 will be summarized and discussed below.

2.5.2 Problems

In almost all countries developing breeder reactors long-term irradiation experiments with failed fuel pins have been performed and are being planned. However, the long-term loop experiments performed in the past have left open some questions regarding the transferability of results to real reactor conditions:

- The measurement and conditioning of the oxygen concentration in sodium loops does not conform to reactor specifications. This could influence the uranate-plutonate (= Na_3MO_4) formation which is a cause of failed fuel pin swelling.

- The time of sodium transit to the location of the DN monitors is extremely short under the conditions in an experimental loop and different delayed neutron groups dominate.

- The fission product concentration responsible for the sensitivity of failure detection is lower by several orders of magnitude in a reactor than in the loops.

2.5.3 Description of the test equipment in the KNK II experiments

The fuel was fresh UO_2 with U-235 enrichment of 37 at.%. The specification of the fuel and the cladding tubes corresponded to that of the KNK II driver zone.

To obtain a free fuel surface the pins were provided with 1 and 0.1 mm^2 boreholes or with 1 mm x 5 mm slits in the cladding tube.

The pins were mounted in a plug placed on the KNK II peripheral position 511. As the primary sodium is used for fuel pin cooling the operational fission product measuring equipment could be used: the two DN monitors and the cover gas monitoring devices such as germanium gamma spectrometer, precipitators and Na(I) scintillators.

2.5.4 Test programme

The first test series including five single-pin tests indicated in Table I were performed under normal KNK II operation conditions at different power steps. In this way, the fission rate, the activity concentration in the sodium, and the fission product transit time were varied.

Table I: Test Programme

Test No.	Defect Area (mm^2)	Type of Defect	Failure Location	Number of Fuel Pellets
1	1	borehole	at the fuel column	1
2	10	two slits		1
3	10	two slits		12
4	1	borehole	at the upper gas plenum	12
5	.1	borehole		12

2.5.5 Main results

At the beginning of the irradiations in tests nos. 1 to 3 the DN signal showed great fluctuations. High count rates were obtained in tests nos. 1 and 3. Tests nos. 4 and 5 no measurable DN signals.

The ratio of the effective fuel surface to the geometrical fuel surface is often called the fissuring factor k. For the initial phase of the irradiation values of k up to 217 were found. After stabilization the values ranged between 9 and 69.

The post-irradiation examination (PIE) consisted in X-ray radiographs, ceramography, microprobe analysis, and burn-up measurement. Important results from PIE work are that no significant displacements of fuel and cladding occurred during irradiation, but that some uranate was formed in the defect area.

2.5.6 Discussion

- At the beginning of the irradiation and in case of great ratios of fuel inventory to failure size high maximum values were measured of the k-factor. After stabilization the values of the k-factor are more dependent on the geometrical failure size: high values for little failure sizes, low values for great failure sizes. These relations are important for the evaluation of the DN signal and the characterization of the failure.

- Although the pins were irradiated during several weeks, there was no propagation of the failures and no noticeable fuel loss occurred. This means that reactor operation could be continued if failures of these types happened.

- Even with fresh fuel and low O_2-concentration in the sodium some uranate was formed; but the amount would be too small to cause any harm to neighbouring pins.

- The release of the precursors of the DN emitters was controlled by diffusion mechanisms. This partly explains the wide range of k-factors because the diffusion depends strongly on the fuel structure and its change, especially during the first days of irradiation.

- The results of the tests nos. 4 and 5 led to the assumption that by means of gas gamma spectroscopy and DN measurement the classification of the type of the failure could be improved.

Summarizing one can state that with fresh fuel and small failures reactor operation can be continued for several weeks without consequences on safety and availability.

[1] S. Jacobi, editor: Fuel Failure Detection and Location in LMFBRs. Proc. of Int. Atomic Energy Agency Specialists' Meeting, Karlsruhe, May 11-14, 1981, KfK 3202, June 1982

3. Correlation of individual results

K. Schleisiek, KfK/IRE

3.1 Introduction

The reliable detection of disturbances in the core of LMFBR's is rendered difficult because of the fact that many events cause only small signal changes which have to be discriminated against background and normal signal variations. On the other hand advanced detection methods are under development as described in Sect. 2 which allow in many cases diverse disturbance recognition. Some examples for diverse fault detection are compiled in Table 3.1 and Fig. 3.1 to 3.3. Fig. 3.1 shows some signals measured in an in pile experiment where a local blockage caused severe fuel pin failures. In general this can be detected by five diverse systems (DN, CM, AN, TN and FI, see Fig. 1.1). In the experiment the flow rate was not affected significantly, see Fig. 3.1. So FI did not recognize the event. Signals for CM and TM have not been recorded in the experiment. The remaining signals from DN and AN are shown in Fig. 3.1. The increase of the acoustic noise is caused by flow noise due to fission gas bubbles in the sodium whereas DN indicates the presence of DN emitter in the sodium resulting from contact between fuel and sodium in the defect area. The time delay between the start of signal rise of bath systems is due to signal transport time from the pin failures to the respective sensor positions. These are system-specific values which can vary significantly between different loops and plants.

Fig. 3.2 and 3.3 show examples of diverse detection of argon bubbles circulated with the primary sodium through the core of a small LMFBR. Again significant time delay can be seen between the different sensors: At first the arrival of the gas bubbles is indicated by acoustic signal (vibrations of the structures). This is followed by a decrease of the neutron flux (and power) when the bubbles are crossing the central core region. Finally, the fuel subassembly outlet temperature reacts to the power variations after the sodium transport time from the core center to the subassembly outlet. The use of such correlations within the decision making level to increase the sensitivity and reliability of fault detection is one of the main objectives of the development of an integrated core surveillance system. This task is in the following addressed as "event analysis". The second objective is to use the sequence of identified events and the observed correlations to determine the kind of disturbance developing and the plant status reached (disturbance analysis). For this purpose cause-consequence-diagrams or pattern recognition techniques can be used. Thirdly, based on the results of the event and disturbance analysis recommendations can be communicated to the operator with respect to adequate actions on the plant.

For the realization of such a system knowledge is necessary of the properties of the detection system to be incorporated and their "normal" behaviour. Examples for the required kind of information are:

- The time response of each individual system to the occurrence of faults consisting of the transit time from the fault location to the sensor, the time lag of the sensor, and the signal processing time. Some of these parameters are load-dependent.
- The behavior of the individual detection system during plant transient. The surveillance quality depends on the degree to which reference values or classification criteria follow the true status of the plant during the transient. Good agreement may be reached by extensive modelling effort or by adaption during the initial operation phase.
- Long-term effects like burn up, aging, and drifts of the electronic equipment.

Most of these information are qualitatively known but the pre-determination with the precision required would be very expensive. Therefore it seems to be necessary to start the operation of the DML with a learning or training phase to adapt the system to the specific conditions of a specific power plant. Possibly this adaption has partially to be repeated from time to time in the succeeding operational phase of the system.

In the following section it is described in more detail how this objectives can be realized in the DML and which informations and data are to be transmitted from SEL via CCL2 to DML for this purpose.

3.2 Data transfer SEL - DML

In Tab. 3.2 some properties are listed of the individual detection methods which are of importance for the common evaluation within the DML. With respect to the "Flux Tilting Procedure" (FT) no information is included because this system works autonomously within the SEL.

In the first line of Tab. 3.2 the spatial relations are given for the individual systems. This information is important for plausibility checks and for the localization of a fault. The system response times in the second line are needed for signal correlations from the different detection systems. The signal band width is used to determine the frequency range of signal correlations.

Considering the properties of the individual detection systems (Sect. 2, Tab. 3.2) the following requirements can be derived with respect to the informations and data to be transmitted from SEL to DML (see Tab. 3.3):

a) The deviations of the actually measured values from reference or normal values with a rate of 1 s^{-1}. For the individual systems these are:

   - AN: Deviations from background in db
   - NF: It is assumed that NF is a reactivity comparator. Deviations from rated values (≡1) in cent.
   - TM/FI and TM: Difference between measured and rated temperature increase of each subassembly in K.
   - TN: RMS values of the temperature fluctuations devided by the temperature increase of each subassembly (k factor).
   - DN: Effective free fuel surface after substraction of the background in cm^2 (recoil).
   - DM: Cover gas activity after substraction of the background (mainly Ar41) in counts per second.

   Beyond this, with larger intervals additional information on the individual systems are transmitted for storage in the DML, for example: the element parameters of TM/FI, the activity concentration of specific nuclides of CM. The amont of this information is still to be determined.

b) The classification of the deviations (described above under a) determined by the individual systems (only in the case of changes). The following classification system is suggested:

-1 : system not available
0 : normal
+1 : slight deviations
+2 : increased
+3 : high
+4 : very high

The class +1 is reserved for the case that an deviation is recognized only by the DML system. The criteria of the classes +2 to +4 have to be implemented within the SEL. Complementary informations to be transmitted are: clock time, localization, criterion etc.

c) On request by the DML-system or by operator: transmissions of sequences of signals as measured (normally of common time basis) from specified individual systems for correlation analysis. The data rate corresponds to the system band width and amounts to 50 s^{-1} for AN, FN, TN, and 1 s^{-1} for the other systems.

3.3 Data storage in the DML

Two data storage systems are planned for the DML: a short-term and a long-term storage.

a) Short-term store

This system stores the deviations from nominal cf. Sect. 3.2.a. The maximum data rate is 1 per channel and second. The storage capacity is determined by the detection system with the longest response time, i.e. CM with about 2000 s. Consequently a storage capacity corresponding to one hour should be sufficient.

b) Long-term store

This systems stores the following information on the long-term behaviour of the plant:

= The mean, maximum and minimum values of the deviations with a rate of 1 per hour. Additionally the supplementary informations mentioned in Sect. 3.2.a.

= The classified deviations including clock time and identification, however only in the case of class changes. For the dimension of the store it can be assumed that such changes occur with a frequency of 10^{-3} to 10^{-4} per class determination.

Data processing takes place in the central processing unit. All data needed for the evaluation are temporarily transmitted into the memory of this unit as well as the sequences of measurements described in Sect. 3.2.c. Furthermore the central processer contains the whole software necessary for process control, data analysis and evaluation.

3.4 Information processing and evaluation in the DML

As mentioned above it seems to be necessary to start the operation of the DML with a learning and adaption phase. The main tasks during this phase are:

- Learn normal signal pattern and correlations during steady state and transient operation including reactor trip.
- Check and if necessary adapt the criteria and algorithms for decision making.
- Implement and check recommendations for operator actions under abnormal plant situations.

During this phase mainly standard functions and programs are needed. Some of the required capabilities are:

- Plots of the actual values of the individual systems vs. time.
- Plots of the classes of detected events vs. time.
- Automatic stop of the short-term storage about 30 min. after reactor scram; plots of selected data for post-scram analysis.
- Calculation and display of higher-level informations like RMS, PSD, variance, cross and coherency functions from the actual values.

These capabilities are also needed in the succeeding operational phase.

During the learning phase intense interaction with experts is necessary. At the end of this phase the system should be able to recognize independently (i.e. without the assistance of experts) abnormal plant situations and disturbances and give recommendations to the operator for appropriate actions.

The process of evaluation of data and decision making is executed on two levels: the event analysis and the disturbance analysis.

a) Event analysis

The event analysis is performed on the basis of the information contained in the short-term storage. The data base of the DML contains a catalog of credible events including the related reactions of the individual detection systems. If one of the detection systems identifies a deviation from normal behaviour (i.e. a change in the classification) then the DML starts automatically the search of correlated signals in the remaining detection systems which have not been recognized within the SEL. On the basis of the stored catalog of events it is decided which systems have to be checked. In the search procedure the response time of the different detection systems must be taken into account. In some cases it is possible to take advantage of the spatial relations between different sensors and systems. The search and decision process is illustrated by the following two examples:

1. CM indicates an increase of the cover gas activity and a change of class from 0 to 2. It is likely that a pin failure occured with fission gas release. The response time of CM is about 30 min. The DML initiates the search for abnormal signal patterns of the different channels of TN. If such variations are found then the subassembly has been identified which contains the failed fuel pin. If furthermore no DN change is detected then the event is definitely a "leaker" in the identified subassembly.

2. TM/FI indicates a small variation of the flow rate within a subassembly; an increase of the DN signal is not detected. TM and TN of the same subassembly are checked for anomalies. If only TM indicates a deviation then an external blockage is likely of the subassembly concerned. If additionally an increase of TN can be found then the fault probably is an inactive internal blockage.

The deviations identified by the DML are marked as class 1 events; the classification and the result of the event identification is stored for the succeeding disturbance analysis.

b) Disturbance analysis

For the automatic disturbance analysis within the DML, two procedures are actually under consideration which are described briefly in the following section.

Disturbance analysis by pattern recognition

Basis of the analysis is the temporal sequence of classified deviations determined by the individual systems. The absolute time differences are not taken into account because the time scale for the development of faults can vary significantly and is difficult to be predicted. The informations are represented as a 3-dimensional vector with the parameters: detection system, temporal sequence, and classes of deviations. For the initial operation phase synthetic vectors are formed of all known or credible disturbances and stored in the DML system. An example of a synthetic vector is shown in Fig. 3.4. With increasing operation experience the artificial vectors will be replaced by observed ones. The identification of an actually developing disturbance is then performed by a pattern recognition process: By comparison of the patterns it is decided which of the stored vectors has the largest similarity with the observed one and hence, represents with high probability the developing disturbance.

