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Department of Reactor Physics
Chalmers University of Technology

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1. Introduction

The TANSY-KM5 neutron spectrometer is a system containing a lot of advanced electronic and mechanical components. The design of the system has been reported in two documents [1],[2]. The purpose of this documentation is to give a brief overview of the system as it is defined at the time of delivery. Detailed information about the system and the labelling of components and cables is collected in 7 appendices, see " 5. The Appendices", page 34.

The electronic system and related items are described in " 2. The Electronic Components", page 6. Two versions of the system have been used during the test period. The principles of these are presented in two figures, figure 23, "Circuit Diagram for the Alternative Using the TDC OR Circuit", page 24, and figure 24, "Circuit Diagram for the Alternative Using the NBCO OR Circuit", page 25. The choice between these two set-ups is up to the user. Cut-outs of these diagrams are used in the different chapters describing the instrument, e.g. figure 6, "Neutron Signal Discriminator System", page 11. They are included in order to guide the reader through the main diagrams. Some signals are illustrated in diagrams, e.g. figure 7, "Normal Discriminator Signals", page 12. These are copied directly from oscilloscope print-outs taken during the test period of the instrument. More details concerning the set-up, calibration and use of the instrument will be given in another document [4].

Mechanical components such as the vacuum vessel and supporting frames for detectors are described in " 3. The Mechanical Components", page 27. Finally, some tools are needed for the adjustment and mounting of the instrument. A brief description is given in " 4. The Tools", page 32.

2. The Electronic Components

2.1. System Overview

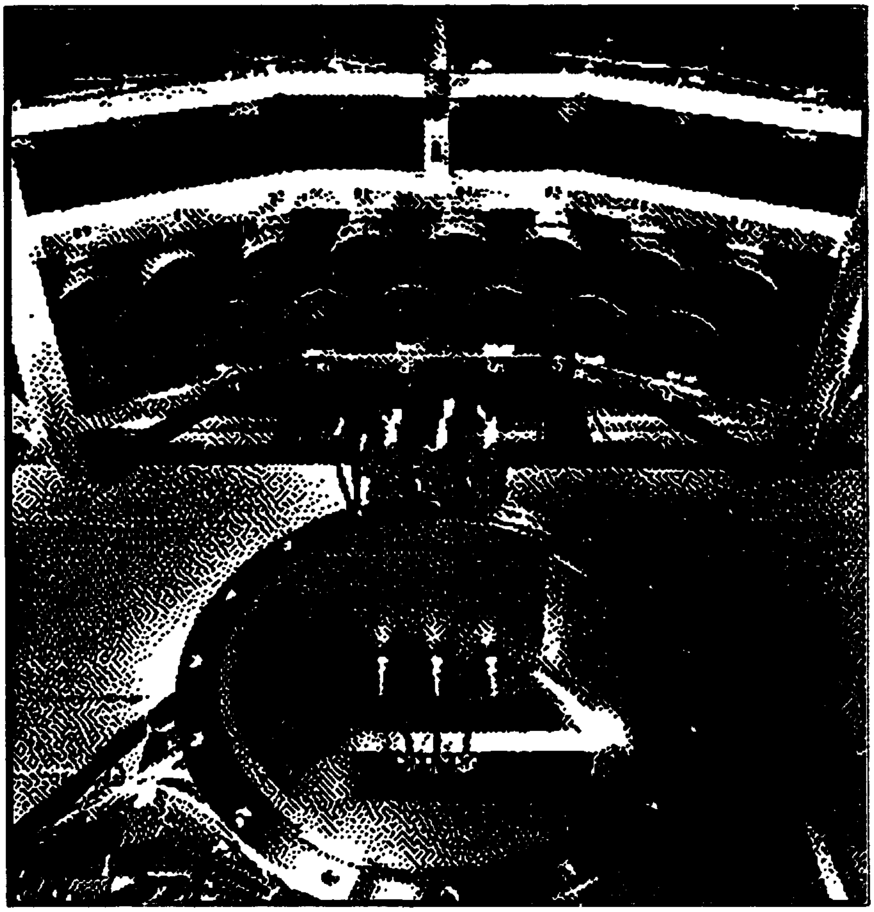

Fig. 1. Proton and Neutron Detectors

The TANSY spectrometer contains six proton detectors and 32 neutron detectors. Three proton detectors and sixteen neutron detectors cooperate and make a natural subsystem. The two subsystems are named branch A and branch B. The two branches are identical. Their electronics are separated as far as possible in order to enhance the reliability of the system. Any malfunction of any detail in one branch should not disturb the operation of the other branch. As the two branches are identical we will normally only describe one of them.

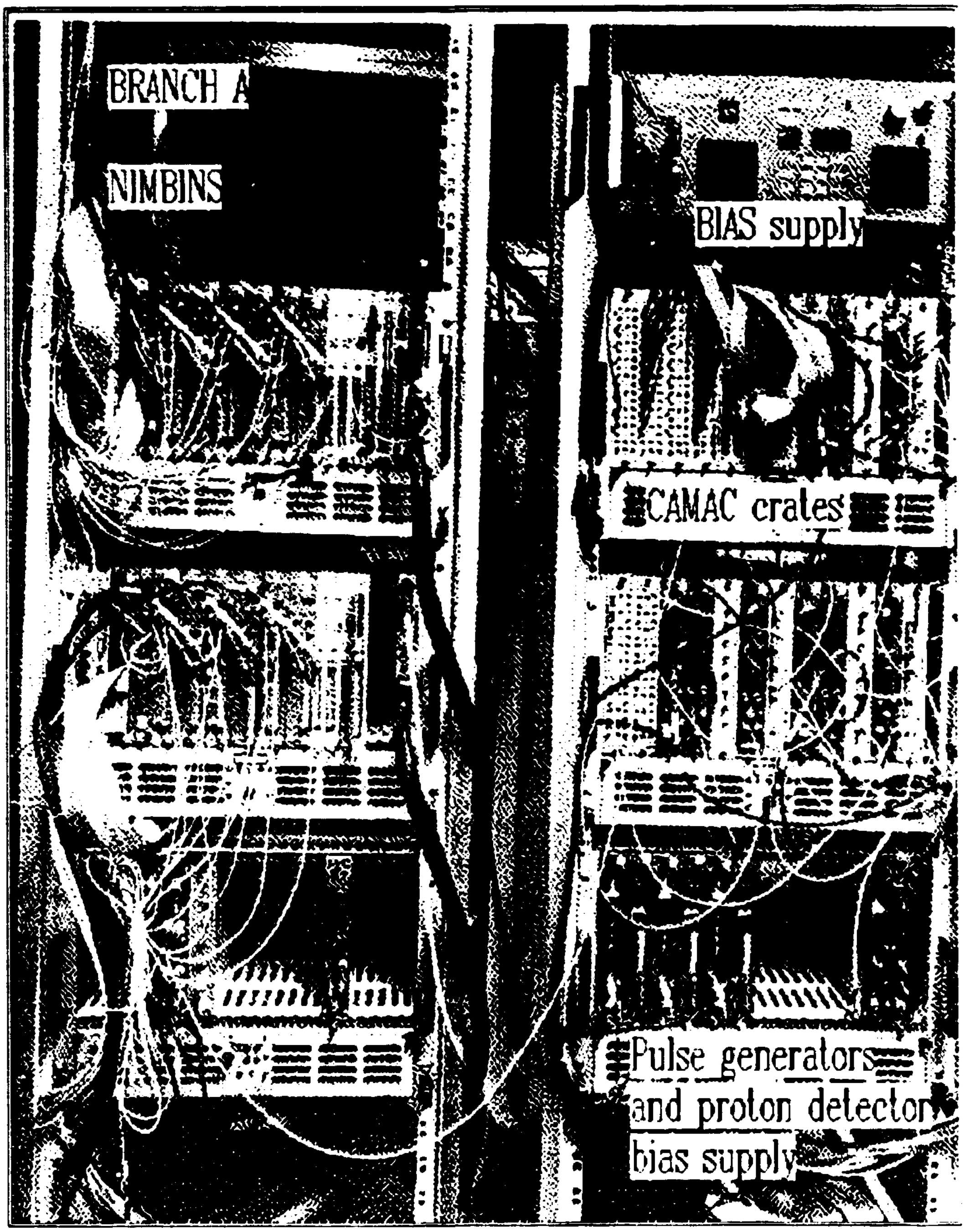

Fig. 2. Electronics during the Laboratory Test Period

The two power supplies for the neutron detector preamplifiers are placed close to the neutron detector bank. One supply is common to sixteen detectors. They are built at the Department of Reactor Physics as corresponding units not are available on the market. The proton detector preamplifiers are powered by an Ortec power supply. Again one power supply is common to three of the detectors.

The signals from the preamplifiers are sent to the main electronic modules. They are housed in three NIMBINs and one CAMAC crate. One extra NIMBIN and one extra CAMAC crate is needed for modules common to the two branches.

Figure 2 shows some of the electronics used during the test period. One CAMAC crate contains most of the CAMAC modules needed for the control of one branch. It is an independent system in the sense that it works without any interactions with the host system during the measurement period. The data are collected in CAMAC memory units and fetched by the host system after the measurement period.

The only CAMAC modules placed outside the main CAMAC crate are the neutron detector bias control module and the pulse generators (CPG3). One CAMAC module is common to the two neutron bias supplies. Two pulse generators are used, one for each of the two branches.

During the test period a CES Starburst computer served as a host computer. The communication was done by the CES parallel crate control system. The only modification needed in order to make the system workable at JET is a special cable between the CODAS crate controller and the slave Starburst. This cable is not delivered with the system as it is a part of the JET CAMAC system.

The CAMAC crate is controlled by the Starburst auxiliary controller. The data taken by ADCs and TDCs are elaborated on by the controller and stored in the CAMAC memory units. The CAMAC data bus is heavily used and should not be disturbed by any interaction from the host system during a measurement.

The analog part of the system uses NIM modules. They are normally standard units obtained from well-known NIM module manufacturers. Two exceptions can be observed. A special FAN-OUT module has been made in order to route the neutron detector time signals to the three TDCs and the multi-scaler. The FAN-OUT module multi-scaler output contains count-down scalers. The other non-standard units are the GATE-KEEPERS. They coordinate the event detection modules, the proton detector discriminator, the time-to-digital converter, the analog-to-digital converter and the pile-up system of the linear amplifier.

