KfK 4139
Oktober 1986

Consulting Core Surveillance System COCOSS I at KNK II

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ISSN 0303-4003

Abstract

Fuel cladding defects cannot be avoided in nuclear power plant operation. In the worst case they may lead to loop contamination or to local cooling disturbance. Especially in case of the liquid metal cooled fast breeder reactor, continuation of plant operation or power set back calls for an expert who possesses comprehensive knowledge of (a) detection and location of failed subassemblies, (b) behavior of failed subassemblies, and (c) questions of safety of the plant while operated with faulty subassemblies. Since such an expert cannot be permanently available, it is intended to transfer this expert knowledge to the COCOSS "Consulting Core Surveillance System." This report gives a description of the status of COCOSS as operated at present at KNK II as a measuring data acquisition and evaluation system. In the final stage of implementation COCOSS - inserted in a large diagnosis system - is to make the same calculations for the reactor operator and to give him the same recommendations as he receives now from an expert commanding of an extensive knowledge in this specialized field.

Zusammenfassung

DAS COCOSS I-SYSTEM ZUR ÜBERWACHUNG DES REAKTORKERNS DER KNK II

Brennstab-Hüllrohrfehler sind beim Betrieb von Kernkraftwerken unvermeidbar. Sie können im ungünstigsten Fall zur Kreislaufkontamination oder zur lokalen Kühlungsstörung führen. Insbesondere beim natriumgekühlten Brutreaktor ist für den weiteren Betrieb der Anlage oder für ein planmäßiges Abschalten ein Experte mit umfangreichem Wissen über (a) Detektion und Lokalisierung defekter Brennelemente, (b) Verhalten defekter Brennelemente und (c) Fragen der Sicherheit und Verfügbarkeit der Anlage beim Betrieb mit defekten Brennelementen erforderlich. Da ein solcher Experte nicht immer zur Verfügung stehen kann, soll dieses Expertenwissen dem "Consulting Core Surveillance System" COCOSS übertragen werden. Dieser Bericht beschreibt den Entwicklungsstand von COCOSS, wie es zur Zeit an der KNK II als Meßdatenerfassungs- und Auswerteanlage betrieben wird. Im Endausbau soll COCOSS im Rahmen eines größeren Diagnosesystems für den Reactor Operator die gleichen Berechnungen ausführen und ihm die gleichen Empfehlungen geben wie heute ein Experte mit seinem umfangreichen Spezialwissen.

Table of Contents:

1. Introduction

It is evident from experience accumulated worldwide that fuel pin cladding damage cannot be avoided in nuclear power plants. Leakers, i.e., minor cladding tube defects detectable only by an increase in cover gas activity, lead to contamination of the primary loops with radioactive fission products which is tolerable to specified limits and does not call for an immediate shutdown. By contrast, cladding damage associated with a DND (delayed neutron detection) signal poses more problems on account of the chemical reaction taking place between the fuel and the coolant in an LMFBR. Due to $Na_3(U,Pu)O_4$ formation from sodium, fuel and oxygen (originating in the sodium as well as in the fuel) an initially minor damage may develop into a larger one because the density of $Na_3(U,Pu)O_4$ is only half that of the fuel /1/. Fuel swelling can lead to cooling disturbances of neighbour pins and could subsequently cause failure propagation /2/.

However, there is a growing desire to avoid reactor shutdown as long as possible and to continue operation, if necessary at reduced power, respectively, and, if shutdown becomes a necessity, to postpone it into a low load period, e.g., a weekend /3/. The choice of the appropriate time to shutdown and the amount of power reduction, respectively, require comprehensive expert knowledge.

After appearance of a cladding defect, i.e., after its detection, defect location is of paramount importance. Besides the methods of individual coolant samplings or tagging, local flux tilting will play an increasing role in the future because of the specific problems associated with the former methods /4/. Under the latter method those core positions are determined at reduced power through variation of power in various core zones where the damage has occurred. However, above all this procedure requires much expert knowledge and can hardly be applied in large reactors without the use of computers.

To improve this condition an expert would have to be available at each LMFBR and at every time with knowledge and experience in:

- failed fuel detection,
- various methods of failed fuel location,
- behaviour of failed subassemblies during reactor operation,
- questions related to the safety and availability of failed subassemblies and to plant operation.

Since it will not be possible in the future to satisfy these conditions at every plant and at every moment, the "Consulting Core Surveillance System" COCOSS, with appropriate expert knowledge and on-line signal evaluation, is intended for consultation of the operator in decision making.

2. Purpose and Objective of COCOSS

COCOSS is presently developed and tested at KNK II /5/. However, it must be underlinded that work is done also with a view to application at the SNR 300 and SNR 2, respectively. COCOSS is permanently run on-line during reactor operation. Its major task in the ultimate phase of development will consist in avoiding unnecessary or too late shutdown. This objective is attained by the following individual measures:

(a) Core surveillance during operation without failed subassemblies:
- information about the status of the plant,
- automatic insepction of the measuring chains,
- plausibility consideration of the measured signals,
- recording of the background signals which change for various reasons (may be important above all during flux tilting on account of the low signal amplitudes associated).

(b) Diagnosis upon occurrence of fission product signals caused by cladding defects:
- correlation of all relevant measurement signals available;
- access to data banks where expert knowledge is stored about types of damage and their behavior in the course of time as a function of various states of plant operation;
- information to the operator about the most probable status of the

failed subassembly: type and location of damage;
- observation of the progress of damage and permanent updating of information given to the operator.

(c) Failure prediction, i.e., comparison of the respective actual condition with the expert knowledge stored in data banks concerning the development with time of previous cladding defects. Output of information about the most probable evolution of the failure.

(d) Output of recommendations for subsequent reactor operation, derived from the failure prediction:
- immediate shutdown of the plant, or
- shutdown of the plant at a time recommended by COCOSS, or
- immediate or very soon reduction in power.

(e) Recommendations for a diagnostic operation of the plant with a view to failure location.

(f) Support in flux tilting:
- comparison of the fission product signals and the coolant temperatures at the subassembly outlet with information contained in the data bank,
- recommendations for future diagnostic operation, i.e., insertion and withdrawal of the individual control rods,
- indication of the core zone in which the cladding failure has occurred up to and including, if possible, indication of a single position.

The more reliable the result of failure location is, the less subassembly handlings are necessary. This aspect should be considered above all in case of subassemblies with a high level of burnup. Less manipulations imply a lower probability of occurrence of human errors or also errors due to plant equipment i.e. machine malfunction. Furthermore, quick location of the failure means a shorter period of non-availability of the plant. In this way, COCOSS within certain specified limits enhances both the safety and the availability of the plant.

3. Status of Work on COCOSS I

Given the novelty of the subject and the simultaneous elaboration of the necessary criteria of decision making through in-pile experiments involving open fuel /6/ COCOSS is being developed at several stages. The stage of implementation I, which is reported here, essentially consists in a data acquisition and processing system for the experiments involving open fuel for acquisition of background data and for assistance during local flux tilting operation. The first decisive step was the development of an on-line gamma spectrometer for evaluation of the cover gas gamma activity /7/. This was followed by feeding and processing of the delayed neutron (DN) signals, the reactor power, and the overall cover gas activity measured by a precipitator.

A further major improvement of signal processing was achieved by installation of a 10-minutes machine as part of the software (see Chapter 5.2).

At this stage of implementation COCOSS I operates already in an interactive mode with respect to the measuring systems installed at the reactor, e.g.,

- automatic setting of the collimator position of the gamma spectrometer,
- preselection of the time of measurement for the Ge-detector,
- output of protocols if results of the measurements are above or below specified limit values,
- evaluation of measured values, and generation of logs and plots to support the operators during defective subassembly location by flux tilting.

4. COCOSS I System Configuration

In a bypass of the cover gas line in KNK II a Ge-detector, a precipitator and a pressure transducer have been installed (Fig. 1). Since the concentrations of the cover gas activities can undergo variations by about seven orders of magnitude between the background activity and the activity resulting from a major rod damage, a variable geometry of measurement had to be previously defined for the Ge-detector. For this reason, the detector was combinded with a collimator /8/ which allows to vary the detector geometry in three steps (Fig. 2). For this purpose, the integral detector counting rate is decoupled at the main amplifier and fed to the computer via the DATANIM counter/timer system. The computer positions the collimator in such a way that the most favorable counting rate for recording the gamma spectrum is available at the multichannel analyzer (MCA). Simultaneously, the time of measurement for the MCA is preselected so as to be as short as possible and still a sufficiently good statistics for spectrum evaluation is achieved. An MCA with 4K memory is used; the 2K gamma spectra are recorded alternately in the first and second half of the MCA memory. In this way, a quasi-continuous measurement of the gamma spectra is ensured. To store the gamma spectra a 9-track tape recorder has been connected to the MCA. The precipitator signal, the DN signals (DN east and DN west), the reactor power, and the cover gas pressure are likewise recorded and evaluated by the computer; on account of grounding problems an optocoupler had to be inserted for the DN signals. A plotter and a printer are available for the output of the measured values and the data calculated from them. The results of evaluation of gamma spectra and other measured signals are stored on two disks. Via a D/A converter with strip chart recorder connected the calculated activity concentrations of two freely selectable nuclide lines are permanently traced on-line.

Besides, a program sequence control is integrated to monitor hardware failures and software errors which may be generated by the continuous improvement of the program. By a red flash light any faulty sequence of the program or failures in the hardware and operating errors, respectively, are indicated.

5. Description of the Function

For hardware operation the RECOS (Reactor Core Observation Software) core surveillance system was established. RECOS assumes both control of the hardware as a function of the measured variables recorded and evaluation of the gamma spectra according to DERAN /9/ and the output of measurement protocols and plots. The largest part of RECOS is written in FORTRAN IV, only the subprograms needed for hardware control were prepared in assembler language (MARCO-11). RECOS is running on a DEC computer PDP 11/34 with 128 KB memory under the RT11 V3B operating system. Essentially, a distinction must be made between two program parts, a synchronous part (Fig. 3) and an asynchronous (interrupt controlled) part for control and data acquisiton of the counter/timer system and for setting alarm marks corresponding to these measured data (Fig. 4).