Disturance analysis by cause-consequence-diagrams

For all credible disturbances cause-consequence-diagrams are constructed and stored in the DML. The diagrams are composed of events which are identical to those used in the event analysis (see Sect. a above). The disturbance is identified by comparing the observed sequence and combination of events with the stored diagrams.

Comparing both methods it seems that the pattern recognition technique has the higher potential because it is able to make a decission also in those cases where none of the stored disturbances is exactly met. This is of particular importance because many of the fault propagation processes under consideration are - at least to a certain degree - of stochastic nature. On the other hand this solution is more expensive with regard to programming and computing time.

The recommendations to the operators with respect to the actions to be executed in the case of disturbances depend on the degree of damage reached. Actually it is planned to attribute such recommendations to the cause-consequence-diagrams and to edit them together with the result of the disturbance analysis. For the future it is envisaged to develop more sophisticated criteria which take into account e.g. the temporal development of the disturbance and the degree of agreement between the actual case and the experience stored in the system.

event	physical phenomenon	measurable effect	detection system
pin failure (leaker)	fission gas release into sodium	increase of temp. noise at subassembly outlet	TN
	transition of fission gas into cover gas plenum	increase of cover gas activity	CM
active blockage in the fission zone of a subassembly	changes of flow and temp. distribution within the subassembly	increase of temp. noise at subassembly outlet	TN
	fission product release into sodium	delayed neutrons in sodium	DN
	reduction of subassembly coolant flow rate	temp. increase at sub-assembly outlet	TM
		increase of sodium transit time within the subassembly	FI
local sodium boiling	generation and collaps of sodium vapor bubbles	boiling noise	AN
		reactivity changes	NF
		increase of temp. noise at subassembly outlet	TN

Tab. 3.1: Examples of diverse fault detection

	AN	NF	TM/FI	TM	TN	DN	CM
spatial identification C = core CS = core sector SA = subassembly	C	C	SA	SA	SA	CS	C
response time /‾s_7	1	1	5	5	5	30	2000
signal band width /‾Hz_7	10^5	10^2	10	1	15	3	0,1

Tab. 3.2: Important properties of individual detection systems

	AN	NF	TM/FI	TM	TN	DN	CM
a) deviations from nominal values							
parameter	S/N	$\Delta\rho$	ΔT	ΔT	k	F	count rate
unit	[db]	[cent]	[K]	[K]	[-]	[cm^2R]	[cps]
time interval [s]	1	1	1	1	1	1	10
b) classification of deviations	(changes only)						
identification	class, clock time, localization, criterion						
time interval [s]	1	1	1	1	10	1	10
c) signals as measured	on request by DML or operator						
parameter	RMS	N-flux	ΔT		T_{noise}	Count rate	count rate
unit	[mbar]	[%]	[K]		[K]	[cps]	[cps]
data rate [s^{-1}]	50	50	5		50	1	0,1

Tab. 3.3: Data transfer SEL - CCL2 - DML

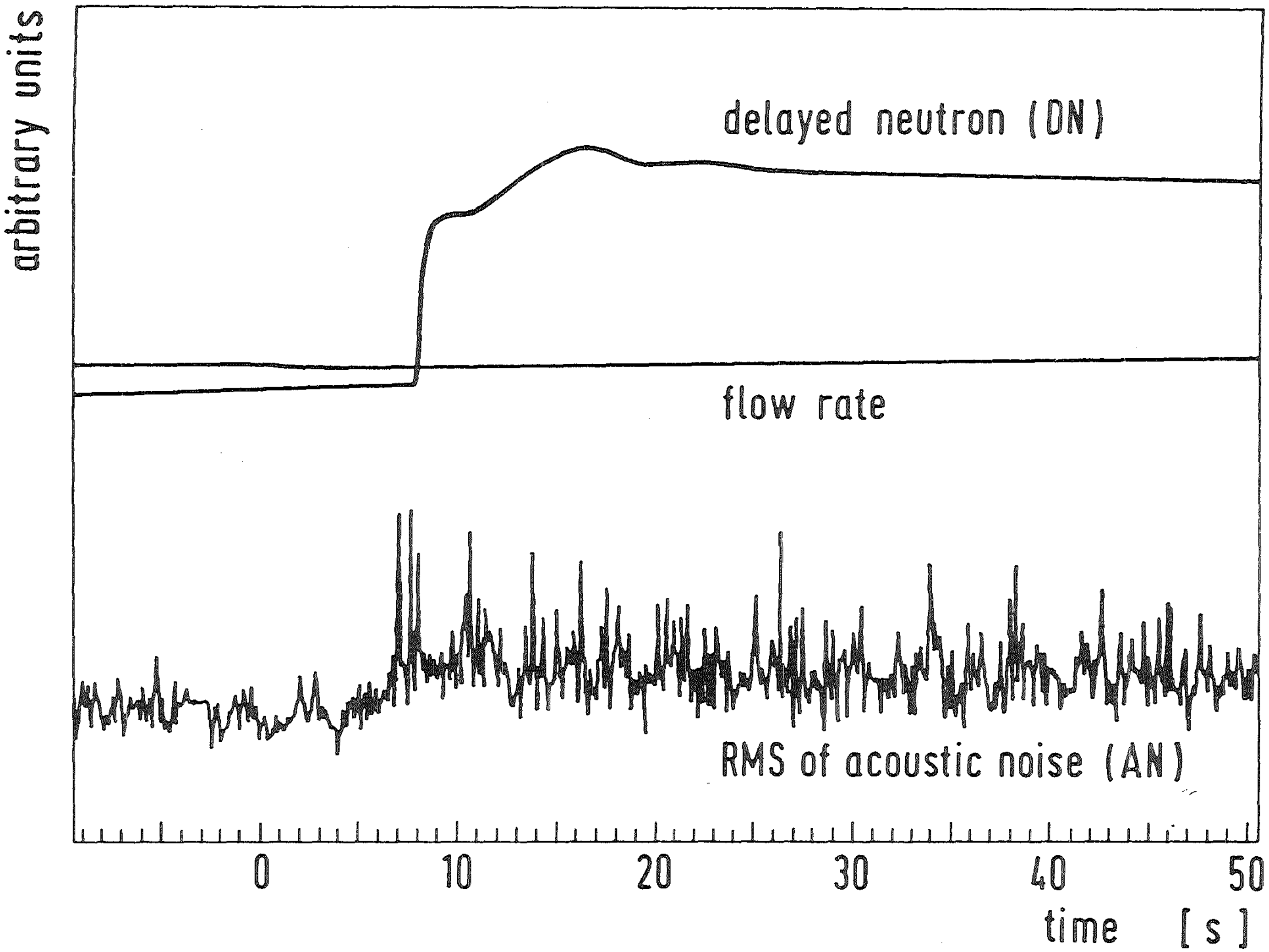


Fig. 3.1: Diverse detection of severe pin failures by acoustic noise and delayed neutron detection

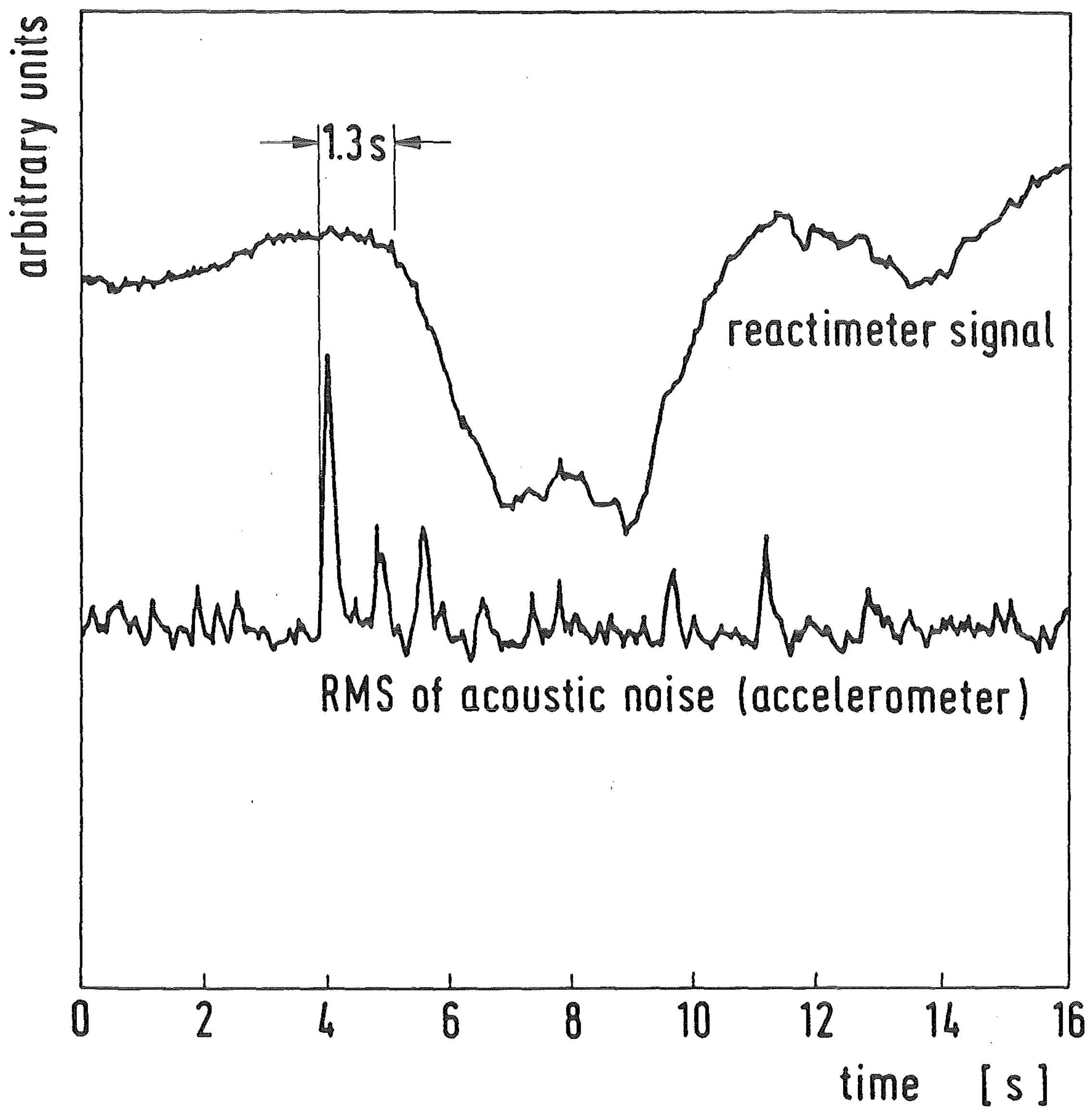


Fig. 3.2: Diverse detection of gas bubbles by noise detection and reactimeter signals

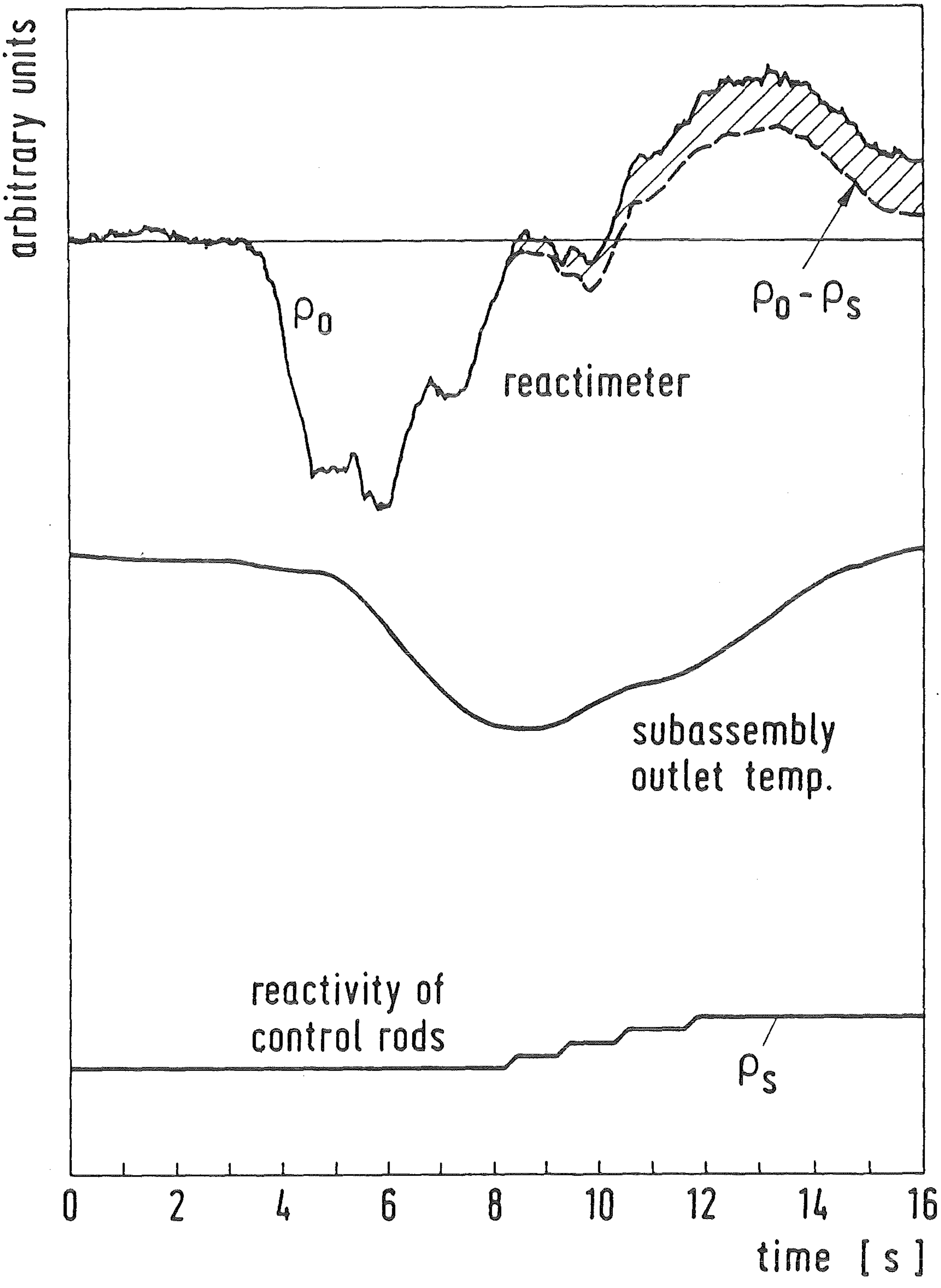


Fig. 3.3: Diverse detection of gas bubbles in the core by reactimeter and subassembly outlet temperature signals

