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User Manual for

TANSY-KM5

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1. Introduction

This document describes procedures for the set-up and use of TANSY. It is a complement to the report "Technical Description of the Tansy Spectrometer, TANSY-KM5" [4] and is aimed to guide the user through the initial adjustments and calibrations to a normal use of the instrument. Details, such as placing of jumpers and settings of potentiometers in electronic modules, are not given here. The reader can find such information in the above mentioned report and its appendices. Information about the auxiliary crate controller is given in "Data Collection Program for TANSY-KM5" [3].

The coordinate system is defined in "2.1 The Coordinate System", page 5. These coordinates are used everywhere for the definition of the placing of the detectors, and other purposes. The definition goes back to our first report [1]. At that time the neutron beam was horizontal and not vertical. That is the reason for the unusual direction of the Z-axis.

After the reassembling of the instrument the detectors shall be placed at the correct positions. The exact position is not as essential as the knowledge of the positions, "3. Mechanical Adjustments", page 8. The measurement of the neutron detector positions is done by a laser system, "3.2 Adjustment and Measurement of the Neutron Detector Positions", page 11. However, the proton detector positions are fixed and can not easily be changed.

The electronic units were calibrated at the time of the delivery. The calibrations should be checked at the time of start-up of the system. If the units have been used for other purposes during the storage time of TANSY it may be necessary to recalibrate them. The items specific for TANSY are described in the chapter "4. System Start-up", page 21.

Three types of calibrations are described, "5. Calibrations", page 23. The energy windows of the neutron detectors are defined by three parameters: the bias voltage for the photomultipliers and the two discriminator levels. The neutron detector check and calibration scheme must be worked through from time to time, "5.1 The Energy Calibration of the Neutron Detectors", page 23. Much work has been done in order to establish reliable routines. Using the parameters obtained during the laboratory tests it is possible to use any neutron energy window of practical interest.

The measurement of the energy of the recoiling protons is one of the most important tasks of the instrument. Therefore, routines are given both for the initial calibration of the detectors, "5.2 The Energy Calibration of the Proton Detectors", page 28, and the automatic calibrations done during the operation of the instrument, "6. Run-Time Considerations", page 37.

The final calibration is the time calibration, the synchronization of the proton detectors and the neutron detectors, "5.3 Time Calibrations", page 31. Using the described procedures all but one of the time calibration parameters can be determined by a measurement on a cobalt gamma source.

The calibration parameters obtained during the test period are listed at the end of each calibration chapter. They can be used as a first estimate of unknown parameters.

2. Preliminaries

The document "Technical Description of the Tansy Spectrometer, TANSY-KM5" [4], defines the instrument. Before going through the procedure described in this document the instrument should be assembled according to instructions given in the reference. Here it is assumed that the electronic modules are mounted, interconnected and adjusted as indicated in the reference and its appendices.

2.1 The Coordinate System

At several places we need to use a coordinate system for the definition of the positions of different parts of the system. The definition of the coordinates can be traced back to the first design of TANSY [1]. It is a right hand defined cartesian coordinate system with the X-axis placed along the neutron beam. The X-Y plane coincides with the foil and the coordinate centre is placed in the centre of the foil. As a consequence of this definition the neutron detector positions have positive Z-values and the proton detector positions have negative Z-values.