In program development much importance was attributed to user friendliness and convenient handling so that COCOSS can be operated also by others than computer specialists. All user inputs are made as dialogs, the majority of faulty inputs are rejected together with appropriate messages. Moreover, the correct connection and setting of the hardware are examined and in case of error a message is given to the user.

5.1 Sequence of the Measurement

The program RECOS starts with a dialog in which the user communicates to the program the hardware configuration connected. This is followed by a test of the hardware with an appropriate meassage to the user in case faulty equipment and equipment settings, respectively, have been detected in the test run. If no errors are found, the starting procedure is continued by printing out the control variables just set (Table 1). If these control variables are not properly acknowledged by the user, the program is stopped; with the help of several auxiliary programs the control variables can then be changed. Otherwise, the measurement is started with the counter/timer system started first which communicates after 10 s via an interrupt and is then read out and restarted. After selecting and approaching of the collimator position and after specification of the time of measurement for the multichannel analyzer the latter is started for measurement in the first half of the memory. When spectrum recording is completed the spectrum is read out and the second MCA memory half is started for measurement. The evaluated gamma spectrum is compared with that measured before and, if significant differences are found, a measurement protocol is prepared and the spectrum from the analyzer written on tape. Moreover, the results of precipitator and DN monitor measurements during spectrum recording as well as the results of spectrum evaluation are stored on disk for future use in the plot programs. If, while the gamma spectrum is recorded, an alarm condition occurs such as a scram or a variation of the detector counting rate by a given limit value, the MCA is stopped, and the spectrum previously measured evaluated and processed. A new time of measurement is defined for the MCA and it is restarted immediately or after a possibly necessary change of the collimator position. Prior to each spectrum evaluation an energy channel calibration is performed automatically if at least two known nuclide lines of adequate quality are available which means that the relative error of these lines must not exceed 30 %.

5.2 10-Minutes Machine

The integral detector counting rate, the counting rate of the precipitator, the two DN signals, the cover gas pressure, and the reactor power are queried every 10 s via the DATANIM counter/timer system, evaluated and stored in the computer and on disk, respectively, for one hour. If this "10-minutes machine" is excited the measured values of these signals are put out automatically both as a protocol and as a plot from 10 minutes before until 10 minutes after the excitation. Excitations for the 10-minutes machine are caused by fast variations of the following signals exceeding defined limit values:

- precipitator counting rate,
- counting rate of DN east and DN west,
- reactor power (e.g. scram).

Besides this automatically prepared protocol and plot also the earlier periods can be put out as a 10-minutes protocol and plot by a user request (up to 1 h back from the time of user request).

5.3 Local Flux Tilting Assistance

The count rate of the DN monitor depends on the thermal power of the defected subassembly. This relation can be used for the prelocalization of the subassemlby concerned applying a procedure called "local flux tilting". At the beginning of such a campaign a reference measurement is taken by reduced reactor power (e.g. 15 %) and with all control rods even positioned on the same level.

Now single rods are moved successively so that in various core zones a reduction of the thermal power (heating rate) of the subassemblies is reached. The changes of the DN net signal (in case of KNK II the sum of the DN net signal of the two DN-monitors at the sodium primary pipes east and west) is compared with the changes of the heating rate of each subassembly. The most suspect subassembly must have the best comformity between both signals. Therefore the following algorithm (equation 1) is implemented into the program RECOS, where the sum of the differences over the whole flux tilting campaign (SUM_i) must be a minimum for the most suspect subassembly:

$$SUM_i = \text{absolute value of}/QTEM_{ik} - QDN_K/ \qquad (1)$$

$$\text{with } QDN_K = \frac{DN_k}{DN_r} \quad \text{and } QTEM_{ik} = \frac{TEM_{ik}}{TEM_{ir}}$$

i = subassembly number

k = number of flux tilting configuration [1)]

DN_k = DN net signal at flux tilting configuration k

DN_r = DN net signal at reference configuration

TEM_{ik} = heating rate of the ith subassembly at flux tilting configuration k

TEM_{ir} = heating rate of the ith subassembly at reference configuration.

1) Corresponding to the number of control rods, 5 different configuration are possible at KNK II

In the present state of implementation the subassemly outlet temperatures and the rod positions are not connected to COCOSS I, also the DN net signal is calculated off line. All these values are putted in via key board to the running program RECOS.

6. Presentation of the Measured Results

Given the different problems in subassembly surveillance and interpretation of the signals the results of measurements and calculations are put out in different ways, either automatically or upon user demand without interruption of data acquisition and evaluation.

6.1 Measurement Protocol

In the measurement protocol (Table 2) the following information is given in the first five lines:

Line	Information
1	Continuous number of spectrum; data of start of tape and tag word under which the spectrum has been stored; disk recording number with column number of the data field in which the results of spectrum evaluation have been stored.
2	Start and end of MCA measurement.
3	Life time, true time, dead time of MCA.
4	Geometry factor used in calculating the activity concentrations; collimator position; monitored gas volume; detector name.
5	Calibration factors of channel energy calibration A = quadratic term; B = linear term; C = additive constant.

This is followed by the first record of measured data: the mean values computed during the MCA measuring period, the maximum and minimum values during this period and the measured values at the start and end of the MCA period of measurement are printed out. This is followed by the output of the nuclide specific data of at the maximum 20 monitored, previously selected nuclide lines. The columns in the part in the box of the table have the following meanings:

Tabulated values	= data from tables of nuclides
Energy	= energy determined by the computer in the maximum of the photopeak evaluated
Channel position	= interpolated channel number
Background	= Compton background across the width of the photopeak
Signal	= number of pulses in the photoline after subtraction of the background
Channel No.	= channel number = number of channels used for evaluation
FWHM	= calculated full width at half maximum of the photopeak
Error	= relative error of the photopeak
Activ. Conc.	= calculated activity concentration

Following these 20 nuclide lines the measured and calculated values of another ten peaks found, although without activity concentrations calculated, can be printed. In the present case five additional peaks are found. At the right margin of the table those peaks are marked by an asterisk which have caused printout of the protocol which means that they have changed by more than the preset limit value as compared with the preceding measurement.

6.2 Spectrum Plot

The last 25 spectra recorded each can be put out under the spectrum number as the identification character in the form of a spectrum plot following a user request (Fig. 5). To facilitate comparison before plotting all spectra are normalized to 1000 s lifetime and 1 bar cover gas pressure. The lines found by the program are marked by their nuclide names.

6.3 Time Function of the Acitivity Concentration of Nuclides

By a user request the time sequence of the activity concentration of the 20 nuclide lines contained in the table of nuclides can be plotted (Fig. 6). Likewise, the time sequence of the integral detector count rate, the precipitator count rate and the two DN signals can be plotted. To be able to evaluate signal fluctuations occurring during the MCA measurement period the average, maximum and minimum values of these signals can be plotted (Fig. 7). The time scale for all these plots can be selected between 1 h and 31 days so that the development of activity concentrations can be represented as hourly, daily, weekly or monthly plots. In all these plots the development of reactor power is included in addition as a significant information for signal interpretation.

6.4 Outputs of the 10-Minutes Machine

The DATANIM counter/timer system records every 10 s the measuring signals of the reactor power, the Ge-detector, the precipitator, the two DN monitors, and the cover gas pressure. By the 10-minutes machine these measured values are put out from 10 minutes before until 10 minutes after excitation at 10 s intervals.

Table 3 shows the 10-minutes protocol prior to excitation, Table 4 is the continuation of the protocol until 10 minutes after excitation. After the 10-minutes protocols have been written the measured values are automatically put out as plots (Fig. 8 and 9). In Fig. 8 no decline of the detector and precipitator signals, respectively, can be recognized because the travel time of the gas between the reactor plenum and point of measurement is 15 minutes /10/. It is planned to convert the 10-minutes machine for these two signals taking into account the gas travel time.

6.5 Flux Tilting Output

The results of a flux tilting campaign are putted out by RECOS in two different ways. Firstly after each flux tilting configuration a protocol is putted out automatically by the printer. Table 5 shows such a protocol produced after the last flux tilting configuration on the occasion of the fifth defected subassembly at KNK II. Besides informal values the final result of the flux tilting campaign is represented in the last column of Table 5., the "hit list". The core positions of the subassemblies are sorted in ascending manner of their sum (eq. 1), so that the most suspect subassembly is placed on the top of the list.

Secondly, the flux tilting result can be putted out by the plotter on user request (Fig. 10). A core map is putted out by the plotter, where the subassembly hexagons are filled up corresponding to the agreement between DN signals and subassembly power. The most suspect subassembly has the highest "Water Level" in it's hexagon.

The flux tilting results shown in (Tab. 5) and (Fig. 10) have been obtained on the occasion of the fifth defected subassembly at KNK II. Later it was found by dry sipping in the fuel handling machine that the defected subassembly in fact was at the core position 418.

6.6 Alarm Messages

Besides the protocols and plots indicated before the following alarm messages are put out by the printer together with the data and clock time:

- Scram.
  10-minutes machine was activated.

- Power on.
  At reactor startup power greater than 3 MW.

- Limit value of detector count rate activated.
  The detector count rate has risen or fallen, respectively, such that the MCA was stopped and restarted.

- Collimator started.
  On account of significant changes in the detector count rate another collimator position is necessary for optimum recording of the gamma spectrum; the respective instruction for operation was given.

- Collimator defective.
  The collimator has not attained its target positon within a predefined period; recording of gamma spectra is continued all the same.

- Precipitator - DN east - DN west	Quick rise and fall, respectively, of these signals; the 10-minutes machine was activated.

7. Concluding Remark

Since early 1978 COCOSS had been operated, initially as an on-line gamma spectrometer only, and since late 1983 it has been run at KNK II at the stage of implementation described here for data acquisition and evaluation. Work on COCOSS will be continued as follows.