AN	NF	TM/FI	TN	TM	DN	CM	events/comments
0	0	0	0	0	0	0	normal state
1	0	0	1	0	0	0	failure of a
0	0	0	0	0	0	0	high burn up
0	0	0	0	0	2	0	fuel pin
0	0	0	0	0	1	0	
0	0	0	0	0	1	2	
0	0	0	0	0	1	1	
0	0	0	0	0	2	1	
0	0	0	0	0	1	2	
0	0	0	0	0	1	1	
1	0	0	1	0	1	1	propagation of
0	0	0	0	0	1	1	the failure,
0	0	0	0	0	2	1	blockage formation
0	0	0	0	0	2	2	
0	0	0	1	0	2	2	
0	0	1	1	1	2	2	
0	0	1	2	1	3	2	
2	0	1	3	1	3	2	local boiling
1	0	1	2	1	3	2	and melting
1	0	1	2	1	4	2	
1	0	1	2	1	4	3	
1	0	1	2	1	4	4	

Fig. 3.4: Example of a synthetic vector of deviation classes ("active local blockage")

4. Systems Analysis

V. Elies, KfK/IDT

4.1. Requirements Analysis of the RIL

As a first step in defining the Reading and Input Level RIL (cf. Fig. 1.2.) and the Common Communication Level 1 (CCL1) the requirements of the single preprocessing units in the RIL are analyzed from the viewpoints of the different systems in the Separate Evaluation Level (SEL). Common requirements are identified and the preprocessings of the same input signals for different SEL-systems are combined where possible.
The input signal identifiers (i1,...) are the same as in Part 1 of this study, chapter 3.

Concerning the numbers of signals to be processed this analysis is based on numbers which are considered for the SNR 2 reactor.

4.1.1. Acoustic Signals (i1)

The acoustic signals are used only by the Acoustic Noise Detection (AN). Due to the high signal bandwidth (100 kHz) part of the preprocessing has to be done by specialized hardware.

The instrumentation for the acoustic signals consists of 10*2 sensors. The preprocessing is divided into two parts:

a.) RMS generation by integration of all acoustic signals and subsequent digitalisation. The generated output to be transferred to the SEL is about 100 Bytes/sec.

b.) Analog to digital conversion of the signals for subsequent FFT. For each channel a sample of 500 values has to be transmitted once per second. This yields a total amount of 10 KBytes/sec.

Since these data are used only by the AN system and because of the required high transfer rate a direct transmission to the AN system without using a common communication medium will be preferred.

4.1.2. Pump Rotation Speed (i2)

This signal considered only for the AN system is not taken into account any more. Signal i4 (primary flow rate) will be used instead.

4.1.3. Neutron Flux (i3)

For processing of the neutron flux another separate evaluation unit NF is added to the SEL.

Scanning frequency for the triple redundant neutron flux signal is 50 .. 100 Hz for NF, 1 Hz for the following systems: AN, TM, DN/CM and FT. For all of these systems the preprocessing does consist only of an A/D-conversion with a 12-bit-resolution being sufficient. The converted digital data can be transmitted to the systems listed above via a common communication medium.

Additionally the neutron flux is used by the TM/FI system, but here it is used as a reference signal for analog preprocessing (cf. 4.1.6.), thus being needed in analog form.

4.1.4. Primary Coolant Flow Rate (i4)

Coolant flow is used by the following systems: AN, TM/FI, DN/CM and FT. Two signals, one for each primary loop, are available. Sampling rate is 5 Hz for TM/FI, 1 Hz for the other systems. The only preprocessing necessary is A/D-conversion, subsequently the data can be offered to the different systems via a common communication medium.

4.1.5. Core Inlet Temperatures (i5)

There is a triple redundant signal for each primary loop. The redundancy is needed only by the TM system, the other ones use only one signal per loop.

The preprocessing for TM consists of the following steps:

- A/D-conversion,
- plausibility checks, identification of defective thermocouples,
- mean value computation of the three redundant input channels,
- conversion to Kelvin

The mean temperatures evaluated by the preprocessing for TM can be used by the following systems as well: AN, DN/CM and FT. The sampling rate is 3 Hz for TM, the other systems do only need a rate of 1 Hz. The mean temperatures are offered to these systems via a common medium.

The TM/FI and TN systems need analog signals again for analog preprocessing (cf. 4.1.6.).

4.1.6. Core Outlet Temperatures (i6)

Core outlet temperatures are available as triple redundant signals for each fuel element.

Preprocessing for TM consists of the same steps as in the case of the inlet temperatures. Additionally the coolant temperature rise is computed. The mean temperatures can be used again by AN, DN/CM and FT, thus transmission via a common medium is possible.

12-bit resolution attainable by A/D-conversion is not sufficient for processing of temperatures within TM/FI and TN systems. Therefore these require a special analog preprocessing. The existing preprocessing units are shown in fig. 4.1. and 4.2.

Because of the special kind of the data resulting from preprocessing they are sent directly to the SEL units after A/D-conversion.

4.1.7. DND Signal (i7) GeLi-system Count Rate (i9) Precipitator Count Rate (i10)

These signals are used only by DN/CM and FT. Preprocessing is performed by special hardware, e.g. counting tubes, multi-channel analyzer. The output generated by these is transmitted directly to the SEL units.

4.1.8. Reactor Power (i8)

Reactor power is measured via neutron flux, thus no separate signal is necessary any more.

4.1.9. Position of Absorber Rods (i11)

There is one signal for each absorber. They are required only by FT, only A/D-conversion is necessary, sampling rate is 1 Hz.

4.1.10. Conclusions

After comparing the requirements it can be seen that in most cases the preprocessing depends very much on the system which processes the generated data. Only for the following signals the preprocessing for different SEL systems can be integrated:

- i3 neutron flux (NF, AN, TM, DN/CM, FT)
- i4 primary flow rate (AN, TM/FI, DN/CM, FT)
- i5 inlet temperatures (AN, TM, DN/CM, FT)
- i6 outlet temperatures (AN, TM, DN/CM, FT)

In spite that fact a considerable reduction of hardware expense is possible by combining the preprocessings of outlet temperatures because of the great number of fuel elements (about 370).

4.2. Concept of CCL1

Table 4.1. gives an overview of the amounts of data produced by the single preprocessing units and required by the different units in the SEL. As can be seen we can divide the data to be transferred by CCL1 into five groups:

A. Data used only by AN

These are the outputs of the two different preprocessings of i1:

- RMS values, 100 Bytes/s
- Digital form of i1, 10 KBytes/s

Transmission of data to AN can be done via a bus commonly used by both preprocessing units (Bus A).

B. Data with special preprocessing for TM/FI

The output generated by the preprocessing unit consists of 2 Bytes per fuel element, scanning frequency is 5 Hz, thus an amount of about 4 Kbyte/s has to be transmitted to TM/FI.

C. Data with special preprocessing for TN

Output of the analog preprocessing with subsequent A/D-conversion consists of the following parts:

- $\delta_i(t)$ temperature fluctuation, 11100 Bytes/s
- ΔT_i coolant temperature rise, 1480 Bytes/s
- σ_i RMS values of δ_i , 1480 Bytes/s

This makes a total amount of 14KBytes/s, thus requiring a fast direct link to TN for data transmission.

D. Data with common preprocessing for different SEL units

These data contain preprocessed inputs i3, i4, i5, i6:

- neutron flux, max. 200 Bytes/s

- primary flow rate, 10 Bytes/s
- mean inlet temperatures, 15 Bytes/s
- mean outlet temperatures, 2300 Bytes/s
- temperature rise, 2300 Bytes/s

The sum of 5 KBytes/s can be distributed to the single units in SEL via a common bus system (Bus D).

E. Data only used by DN/CM and FT
No information is available yet on the output of preprocessing of i7, i9 and i10. Probably a common transmission to DN/CM and FT together with the digital form of i11 will be possible (Bus E).

A resulting structure of RIL and CCL1 is shown in fig. 4.3. For reliability and availability reasons all the single communication subsystems within CCL1 have to be redundant.

Redundant bus systems are available within process control systems such like Siemens TELEPERM M or BBC's PROCONTROL. One approach in realizing RIL and CCL1 could be the use of such a system. The TELEPERM M bus offers a transfer rate of 250 KBit/s, which is sufficient for all the single bus subsystems mentioned above. One disadvantage of TELEPERM M is nonavailability of fiber optic links, a desirable feature for making data transfer more safe.

4.3. Concept of CCL2 and DML

4.3.1. Requirements for CCL2

The following data amounts have to be transferred from SEL to DML via CCL2 (cf. 3.2., Tab. 3.3.):

a.) Deviations of actually measured values (for each value two bytes are assumed to be necessary):

AN	:	40 Bytes/s
NF	:	2 Bytes/s
TM/FI	:	740 Bytes/s
TM	:	740 Bytes/s
TN	:	740 Bytes/s
DN	:	2 Bytes/s
CM	:	2 Bytes/s

In addition to these 2.3 KBytes/sec approximately there will be more information being transmitted which is not yet defined. Nevertheless a total amount of 5 Kbytes/sec can be estimated as an upper bound.

b.) Classification of the deviations in case of changes:

A status change is assumed to occur with a frequency of 10^{-3} to 10^{-4} per class determination (cf. 3.3), which is done in time intervals of 1 s. Thus a change is to be expected approximately once every hour. A transmission of the complete new state vector after a change having occurred results in a data amount of about 1.2 KBytes/h.

c.) Transmissions of sequences of signals as measured:

The amount of data being transmitted on request can be estimated as the overall data amount produced by the RIL. The data listed in 4.2., A to D, result in 33 KBytes/s. Together with the data transferred by Bus E a total amount of about 40 KBytes/s has to be expected.

The data which have to be transferred via CCL2 amount to about 50 KBytes/s. Possibly the single SEL systems are spatially distributed. Therefore a local area network should be provided for CCL2, thus also allowing to pass some of the transmitted data to OGL, if required. Because of the required realtime behaviour a token passing bus or ring structure is proposed. Those structures are available with data rates of 20 MBits/s (IEEE 802), thus leaving sufficient room for transmission of any additional information. A redundant construction of CCL2 will obviously be necessary.

4.3.2. Requirements for DML

No detailed information is available yet on the algorithms performed in DML. Thus only the storage requirements for the data received from SEL can be estimated.

a.) Short-term store

The short-term storage should be able to keep the data mentioned in 4.3.1.a for the past hour. During one hour these data amount to approximately 8 MBytes. Microcomputer systems with an address space of 16 MBytes are available, but if time constraints are not too strong, a solution using a virtual memory organisation should be chosen.

b.) Long-term store

Long-term store contains the following data:

- mean, maximum and minimum values of deviations, 2 Bytes each, resulting in 6*1.2 KBytes per hour,
- classified deviations evaluated by SEL. If one change per hour is assumed one vector of 1.2 Kbytes is being generated per hour.