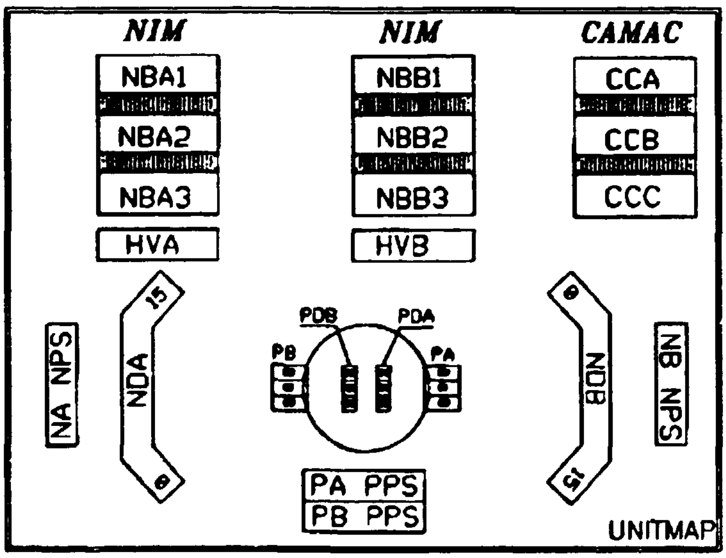

Fig. 3. Placing of the Units

Figure 3, "Placing of the Units", gives a schematic overview of the units. Here NBA1, NBA2, and NBA3 are the NIMBINs housing the A branch NIM modules. NBB1 to NBB3 are the corresponding BINs for the B branch. HVA is the LeCroy bias supply for the A branch neutron detectors and HVB is the bias supply for the B branch. The CAMAC crates are marked CCA, CCB, and CCC. The first two are used for the A and B branch CAMAC units, respectively. The last houses the pulse generators, the common neutron detector bias supply control unit and any CAMAC modules that may be added to the system.

The neutron detector banks are marked NDA and NDB. They cooperate with the proton detector banks PDA and PDB, respectively. The proton preamplifiers are marked PA and PB.

The power supplies for the proton detectors are marked PA PPS and PB PPS. The power supplies for the neutron detectors are marked NA NPS and NB NPS.

Figure 3, "Placing of the Units", page 8 gives only an overview of the system. More detailed definitions of module names and cable labelling are given in the appendices referred to in the chapters " 5.3. Module and Cable Lists" and " 5.2. Electronic Module Specifications", page 34.

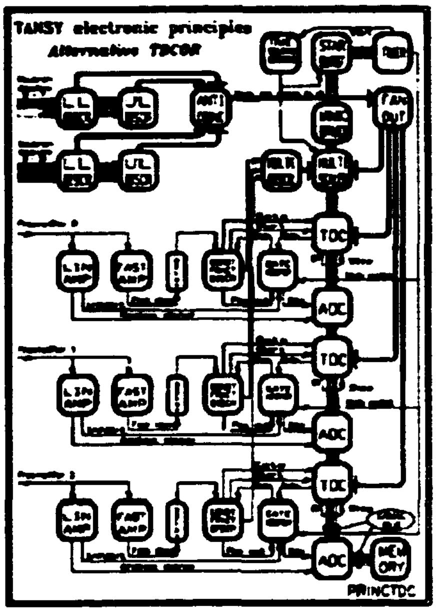

Fig. 4. Tansy Electronic Principle

(For details see figure 24, "Circuit Diagram for the Alternative Using the NBCO OR Circuit", page 25 and figure 24, figure 23, "Circuit Diagram for the Alternative Using the TDC OR Circuit", page 24).

A rough sketch of the TANSY electronic principle is given in figure 4. Two alternatives have been tested, one using the TDC internal neutron coincidence circuits, another using the coincidence circuit in the ORTEC/ESN CO1600 unit [NB CO]. Full page figures of these alternatives are given in figure 23, "Circuit Diagram for the Alternative Using the TDC OR Circuit", page 24, and in figure 24, "Circuit Diagram for the Alternative Using the NBCO OR Circuit", page 25. Both alternatives works satisfactorily, the alternative using the TDC OR-circuit is straight forward but gives a somewhat poorer result than the other one. However, the difference is small and the choice of method is mostly a matter of personal taste. We will use the TDC OR alternative as the standard method in this description.

In figure 4, "Tansy Electronic Principle", the signals from the neutron detectors are fed to a discriminator system selecting only amplitudes corresponding to the energies of the neutrons reaching the neutron detectors from the foil. The signals are distributed to the three TDCs and the scaler system. Each TDC belongs to a proton detection chain. There are three of them, one for each proton detector in the branch. The proton detection chains contain linear and fast amplifiers which supply the ADCs with an analog proton energy signal and the TDCs with a start pulse for the time measurement. The stop signal is delivered by the TDC internal OR circuit.

The multi-scaler system is used for counting of the number of proton and neutron events. Only 19 channels are used, leaving 13 spare channels for other purposes. Other service modules are the time sequence generators for real-time markers, the timer controlling the measurement cycle, and the mimic driver. The systems will be described one by one starting with the neutron detection system.

2.2. Neutron Detection

The system contains two banks of neutron detectors. Each bank contains sixteen detectors. Here, we will present the neutron detector design and the associated electronics.

2.2.1. The Neutron Detectors

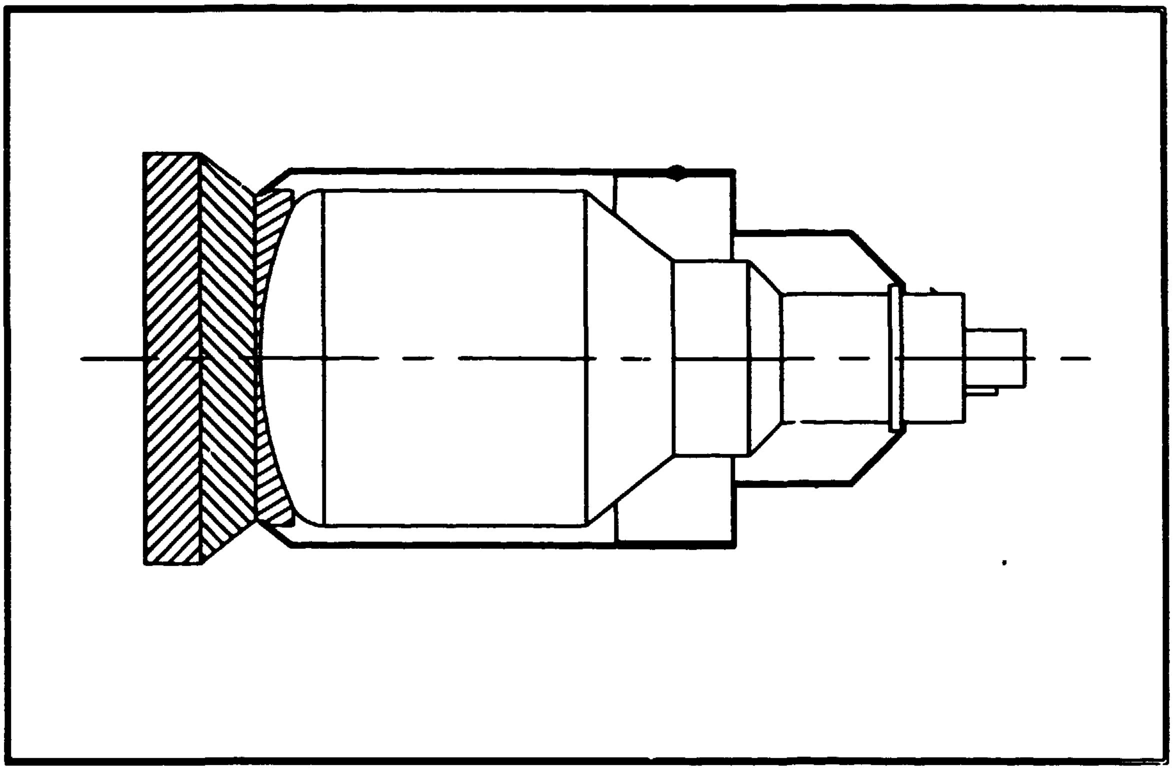

Fig. 5. Cross Section of a Neutron Detector

The principal parts of a neutron detector are shown in figure 5. The Bicron BC-420 scintillator has a height of 20 mm and a diameter of 145 mm. It is connected to the photomultiplier by a 20 mm thick plexiglass light pipe. The optical grease supplied with the photomultiplier was not considered to be stable for a long time of use. Therefore, a silicon compound (KE-420) from Shin Etsu Chemical was carefully tested and finally chosen as a coupling material between the optical parts. The refractive index was measured to 1.45. The optical properties of the scintillator-to-photomultiplicator system are summarized in table 1 and an autoshade figure of the system is shown in figure 26, "Neutron Detector without Magnetic Shield", page 26.

Item	Refractive index	Angle of total reflection, degrees
Scintillator	1.58	
		66.6
Silicon rubber	1.45	
		None
Light pipe	1.48 to 1.50	
		69.5 to 71.7
Silicon rubber	1.45	
		None
Adapter	1.48 to 1.50	
		75.2 to 78.5
Silicon rubber	1.45	
		None
PM tube	1.48	

Table 1. Optical Properties of the Neutron Detector

The neutron detector is enclosed in a magnetic shield, see figure 25, "Neutron Detector with Magnetic Shield", page 26. The shield is made of μ-metal. It has a thickness of 1.5 mm. The magnetic shielding effect has been carefully investigated using a calibrated coil. No significant effects were found below a field strength of 20 Gauss.

A sensitivity test was done using a collimated gamma beam from a Na-22 source. The response is flat for detector-centre to beam distances up to 5 cm. Then the response decreases and reaches a relative value of 75% at the edge of the scintillator.

The Photomultiplier base obtained from RG&G-ESN (Model XP 2041 MM 11E/Aktiv) includes an active dynode supply chain, one linear amplifier, and one fast amplifier. The linear amplifier is only used during test measurements. The fast amplifier (LeCroy VV 100B) shapes the signal and gives a possibility to run the photomultiplier (Philips XP2041) at a low bias supply. The behaviour at high counting rates has been tested showing a linear intensity response up to 1 MHz.

2.2.2. Electronics for Neutron Detection

The bias supply system for the neutron detectors is a LeCroy Model HV4032A high voltage system. Two units are used, one for each branch. Both are controlled from a common controller placed in the CAMAC crate CCC.