- Improvement of DN signal acquisition by feed of the gamma signal of Na-24 activity to calculate the DN net signal.

- Improvement of Ge-detector calibration with a view to achieving better agreement with the cover gas activities measured off-line through sampling.

- Code development with a view to damage classification and calculation of free fuel surfaces based on information obtained from background measurements and the measurements involving artificial and natural cladding defects.

- Failure prediction through input of expert knowledge concerning the most probable defect development and time until attainment of the DN scram value.

In the stage of implementation attained at that time COCOSS will be capable of providing to the reactor operator important assistance in decision making during operation with defective fuel pins.

8. Literature

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Table 1: Control variables

```
Control variable for RECOS system:

Measurement periods for the multichannel analyzer:
Short period of measurement = 500 s
Medium period of measurement = 1000 s
Long period of measurement = 2000 s
Limit values for the MCA measurement periods:
Limit value for short period of measurement = 5000 CPS
Limit value for long period of measurement = 1000 CPS
Collimator position = 1
Limit values for the collimator positions:
Upper limit = 8000 CPS (if overrun, close collimator by one position)
Lower limit = 200 CPS (if underrun, open collimator by one position)
Geometry factors for the three collimator positions:
Position 1 = 0.133E-05
Position 2 = 0.224E-07
Position 3 = 0.158E-09
Monitored gas volume = 64.28 ccm
Admissible relative error = 50.00 %
Conversion factor for the reactor power = 0.87000E-01
Conversion factor for the cover gas pressure = 0.40000E-02
Quadratic energy calibration
1. Energy =  249.80 keV
2. Energy = 1293.64 keV
3. Energy =   80.99 keV
Calibration factors: A = -0.00000246  B = 1.00481880  C = -2.07313538
Limit for scram (if underrun) = 3.00 MW
Change of signal for burst recognition
Precipitator = 20.00 %
DND east     = 20.00 %
DND west     = 20.00 %

Percentage changes causing the output of protocols
Reactor power                 = 20.00
Integral detector count rate = 20.00  coefficient of change for new measurement = 2.00
Precipitator count rate       = 20.00
DND east                      = 20.00
DND west                      = 20.00
Cover gas pressure            = -1.00
```

Table 1 continued

Table of Nuclides

No.	Nuclide	Half-life	Abundance	Energy	Coefficient of Change	
1	Xe 133	5.65 d	36.6	80.99	1.20	with log. 6 decades on strip chart recorder
2	Kr 85m	4.40 h	74.0	150.99	1.20	
3	Kr 88	2.80 h	37.0	196.10	1.20	
4	Xe 133m	2.26 d	14.0	232.90	1.20	
5	Xe 135	9.14 h	91.0	249.80	1.20	with log. 6 decades on strip chart recorder
6	Xe 138	14.1 m	31.0	258.30	1.20	
7	Kr 87	76.0 m	53.0	402.80	1.20	
8	Ne 23	38.2 s	33.0	440.00	1.20	
9	Cs 138	32.2 m	27.8	462.80	1.20	
10	Xe 135m	15.6 m	80.0	526.80	1.20	
11	Xe 135	9.14 h	2.4	608.60	1.20	
12	Kr 88	2.80 h	13.0	834.70	1.20	
13	Rb 89	15.1 m	60.0	1030.70	1.20	
14	Ar 41	1.84 h	99.0	1293.64	2.00	
15	Cs 138	32.2 m	75.0	1435.90	1.20	
16	Kr 89	191. s	9.5	1472.10	1.20	
17	Kr 88	2.80 h	11.3	1529.80	1.20	
18	Xe 138	14.1 m	17.7	1768.20	1.20	
19	Rb 88	17.8 m	30.2	1836.13	1.20	
20	Xe 138	14.1 m	12.5	2015.80	1.20	

10 additional peaks at the maximum are evaluated starting from 70.00 keV.

Tape Name	Tag Word	Detector Name	Spectrum No.
160284	199	N18A	466

Generated Detector Efficiency Values

Energy (keV)	Collim. Pos. 1	Collim. Pos. 2	Collim. Pos. 3
80.99	17.4004	21.3902	6.6807
150.99	16.7345	16.8896	10.5130
196.10	11.4323	10.6208	7.7961
232.90	8.3015	7.5250	6.0367
249.80	7.2080	6.4895	5.3485
258.30	6.7264	6.0384	5.0284
402.80	2.6273	2.2744	1.9456
440.00	2.2820	1.9084	1.7048
462.80	2.0999	1.7403	1.5856
526.80	1.6850	1.4300	1.3283
608.60	1.3083	1.2186	1.1043
834.70	0.7670	0.7757	0.7650
1030.70	0.5876	0.5444	0.6130
1293.64	0.3154	0.3599	0.4583
1435.90	0.2434	0.2953	0.3990
1472.10	0.2296	0.2815	0.3862
1529.80	0.2104	0.2614	0.3674
1768.20	0.1544	0.1970	0.3078
1836.13	0.1430	0.1828	0.2952
2015.80	0.1190	0.1519	0.2691

Table 2: Measurement protocol

Spectrum No.: 7055 Tape: 041085 / 45 Disk: 75 / 23

Start: 4. Okt. 1985 23:38:56 End : 23:55:57
Lifetime = 1000. s Truetime = 1014.00 s Deadtime = 1.4 %
Geometry factor = 0.223630E-07 Collimator position: 2 Volume = 64.28 ccm Detector name: N18A
Calibration factors: A = -0.00000003 B = 1.00500631 C = -1.30761719

		Mean Values	Starting Values	Final Values	Maximum Values	Minimum Values
Reactor power	(%)	79.31	79.24	79.35	79.54	79.05
Detector count rate	(cps)	1412.71	1421.45	1402.14	1438.04	1382.35
Precipitator count rate	(cps)	24.45	24.34	22.62	28.45	20.91
DND east	(cps)	1012.69	1010.50	1119.40	1119.40	905.10
DND west	(cps)	499.33	490.70	487.90	534.40	457.10
Cover gas pressure	(bar)	1.34	1.34	1.34	1.34	1.34

Tabulated Values					Measured Values								
No.	Nuclide	Half-life	Abundance (%)	Energy (keV)	Energy (keV)	Channel position	Background (pulses)	Signal (pulses)	Channel Num.	FWHM (keV)	Error (%)	Activ. Conc. (I/s*Nccm)	
1	Xe 133	5.65 d	36.6	80.99	80.99	81.9	92709.	418345.	9.	1.5	0.8	0.278E+06	
2	Kr 85m	4.40 h	74.0	150.99	151.29	151.8	24085.	19745.	5.	1.5	5.6	0.821E+04	
3	Kr 88	2.80 h	37.0	196.10	196.44	196.8	11925.	6405.	5.	1.5	11.8	0.847E+04	
4	Xe 133m	2.26 d	14.0	232.90	233.16	233.3	12072.	1615.	6.	2.5	47.8	0.796E+04	*
5	Xe 135	9.14 h	91.0	249.80	249.80	249.9	10112.	165010.	8.	1.5	0.8	0.145E+06	
6	Xe 138	14.1 m	31.0	258.30									
7	Kr 87	76.0 m	53.0	402.80	402.60	401.9	846.	1274.	5.	1.5	18.3	0.549E+04	
8	Ne 23	38.2 s	33.0	440.00									
9	Cs 138	32.2 m	27.8	462.80									
10	Xe 135m	15.6 m	80.0	526.80	526.84	525.5	492.	204.	4.	2.5	69.4	0.926E+03	
11	Xe 135	9.14 h	2.4	608.60	608.34	606.6	666.	973.	6.	2.5	21.3	0.173E+06	
12	Kr 88	2.80 h	13.0	834.70									*
13	Rb 89	15.1 m	60.0	1030.70									
14	Ar 41	1.84 h	99.0	1293.64	1293.64	1288.5	240.	1086.	8.	2.5	14.8	0.158E+05	
15	Cs 138	32.2 m	75.0	1435.90									
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	1836.70	1828.9	51.	140.	6.	1.5	44.2	0.132E+05	
20	Xe 138	14.1 m	12.5	2015.80									
1					75.08	76.0	106396.	76828.	18.	5.5	5.8		
2					108.91	109.7	19029.	1688.	3.	3.5	46.2		
3					305.00	304.8	1585.	1180.	5.	1.5	24.0		
4					898.39	895.2	280.	311.	5.	3.5	41.5		
5					1370.02	1364.5	108.	291.	6.	2.5	32.4		

* Reason for protocol output

Table 3: 10 minutes protocol

12 April, 1984 10 minutes protocol (before scram) Sheet 1

Collimator position = 1

Time	Power (MWt)	Ge-detector (cps)	Precip-itator (cps)	DND East (cps)	DND West (cps)	Gas Pressure (bar)
11:48:53	47.10	876.76	168.26	60.10	67.00	1.46
11:49:03	47.10	882.52	161.02	64.50	65.00	1.46
11:49:13	47.09	871.72	163.27	62.70	66.10	1.46
11:49:23	47.08	878.73	165.85	66.30	71.20	1.46
11:49:33	46.98	876.44	162.95	64.90	65.40	1.46
11:49:43	46.89	881.32	168.24	58.80	67.70	1.46
11:49:53	46.85	874.11	159.53	65.30	62.00	1.46
11:50:03	46.92	875.17	161.62	63.00	63.20	1.46
11:50:13	46.91	871.00	163.41	59.30	68.50	1.46
11:50:24	46.75	879.65	167.62	60.20	60.90	1.46
11:50:34	46.99	881.09	169.27	63.00	68.90	1.46
11:50:44	47.01	865.60	166.89	63.40	62.90	1.46
11:50:54	46.95	863.57	164.07	67.30	64.00	1.46
11:51:04	47.00	861.93	165.71	67.60	66.90	1.46
11:51:14	47.07	862.21	165.23	66.70	68.20	1.46
11:51:24	47.06	856.15	165.00	64.80	63.70	1.46
11:51:34	47.17	865.11	163.63	67.30	71.90	1.46
11:51:44	47.05	872.20	166.26	66.30	67.60	1.46
11:51:54	47.11	867.51	165.28	64.60	66.60	1.46
11:52:04	47.15	865.52	167.74	64.70	67.40	1.46
11:52:14	47.13	875.99	164.52	64.00	66.70	1.46
11:52:24	47.19	852.59	165.14	62.40	65.10	1.46
11:52:34	47.15	887.08	165.48	62.00	62.70	1.46
11:52:44	47.18	877.63	165.55	60.40	64.00	1.46
11:52:54	47.21	870.51	160.13	66.20	65.70	1.46
11:53:04	47.09	863.54	165.82	62.00	67.00	1.46
11:53:14	47.15	878.94	169.38	65.50	63.10	1.46
11:53:24	47.30	861.48	161.58	61.90	69.70	1.46
11:53:34	47.28	872.37	169.45	66.90	69.90	1.46
11:53:44	47.27	881.81	163.50	65.30	69.50	1.46