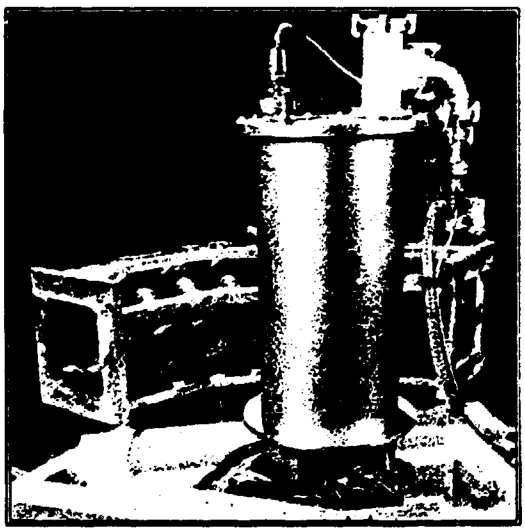

Fig.1. The Vacuum Vessel and the Neutron Detectors

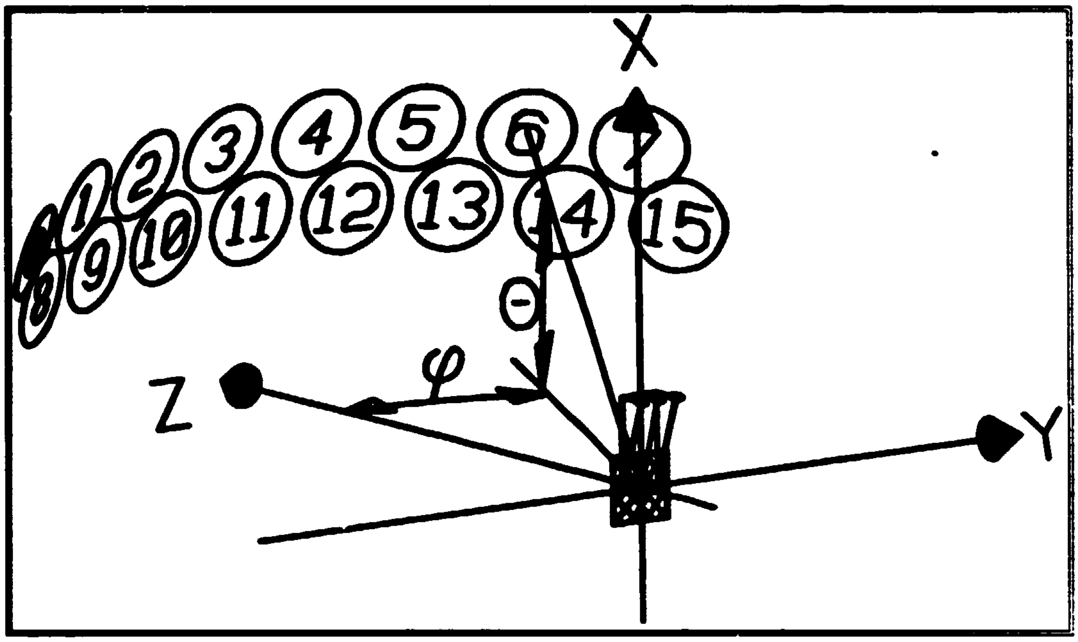

Fig.2. The TANSY Coordinate System

Two coordinate systems are used, one for each of the two branches. The systems are identical from the detector position point of view. They coincide if one of them is turned 180 degrees around the X-axis. One of the branches is illustrated in figure 2 and a corresponding picture is shown in figure 1.