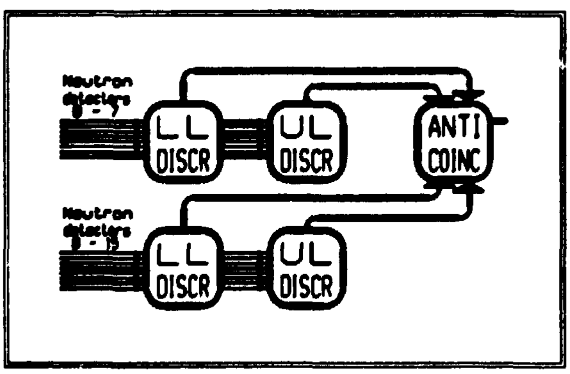

Fig. 6. Neutron Signal Discriminator System

The sixteen fast neutron detector signals from a neutron bank are fed into two ESN CF8000 constant fraction discriminator modules. These serve as lower level discriminators for eight channels each. The analog outputs from the lower level discriminators are connected to two upper level discriminators. These two CF-8000 discriminator modules are modified to handle a higher discrimination level setting. The ECL outputs from the lower level and the upper level discriminators are combined in a coincidence unit, ESN CO 1600 16 channel 3 input overlap coincidence unit. Two inputs are used in anticoincidence in order to produce a signal only if the amplitude of the neutron detector signal is between the lower and upper bias level settings.

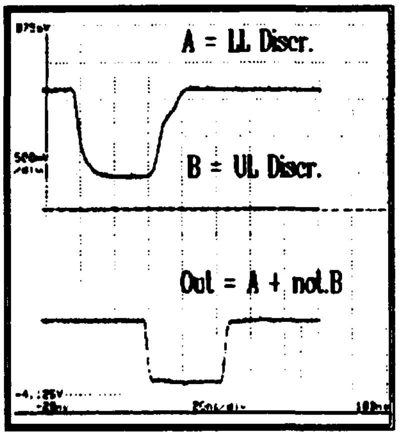

Fig. 7. Normal Discriminator Signals

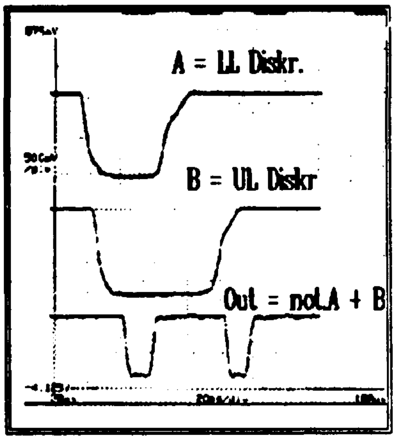

Fig. 8. Test of Discriminator Signals

The timing of the signals is essential. The lower level signals must be delayed in order to match the upper level signals in time. This has been achieved by using the cables as delays. The cable lengths are chosen for an optimum matching considering time amplitude and pulse shape variations of the incoming signal.

The input and the output signals during normal operation is shown in figure 7. The lower level discriminator signal is ORed with the conjugate of the upper level signal. The resulting signal is an ECL signal, about 40 ns long, which is used as an input to the time-to-digital converters. It is important that the overlap between the upper and lower level signals is correct. A nice way to check this is to set up the CO 1600 coincidence condition inversely to the normal setting. A result of a test is shown in figure 8, "Test of Discriminator Signals", page 12. The overlap of the upper level signal is here about 15 ns at each side. That gives enough margins for variations of the signal lengths.

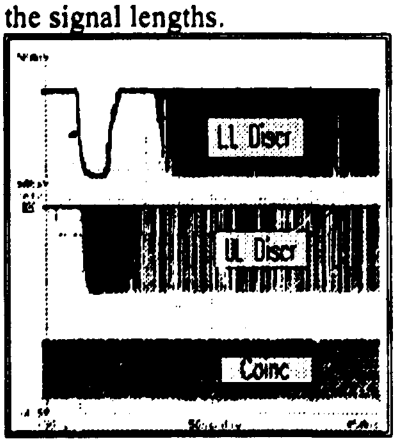

Fig. 9. High Rate Discriminator Signals

The behaviour of the system at very high intensities, several megahertz, is shown in figure 9. The dead-time of the lower level discriminator is controlled by the length of CF 8000-A output. It is here set to 150 ns. The upper level discriminator is set to the same value in order to achieve the best possible cooperation between the two discriminators.

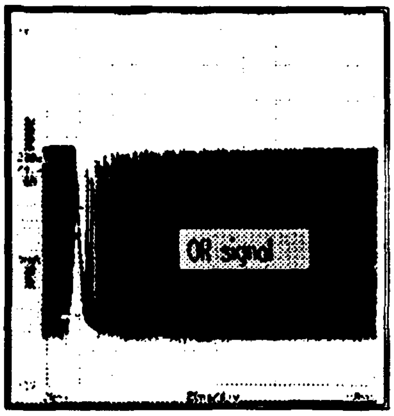

Fig. 10. The OR-Signal at High Intensities

The common coincidence signal looks black in the figures as all of the sixteen detectors produce signals and the oscilloscope is only triggered by one of them. The coincidence unit overlaps the signals. Figure 10 is fetched from a measurement with the oscilloscope triggered by the OR-signal. The unit recovers almost immediately. The time gap after the triggering can from the figure be estimated at one or two nanoseconds. Therefore, the OR signal may be used as a stop signal for the TDCs. That has been done in the alternative shown in figure 24, "Circuit Diagram for the Alternative Using the NBCO OR Circuit", page 25

Although the neutron detection system has the capacity to handle very high intensities one should try to limit the load to a few megahertz at the coincidence unit output. Limiting factors are the TDCs and the time shadowing (time shielding) effect caused by the sum of the signals from all the sixteen neutron detectors. Measurements have shown that it may be favourable to limit the number of neutron detectors at very high intensities. The third input to the coincidence unit can be used for that purpose. It is possible to build a unit that automatically limits the number of neutron detector input channels used. The dynamic range of the instrument will then be increased by a factor of ten or perhaps more.

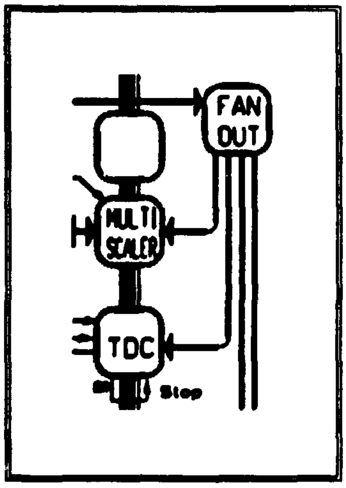

Fig. 11. FAN-OUT

The CO-1600 coincidence unit has only three ECL out-puts. We need four, one for the multiscaler unit and three for the TDCs. Moreover, the scalers are filled and wrap around already at moderate intensities and low time interval settings. Therefore, prescalers are useful. The special FAN-OUT unit delivered with the system has three direct ECL and one down-scaled outputs. In the last one the pulse frequency may be divided by a count-down factor of 1, 4, 32, or 256. The maximum input pulse rate is estimated at 20 MHz. Therefore, no frequency limit is imposed on the system by the FAN-OUT module.

2.3.Proton Detection

The main part of the neutron energy is determined by the six proton detectors. Being semiconductors they are damaged by radiation. On the other hand they should be placed as close to the foil as possible in order to be effectively used. The final position, 5 cm from the foil is a compromise between good shielding and efficiency.

The proton detector and the electronics belonging to it are described in this chapter. However, the limit between the proton detector electronics and the event detection electronics described in the next chapter is somewhat diffuse. Details missing here may be found in the next chapter.

2.3.1. The Proton Detectors

Fig. 12. Three of the Proton Detectors

Serial number	Resolution measured by Intertechnique
9353	40 keV
9354	35 keV
9356	38 keV
9358	35 keV
9360	35 keV
9361	35 keV

Table 2. Resolution of the Delivered Proton Detectors

The proton detectors are 2.5 mm thick lithium compensated silicon-detectors. 2.0 mm was considered to be sufficient at the time of design. However, the later decided extension of the energy range of the spectrometer had to be followed by an increased thickness. Accordingly, the background sensitivity is increased by 20%.

The detectors are delivered by Intertechnique. The detectors have an area of 3 cm^2, and are supposed to operate at 1000 V. The warranted resolution is 40 keV at 5.5 MeV, the americium α-peak. The detectors were checked at the time of delivery. The resolution measured by Intertechnique is summarized in table 2.

The detectors are supplied with a female BNC connector. A cable connects the detector to a vacuum feed-through connector. The preamplifiers are mounted as close to the vacuum vessel as possible, the total connector and cable length is 30 cm which gives a capacitance less than 20 pF. The detector capacitance is about 12 pF. This system, the detector, the feed-through, and the preamplifier, is insulated from the vacuum vessel. It should be noted that the preamplifiers are delivered with shielding caps for the connectors. These are fastened to the preamplifiers by chains. At the mounting of the system it should be ensured that the chains or the caps do not make any contact with the vacuum vessel system. They may be removed completely as they have no function except during transport.

The bias for the detectors is supplied by six N-126 High Voltage Supplies from CAEN. They are placed in the NIMBINs NBA3 and NBB3, see figure 3, "Placing of the Units", page 8. The units have been used with a ramp-up rate of 1 V/s and ramp-down rate of 100 V/s. They have built-in current limitation and the start and stop can be remotely controlled.

In the preamplifiers the leakage current passes through a resistor chain of 104.5 Mohm. The stipulated high voltage for the detectors is 1000 V. The voltage at the voltage supplies must be set about 400 V higher in order to compensate for the voltage drop in the resistors. The correct value can be calculated using the leakage current measured by the voltage supply unit. However, it should be emphasized that we are working with currents with magnitudes at the low end of the measurement interval. Therefore, it is important to calibrate the instrument for the best possible zero point setting. The bias settings must be checked from time to time and adjusted according to the changes in leakage current. A detector bias voltage shift of 100 V gives normally a depletion thickness shift of about 0.1 mm. Here the detector is over-biased which gives a depletion depth independent of the bias. However, the pulse shape depends on the voltage.