Table 3 continued

12 April, 1984 10 minutes protocol (before scram) Sheet 2

Collimator position = 1

Time.	Power (MWt)	Ge-detector (cps)	Precip-itator (cps)	DND East (cps)	DND West (cps)	Gas Pressure (bar)
11:53:54	47.27	877.36	162.26	63.90	65.60	1.46
11:54:04	47.35	871.85	165.87	63.20	63.50	1.46
11:54:14	47.28	872.60	165.46	69.20	65.20	1.46
11:54:24	47.35	871.07	164.04	63.80	66.70	1.46
11:54:35	47.35	863.26	168.15	60.90	63.90	1.46
11:54:45	47.39	870.31	171.57	63.20	67.10	1.46
11:54:55	47.44	867.06	164.43	64.60	63.00	1.46
11:55:05	47.36	871.27	170.89	61.00	68.70	1.46
11:55:15	47.37	866.21	165.69	63.90	68.40	1.46
11:55:25	47.42	867.74	166.07	63.60	63.90	1.46
11:55:35	47.41	865.06	165.87	61.90	63.60	1.46
11:55:45	47.48	881.30	164.57	62.50	67.00	1.46
11:55:55	47.46	883.49	162.45	65.90	69.80	1.46
11:56:05	47.57	866.41	160.42	68.40	68.50	1.46
11:56:15	47.60	872.54	171.21	61.00	67.30	1.46
11:56:25	47.59	871.13	163.36	61.90	65.60	1.46
11:56:35	47.66	874.73	167.03	65.20	63.50	1.46
11:56:45	47.59	866.31	164.84	66.60	62.40	1.46
11:56:55	47.60	871.07	166.51	60.00	69.10	1.46
11:57:05	47.57	865.76	161.62	63.20	63.60	1.46
11:57:15	47.62	890.54	163.75	62.60	67.90	1.46
11:57:25	47.75	868.74	163.36	64.40	66.90	1.46
11:57:35	47.55	868.22	169.63	67.50	64.30	1.46
11:57:45	47.56	865.59	170.34	64.40	61.90	1.46
11:57:55	47.64	874.93	167.92	64.60	63.50	1.46
11:58:05	47.62	871.48	164.18	60.80	73.90	1.46
11:58:15	47.58	884.72	165.66	61.50	67.50	1.46
11:58:26	47.52	881.55	162.67	66.30	69.20	1.46
11:58:36	47.54	865.42	161.42	66.80	65.40	1.46
11:58:46	42.38	877.29	160.21	63.70	66.40	1.46

Table 4

12. Apr. 1984 10 minutes protocol (after scram) sheet 3

Collimator position = 1

Time	Power (MWt)	Ge-detector (cps)	Precipitator (cps)	DND East (cps)	DND West (cps)	Gas Pressure (bar)
11:58:56	1.22	888.49	160.53	47.10	55.60	1.46
11:59:06	0.56	891.39	160.96	41.80	60.00	1.46
11:59:16	0.43	889.65	166.00	42.50	64.00	1.46
11:59:26	0.37	895.61	167.17	41.80	66.80	1.46
11:59:36	0.32	888.52	165.55	41.10	55.20	1.46
11:59:46	0.30	871.31	165.30	40.20	54.00	1.46
11:59:56	0.27	884.17	167.21	39.20	51.00	1.46
12:00:08	0.25	882.52	171.23	40.40	46.20	1.46
12:00:18	0.24	892.68	165.66	41.80	46.80	1.46
12:00:28	0.23	887.38	163.91	38.90	43.90	1.46
12:00:38	0.22	883.58	164.21	37.50	73.60	1.46
12:00:48	0.22	899.99	173.02	39.30	56.90	1.46
12:00:58	0.21	900.94	168.31	38.30	47.30	1.46
12:01:08	0.20	903.48	162.65	36.50	43.30	1.46
12:01:18	0.20	888.87	167.71	38.70	73.70	1.46
12:01:28	0.20	886.38	168.42	34.40	43.40	1.46
12:01:39	0.20	889.11	170.13	35.10	43.50	1.46
12:01:49	0.19	891.26	173.84	35.00	54.40	1.46
12:01:59	0.20	885.76	168.94	36.50	40.60	1.46
12:02:09	0.19	886.80	162.87	36.40	44.10	1.47
12:02:19	0.19	908.12	170.26	37.20	44.60	1.47
12:02:29	0.19	893.64	171.57	38.10	40.10	1.47
12:02:39	0.19	893.53	172.56	40.50	44.50	1.47
12:02:49	0.19	887.40	167.17	36.70	46.00	1.47
12:02:59	0.18	911.73	169.54	38.40	40.20	1.47
12:03:09	0.18	901.71	168.95	35.90	43.30	1.47
12:03:19	0.19	893.73	165.72	35.90	49.50	1.47
12:03:29	0.18	903.06	164.72	38.10	40.70	1.48
12:03:39	0.19	905.20	165.56	35.20	39.60	1.48
12:03:49	0.18	890.55	164.14	36.30	44.40	1.48

Table 4 continued

12. Apr. 1984 10 minutes protocol (after scram) sheet 4

Collimator position = 1

Time	Power (MWt)	Ge-detector (cps)	Precipitator (cps)	DND East (cps)	DND West (cps)	Gas Pressure (bar)
12:03:59	0.19	906.38	172.15	40.60	42.50	1.48
12:04:09	0.18	893.48	165.04	36.70	50.60	1.48
12:04:19	0.18	907.31	169.21	39.20	43.40	1.48
12:04:29	0.18	903.21	168.90	38.50	41.20	1.48
12:04:39	0.18	884.00	169.60	38.90	41.60	1.48
12:04:49	0.19	878.42	168.07	39.50	41.00	1.48
12:04:59	0.18	876.80	167.21	34.80	42.20	1.47
12:05:09	0.18	877.87	167.26	39.30	49.50	1.46
12:05:19	0.18	893.95	169.12	41.50	44.90	1.45
12:05:29	0.18	871.17	169.52	35.30	44.90	1.45
12:05:39	0.18	885.41	164.01	35.10	46.00	1.44
12:05:49	0.19	891.19	165.20	38.60	45.60	1.44
12:06:00	0.18	873.12	171.50	33.30	47.60	1.43
12:06:10	0.18	882.56	164.69	40.30	45.40	1.43
12:06:20	0.18	889.14	165.90	40.40	44.60	1.44
12:06:30	0.18	894.53	158.94	37.60	50.30	1.44
12:06:40	0.18	903.54	163.98	37.30	42.40	1.44
12:06:50	0.18	894.26	165.85	34.60	50.10	1.44
12:07:00	0.18	889.66	172.11	34.30	45.40	1.44
12:07:10	0.19	902.76	171.99	39.30	43.00	1.44
12:07:20	0.18	895.72	162.00	38.20	45.70	1.44
12:07:30	0.19	895.10	165.72	36.40	52.30	1.45
12:07:40	0.18	903.23	171.73	39.40	43.20	1.45
12:07:50	0.18	904.77	166.90	38.10	42.00	1.45
12:08:00	0.19	900.30	166.90	36.60	44.90	1.45
12:08:10	0.18	911.22	172.90	37.90	48.00	1.46
12:08:20	0.19	900.97	166.55	37.00	42.70	1.46
12:08:30	0.18	902.47	172.22	40.30	47.00	1.46
12:08:40	0.18	917.65	167.79	37.90	43.40	1.46
12:08:50	0.19	904.64	165.80	37.20	41.00	1.46

Table 5. Flux Tilting Protocol

Flux Tilting Dataset No. 5 case: Rod YA24 inserted

May 21, 1986 17:27:41

Reactor power		15.10 %
Level of control rod	YA20 =	542.6 mm
Level of control rod	YA21 =	542.6 mm
Level of control rod	YA22 =	542.6 mm
Level of control rod	YA23 =	542.6 mm
Level of control rod	YA24 =	972.9 mm
DN-East		55.2 cps
DN-West		39.1 cps
DN-East + DN-West		94.3 cps
DN-East/DN-West		1.4
Sodium inlet Temperature		267.5 C