Under these assumptions the following data amounts are being produced approximately:

8.5 KBytes per hour,
200 KBytes per day,
1.4 MBytes per week,
6 MBytes per month,
72 MBytes per year.

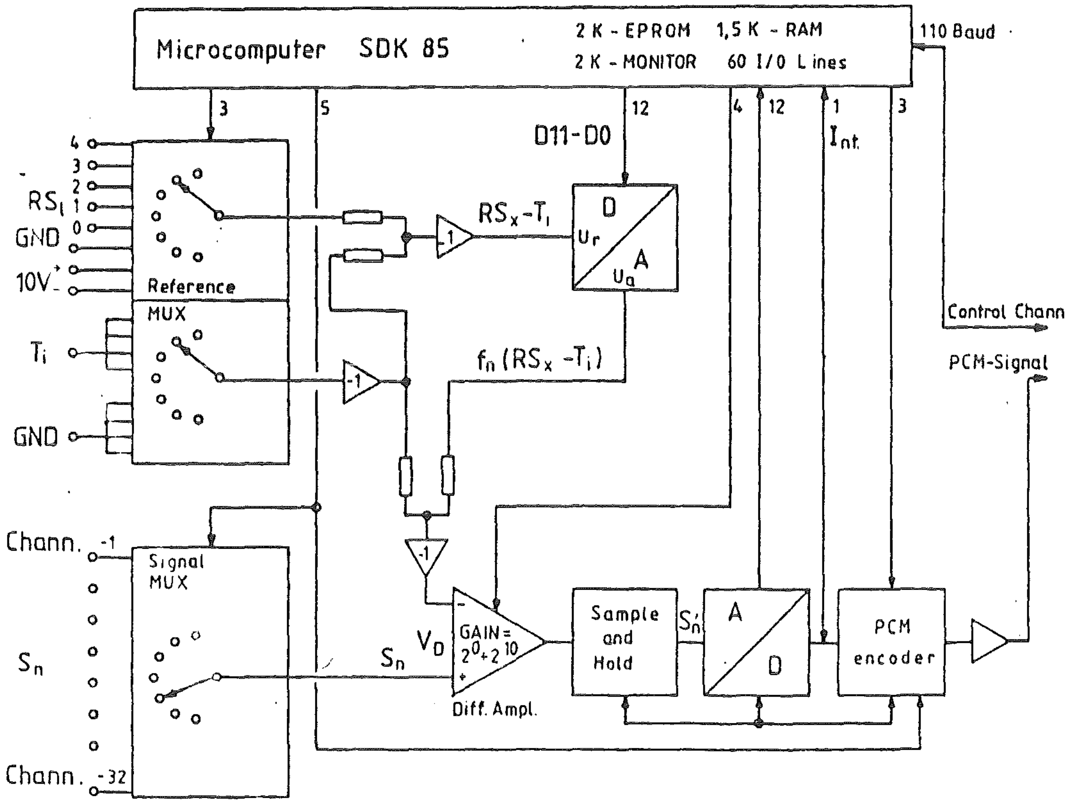
Long-term storage should contain the history of the past year, this is possible by use of a winchester disk device, thus the data being available within some 50 ms. The actual data for one day or one week, if desired, can be kept in main memory for faster access.

Input	Instr.	AN	NF	TM	DN/CM	FT	TM/FI	TN
i1	10*2	11 K/s						
i3	1*3		$\frac{1 * 3}{0.01s}$	1*3/s	1*3/s	1*3/s		
i4	2*3	2*1/s			1*1/s	1*1/s	1*1/s	
i5	2*3	2*1/s		$\frac{2 * 3}{0.33s}$	1*1/s	1*1/s		14 K/s (i5–i6)
i6	370*3	$\frac{370*1}{s}$		$\frac{370*3}{0.33s}$	$\frac{370*1}{s}$	$\frac{370*1}{s}$		
i7								
i9						?		
i10								
i11	30*1					30*1/s		

Instrumentation : n*r   n : number of measuring points
r : redundancy

Data output : n*r/t   1/t : sampling rate

Table 4.1. Data required by SEL units



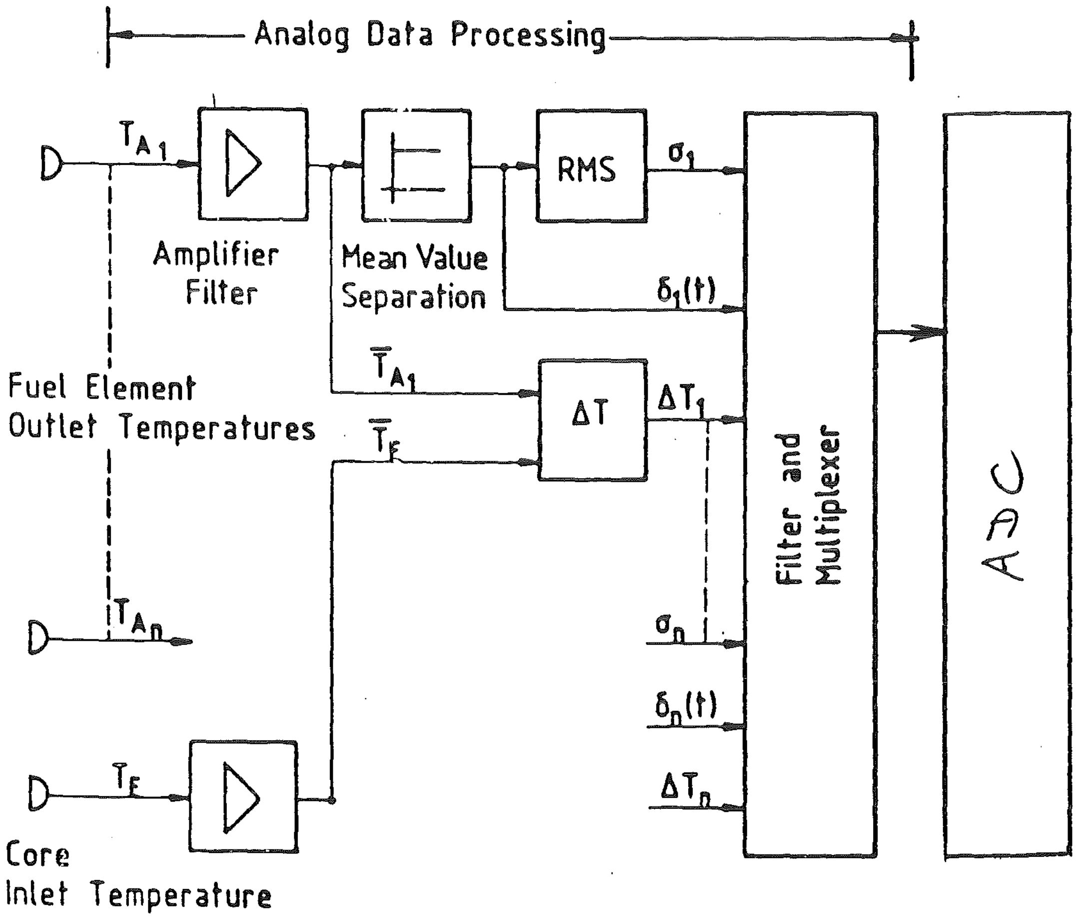
S_n = inlet temperatures $T_i(t)$,
outlet temperatures $T_o(t)$,
neutron flux $\phi(t)$

$RS_l \subset S_n$ reference signals

$S_x(t)$ outlet temperature

$$S_n'(t) = \begin{cases} (S_n(t)-f_n(S_x(t)-T_i(t))-T_i)G_n & \text{(outlet temperature is reference signal)} \\ (S_n(t)-f_n'\phi(t)-T_i(t))G_n & \text{(neutron flux is reference signal)} \end{cases}$$

Fig. 4.1. Analog preprocessing for TM/FI



$\bar{T}_{Ai}$	fuel element outlet temperatures
$\bar{T}_E$	core inlet temperature
$\delta_i(t)$	temperature fluctuation signal
ΔT_i	temperature rise
σ_i	RMS values of δ_i

Fig. 4.2. Analog preprocessing for TN

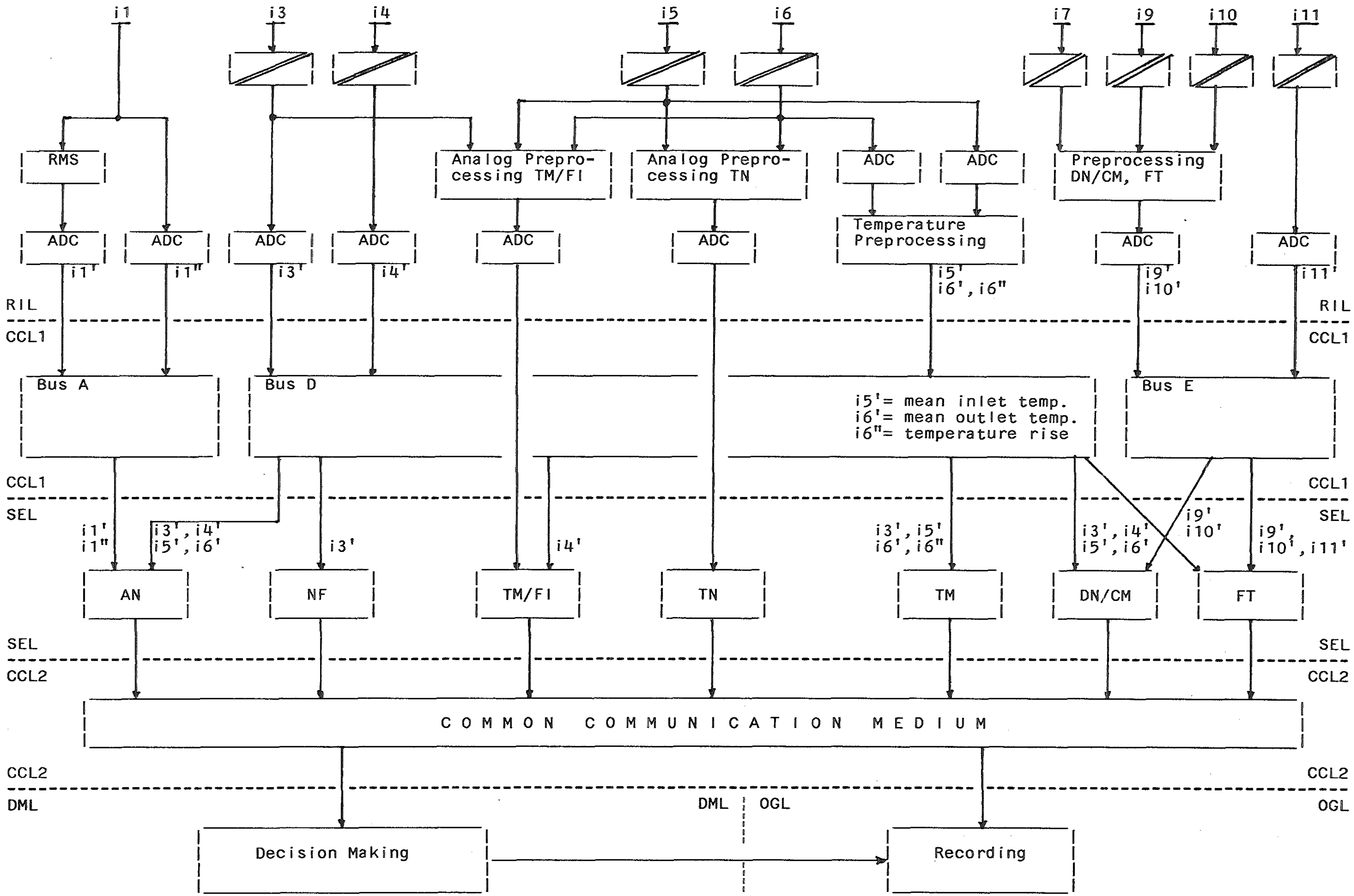


Fig. 4.3. Structure of integrated system

4.4 Software

4.4.1 Software within the subsystem "Subassembly state and performance Monitoring"

M. Edelmann, KfK-INR

Corresponding to the major functions of KASUMOS described in paragraph 2.1 three software modules exist for subassembly state and performance monitoring:

- Parameter estimation module
- SA simulator module
- Monitor and diagnosis module.

These modules can handle up to 32 signal channels in the present configuration of KASUMOS. This is sufficient to monitor the performance of all of the KNK II subassemblies on-line. However, the core of a breeder reactor consists of some 500 fuel elements. Therefore, the sequential signal processing used in KASUMOS has to be replaced by parallel processing procedures in an integrated LMFBR core surveillance system. Furthermore, the existing software is partly depending on the present hardware configuration and data structure produced by an additional data aquisition module in KASUMOS. Thus, most of this subsystem software has to be newly written.

The parameter estimation module has to cover the following functions

- auto and cross power spectral density calculation (FFTF) of neutron and outlet temperature signals
- signal correlation
- calculation of SA transfer function from power spectral densities
- least-squares parameter fit of SA model transfer functions to measured ones (frequency domain)
- transient signal recording
- signal averaging
- least squares model parameter fit with transient signals (time domain) and correlation functions.

The functions to be performed by the simulator and monitor modules are schematically described by Fig. 4.4.1-1. The SA simulator consists of a second-order digital low-pass filter. The signal surveyor compares original and balanced SA outlet temperatures with individual thresholds and monitors statistical signal parameters. In case of specified anomalies recording of all or of suspicious signals is triggered.

The overall SA state and performance monitoring procedure realized in KASUMOS is represented by the flow chart shown in Fig. 4.4.1-2. Its basic structure is still valid but some modifications and extensions will be necessary to include recent experience and to adapt the existing software to the hard- and software structure for the integrated core surveillance system.