2.3.2. Electronics for Proton Detection

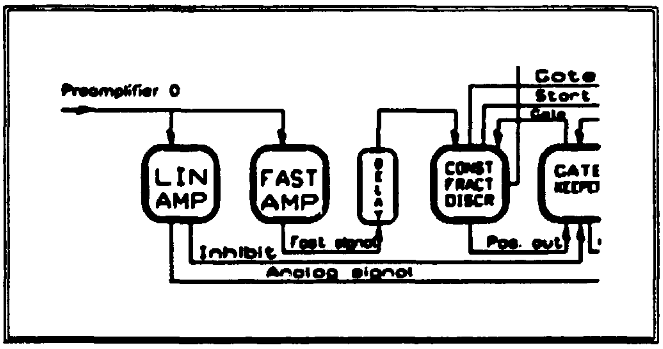

Fig. 13. Proton Detection Electronics

The signal from the preamplifier is picked up by a linear amplifier and a fast amplifier. The linear amplifier has a high impedance input. The input impedance of the fast amplifier is 100 ohm. Therefore, this unit should terminate the cable. The possibility to use the fast signal output from the preamplifier has been tested. However, it was found that it was difficult to avoid noise problems. Although a high bias voltage is used in the detector we still have a rather poor rise time of the signal. The amplitude is low and it is difficult to separate it from the noise. Several experiments showed that the best solution was to use one common signal and filter out a fast timing signal and a slow energy signal by main amplifiers. As the preamplifier time output not is used it must be terminated at the preamplifier (50 ohm).

The linear amplifier output is sent to the ADC. It is delayed in order to match a gate signal. The Ortec model 572 spectroscopy amplifier, the amplifier used here, is equipped with a pile-up rejector. The resulting inhibit signal is picked up and used by the system, see chapter " 2.4. Event Detection", page 16. The amplifier internal amplification factor is set to 1.

The fast amplifier, Ortec model 579, gives an output signal which is delayed a few nanoseconds before it enters the constant fraction discriminator, Ortec model 584. The constant fraction discriminator is responsible for the timing of the proton signal. It has only a low level discriminator. An upper discriminator was not considered to be necessary as very few signals have amplitudes higher than the amplitude region of interest.

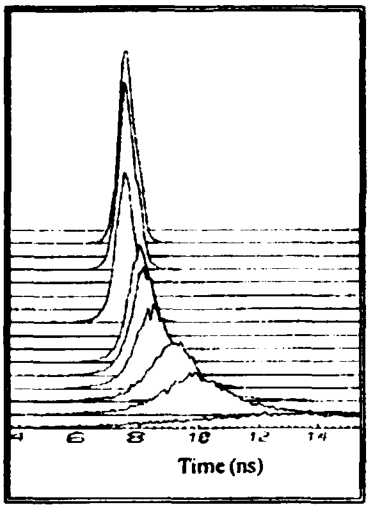

Fig. 14. Time Shifts in the Constant Fraction Discriminator

The time walk adjustment is important for a proper use of the module. Figure 14, "Time Shifts in the Constant Fraction Discriminator" is fetched from one of the time walk adjustment experiments. A pulse generator is used to simulate the pulses from different amplitudes. The unit was adjusted for a minimum time walk in the interval used during measurements, the upper part of the amplitude distribution. The lower part is only used during time calibrations aiming to synchronize the signals in the neutron detectors. A cobalt gamma ray interaction in the proton detectors gives a start signal common to all the neutron detectors. The time shifts of the neutron detector signals in relation to each other can be determined. However, the precision is not sufficient for an exact determination of the time delays relative to the proton detector signal.

2.4. Event Detection

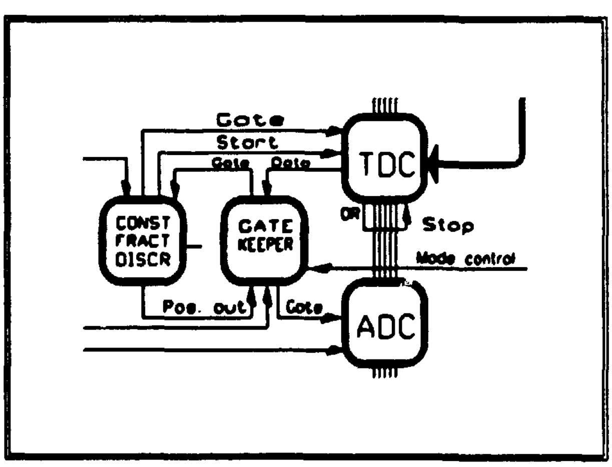

Fig. 15. Event Detection System

Three modules, the constant fraction discriminator, the gate keeper, and the TDC control the event detection cycle. The constant fraction discriminator is controlled by a gate control signal from the gate keeper. The gate is open as long as no event detection is underway.

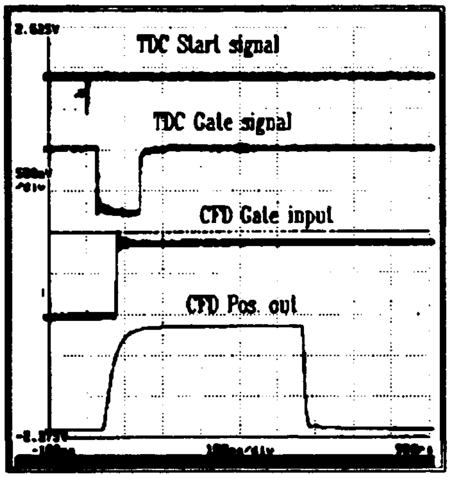

Fig.16. Fast Control Signals

Three signals are activated by the constant fraction discriminator. A start signal and a gate signal are given to the TDC. The start signal starts the time measurement and the gate defines a time interval during which the TDC is enabled to receive a stop signal, a hardware time interval gating. The third signal (Pos. out) activates the gate keeper which closes the constant fraction discriminator input until the end of the event detection cycle. A gate signal with a start time and a duration adjusted to match the analog signal from the linear amplifier opens the ADC.

The TDC gate input signal defines the external time measurement interval. Any stop pulse during this interval terminates the time measurement. In the case of no stop pulse the time measurement interval is terminated by an internal stop pulse. In this context it should be noted that the Starburst data fetching program contains software defined limits for the time information transferred to the measurement data list in the memory units [3].

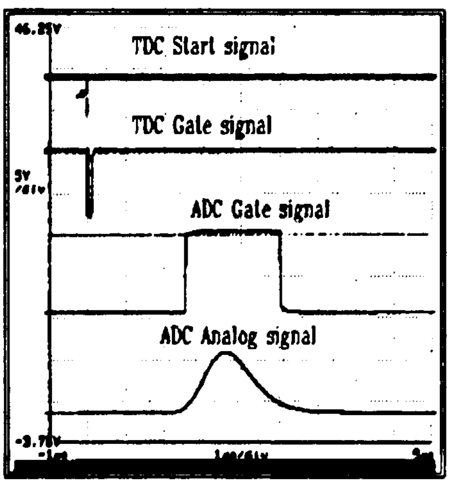

Fig. 17. ADC Signals

From now on the system is waiting for the conversions to be finished and the data to be fetched from converters. It is locked by the TDC Data signal. The last data word fetched is the TDC time information which releases the Data signal causing the gate keeper to open the constant fraction discriminator.

Figure 16 shows the fast control signals relative to the start signal from the constant fraction discriminator. The time scale is 100 ns/division. The TDC gate signal is the blocking signal from the constant fraction discriminator. It may be used as a hardware time limit. Software time limits are included in the Starburst data taking program. However, unnecessary data collection can be avoided by a proper setting of the length of this signal. The second signal in the figure, the CFD gate input is the locking signal that prevents the system to start a new cycle before the present is finished. It is activated by the "CFD Pos. out" signal coming from the contant fraction discriminator. The blocking signal ensures that there is an overlap in time between the CFD dead-time and the locking signal from the gate keeper.

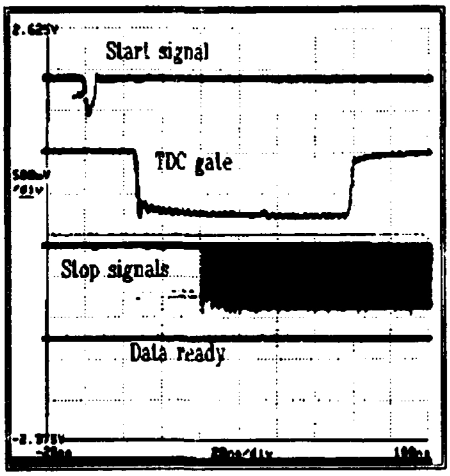

Fig. 18. TDC Start and Stop Signals

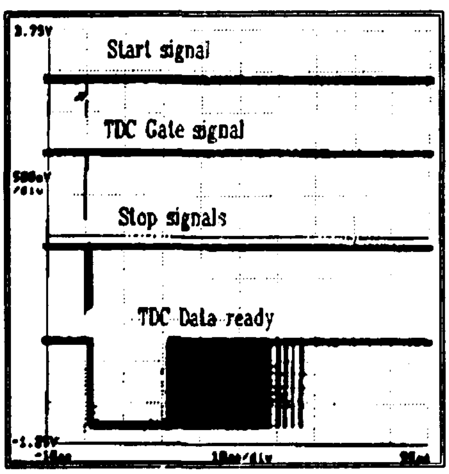

Fig. 19. TDC Data Ready

The ADC signals are presented in figure 17. The time scale is here 1 μs/division. The ADC gate signal produced by the gate keeper can be adjusted to gate a proper part of the ADC analog signal into the ADC. Both a delay and a gate width are available for adjustments.

The start and the stop signals are illustrated in figure 18. The time scale is 20 ns/division. The stop pulse frequency is fairly high as can be imagined from the black part of the diagram. This as well as the other figures in this context are obtained using a sampling oscilloscope. Therefore, high frequencies are needed in order to enhance the topics to be illustrated. The stop signals are here taken from the TDC OR output. The internal circuits cause a delay between the start of the gate and the first accepted stop pulses. The internal OR circuit has another not obvious feature. The OR signal goes on at the arrival of the first stop pulse. Then it stays on until the end of the TDC measurement interval.

During the 120 nanoseconds covered by the figure no conversion has been done in the TDC. Figure 19 illustrates the timing using a time scale of 1 μs/division. The black part of the TDC Data ready signal shows the time span of the system dead-time for different types of events. The shortest corresponds to not fetched events, e.g. events inside the hardware time limits but outside the software time limits. The dead-time is here about 20 μs. The longest time comes from interference with other TDCs. The Starburst auxiliary controller takes care of the TDCs one by one. If an event occurs during the data fetching time of one of the other TDCs it can not be handled until the previous event fetching cycle is completed. A normal cycle takes about 50 μs.

2.5. Mode Control

Fig. 20. The Gate Keeper

The gate keeper, figure 20, controls the event detection during a measurement. Two modes are implemented, one for time and amplitude measurement and one for amplitude measurement only. The first one is the full system mode as described above. The latter is designed for calibration and test measurements. In this mode the data ready feed-back from the TDC is neglected. The ADCs have data buffers and are responsible for the data taking sequence.