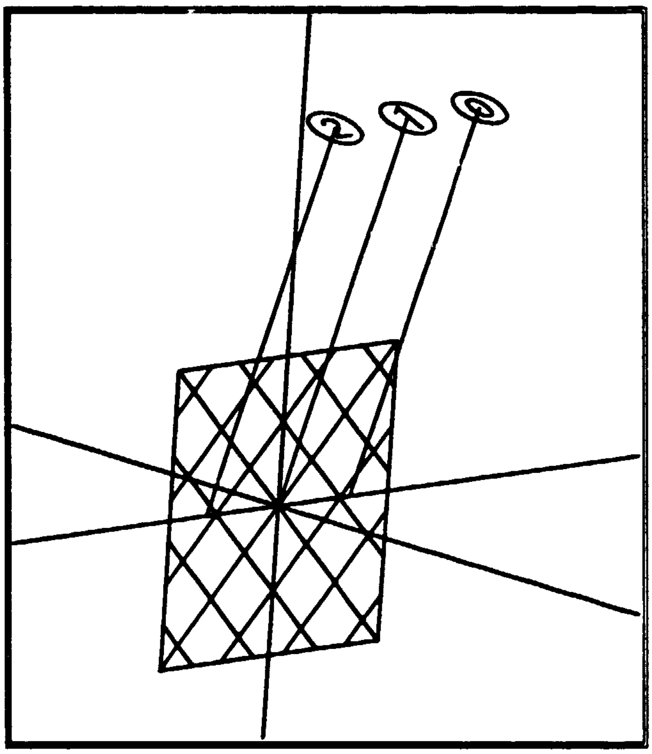

Fig.3. The Proton Detector Positions

The neutron detectors are numbered clockwise from left to right starting with the upper row. The azimuth angle φ goes from negative values at the detector position 0 and 8 to positive values at the detector positions 7 and 15. The elevation angles of the direction from the origin to the neutron detector positions are denoted by Θ.

The proton detectors are numbered from 0 to 2 starting with the leftmost one as seen from the coordinate system origin point. The neutron detectors are pointing towards the origin point of the coordinate system but the proton detectors point towards the Y-axis.

The position of the neutron detectors are defined by the distance from the coordinate system origin point to the centre of the front surface of the magnetic shield of the detector, the elevation angle Θ and the azimuth angle φ. The proton detector positions are defined by the cartesian coordinates of the centre of their front surfaces. These values are written into the data file and used by the evaluation programs to calculate the appropriate flight path lengths for the scattered neutrons and the recoiling protons in the different proton-neutron detector combinations. Corrections for the distances between the surface of the magnetic shields of the neutron detectors and the scintillator surfaces are done during the evaluation process.

3. Mechanical Adjustments

The purpose of the mechanical adjustments is to place the components of TANSY at appropriate predetermined positions. The adjustments involve movements of the neutron detector benches which is not easy to do with a high precision. Actually, we do not need to position the detectors at precise locations. However, it is essential to know the positions with high accuracy. Therefore, the approach chosen is to position the components as well as possible and measure the positions with high accuracy afterwards .

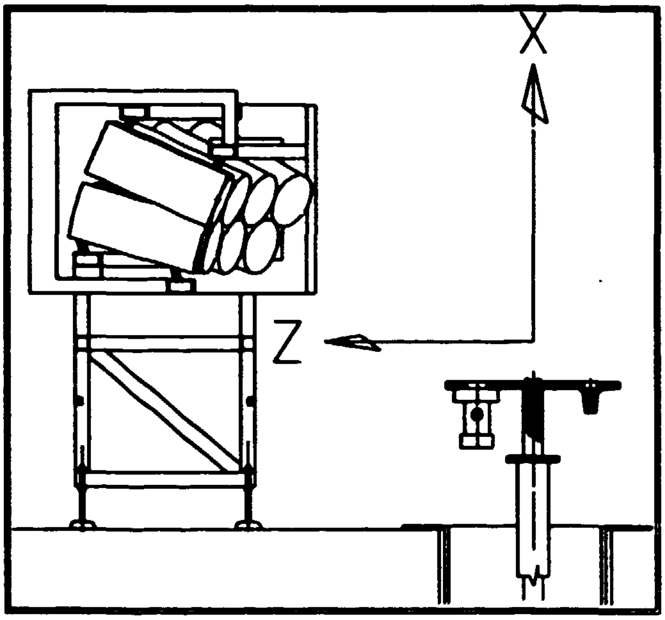

Fig.4. TANSY Arranged for Mechanical Adjustments and Measurements

Detector #	X, cm	Y, cm	Z, cm
0	14	33	-50
1	14	0	-50
2	14	-33	-50

Table 1. Proton Detector Positions

The centre of the foil is the reference point for all measurements. Therefore, the vacuum vessel is dismounted prior to the adjustments. Only the bottom plate is in place as indicated in figure 4. The tools needed are mounted on the bottom plate.