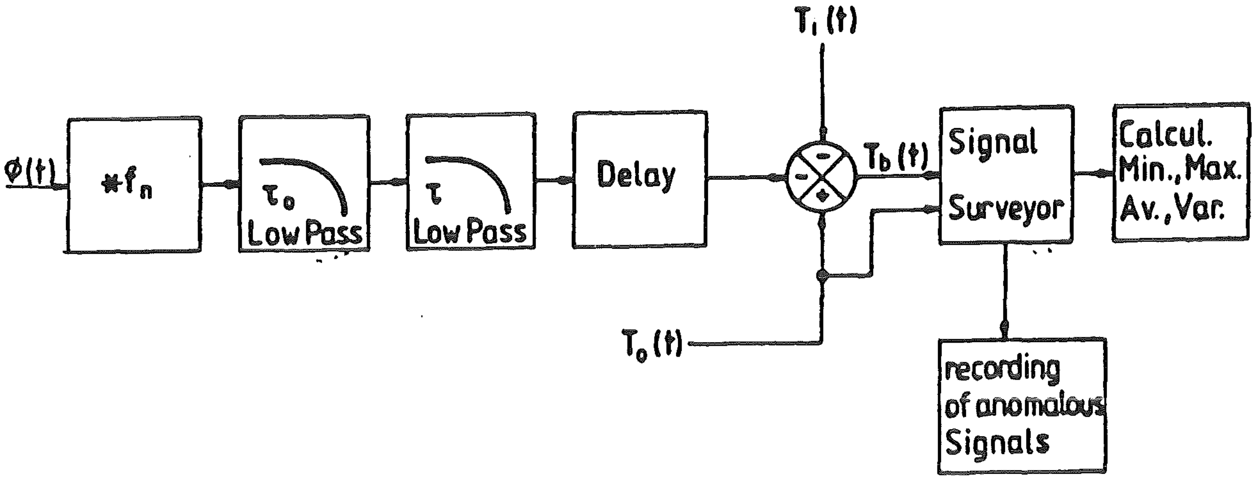


Fig. 4.4.1-1 Fuel element simulation and sensitive SA coolant flow monitoring

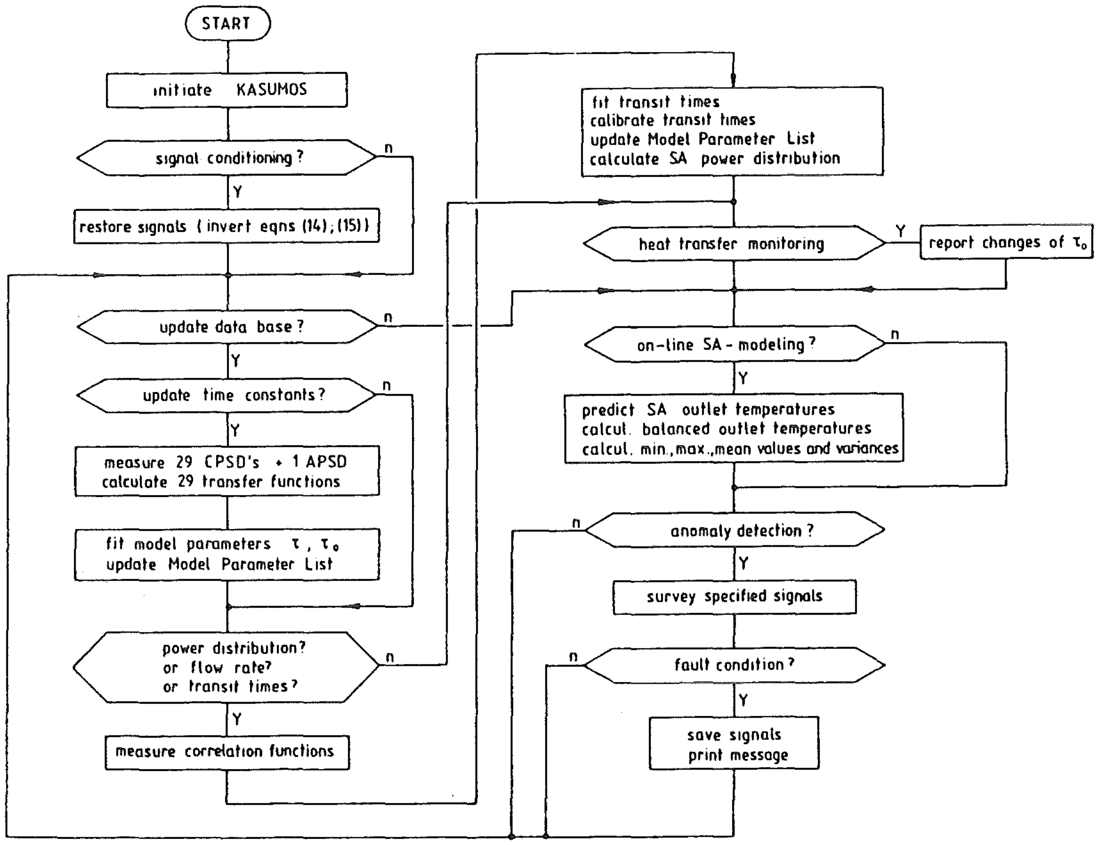


Fig. 4.4.1-2 Flow chart of KASUMOS SA state and performance monitoring

4.4.2 Software within the subsystem

"Individual subassembly temperature monitoring"

U. Voges, KfK/IDT

For the detection of local cooling disturbances the individual subassembly temperatures are monitored. For this the following five algorithms are proposed. They are implemented in the MIRA system at KNK II and some of them will be realised in the LOKUS system at SNR300.

The following definitions are used in the description of the algorithms:

$T(i)$	individual coolant temperature of fuel element i
$High(i)$	individual upper temperature limit for fuel element i
$T(in)$	coolant temperature at core inlet
$\Delta T(i)$	$= T(i)-T(in)$

$$MT(i) = \frac{1}{ng} * \sum_{i \varepsilon g} \Delta T(i)$$

mean group temperature of the group to which fuel element i belongs to

g	group
n_g	number of fuel elements in group g
$K_1,\ldots,K_8$	tolerance limits
p	filtering constant, about 10^1
q	filtering constant, about 10^2
N	total number of fuel elements in core.
$f(i)$	individual correction factor

1. Monitoring of the test zone

```
if T(i) > High(i)
     then "urgent alarm".
```

This is a special algorithm for KNK II, where the center of the core contains certain test elements which have differing individual temperature limits.

A more homogeneous core would not need this kind of special treatment.

2. Comparison with group mean value

if $\Delta T(i) > f(i) * MT(i)+K_1$
then "urgent alarm"

orif $\Delta T(i) > f(i) * MT(i)+0.6 * K_1$
then "alarm"

orif $\Delta T(i) < f(i) * MT(i)-K_2$
then "message"

Several fuel elements are grouped together according to similar behaviour, e.g. similar reaction to control rod movements.

3. Comparison with fixed upper and lower limits

if $T(i) > K_3$
then "urgent alarm"

orif $T(i) < K_4$
then "message"

These comparisons can be considered as a fixed second line of defense or as plausibility check. Before they are activated other limit checking algorithms should produce alarms.

4. Comparison with short-term mean value

$$\Delta T_s(i,tn) = \frac{1}{p} * \Delta T(i) + \frac{p-1}{p} * \Delta T_s(i,t_{n-1})$$

if $\Delta T(i) > \Delta T_s(i,t_n) + K_5$
then "urgent alarm"

orif $\Delta T(i) > \Delta T_s(i,t_n) + 0.5*K_5$
then "alarm"

orif $\Delta T(i) < \Delta T_s(i,t_n) - K_6$
then "message"

This algorithm shall detect fast developing disturbances (more than 10K/min) better than algorithm 2.

5. Comparison with long-term mean value

$$\Delta T_L\ (i,t_n) = \frac{1}{q} * \Delta T(i) + \frac{q-1}{q} * \Delta T_L\ (i,t_{n-1})$$

(with q 100: long term individual mean temperature)

$$LMT = \frac{1}{N} * \sum_{i=1}^{N} \Delta T_L\ (i,t_n)$$

(long term global mean temperature)

if $\Delta T_L\ (i,t_n) > f(i) * LMT + K_7$
then "urgent alarm"

orif $\Delta T_L\ (i,t_n) > f(i) * LMT + 0.6 * K_7$
then "alarm"

orif $\Delta T_L\ (i,t_n) < f(i) * LMT - K_8$
then "message"

This algorithm is suitable for rather slowly developing disturbances and temperature gradients (about 1K/min).

In a large LMFBR it might be necessary to have several long term group mean temperatures instead of one global in order to have a narrower bandwith, similar to algorithm 2.

Further analysis and tests are necessary to decide on the optimal values for p,q, $K_1,\ldots,K_8$ concerning availability and safety. To a certain extent they depend also on the reactor and its instrumentation.

For the output of the produced information different means have to be used. On an alphanumeric VDU the following information should be shown:

- urgent alarms
- alarms
- messages.

The general form of the information should be

time   fuel element position   alarm/message text

In addition different pictures and tables are wanted on a graphic colour VDU

core picture with temperature range indicated by colour
core picture with algorithm status indicated by colour
table with current temperature
table with current algorithm status.

Besides this presentation of actual information some data logging is necessary, mainly identical to the output of the alphanumeric VDU. This information shall be available for later on-line look-up or off-line analysis.

4.4.3 Software within subsystem "Temperature Noise"

G. Weinkötz, L. Krebs

Studies of the temperature fluctuations signals $\delta(t)$ at the fuel subassembly outlet have shown that with defined conditions in signal analysis taken into account a bundel coefficient K can be deduced from the temperature fluctuation signal. Independent of the respective power condition of the reactor, this coefficient essentially covers solely cooling disturbances within the fuel subassembly.

Accordingly, the bundle coefficient k, here after termed k-value, is defined as follows:

$$\text{k-value} = \frac{\text{RMS value of } \delta(t)^{*}}{\text{coolant temperature rise } \Delta T}$$

For evaluating incipient cooling disturbances in the fuel subassembly the power spectral density (PSD) of the temperature fluctuation signal $\delta(t)$ is of importance besides the k-value.

On the RIL preprocessing level the reactor signal variables required, namely

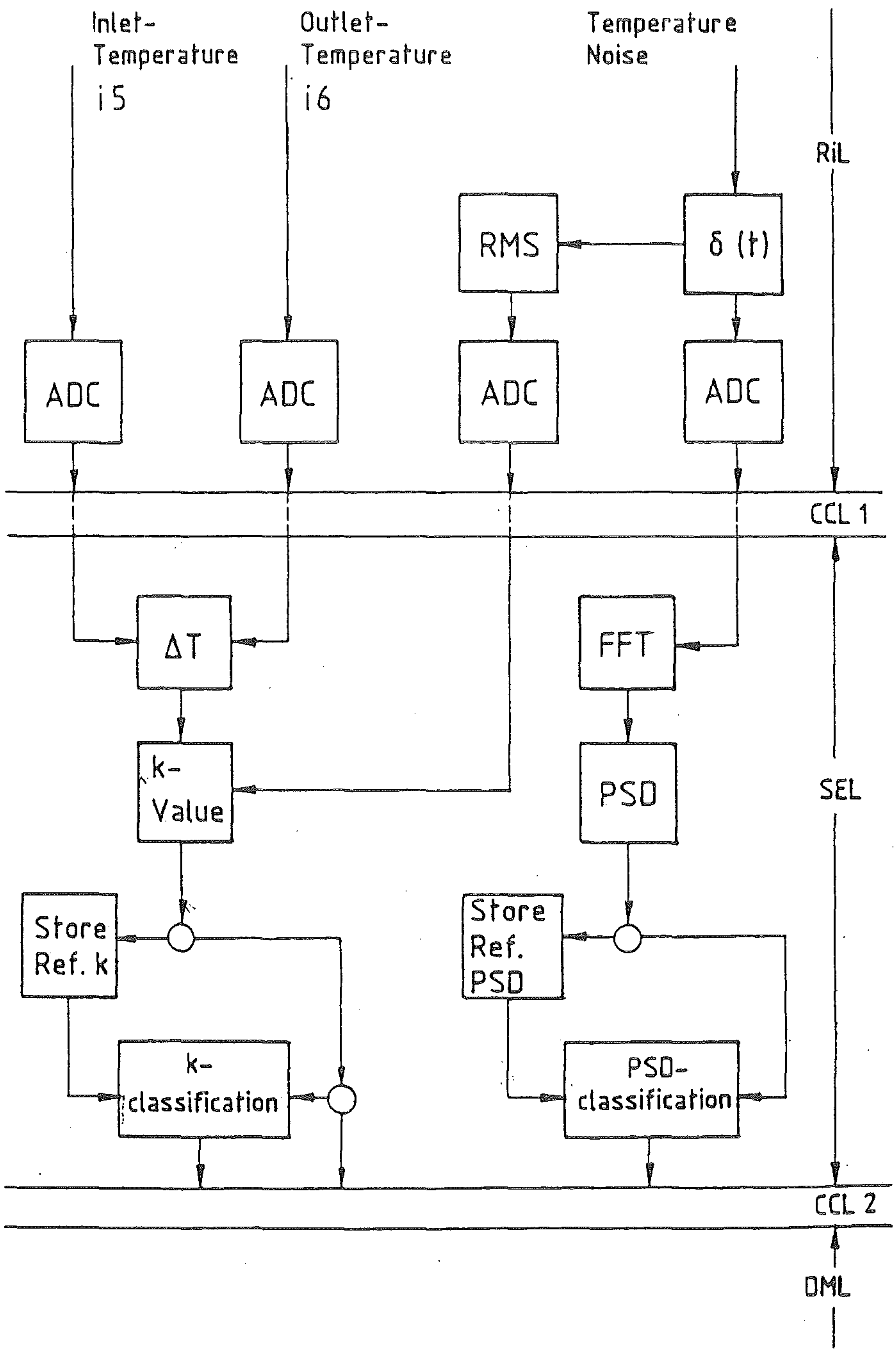
coolant inlet temperature	i5
fuel subassembly outlet temperature	i6
temperature fluctuation signal	$\delta(t)$
RMS value of $\delta(t)$*	

are generated in conformity with the requirements of digital processing.