The mode control can be set manually or remotely. A switch on the gate keeper front panel has three options, Amp, Time, or Ext. Amp and Time are the manual settings for amplitude only or full measurement. Ext must be used during a normal measurement. The mode is then controlled by the timer, CTM1. Between the JET pulses the timer module sets the mode to Amp for calibration measurements. During the measurement the Time mode is used for full registrations of the events.

2.6. Time-Interval Detection

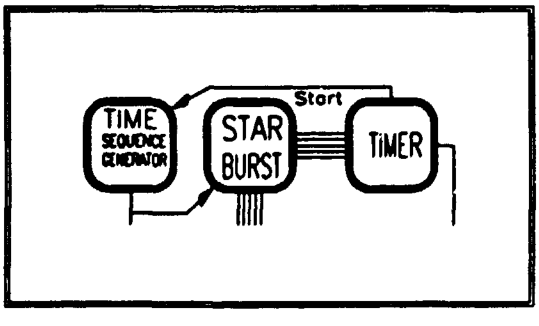

Fig. 21. Time Interval Generator

Time markers are used in the data stream in order to enable a possibility to build spectra for certain time intervals. The time marker sequence starts at the beginning of the measurement interval. According to the JET PULSE FILE standards the first time marker is inserted after the first time interval.

The time sequence generator (CPG3) used for time marking is placed in CAMAC crate CCC, see figure 3, "Placing of the Units", page 8. There is one unit for each branch. They are set up during the prepulse and started by the timer (CTM1). The pull-up resistors needed are included in the cables. At the time of writing of this report the measurement starts 40 seconds after the CODAS start pulse.

At every preset time interval a pulse is sent to the Starburst auxiliary crate controller, interrupt 2. As requested by JET, the data collection program fetches the time of the interrupts from the internal clock. The times obtained may be used as a check of the timing. It should not be used as a measure of the time interval but only as a check for a missing time marker [3]. . The system has never failed during the test period. High intensities have been simulated without any problems.

2.7. The Scaler System

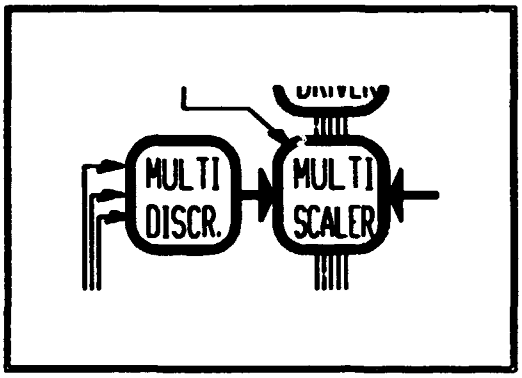

Fig. 22. The Scaler System

Another use of the time pulses from the time sequence generator is the control of the multiscaler modules (CCT4 + CME5). Sixteen of the thirtytwo possible inputs are used for the neutron detectors. The remaining 16 inputs are fed by two discriminator modules (CF 8000). Only four have been used during the test period, three for the counting of the number of proton detector signals and one for a neutron intensity monitor. The monitor is not a part of the instrument. Therefore, 13 inputs are available as spare inputs.

The scaler system is not taken care of by the Starburst auxiliary controller. It is entirely up to the CODAS system to set up the scalers and fetch the data from the scaler memory units.

2.8. Mimic Control

An output register (CPR1) is included for transfer of information to the MIMIC. The meanings of the different bits in the output word are given in table 3, "Output Register Definitions" [see also reference 3]. The bits 0 to 4 define the state of the Starburst. It starts in the "Idle" state. The normal state during a measurement is the "Measurement" state. The other states are used during calibration measurements which need manual intervention by remote control.

Each state except the "Idle" state has a program sequence. The sequence in the "Measurement state" is: Calibrate - Wait after calibration - Measure - Wait after measurement. The other states contain only the two first steps. The steps are indicated by the bits 7 to 10.

The "Measurement" state can be controlled in three different ways. It can be automatically controlled by the CTM1 module only or by the CTM1 module and the CODAS standby signal. The standby signal is read by the Starburst from bit 0 of the CPR1 input register, the only input bit used. A manual control option is included for test purposes. The control mode is indicated in bits 12 to 14.

Bit #	Purpose
0	Idle state
1	Measurement state
2	Amplitude calibration state
3	Time calibration state
4	Time-Amplitude calibration state
5	Set parameters option
6	Not used
7	Run calibration
8	Wait after calibration
9	Run measurement
10	Wait after measurement
11	Not used
12	CTM1 control
13	Standby control
14	Manual control
15	Include inaccurate input data

Table 3. Output Register Definitions

During a normal measurement multiple hits in the TDC are disregarded and not recorded in the resulting data list. However, if there is enough space in the memory units it may be worthwhile to record these erroneous events. If this recording is on it is reported by bit 15.

A lot of parameters can be stored in the Starburst and transferred to the data list. One way to set these parameters is to use the SET option. Normally the SET option should be off during a measurement. Therefore, bit 5 gives the possibility to set up a reminder for the user on the MIMIC.

KM5-TANSY-KM5			
Branch A			
Calibrate	**Wait**	**Run**	**Wait**
	State:	@STATE	
	Measurement control:	@CONTROL	
	Record multiple hits:	@MHIT	
	Input parameters:	@SETPAR	
Branch B			
Calibrate	**Wait**	**Run**	**Wait**
	State:	@STATE	
	Measurement control:	@CONTROL	
	Record multiple hits:	@MHIT	
	Input parameters:	@SETPAR	

Table 4. Proposal for the MIMIC

A proposal for the output on the MIMIC is given in table 4. The rows enclosed by double lines contain the program steps. One of the items "Calibrate", "Wait", "Run", or second "Wait" should be enlightened by colour or other means if the register bit 7, 8, 9, or 10, respectively, are on. The variable @STATE is "Idle", "Measurement", "Amplitude calibration", "Time calibration", or "Time-Amplitude calibration" according to one of the bits 0 to 4. The variable should be set to "Error" if more than one or none of the bits are set. Probably "Error" will indicate a communication error or that the Starburst is not switched on. The variable @CONTROL should be set to "CTM1 only", "CTM1+STANDBY", or "Manual" as given by the bits 12 to 14. Again "Error" could be used if more than one or none of the bits are set. The variable @MHIT is "Yes" if bit 15 is set and "No" if not. The variable @SETPAR is "On" if bit 5 is set and "Off" if not.

2.9. Power Supplies

The power supplies for the proton detector preamplifiers and for the neutron photomultiplier bases are indicated in figure 3, "Placing of the Units", page 8. The power supplies for the proton detector pre-amplifiers are delivered by Ortec, Model 4002P, Portable Power Supply. There is one unit for each branch. The supply contains four outputs. Three of them are used leaving one output as a spare.

The power supplies for the neutron detector bases are made by the Department of Reactor Physics. Again one unit is used for each branch in order to ensure that the two branches are independent. For details see " 5.5. Manuals for the Electronic Units", page 35.

2.10. Markings of Units and Cables

TANSY contains a lot of modules and cables which have to be marked in some way in order to organize the system. Three types of names are used. The manufacturer has given names to the modules which often are too long to be put on labels. The CAMAC modules have been given internal names at JET. However, identical modules are used at several places. Therefore, labels have been put on all modules in order to indicate their position in the KM5-TANSY system. As far as possible the KM5 names are only extensions of the JET names.

As an example we may have a look at one of the time-to-digital converters. The manufacturer LeCroy has given it the name "4204 TDC". At JET it is named "CTD1". We extend that name to "PA1 CTD1". P means that it is used by a proton detector signal chain, A means that it is branch A and 1 indicates that it is proton detector signal chain 1. The proton detectors are numbered from 0 to 2 and the neutron detectors are numbered from 0 to 15, a standard coming from the LeCroy High Voltage Unit. When neutron signal chains and proton signal chains come together, as in the TDC, the proton signal chains logically dominate and are used for the labelling.

The cables have been marked according to the modules and the labels at the connectors. As an example the gate signal cable for one of the ADCs is marked PB2 CAD9 STB/GTE at the end to be connected to the ADC used by protondetector signal chain 2 in branch B. The connector on the ADC is marked STB/GTE. The other end of the cable has the label PB2 GK ADC GATE OUT. It shall be plugged into the connector marked "ADC GATE OUT" at the gate keeper used by the proton signal chain 2 in branch B.

Complete lists of the modules and the cables are given in the appendices. Manuals and lists of modifications, straps, and settings of every module in the system are also included. A summary and introduction to the lists supplied are given in " 5. The Appendices", page 34.