The collimator should be positioned before the adjustments. We do not discuss the adjustments of the collimator here. However, it should be pointed out that the laser was initially chosen to be used also for the positioning of the collimator.

The proton detectors are mounted in fixed positions which can not easily be adjusted. The positions for both the branches are given in table 1. The proton detectors are numbered from left to right as seen from the reference point.

The adjustment and the measurement of the neutron detector positions are done in 9 steps:

1) Mount a laser and align it with the collimator
2) Mount a mirror board and adjust it perpendicularly to the laser beam
3) Adjust the height and the centre position of the neutron detector bench

4) Adjust the tilt and the distance of the detector bench
5) Check the detector bench position
6) Mount the neutron detectors and adjust the individual detector positions
7) Measure the elevation angles Θ
8) Measure the azimuth angles φ
9) Insert the neutron detector positions in the data base

3.1 Adjustment Tools

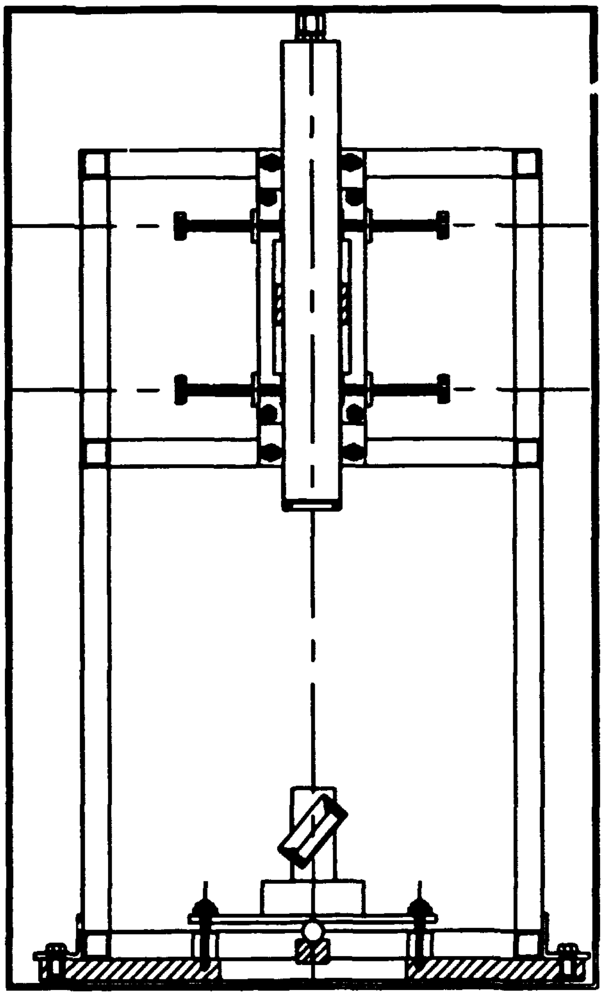

Fig.5. The Adjustment Tools Mounted on the Bottom Plate

A sketch of the laser assembly is shown in figure 5. The tools are displayed in figure 6, "Tools", and figure 7, "More Tools", page 10. The items in the figures are referenced below using the brackets "{}".

The He-Ne laser {1} is mounted in a laser bench {2}. The tool box {3} contains some aids such as screw drivers and spanners. Two detector dummies {4} are supplied. They can be mounted in the detector bench for checks of the detector positions and orientation.

A distance arm {5} can be mounted at the reference point. It is supposed to be used together with one of the two distance arm ends {6} for positioning of the detector bench and the detectors. The combinations give lengths of 1034 and 1000 mm, respectively.

A black pin {7} is used together with the mirror holder {8} for the determination of the position of the neutron detector bench. When the black pin is mounted in front of the mirror holder and the reflected beam from the pentagon prism

{9} hits the upper part of the black pin then the laser beam marks the middle of the position of the neutron detector bench.