---

* Low pass filtered temperature fluctuation signal (low pass design dependent on the reactor operating data).

The Figure shows the functional sequence of Temperature Noise (TN) measurement of a fuel subassembly to be monitored. For i-fuel subassemblies the signal sequences are repeated by the factor i. Digital process handling for the TN subsystem takes place on the SEL level.



Configuration of Temperature Noise Measurement

The coolant temperature rise ΔT is formed by the coolant inlet temperature i5 and the subassembly outlet temperature i6.

$$T = i6 - i5 \qquad (1)$$

To calculate the k-value the RMS value of $\delta(t)$ generated in the TN preprocessing system is taken over so that we obtain:

$$\text{k-value} = \frac{\text{RMS value of } \delta(t)^{*}}{i6 - i5} \qquad (2)$$

Executing Equation (2) the signal variables are scanned at $1\ s^{-1}$.

The power spectral density (PSD) is calculated via the Fast Fourier Transformation (FFT) of the unfiltered temperature fluctuation signal $\delta(t)$, the scanning frequency being $50\ s^{-1}$.

The k-values K(i) and the characteristic functions PSD(i) are classified using reference variables R(i) and reference functions RF(i). The latter are determined during the startup phase of the reactor at the undisturbed (i) fuel subassemblies and stored into the reference memories Ref. k and Ref. PSD of the TN subsystem. To monitor the fuel subassemblies the K(i) values are continuously compared with the stored reference variables R(i) and evaluated on the basis of a specified bandwidth b.

If the calculated K(i) actual values lie within a bandwidth specified for the R(i) reference values, a normalized signal vector = 1 is generated for a monitor display.

We obtain: Graph $K(i) = 1$ (3)

for $R(i) - b < K(i) < R(i) + b$ (4)

The graph K(i) = 1 is mapped as a circle with i circular segments, where i is the number of the fuel subassemblies to be monitored.

If a detected K(i) actual value lies outside the specified bandwidth, the respective fuel subassembly position is displayed on the monitor and an alarm signal is given.

All K(i) actual values are additionally stored in a long-term memory. If a cooling disturbance in a fuel subassembly is diagnosed by the K(i) value, the subsequent development with time of the k-values determined for the respective fuel subassembly is traced by a plotter. Moreover, the k-values of the fuel subassembly in question which had been measured before the alarm, can be called from the long-term memory and used for the further diagnosis of the disturbance in cooling.

Whereas classification of the parameters K(i) in the TN subsystem is done continuously, classification of the characteristic functions PSD(i) takes place only in case of indication of a cooling disturbance in a fuel subassembly. If a cooling disturbance has been indicated, the power spectral density of the unfiltered temperature fluctuation signals $\delta(t)$ at the outlet of the respective fuel subassembly is calculated and evaluated in terms of frequency range and power amplitude using the stored reference function Ref. PSD(i).

4.4.4. Software within subsystem 'Acoustic Noise'

H. Rohrbacher, KfK/IRE

All analog signals coming from the acoustic instrumentation need to become preconditioned in order to meet the registration and S/N levels for signal recording and the following raw data input system level. This procedure is used for reducing and compressing data and it uses in parallel the following techniques:

a) RMS formation by integration of all acoustic signals with an associated subsequent digitalization (8 bit accuracy)

b) analog-to-digital conversion and Fast Fourier Transform (FFT) with the aim to generate the autocorrelated power density spectra and the cross-correlation function for different channels of the acoustic surveillance system.

c) determination of the coherence function with the object to get created input data for a pattern recognition system being part of the main processing level (DML).

For the Acoustic Noise system AN all input data are offered in a digital format. The incoming data are analyzed and weighted by means of the procedures mentioned below:

A. In the course of following transients in the RMS values from the RIL-level (a) all all events exceeding a predetermined trip margin will become stored in (a2). The assessment of the background RMS-information itself is performed in the AN RMS-trip system (a1). It is based on a logarithmic weighting procedure following an internal digitizer implemented at the front end of (a1).

The trip signals yield a new RMS-information RMS' (a3).

In parallel, a counting rate subsystem (a4) enregisters the absolute frequency of the accumulated events.

Both, the frequency and the new RMS' information indicate the actual state for an internal classification (a5) of the acoustically measured system conditions in a first approach. The result from the RMS data evaluation is part of the input data for the main classificator ANMC on the AN-SEL level.

B. The preconditioned and analog-to-digital converted signals (a) from the RIL level are fed into the FFT subsystem with the aim to form the autocorrelated power density spectra PSD (b4) and by a next step, to calculate the coherence function (b3) and the cross-correlation function (b2) for a selected number of acoustic channels.

From an associated data limiter (b5) it is defined the degree of the correlation, to say the coherence of the detected acoustic signals. This response serves to classify the result from the FFT preprocessing in AN on the SEL level by using a pre-classificator (b6) which is responsible for the FFT relevant procedures. The contents of the classificator is an input information destinated to the AN main classificator unit ANMC.

C. The output from an A/D converter (b) and from the subsequent coherence function device generates a data set for the Pattern Recognition PRS-System which is not implemented in the AN-preprocessing unit but is a constituent of the DML.

As the acoustic background of a reactor is always an individual varying within not too extended margins due to all thought operating conditions, the scope of the features to be considered from the background composition seems to be restricted. But it is suitable to start up with a learning process only under normal operating conditions with the determination to prove the criteria and to check the algorithms permanently with proceeding operation time.

The PRS is a fully computer aided digital system, thus it is appropriate and advisible to have it installed on the DML, that is, to incorporate it entirely on this level.

D. In order to support the classification process on the ANMC level other redundant signals from the reactor instrumentation are needed. Since the AN is a digitally working device, only digital data coming from the RIL system may be accepted. There are the following four external signal groups:

1. neutron flux (i3)
2. coolant flow rate (i4)
3. inlet temperature (i5)
4. outlet temperature (i6)

For the processing of neutron noise signals from RIL/i3 a cross-correlator unit (c3) is implemented in the AN and its output going to the ANMC main classificator.

The neutron flux information takes precedence of all other external signals. In practice it may happen that in the RMS channels no significant change or trip-valid fluctuation is indicated although boiling is present and becomes detected by only a few or single microphones via the ADC-FFT path. As a consequence, this would be stated in the cross-correlation section (c3) and is confirmed accordingly by the neutron noise signals without any noticeable time delay.

The flow rate (i4) is linearly correlated to the pump speed in a wide domain. The mechanical rotation of the pumps is considered to be an important information in the frame of the prominent acoustic noise sources in a reactor. Normally, the rpm values remain constant in the range of usual and possible reactor power levels. In that way the flow rate is an operating parameter for the RMS-analyzing system (a1 - a5).

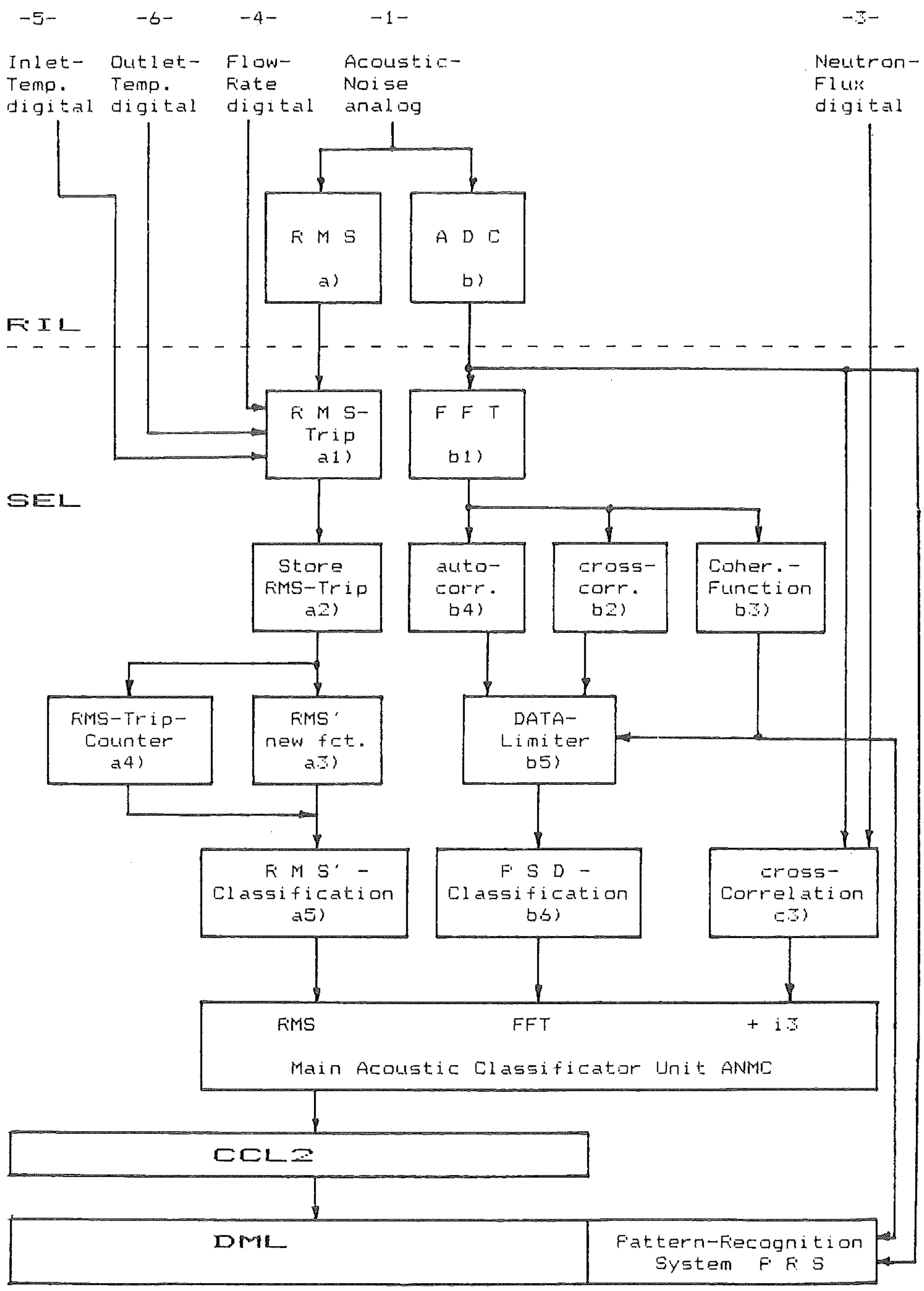
The relations between the flow rate signals and the contents of the calculated PSD (b4) are expressed much fewer and it was shown from in-pile background measurements that the acoustic PSD spectra become linearly amplified while their power density distribution was kept almost unchanged for a wide span of the pump speed.

Restrictions are given for the upper domain of the nominal flow rate in case the pumps or parts of the relevant flow guiding systems start up to cavitate. This would result in a new and additional noise source with a very high frequency content and consequently, the onset of its appearance must be known in advance.

Both the RMS chain and the FFT part are working with a 1 Hz repetition rate for the RMS integration and the PSD generation respectively. In that way, the main acoustic classificator in AN receives a new data set in steps of one second. The stated classified results are then presented to the succeeding communication medium CCL2 where it is evaluated together with the response from the PRS channel.

For the AN, provisions are made for a terminal protocol which allows to monitor the actual data from the RMS channel on a display. Furthermore, it is requested to print out the the PSD spectra from the short-time and as well from the long-time computer memory. Additionally, the decision level of the DMC will be indicated optically and in parallel, this information is made available in a TTL-BCD format.

Functional Block-Diagram - Acoustic Noise Measurement



S. Jacobi

EC Study

4.4.5 Software in the "delayed neutron detection and cover gas monitoring" subsystem

by

S. Jacobi

KfK - IRE

4.4.5.1 Indication of a leaker

Cladding tube defects generating only a cover gas signal and not causing a DN signal exceeding normal background are termed "gas leakers" or briefly "leakers." This denomination is justified by the fact that there is no contact between sodium and fuel so that no DN signal can be generated. In general, the defect consists in a flaw in welding at an end plug of a pin or in defects due to corrosion at the cladding tube itself. In both cases only fission product gas is blown off into the sodium through these small holes.

Treatment of a leaker by the software in the "delayed neutron detection and cover gas monitoring" system has been represented in fig. 1, the related hardware configuration in fig. 2 [1, 2].