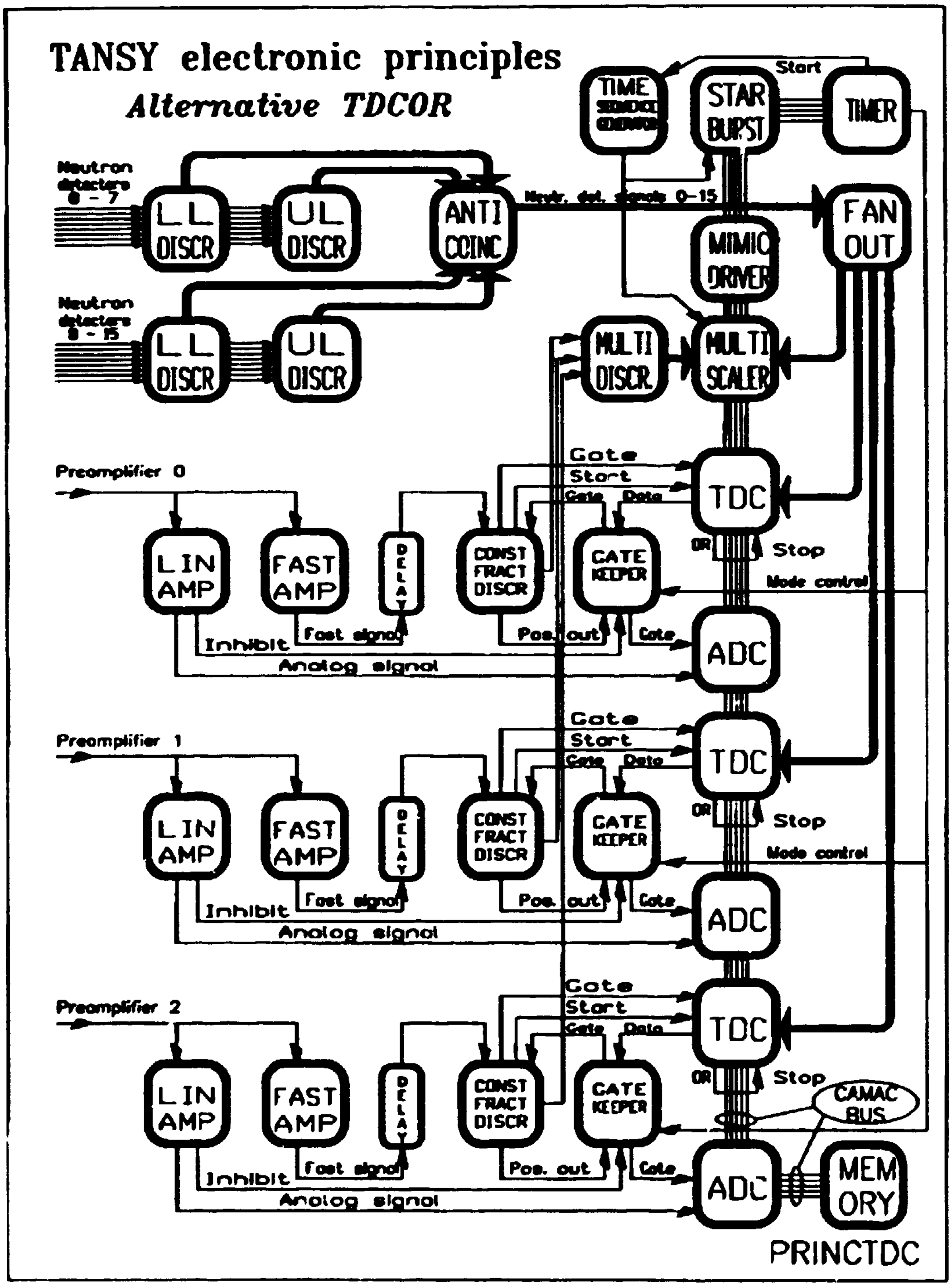

Fig. 23. Circuit Diagram for the Alternative Using the TDC OR Circuit

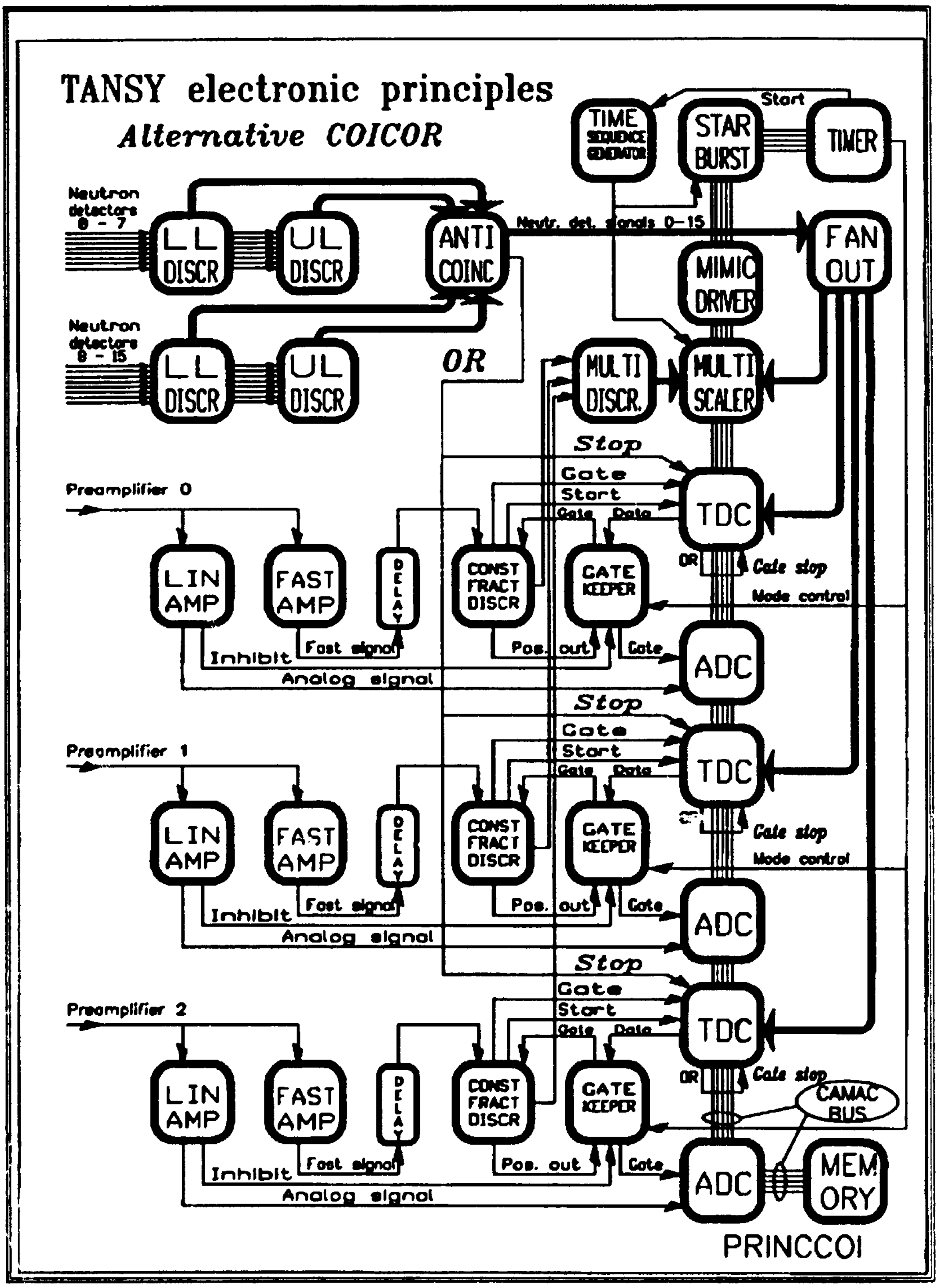

Fig. 24. Circuit Diagram for the Alternative Using the NBCO OR Circuit

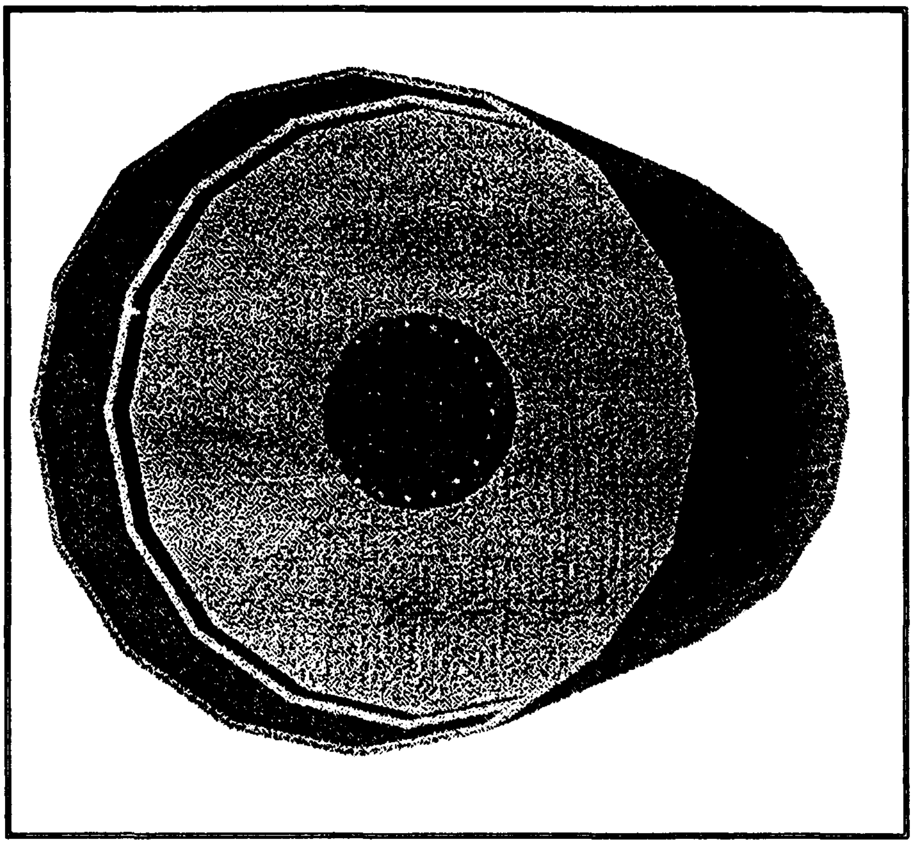

Fig. 25. Neutron Detector with Magnetic Shield

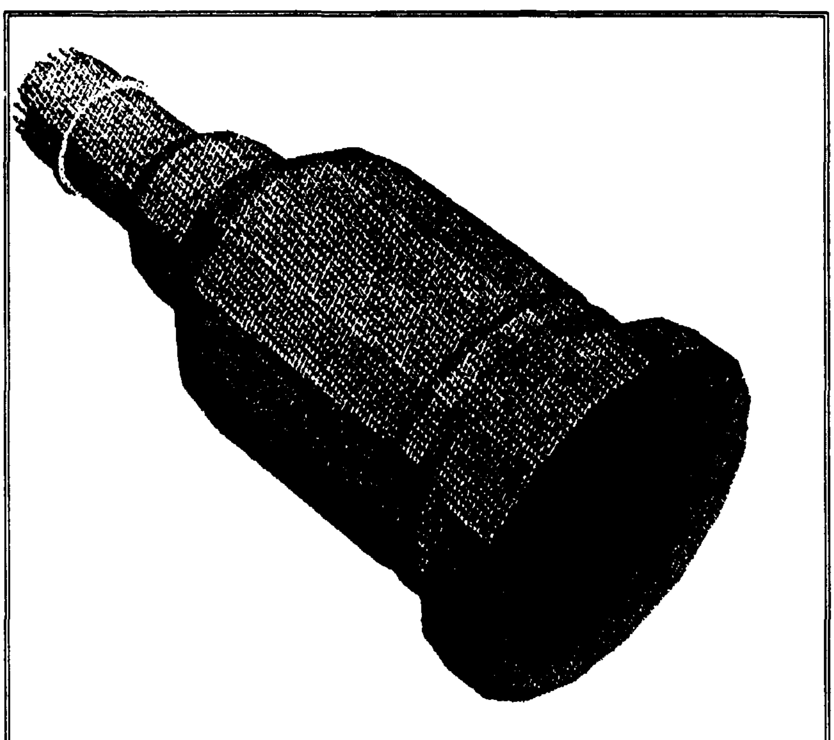

Fig. 26. Neutron Detector without Magnetic Shield

3. The Mechanical Components

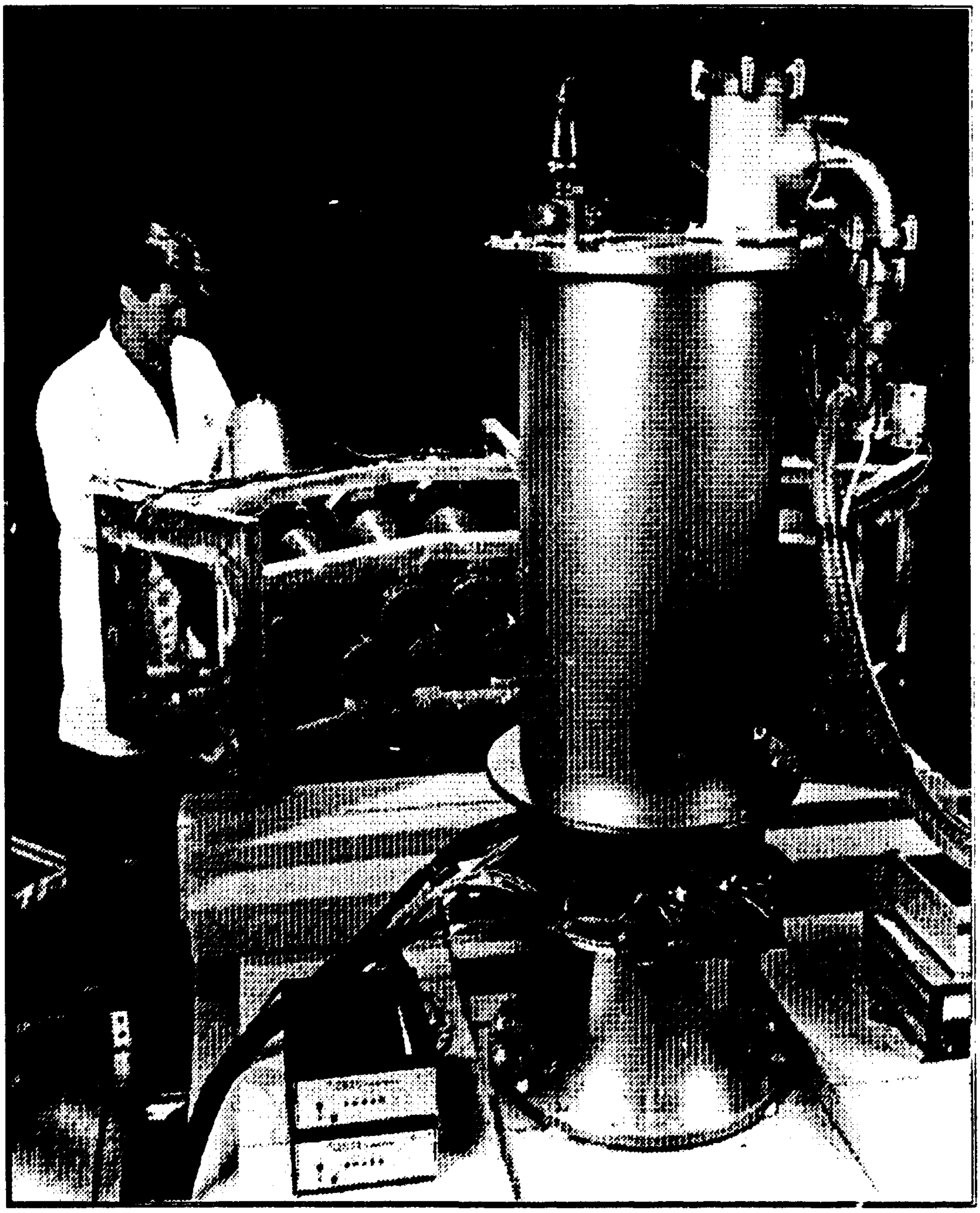

Fig 27. TANSY in the Test Bed

The mechanical parts of TANSY are the collimator, the vacuum vessel, the foil ship, the neutron detector frame and the vacuum pump system. A picture from the test period is shown in figure 27, "TANSY in the Test Bed". A brief description of the system will be given in this chapter. Details may be found in the drawings supplied with the instrument and in the manuals for the vacuum pump system.

3.1. The Collimator

Preliminary drawings for the collimator were made at the time of the design of TANSY. However, it is difficult to manufacture it and JET has taken over this task. The collimator was redesigned by JET to some extent. Therefore, we only give here some fundamental remarks.

The collimator has a length of two meters and is made by steel. It is tapered in order to decrease the amount of scattered neutrons reaching the scattering foil. The collimator points towards the centre of the diagnostic port. The entrance to the collimator is vacuum tight. The vacuum volume extends through the whole collimator. On the inside of the entrance cover there is painted a small white spot to be used as a reference for a laser beam during adjustments of the system.

3.2. The Vacuum Vessel

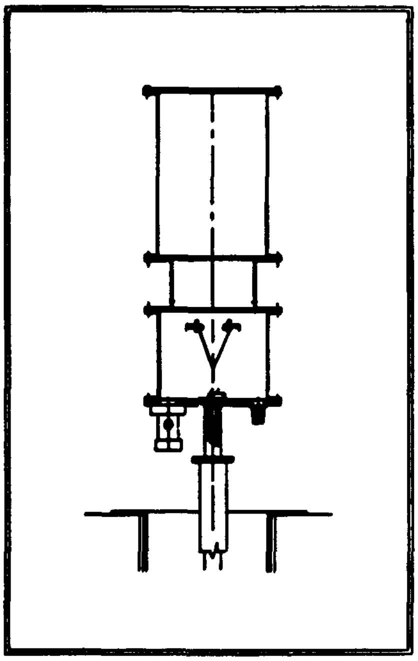

Fig. 28. The Vacuum Vessel

The vacuum vessel consists of five parts, the base plate, the lower vacuum vessel, the connection vacuum vessel, the upper vacuum vessel, and the cover.

The base plate, which is 20 mm thick and has a diameter of 510 mm, is made of stainless steel and serves as a support for the vacuum vessel. The collimated neutron beam passes a 20x174 mm slot which is cut in the plate. The slot is surrounded by 18 threaded holes which enable the attachment between the collimator and the base plate. Furthermore, there is a hole for the turbo-molecular pump and flanges for the low-vacuum and high-vacuum gauges. Next to each end of the slot an M6 screw is used to fasten the foil ship (figure 29, "The Foil Ship", page 29). Near the edge of the base plate is a groove for the O-ring (439.3x5.7 mm).

The wall of the lower vacuum vessel is 3 mm thick and is made of aluminium in order to minimize the amount of wall scattered neutrons. The inner diameter of the vessel is 400 mm and the height is 320 mm.

The walls of the connection vacuum vessel are made of 2 mm thick stainless steel. The wall consists of two semi-circular and two straight walls. Each of the two straight parts contain three feed through SHV connectors that allow the electronic connections to the proton detectors.