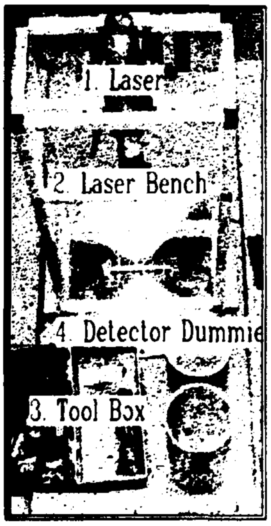

Fig.6. Tools

The mirror holder {8} is mounted with its centre at the reference point. The holder can be equipped with either a pentagon prism {9} or a mirror {10}. The pentagon prism reflects the laser beam 90 degrees independent of the mirror holder angles. The mirror is used for the measurement of the elevation and azimuth angles of the neutron detectors.

The mirror or the distance arm are mounted on a mirror holder board {11}. The board rests on a ball placed on a pinhole board {12}. The orientation of the mirror holder board is done using 4 winged nuts mounted on screwbolts {13}.

Finally, it should be emphasized that a high degree of precaution is required when dealing with a laser. Reflecting items such as watches and jewelleries should be removed. Protection glasses are provided {14} in order to protect the user against reflections of the laser beam.

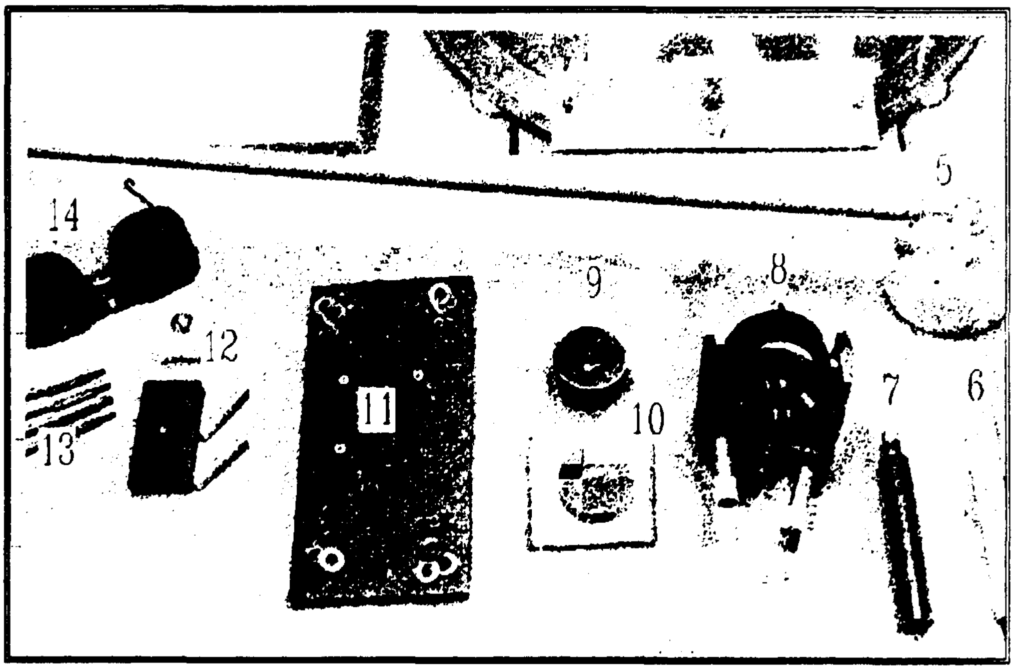

Fig.7. More Tools

3.2 Adjustment and Measurement of the Neutron Detector Positions

3.2.1 Mount the Laser and Align it with the Collimator

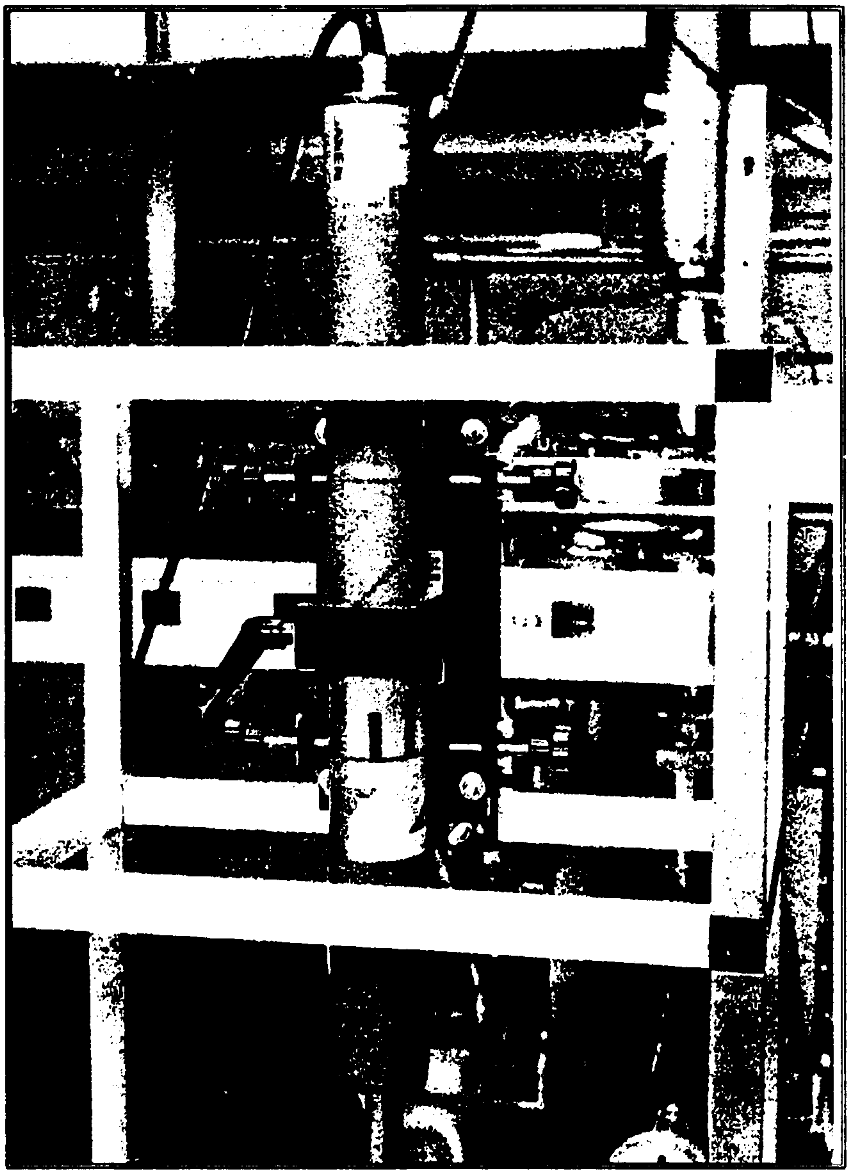

Fig.8. The Laser Mounted in the Laser Bench

The laser is mounted in an adjustable laser holder. The laser can be adjusted to any angle and position within the limits of the holder.

Fig.9. Magnus Aligns the Laser

The laser bench is mounted on the bottom plate. Two reference points are needed in order to align the laser beam. The first is a white spot painted at the centre of the neutron beam entrance window of the collimator. The second is a hole in the pinhole board, figure 7, "More Tools", page 10, item {12}. The laser is correctly adjusted when the beam goes through the hole and hits the white spot.