Core pos.	TE-Number	Outlet Temp.	Heating rate	Quotient	Difference	Sum Diff.	I	Hit list		
100	T201	342.6	75.1	0.977865E+00	0.196330E+00	0.147055E+01	I	BE418	0.995271E+00	most suspect
201	T202	343.0	75.5	0.926380E+00	0.144845E+00	0.121474E+01	I	BE301	0.102533E+01	
202	T203	351.0	83.5	0.988166E+00	0.206631E+00	0.132996E+01	I	BE417	0.110654E+01	
203	T204	363.0	95.5	0.103243E+01	0.250898E+00	0.154662E+01	I	BE402	0.118327E+01	
204	T205	347.0	79.5	0.105298E+01	0.271445E+00	0.169855E+01	I	BE201	0.121474E+01	
205	T206	356.0	88.5	0.101143E+01	0.229894E+00	0.165442E+01	I	BE403	0.126359E+01	
206	T207	359.0	91.5	0.919598E+00	0.138063E+00	0.141993E+01	I	BE404	0.128131E+01	
301	T208	344.0	76.5	0.864407E+00	0.828719E-01	0.102533E+01	I	BE303	0.129939E+01	
303	T210	354.0	86.5	0.100000E+01	0.218465E+00	0.129939E+01	I	BE202	0.132996E+01	
305	T212	358.0	90.5	0.104624E+01	0.264708E+00	0.161042E+01	I	BE405	0.134318E+01	
307	T214	359.0	91.5	0.109581E+01	0.314273E+00	0.185535E+01	I	BE311	0.135318E+01	
309	T216	363.0	95.5	0.104372E+01	0.262181E+00	0.179893E+01	I	BE416	0.137730E+01	
311	T218	348.0	80.5	0.860963E+00	0.794277E-01	0.135318E+01	I	BE206	0.141993E+01	
402	T221	353.0	85.5	0.944751E+00	0.163216E+00	0.118327E+01	I	BE100	0.147055E+01	
403	T222	365.0	97.5	0.989848E+00	0.208313E+00	0.126359E+01	I	BE406	0.150638E+01	
404	T223	350.0	82.5	0.100000E+01	0.218465E+00	0.128131E+01	I	BE203	0.154662E+01	
405	T224	354.0	86.5	0.101170E+01	0.230161E+00	0.134318E+01	I	BE415	0.158168E+01	
406	T225	355.0	87.5	0.101156E+01	0.230026E+00	0.150638E+01	I	BE407	0.159511E+01	
407	T226	353.0	85.5	0.104908E+01	0.267545E+00	0.159511E+01	I	BE305	0.161042E+01	
408	T227	362.0	94.5	0.106780E+01	0.286262E+00	0.174262E+01	I	BE205	0.165442E+01	
409	T228	365.0	97.5	0.108939E+01	0.307851E+00	0.182885E+01	I	BE204	0.169855E+01	
411	T230	363.0	95.5	0.109143E+01	0.309894E+00	0.188299E+01	I	BE408	0.174262E+01	
412	T231	365.0	97.5	0.106557E+01	0.284039E+00	0.187544E+01	I	BE414	0.175392E+01	
413	T232	357.0	89.5	0.103468E+01	0.253147E+00	0.177227E+01	I	BE413	0.177227E+01	
414	T233	356.0	88.5	0.100000E+01	0.218465E+00	0.175392E+01	I	BE309	0.179893E+01	
415	T234	353.0	85.5	0.944751E+00	0.163216E+00	0.158168E+01	I	BE409	0.182885E+01	
416	T235	341.0	73.5	0.869823E+00	0.882876E-01	0.137730E+01	I	BE307	0.185535E+01	
417	T236	339.0	71.5	0.790055E+00	0.852036E-02	0.110654E+01	I	BE412	0.187544E+01	
418	T237	340.0	72.5	0.783784E+00	0.224888E-02	0.995271E+00	I	BE411	0.188299E+01	not suspect