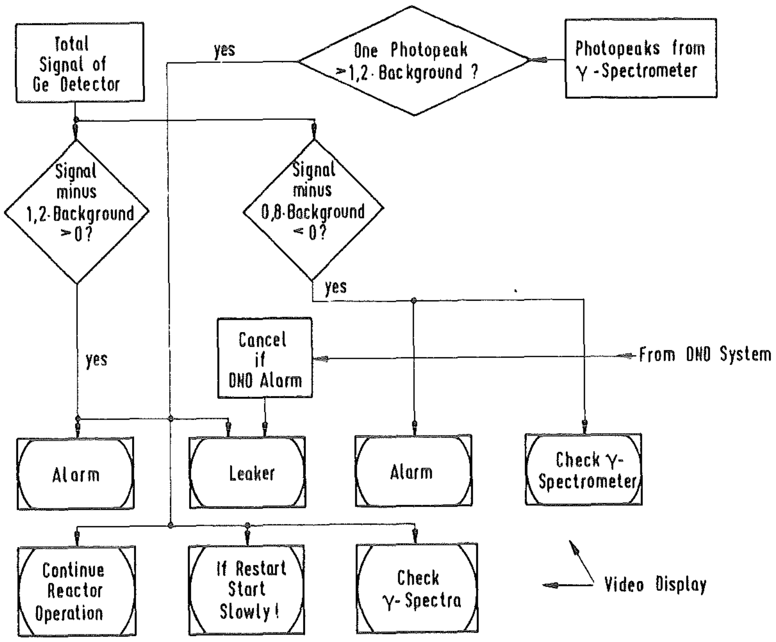


Fig. 1: Indication of a leaker with information and instructions to the operator.

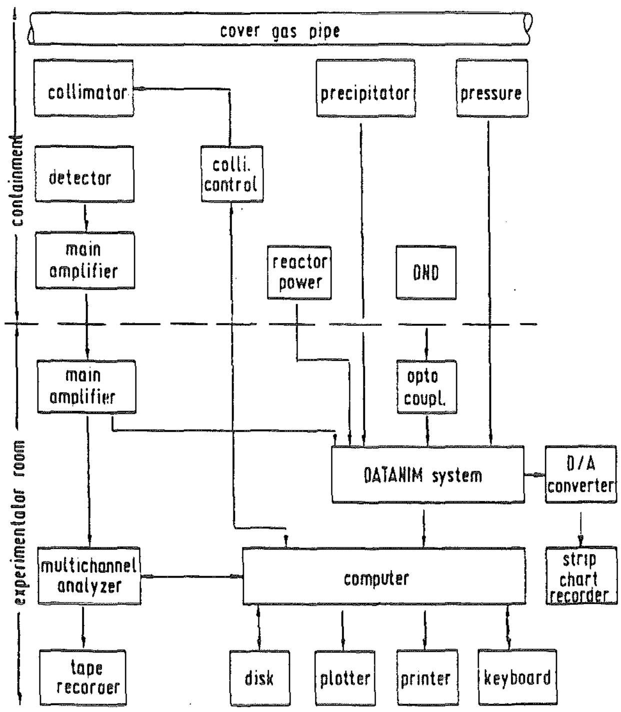


Fig. 2: Gas detection system.

The development of a leaker is shown by way of example in fig. 3 and in table 1 [2]. With the power increasing in the BR2 reactor in Mol, Belgium, a strongly rising Kr-85m activity concentration was observed. Plots and measurement protocols of this type as well as further plant specific information are typical tools to assist the operator in continuing reactor operation with failed fuel elements.

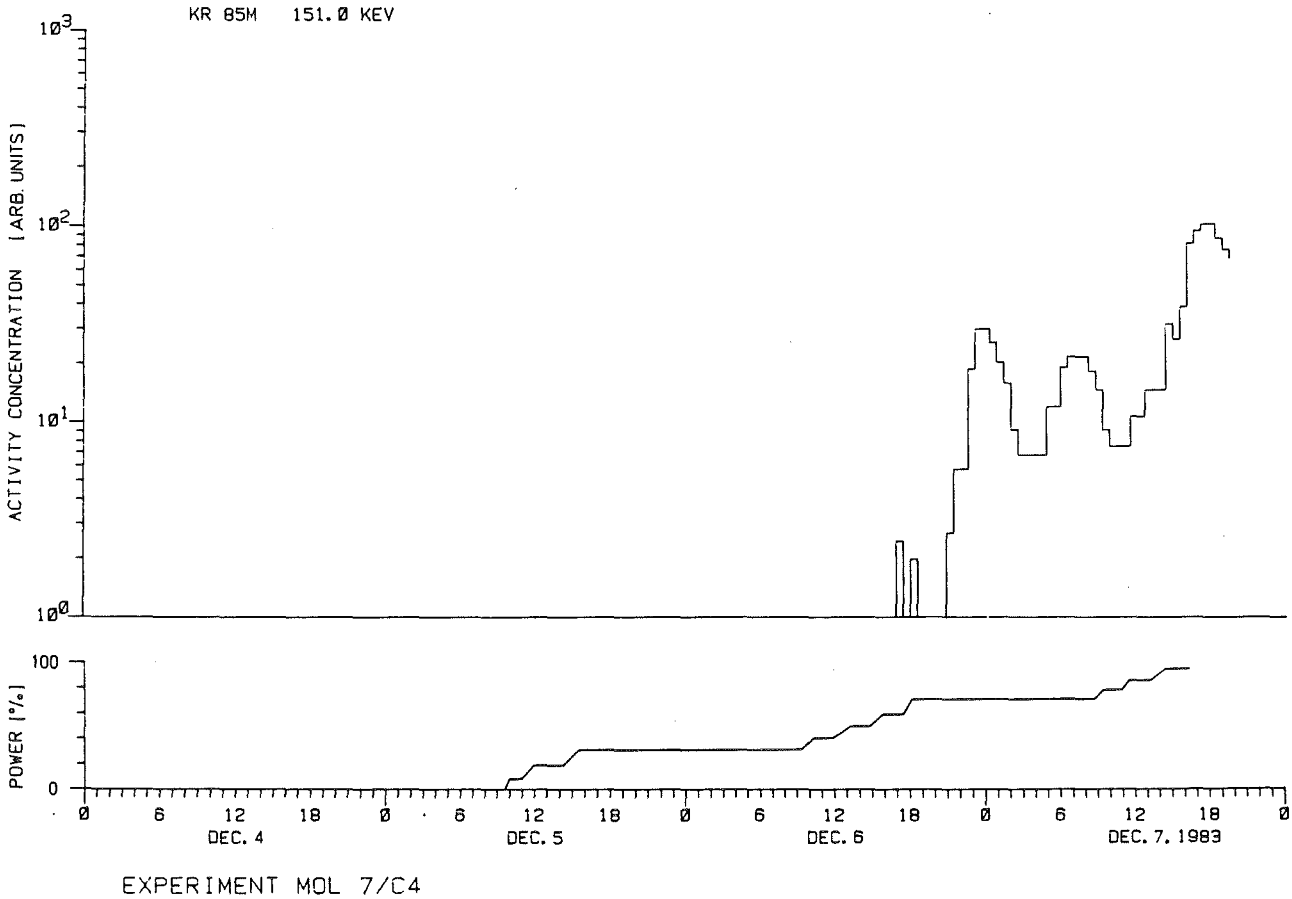


Fig. 3: Increasing Kr-85m activity concentration during reactor start

Table 1: Measurement protocol of a fission product gas leaker; cf. fig. 3.

COCOSS Vers. 1.0   Schutzgas-Messung Mol 7C/4

Messprotokoll

Spektrum Nr.: 309   Bandgeraet defekt   Platte: 15 / 25

Start: 7. Dez. 1983 19:22:05   Ende: 19:55:43
Lifetime = 2001. s   Truetime = 2011.00 s   Deadtime = 0.5 %
Geometriefaktor = 0.132780E-05   Kollimatorposition: 1   Volumen = 64.28 ccm   Detektorname: N18A
Eichfaktoren: A = -0.00000041 B = 1.00048578 C = -0.76124573   keine automatische Eichung

		Mittel-	Start-	Ende-	Maximal-	Minimalwerte
Reaktorleistung	(MWt)	29.08	29.08	29.07	29.08	29.07
Detektorzaehlrate	(Imp/s)	418.56	427.60	448.90	451.60	395.80
Praezip.-Zaehlrate	(Imp/s)	0.00	0.00	0.00	0.00	0.00
DND-Ost	(Imp/s)	0.00	0.00	0.00	0.00	0.00
DND-West	(Imp/s)	0.00	0.00	0.00	0.00	0.00
Schutzgasdruck	(bar)	0.00	0.00	0.00	0.00	0.00

S c h u t z g a s d r u c k zu niedrig, gerechnet mit 1 Bar

Tabellenwerte					Messwerte								
Nr.	Nuklid	Hwz.	Abund. (%)	Energie (keV)	Energie (keV)	genaue Kanall.	U-Grund (Imp)	Signal (Imp)	Kz.	Hwb. (keV)	Fehl. (%)	Akti.Konz. (1/s*Nccm)	
1	Xe 133	5.65 d	36.6	80.99	79.32	80.0	9015.	3184.	3.	1.5	17.8	0.293E+02	
2	Kr 85m	4.40 h	74.0	150.99	149.52	150.2	13225.	14945.	5.	2.5	5.7	0.707E+02	
3	Kr 88	2.80 h	37.0	196.10	194.61	195.3	9703.	6646.	5.	2.5	10.5	0.920E+02	
4	Xe 133m	2.26 d	14.0	232.90									
5	Xe 135	9.14 h	91.0	249.80	248.09	248.8	8957.	29867.	7.	2.5	3.0	0.267E+03	
6	Xe 138	14.1 m	31.0	258.30									
7	Kr 87	76.0 m	53.0	402.80	400.69	401.3	2304.	939.	4.	2.5	32.6	0.395E+02	
8	Cs 138	32.2 m	27.8	462.80	460.97	461.6	2830.	1695.	5.	2.5	22.0	0.170E+03	*
9	Kr 85	10.7 a	0.4	513.99									*
10	Xe 135m	15.6 m	80.0	526.80									
11	Xe 135	9.14 h	2.4	608.60									
12	Kr 88	2.80 h	13.0	834.70	832.59	833.2	751.	444.	5.	2.5	43.9	0.260E+03	
13	Rb 89	15.1 m	60.0	1030.70									
14	Ar 41	1.84 h	99.0	1293.64	1291.25	1292.1	410.	3993.	8.	3.5	6.4	0.749E+03	
15	Cs 138	32.2 m	75.0	1435.90	1433.37	1434.3	252.	955.	7.	2.5	16.0	0.306E+03	*
16	Kr 89	191. s	9.5	1472.10									
17	Kr 88	2.80 h	11.3	1529.80									
18	Xe 138	14.1 m	17.7	1768.20									
19	Rb 88	17.8 m	30.2	1836.13	1833.44	1834.7	147.	288.	6.	2.5	35.1	0.390E+03	
20	Xe 138	14.1 m	12.5	2015.80	2027.15	2028.6	30.	96.	4.	1.5	53.1	0.376E+03	
1					73.21	73.9	24736.	10094.	8.	2.5	12.5		
2					83.14	83.9	16738.	2148.	5.	1.5	39.7		
3					164.22	164.9	6861.	1136.	3.	1.5	41.0		
4					303.23	303.9	3715.	1052.	5.	1.5	39.9		
5					508.87	509.5	2538.	1298.	8.	3.5	32.2		
6					545.04	545.7	1368.	581.	5.	2.5	43.7		
7					659.66	660.3	1782.	7263.	7.	2.5	5.7		
8					895.93	896.6	635.	477.	4.	2.5	36.2		
9					1007.42	1008.1	907.	681.	5.	1.5	32.6		
10					1367.71	1368.6	180.	212.	4.	2.5	43.9		

* Ursache fuer Protokollausg.

4.4.5.2 DN failure

Treatment of a DN failure is much more complicated than treatment of a leaker. The reason are the possible consequences on reactor operation - as described in chapter 2.5 - and the authorization of the DN signal to shut down the reactor automatically. Figure 4 is a block diagram showing the treatment of a DN failure by the example of KNK II [1].

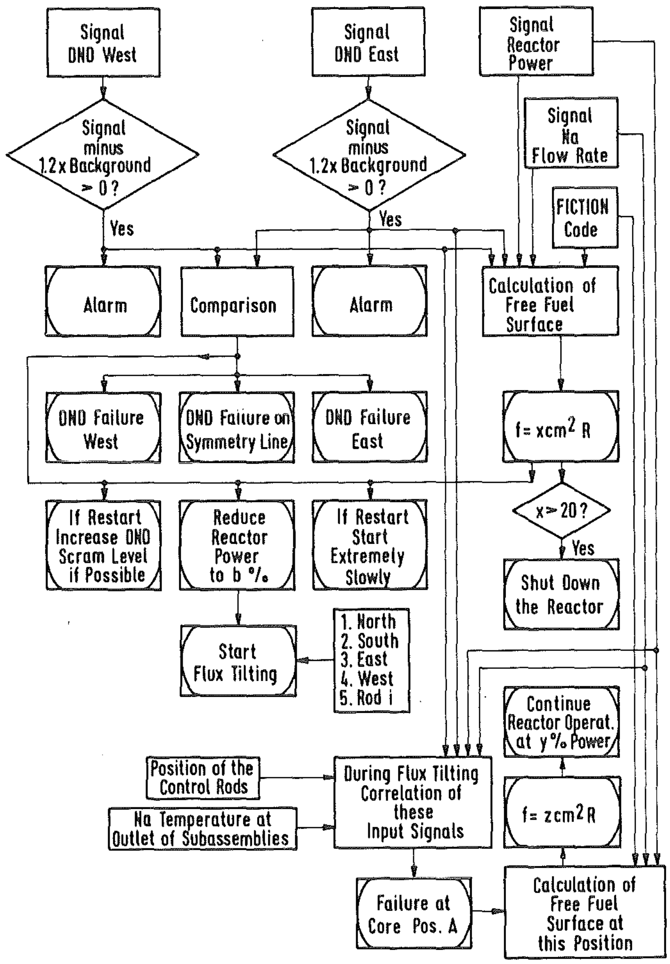


Fig. 4: Treatment of a DN failure with information and instructions to the operator, shown by the example of KNK II.