The wall of the upper vacuum vessel is made of stainless steel. The thickness is 1.5 mm, the diameter 400 mm and the height is 805 mm. The walls are welded to two flanges where the upper flange has a groove for the O-ring (439.5x5.7 mm).

The top cover of the vacuum system is a disk made of aluminium. The disk is 10 mm thick and has a diameter of 510 mm. In the centre of the cover is an excavation (140x380 mm area). The remaining material (1.5 mm thickness) is an exit window for the direct neutron beam. This exit is considered to be one of the most serious sources of background for the neutron detectors. Therefore, the window has been made as thin as possible and is placed far from the neutron detectors. This is the reason for the large height of the vacuum vessel. During the design study [2] a shield was included between the window and the detectors. However, it gave considerable complexity to the system. Therefore it was decided to leave it out. However, it can included in a later stage if it at this time is considered to be necessary.

3.3. The Foil Ship

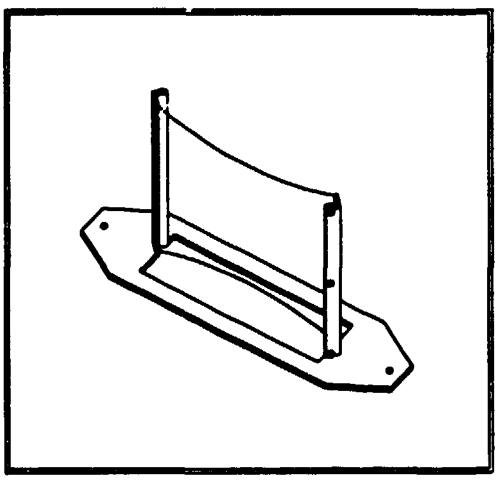

Fig. 29. The Foil Ship

The foil ship is a frame made of aluminium over which a plastic foil can be stretched. The frame consists of two arms which support the foil. They are mounted on a foil plate. Two versions are delivered with the system. In one of them the arms are screwed, in the other one they are welded to the base plate. The welded version gives the possibility to use a larger foil which will increase the efficiency somewhat. However, the design is weaker.

The spectrometer is designed for a foil thickness of 1 mg/cm^2. However, the efficiency can be increased by the use of a thicker foil. The efficiency is proportional to the foil thickness. The resolution depends on the thickness. As a rule of thumb the resolution increase is about 100 keV/(mg/cm^2).

It is not possible to use a thinner foil. One of two methods can be used in order to decrease the sensitivity. The most simple way is to disconnect some of the neutron detectors. The background sensitivity will then decrease but the resolution will be approximately constant. If only neutron detectors in one of the branches are disconnected the dynamic range may be increased, one branch is optimized for lower intensities, the other one for higher intensities.

The other way to decrease the efficiency is to use a venetian blind type of scattering foil. Strips of the foil material is mounted perpendicular to the direction of the neutron beam. This will lower the influence of the foil thickness to the resolution with a factor of about 2.75. The efficiency will decrease accordingly. However, the background in the neutron detectors may cause problems and it is in this case not possible to use the above trick to enhance the dynamic range of the system.

3.4. The Vacuum Pump System

Legend to figure 30.