quotient DN = 0.781535E+00

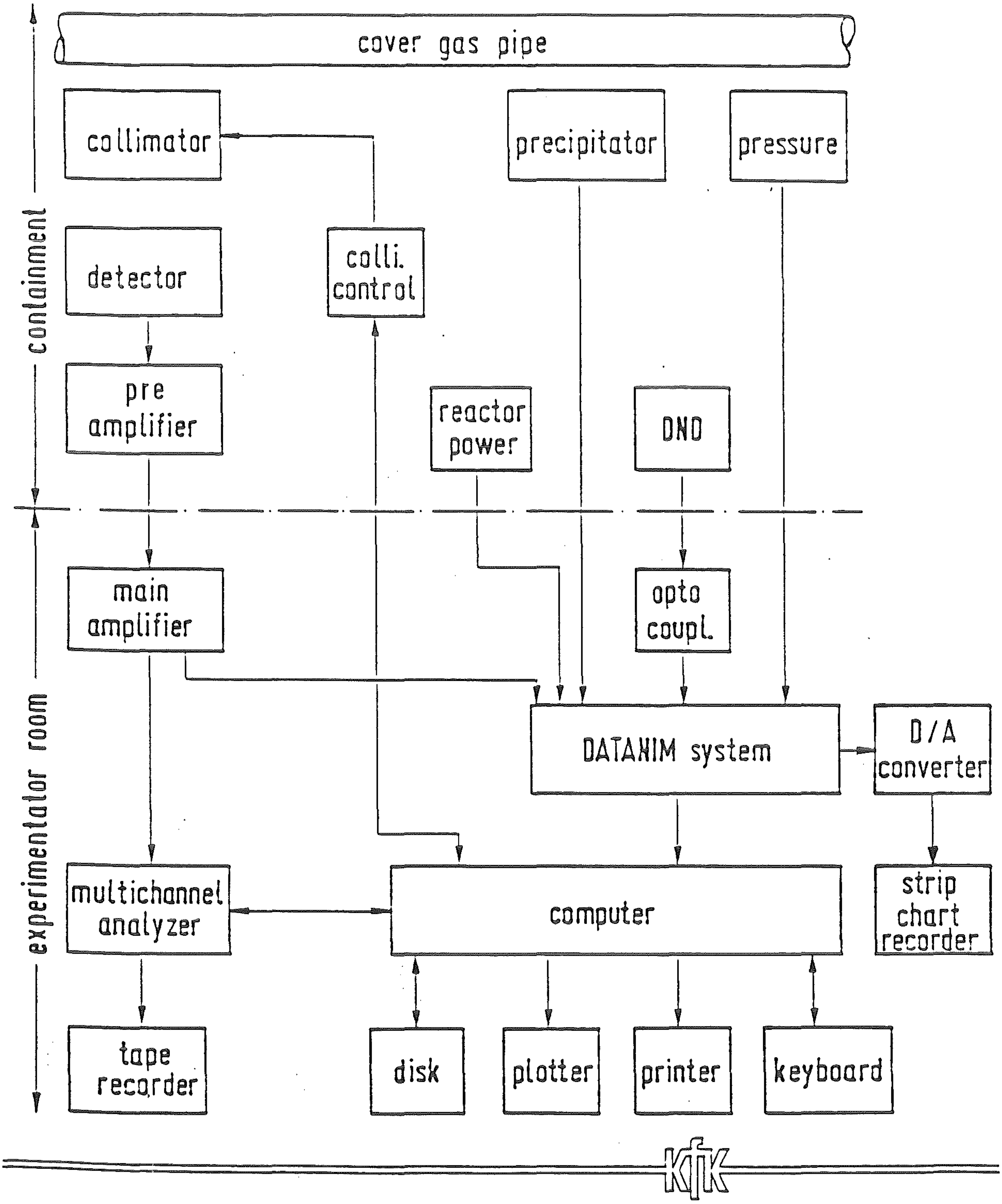


Fig: 1: CÓCOSS I System Configuration

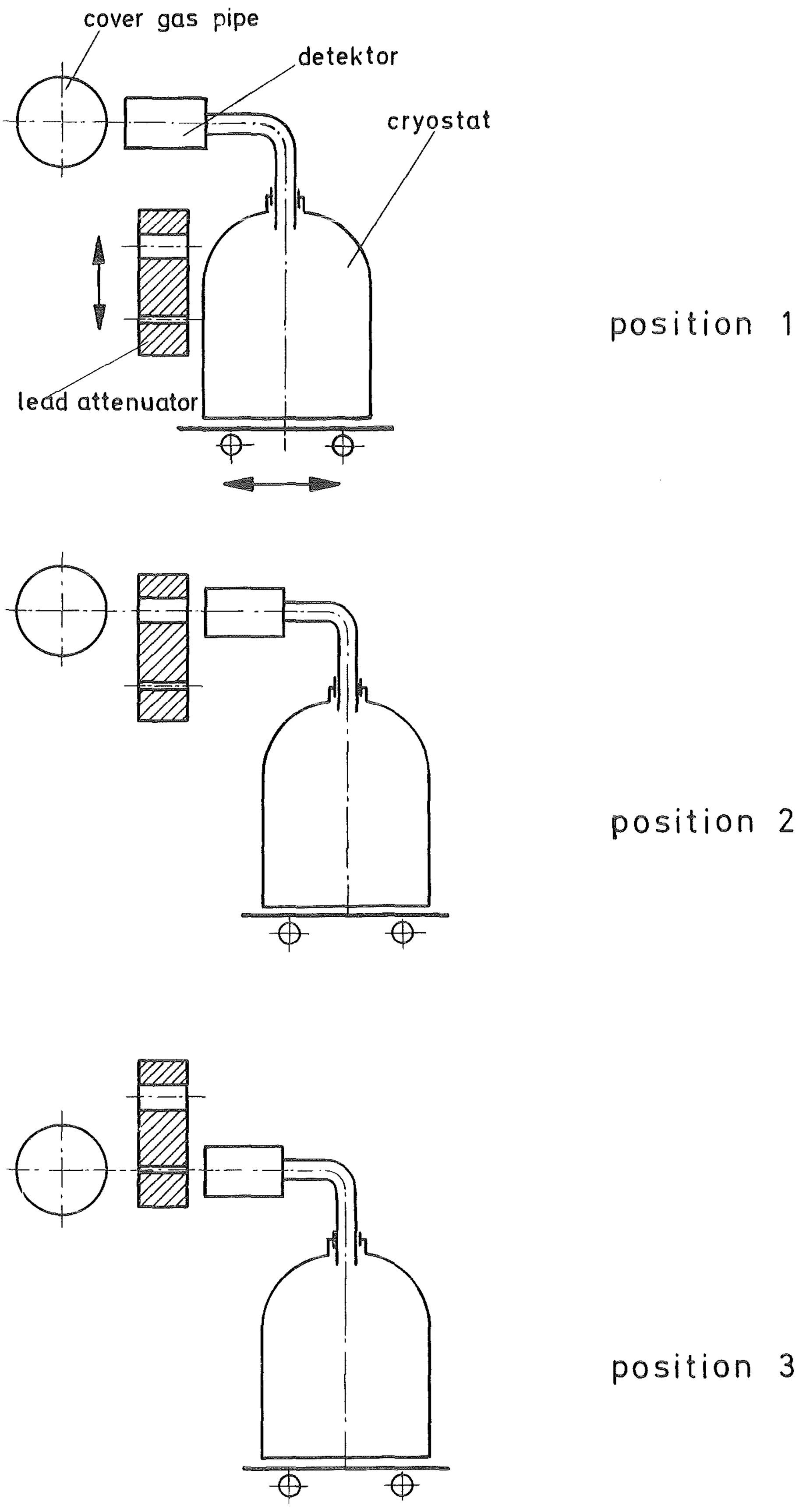


Fig. 2 Collimator Positions

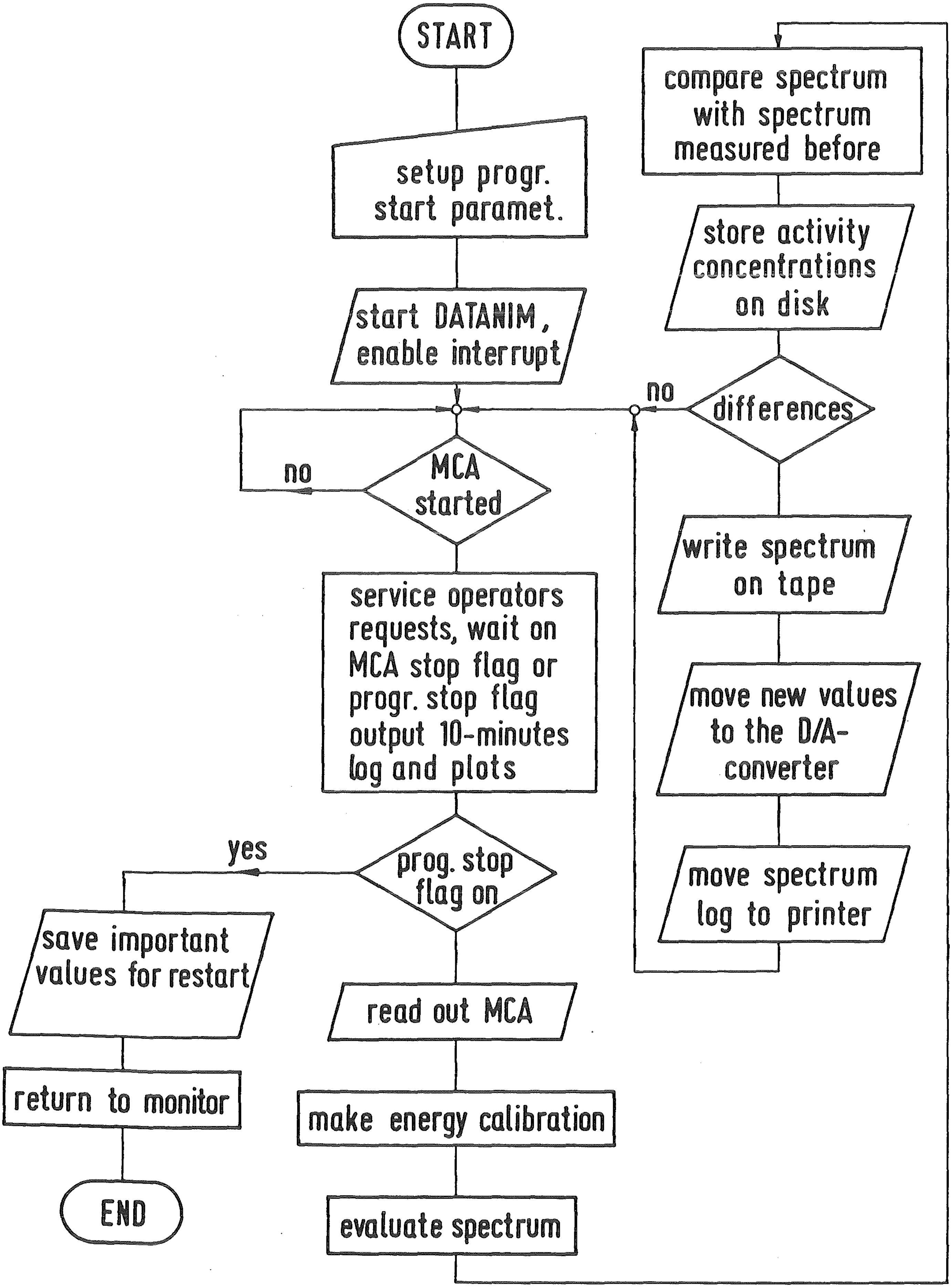


Fig. 3: RECOS program flow chart synchronous part

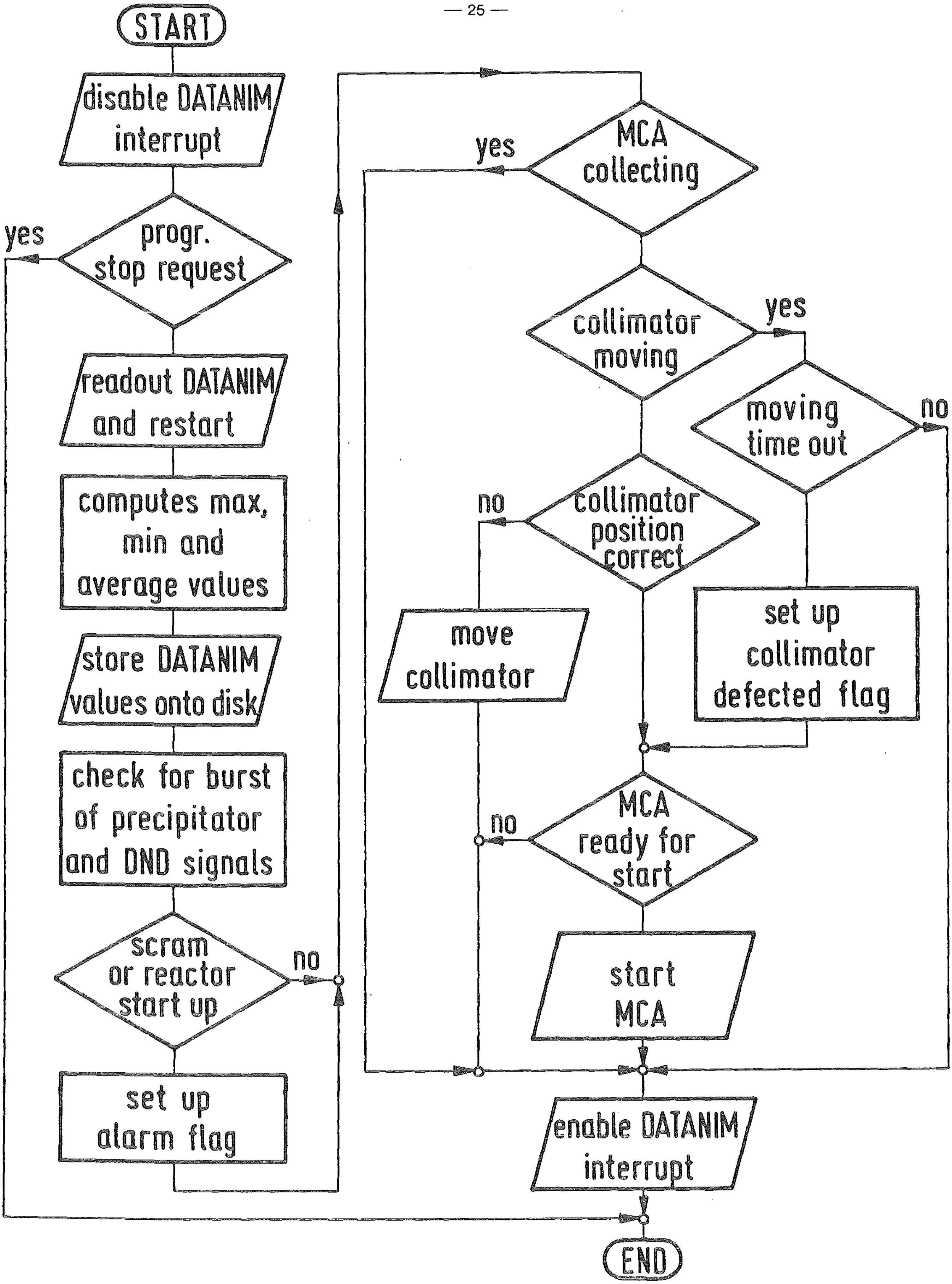


Fig. 4: RECOS program flow chart asynchronous part

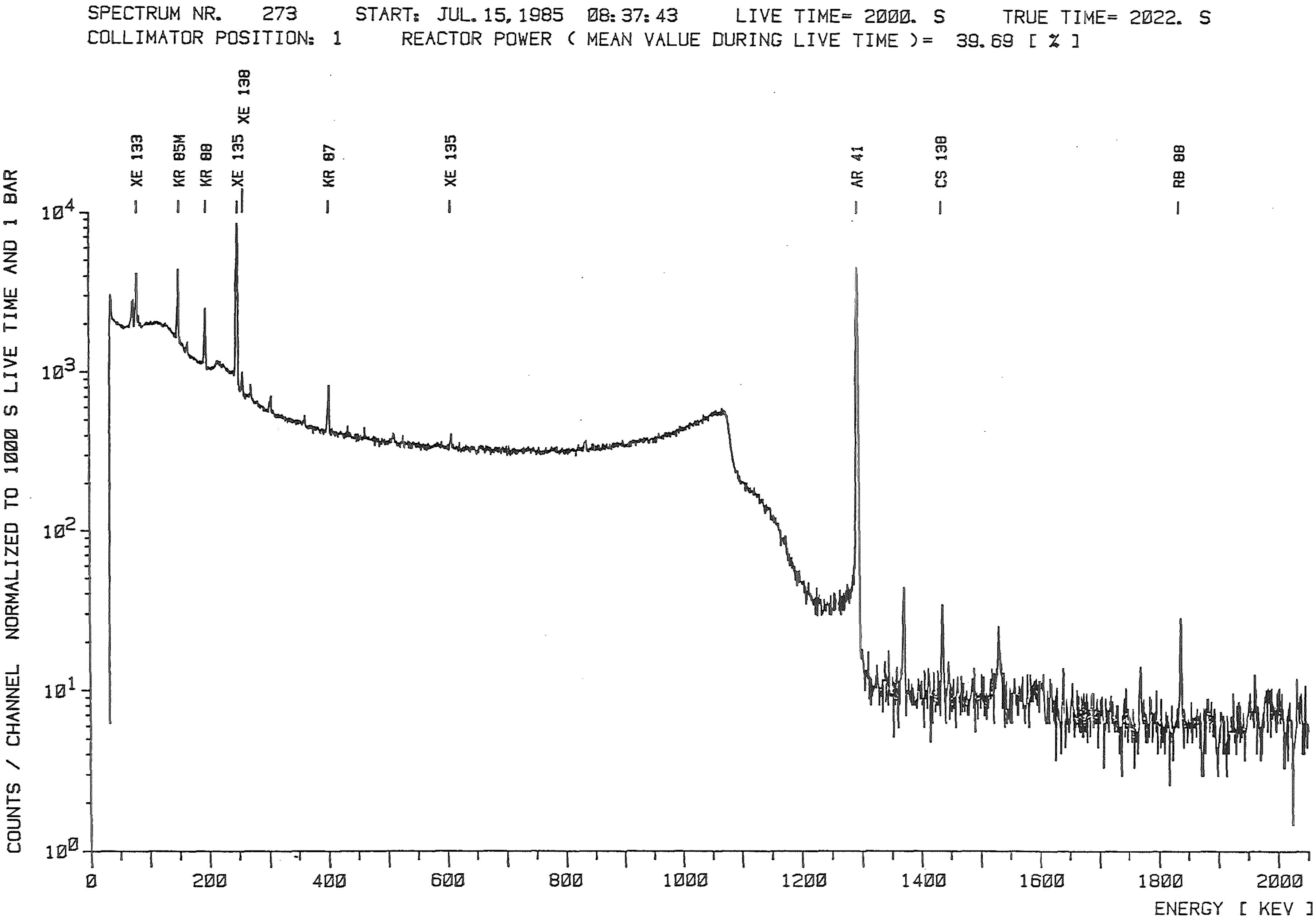
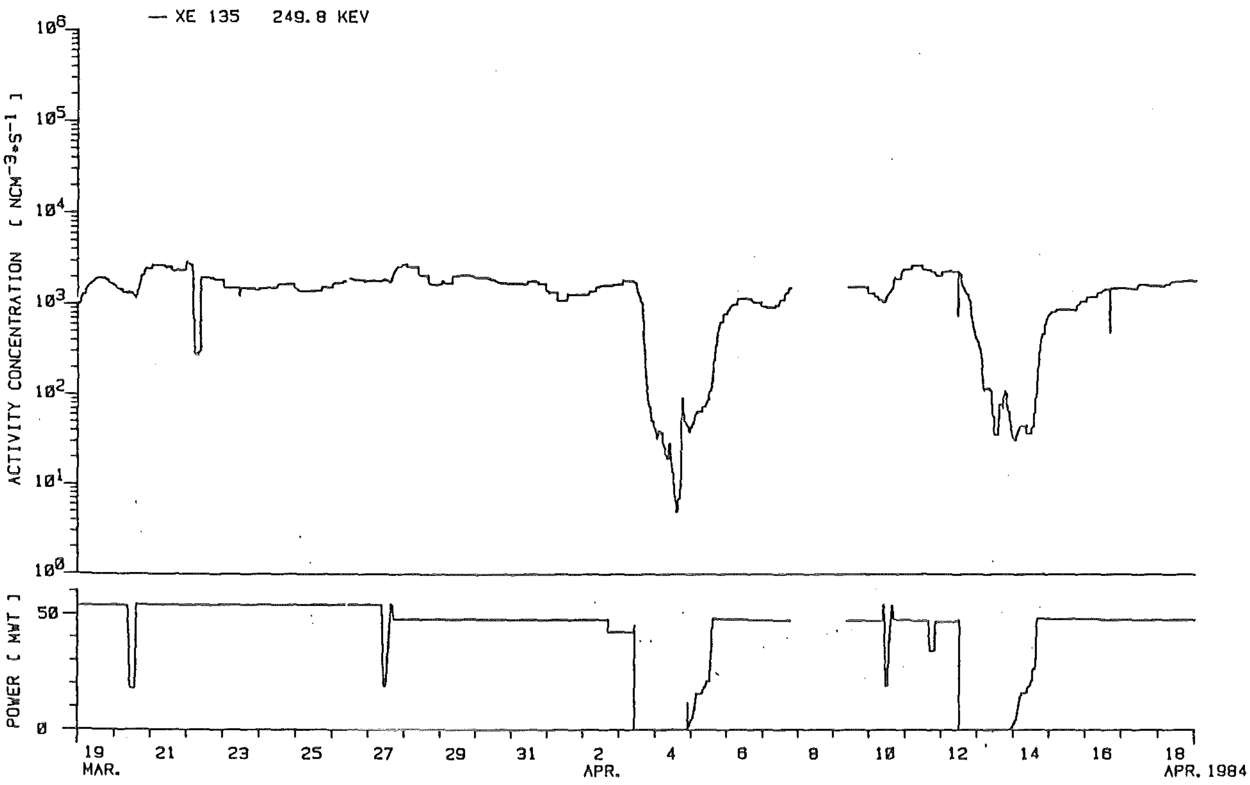