As other subsystems are not affected by the DN signals and the cover gas signals, these signals are not preprocessed on the RIL plane. The measured DN signals are evaluated in the "delayed neutron detection and cover gas monitoring" subsystem according to the algorithms described below [3].

For radioactive fission products released as result of recoil mechanisms it is assumed that fission products formed in a layer of the thickness L_i right underneath the defect area F are spontaneously released into the coolant by recoil as a fraction δ. After an equilibrium condition has become established, the following equation holds:

$$R_i^R = \delta \cdot F \cdot L_i \cdot \lambda_i \cdot \nu_i \cdot S \qquad (1)$$

R_i^R / s^{-2} /	rate of activity release of a nuclide i into the coolant by recoil
δ / 1 /	geometric escape coefficient
F / cm^2/	defect area
L_i / cm /	recoil length of nuclide i
λ_i / s^{-1}/	decay constant of nuclide i
ν_i / 1/	cumulative fission yield of nuclide i
S / $s^{-1}cm^{-3}$ /	specific fission rate

$$A_i^R = R_i^R \cdot \mu_i \cdot \frac{1}{Q} \cdot e^{-\lambda_i \cdot t_t} \qquad (2)$$

A_i^R / $s^{-1}g^{-1}$ /	neutron activity concentration of nuclide i in sodium at time t_1
μ_i / 1 /	fraction of decays with neutron emission
Q / gs^{-1} /	sodium flow rate
t_1 / s /	transit time of sodium from defect area to DND monitor

$$Z_i^R = A_i^R \cdot \rho \cdot \eta \cdot V^P \qquad (3)$$

Z_i^R / s^{-1} /	count rate caused by nuclide i
ρ / gcm^{-3} /	sodium density
η / 1 /	neutron sensitivity of the DN monitor
V^P / cm^3 /	sodium volume in front of the DN monitor

With these three equations (1), (2), and (3) and assuming a mean specific fission rate S, the DN signal

$$Z^R = \sum_i Z_i^R$$

is used to calculate the defect area which is effective according to the recoil model. Following signal stabilization a k-factor can be put in depending on the fission material inventory of the fuel rod and the size of the defect area F; cf. chapter 2.5. In the following "local flux tilting" campaign the position of the failed fuel element is determined for different configurations of absorber rod positions. The necessary criteria of selection are known to the specialists but, because they are highly complex, the respective algorithms are still in the phase of development.

[1] G. Hoffmann, S. Jacobi, G. Schmitz:
Transfer of expert knowledge to the consulting core surveillance system COCOSS at KNK II.
In Proc. Fifth Power Plant Dynamics, Control and Testing Symposium, March 21-23, 1983, Knoxville, Tenn., USA.

[2] G. Hoffmann, KfK-IRE, personal communication, August 84.

[3] G. Hoffmann, S. Jacobi, G. Schmitz, M. Relic:
Fuel failure detection and location in fast breeder reactors.
In: S. Jacobi, editor: Fuel failure detection and location in LMFBRs. Proc. of Int. Atomic Energy Agency Specialists' Meeting, Karlsruhe, May 11-14, 1981, KfK 3203, June 1982.

4.4.6 Software within decision making level (DML)

K. Schleisiek, KfK/IRE

The principles and functions of the DML have been described in detail in Sect. 3. The structure of the system is shown in Fig. which represents only the most important elements of the decision making process. Detailed programs and software have not yet been elaborated. So, only some general remarks will be made in this section.

The first subsystem of the DML concerns the preprocessing of data transmitted from the SEL. It is assumed that the data are edited from SEL in suitable format and levels. Hence, the main task of this subsystem is the distribution of informations to the following subsystems and the storage devices. In detail these are:

- Sequences of measured signals to the event analysis subsystem upon system or operator request,
- valuated signals to the short-term storage with a rate of $1\ s^{-1}$,
- determination of maximum, minimum and average of the valuated signals and transfer to the long-term storage at time intervals of one hour,
- check of classified deviations for changes and initiation of event analysis process.

The next subsystem is the event analysis procedure which is performed in the time and frequency domain. At the beginning of the analysis the relevant detection systems and signal channels have to be selected. This will be done on the basis of the stored list of events and the related detection possibilities. Each channel will then be checked for undetected deviation taking into account the response time of the related detection system. The corresponding sequences of data have to be called up from the short-term storage. The search procedure could consist in the analysis of density and amplitude of peaks in the signal compared "normal" phases. For some detection system an analysis in the frequency domain is suitable. The relevant data must have a common time base and partially a band width larger than the data stored. Therefore in cases when a frequency analysis is requested, sequences of signals as actually measured are transmitted to the event analysis subsystem. The software necessary for this taks is generally available: these are the methods usually used for the analysis of stochastic signals like PSD, CPSD, RMS, etc. The criteria for the recognition of abnormalies are still to be evaluated. Partially this can only be done on the basis of the experience gained in the initial training phase of the system.

For the final identification of events again the stored list of events and related detection possibilities is used. In the general case definite attribution of a distinct event to one detected deviation is not possible. But as explained in Sect. 3 the possibility of diverse detection by correlating signals from different systems provides more information on the actual event and support its identification.

The identified events are stored in the disturbances analysis subsystem. Besides, this system contains the cause-consequence-diagrams (or event trees) of possible disturbances established in advance or on the basis of experience.

If one or more events have been detected then the stored diagrams are checked for the observed event or event sequence. The required algorithms are simple and need no further description. It is evident that the detection of only one event is normally not sufficient for the definite identification of the actual disturbance. But with the progression of the fault the number of identified events will increase and consequently also the chance of correct identification.

For the pattern recognition method the classified deviations stored in the long-term storage will be used. The principles of pattern recognition are well known and need no further explication. In this particular application one of the main difficulties of pattern recognition is not existing: the classified deviations can be used as pattern and no special procedure for pattern extraction is necessary. Synthetic or previously observed sets of results are used for training of the system. Each disturbance corresponds to a class of results of the pattern recognition process. During operation the actual set of data is compared with the pattern of the stored disturbances using the usual procedures e.g. the nearest neighbour method. By this way it is determined which of the stored disturbances has the highest probability to be identical with the observed one.

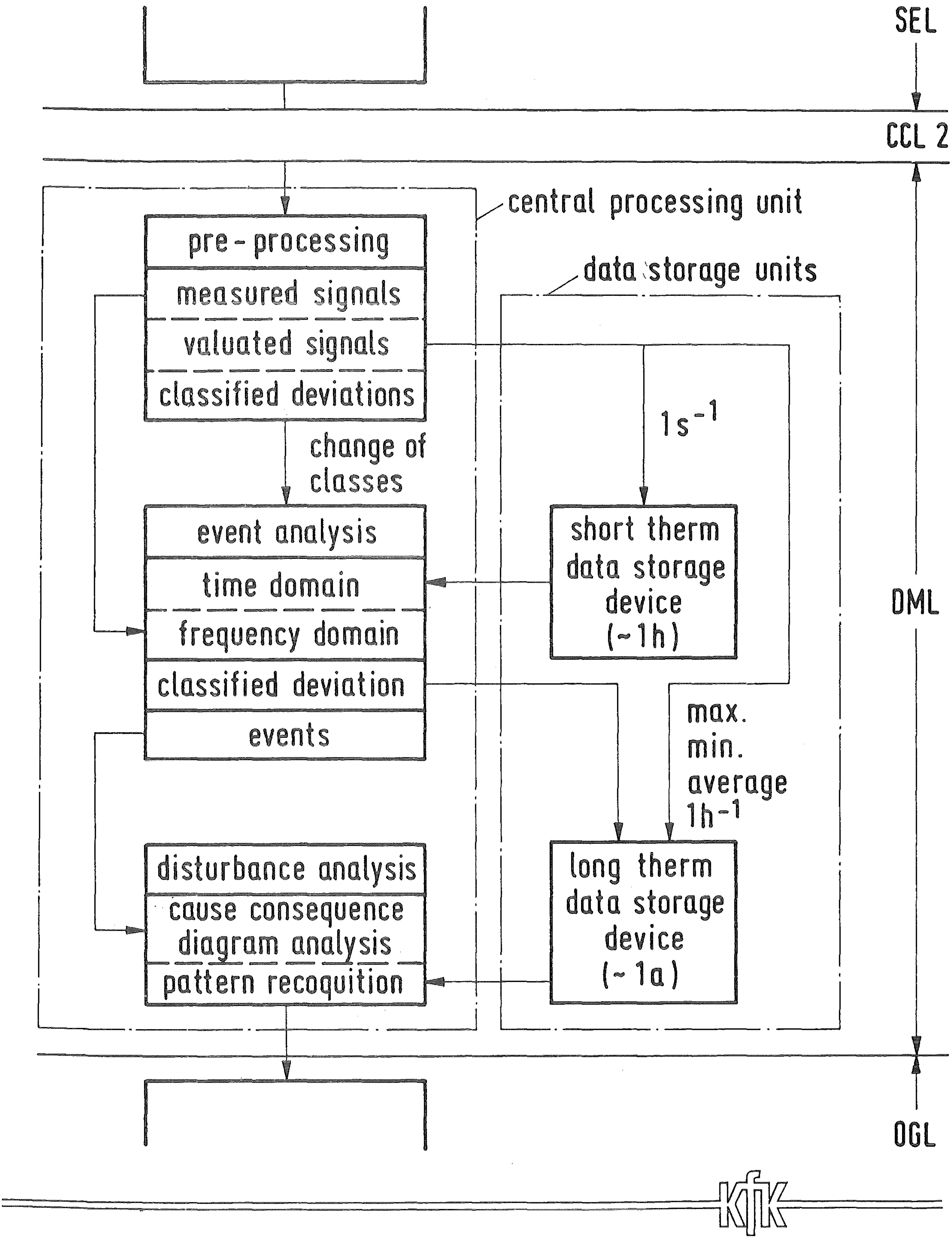


Fig. 4: Software structure of the DML

5. Implementation plan

Due to the complexity of the proposed concept it is necessary to plan a stepwise realization. This realization can to some degree use the know-how from the existing core surveillance systems.
The proposed realization is subdivided in four steps:

Step 1: Realization of a vertical subsystem which consists of

- preprocessing (RIL)
- data exchange (CCL1)
- individual processing (SEL)

and interfacing to the decision-making-level (DML).

Step 2: Implementation of the DML-algorithms.
This implementation uses simulated input data and produces messages, warnings and protocols. The detailed layout and optimal presentation is fixed in a later stage (in the realization of the OGL).

Step 3: Relization of all seperate subsystems according to step 1.

Step 4: Construction of the output generation level (OGL) and integration of the compete system.

Remarks:

Instead of this sequential plan, some of these steps can be executed in parallel. Depending on the available man-power and other resources step 1 and step 2 are candidates for parallel implementation.
The same holds for step 3 and step 4.

6. Conclusions

The KfK-part of the study consists of three main topics:

The first topic deals with the existing core surveillance techniques. Operational experience with this seperate system is reported on.

The second topic handles the integration aspect. Main emphasis is given to the development of algorithms for combination and correlation of results of individual systems. The prerequisite for this task of algorithm development is a very good knowledge of the physcial process. This algorithm is to some degree comparable with the development of a 'knowledge base' known from the artificial intelligence discipline.

The third topic, entitled systems analysis, is concerned with the refinement of the hardware- and software-requirements for the proposed system concept.

Based on these results subsequent development work should concentrate on following main aspects:

- According to the refined concept of the integrated system a prototype-subsystem should be realized, which is limited to one surveillance technique (e.g. the monitoring of individual fuel elements). This implementation requires the fixing of the interface between the seperate evaluation level (SEL) and the decision-making-level (DML).
- The most important and difficult work concerns the implementation of the DML-algorithms together with the associated data structures.

III. Summary

This joint KfK- and INTERATOM-study shows the potential of modern information technology in the area of LMFBR control.
In the first part a distributed system for process control is suggested. One aspect of this system is the built-in redundancy and diversity. This leads to a graceful degradable system even in cases of single failed subsystems.
Another important topic is the usage of artificial intelligence techniques, especially pattern recognition techniques.

In the second part a new attempt is made for the construction of an expert system for LMFBR-control.
One of the difficult tasks is the construction of a high quality knowledge base. Unfortunately characteristic information available in expert systems is of imprecise and hardly quantifyable nature. That is the reason for consideration of the 'fuzzy-set' approach.

To summarize the state of the art, we can say that sophistication of methods, especially in the area of pattern recognition , has reached a stage of ripe, which makes this technique a serious candidate for the usage in modern computer-based control systems.