1. Backing Pump Leybold-Heraeus Rotarypump D16A
2. Turbomolecular Pump Balzer TPU050
3. Vent Valve Baltzer TSF012
4. Electronic Drive Balzer TCP121
5. Vacuum Meter Leybold-Heraeus Combitron CM330.
6. Gauge Head Leybold-Heraeus Penningvac PR31
7. Gauge Head Leybold-Heraeus Thermovac TR201

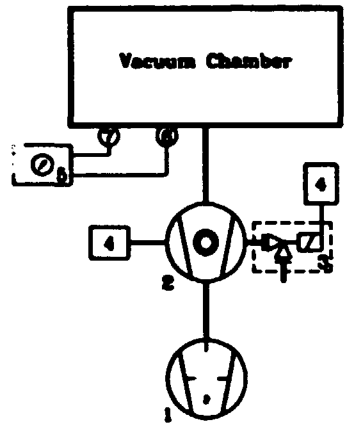

Fig. 30. The Vacuum Pump System

The vacuum vessel and the collimator are pumped by a Baltzar pump system. Vacuum is necessary in order to avoid proton energy loss and ensure a proper function of the proton detectors. It is also favourable to avoid air scattered neutrons from the primary neutron beam. A schematic picture of the system is given in figure 30, "The Vacuum Pump System", page 30.

The vacuum is created by an air-cooled turbo-molecular pump. The pre-vacuum is established by a Leybolds rotary pump D16A. The two pumps are started simultaneously. A pressure of about 0.1 mbar is reached in a few minutes. The turbo molecular becomes effective at this pressure and pumps the 200 l system volume to $3x10^{-4}$ mbar within 20 minutes. The turbo-molecular pump may then be switched into the standby mode and be run at 66% of maximum speed sustaining a pressure of $5x10^{-5}$ mbar.

The turbo molecular pump has a vent valve that is used in combination with the electronic drive unit. The valve closes when the electronic unit starts. After a stop caused by malfunctioning, main supply failure, or switch-off, venting starts when the turbo pump reaches half its normal speed. The vent remains open until the next start of the drive unit.

The vacuum vessel pressure is measured by a Combitron CM330 control unit with a PR31 Penningvac gauge head and a TR201 Thermovac gauge tube. The head and the gauge are mounted on the base plate. Together they cover a pressure range from 10^{-6} to 10^{3} mbar.

Control signals are available at the vacuum meter and at the electronic drive. The signals may be used for the MIMIC as well as safety signals for the proton detector bias supplies.

3.5. The Neutron Detector Frame

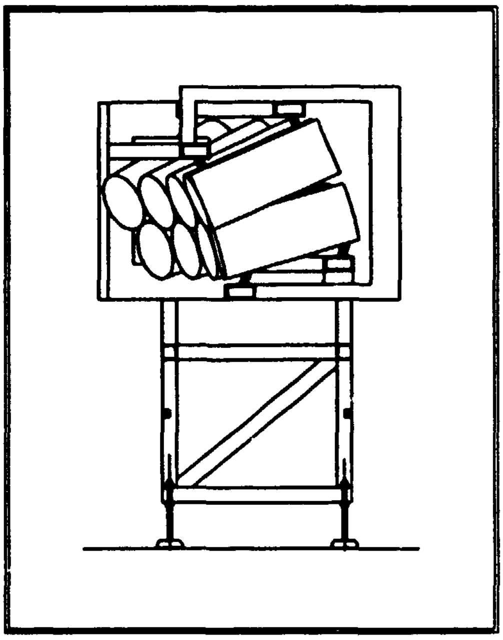

Fig. 31. The Neutron Detector Frame

The neutron detectors are located in two neutron detector supporting frames. Each frame has room for 16 detectors. The frames are made of aluminium and are equipped with PVC-tubes serving as holders for the neutron detectors.

The frame rests on a table made of steel. The height and tilt of the table can be adjusted by screws at the legs of the table

4. The Tools

Tools are supplied with the system for the mounting and adjustment of the system. Some of the tools are displayed in the figure below.

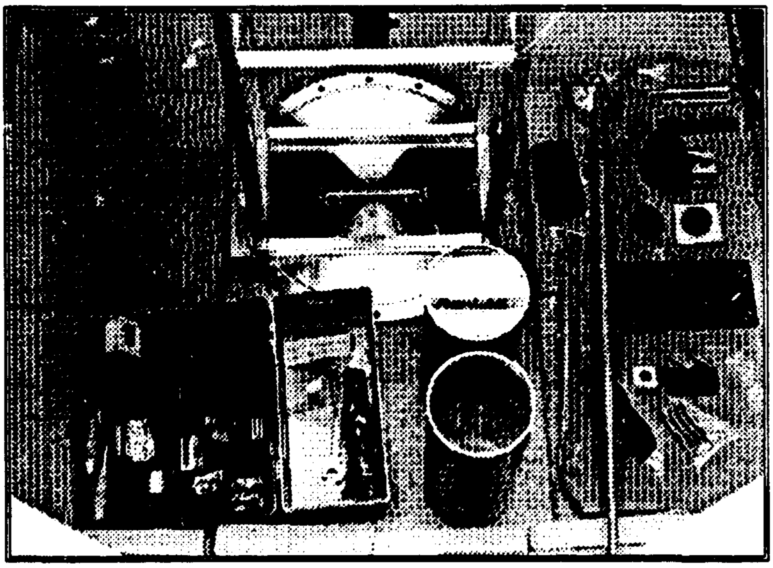

Fig. 32. Tools

Qty	Item
2	Al-rod, diameter 20 mm
1	Steel ball
1	Ball socket
2	Brass rod
1	Plate with 3 rods
4	Hexagonal brass rod
4	Washer to M6
4	Lock washer to M6
4	Set of 3 washers for positioning of plate
4	Finger nut to M6
4	Nut M4
4	Washer M4
4	Lock washer
1	Flat pliers
1	Adjustable Wrench
2	Dark protective goggles
1	Steel measuring ruler
1	Torch
1	Insulating tape
1	Wrenches 8, 10, 13, and 19 mm
1	Hexagonal spanners 2.5, 5, and 6 mm
1	Screw driver with screw holder
1	Screw driver
1	Pentagonal prism
1	Spring for gauge
2	Ending of gauge
1	Mirror

Table 5. Contents of the Tool Box

The contents of the tool box are listed in table 5. Most of the items are details supposed to be used for the measurement and adjustment of the neutron detector positions. It is a laser system using a pentagonal prism and a mirror for the determination of distances and angles. The laser beam is aligned to the symmetric axis of the collimator. The pentagonal prism defines a perpendicular plane to which the neutron detector frames can be adjusted. The prism is then replaced by a mirror reflecting the laser beam to the neutron detectors. The angles of the mirror are determined using rulers. The details of the method used will be described in another document.

Shown in the figure are also distance bars for a precise adjustment of the neutron detector positions. Furthermore, two detector dummies are supplied to be used together with the laser beam system.

4.1. Calibration Sources

One cobalt source and two americium sources are used for the calibration of the instrument.

The cobalt source (Co-60, 1 to 2 mCi, 37 to 74 MBq) is used for energy and time calibration of the neutron detectors. It is placed at the centre of the system in a special holder during the tests. The calibrations should be done at start-up of the system and at the replacement of any of the neutron detectors. The system has been found to be stable. Normally, recalibrations are needed only if the environment situation changes, e.g. large temperature changes. Checks should be done once every other month.

The americium-241 sources (150 nCi, 5.55 kBq) are used for the energy calibration of the proton detectors. The delivered sources are made by Amersham, have the code AMR.13 and serial numbers 7536 RA and 7578 RA.

The sources are placed symmetrically at the bottom of the vacuum chamber and are kept there as long as the instrument is used. Americium spectra are obtained between the pulses and are continuously used for energy calibration and checks of the condition of the proton detector. Any sign of radiation damage will show up as a broadening of the americium peak.

5. The Appendices

The detailed information about the different parts of the instrument is given in a number of appendices. These are only included in those copies of this document that are delivered to JET.

5.1. Drawings

Appendix 1. A full set of drawings is given. The drawings are updated at the time of the delivery of the instruments. Drawings of the collimator and related items are not included.

5.2. Electronic Module Specifications

Appendix 2. All modules used are listed. The factory name, the JET name in case of a standard JET module, and the name used at the modules and in this documentation are listed.

The settings and the straps of the modules are listed. The indicated straps and settings have been used during the time of test of the instrument. The modules have been modified in a few cases. These modifications as well as some remarks about the use of the modules are included.

5.3. Module and Cable Lists

Appendix 3. Here we give an overview of the system. The cables and their labelling are defined.

The names used as labels on the cables correspond to the names given on the modules at the connectors. The lists are made for an identification of the system as it was used during the test period. No conversion to the JET standard has been done. This can be done first at the time of decision about the number of cubicles and the organisation of the units within the cubicles.

Crate CCC contains spare space for units to be added at JET. Remote control of the vacuum pump system and protection of the diodes in the case of vacuum pump failure are examples of items not taken care of.

5.4. Neutron and Proton Detector Data

Appendix 4. Data sheets for the neutron detector photomultiplier tubes and the supplied proton detectors are collected here. Data sheets for the americium sources are also included.

5.5. Manuals for the Electronic Units

Appendix 5. Copies of manuals of the electronic modules. In order to have a complete set of manuals available at the instrument copies of the JET standard units are included.

5.6. Manuals for the Vacuum Pump System

Appendix 6. Copies of manuals for the vacuum pump system. Any manual for units added to KM5-TANSY should be included in this file at JET.

5.7. Packing Lists

Appendix 7. Lists of the contents of the boxes delivered to JET.

References

1. Gudmar Grosshög, Dan Aronsson, Erik Arvidsson, Klaes-Håkan Beimer, Lars-Olof Pekkari, Ryszard Rydz, and Nils G. Sjöstrand, Combined Proton-Recoil and Neutron Time-of-Flight Spectrometer for 14 MeV Neutrons, Report **CTH-RF-43, JET-JB2-9008,** Chalmers University of Technology. 1983.

2. Gudmar Grosshög, Dan Aronsson, Klaes-Håkan Beimer, Lars-Olof Pekkari, Ryszard Rydz, Örjan Skeppstedt, and Nils G. Sjöstrand, TANSY, a Neutron-Spectrometer for Fusion-Plasma Diagnostics, Report **CTH-RF-54, JET-JE4-9002,** Chalmers University of Technology. 1985.

3. Gudmar Grosshög, Data Collection Program for TANSY-KM5, Report **CTH-RF-76,** Chalmers University of Technology. 1991.

4. Gudmar Grosshög, Dan Aronsson, Krzysztof Drozdowicz, Magnus Hoek, Ryszard Rydz, Lennart Norberg, and Lasse Urholm, User Manual for TANSY-KM5, Report **CTH-RF-82,** Chalmers University of Technology. 1991.