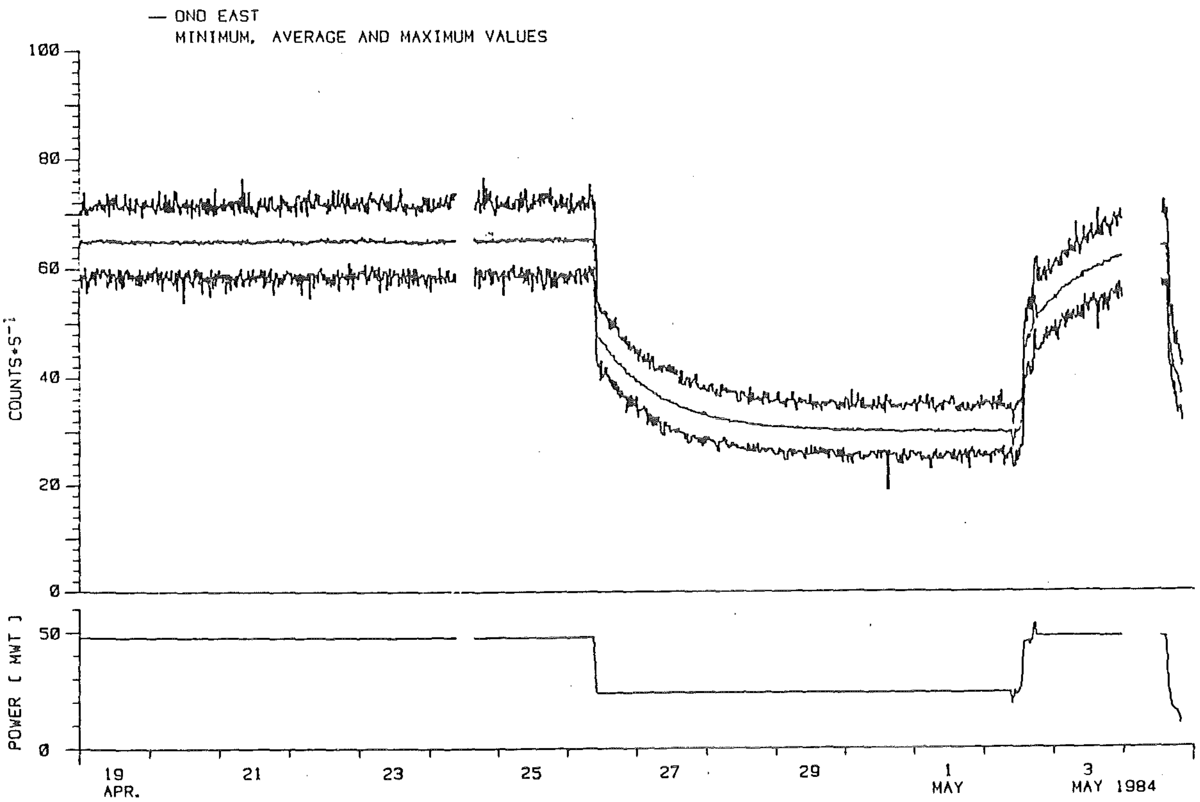


Fig. 5: Cover-gas gamma-spectrum



KNK II/2 EXPERIMENT: YE 705-511/8 BORE HOLE .1 MM**2 UPPER PLENUM 12 PELLETS

Fig. 6: Activity concentration of Xe 135 and reactor power from March 19 till April 18, 1984



KNK II/2 EXPERIMENT: YE 705-511/8 BORE HOLE .1 MM**2 UPPER PLENUM 12 PELLETS

Fig. 7: Minimum, average and maximum values of DND East and reactor power from April 19 till May 4, 1984

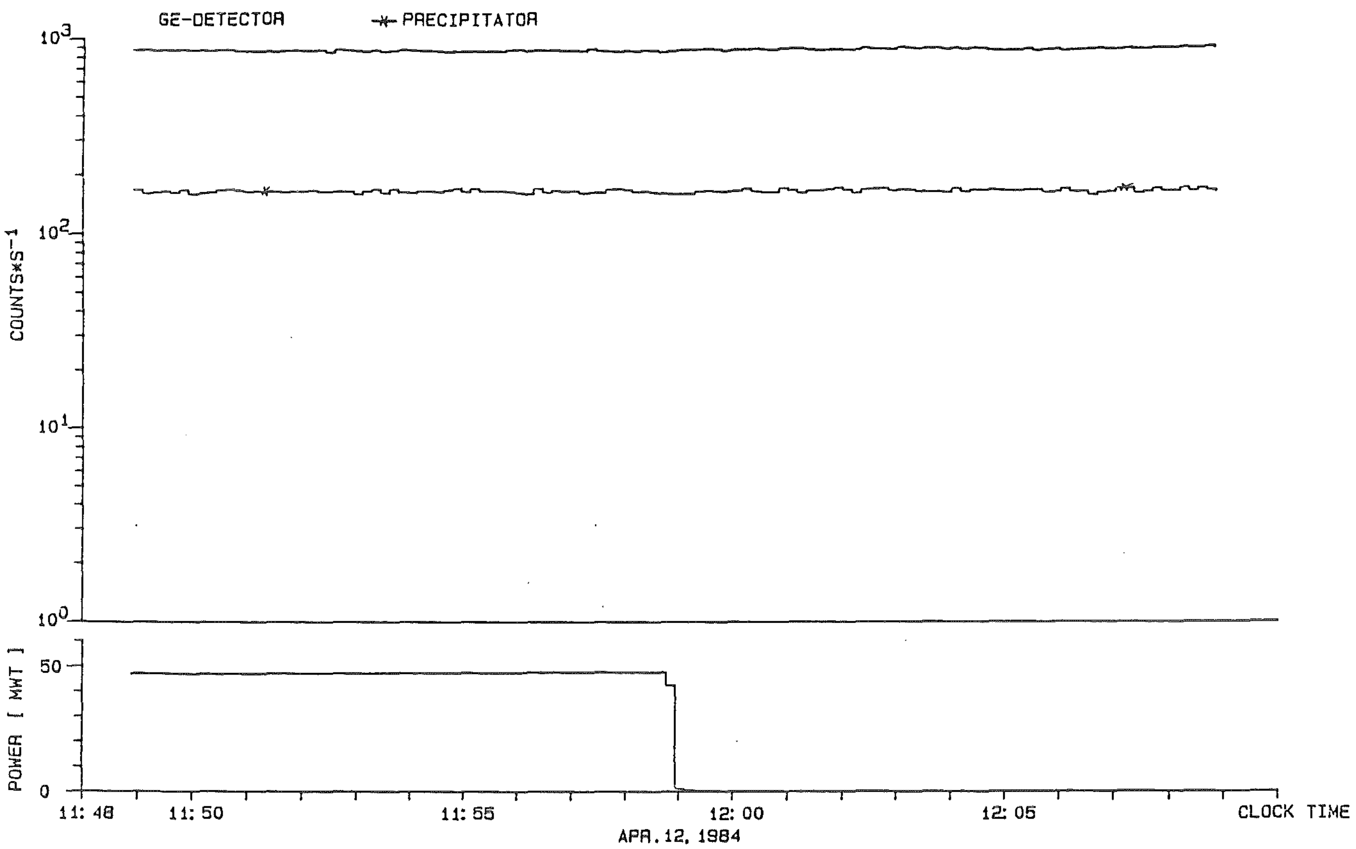


Fig. 8: 10-Minutesplot. Signals of Ge-detector and precipitator

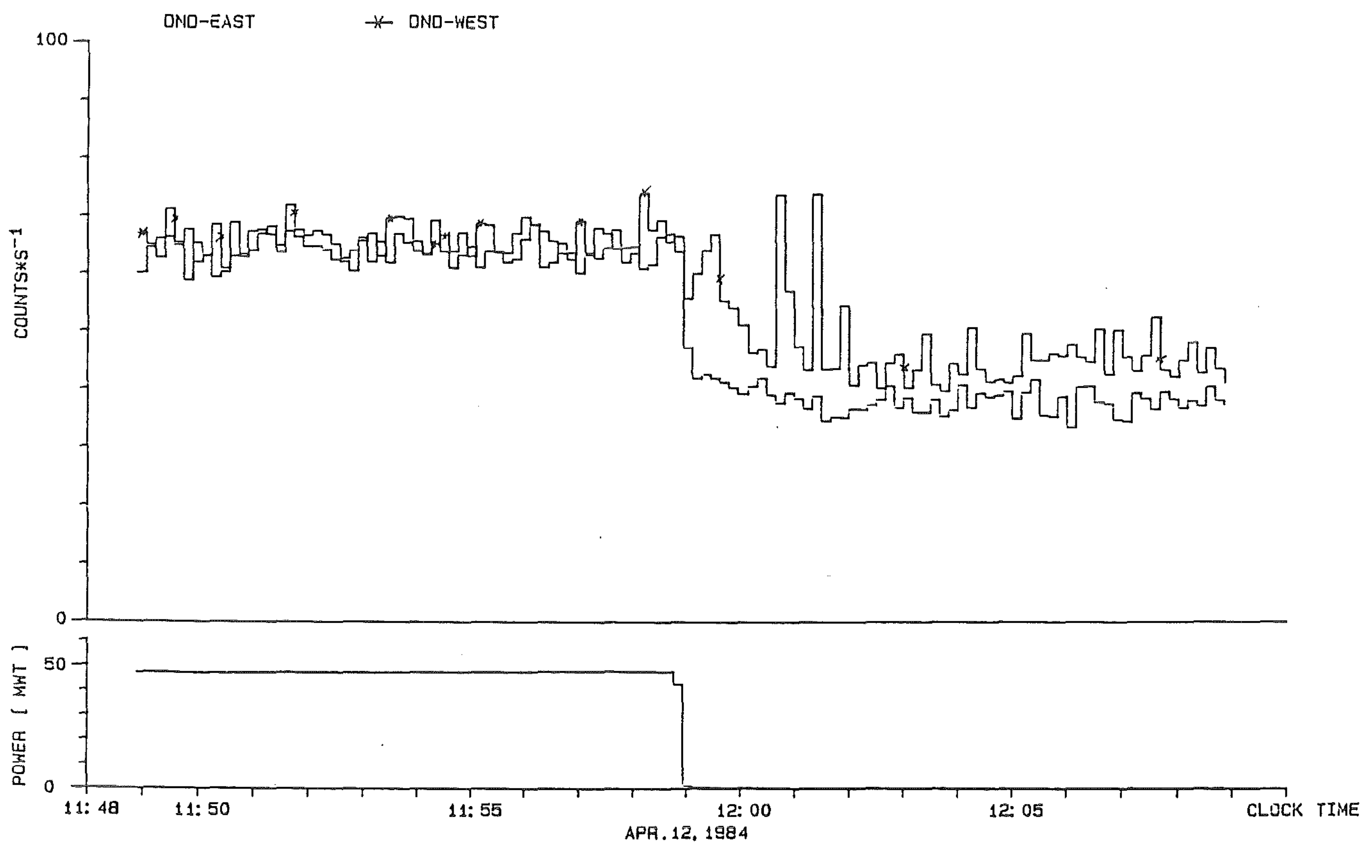


Fig. 9: 10-Minutesplot. Signals of the two DND monitors

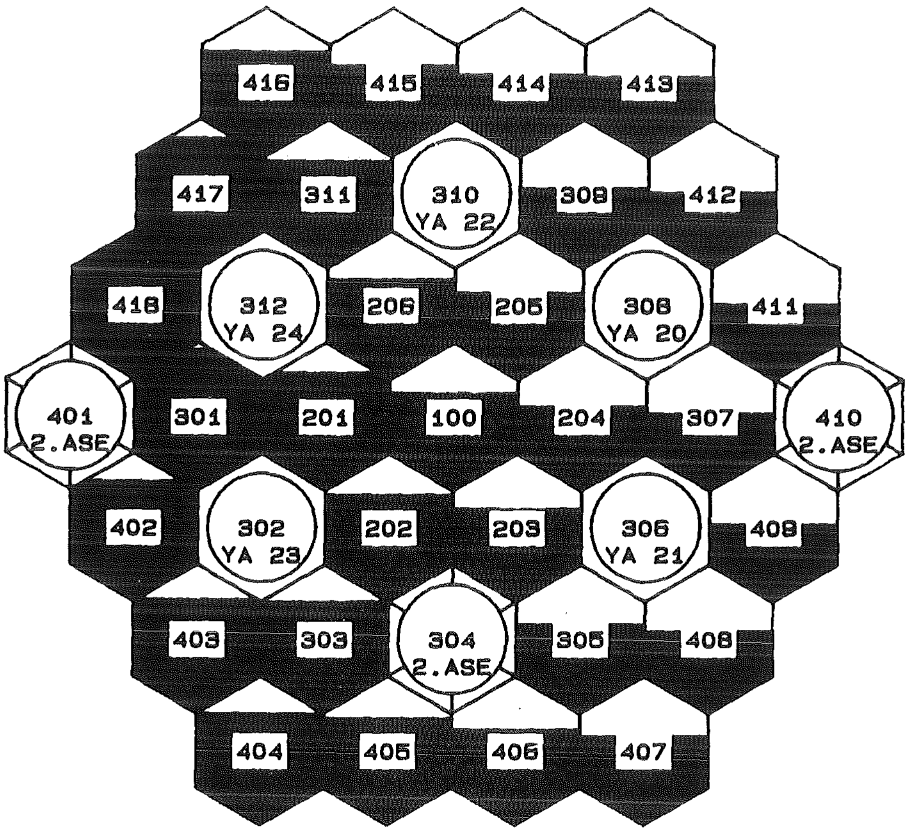


Fig. 10: Core Cross Section KNK II, Flux Tilting Result
Level of blackening as a measure of probability of failure occurrence. Circles indicate absorber positions.