3.2.2 Mount the Mirror Board and Adjust it Perpendicularly to the Laser Beam

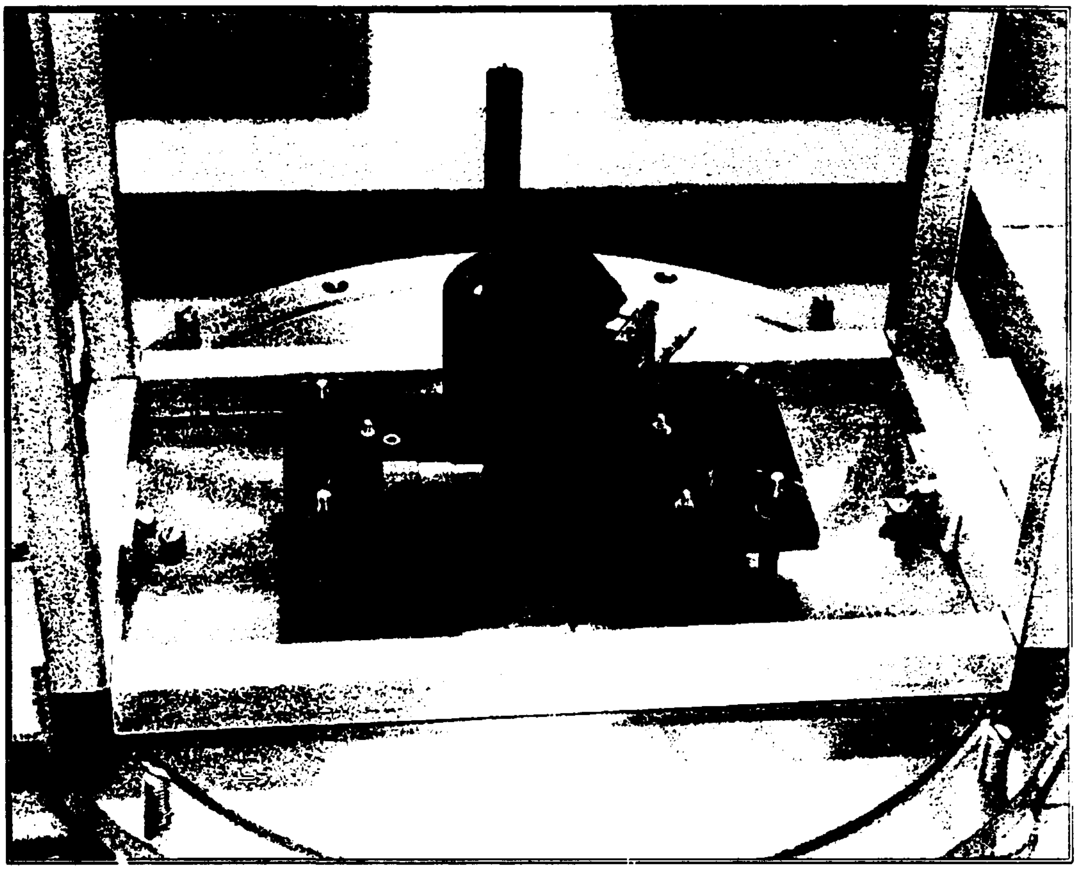

Fig.10. The Mounted Mirror Board

Apply the ball on the pinhole, figure 7, "More Tools", page 10, {item 12}. Fasten the four pins {item 13} in the bottom plate and mount the mirror board {item 11}. Mount the mirror holder {item 8} equipped with the mirror {item 10}.

Adjust the tilt of the mirror board by the winged nuts until the direct beam of the laser coincides with the beam reflected by the mirror. A coarse adjustment is done when the beams coincide for all azimuth angles of the mirror holder. It is easier to do the adjustment with a somewhat tilted mirror. Then the reflected beam creates a spot at the front of the laser. If the board is perpendicular to the incoming laser beam, the spot describes a circle with the exit beam at the centre when the mirror holder is turned around the X-axis. This is one of several possible methods for the coarse adjustment of the mirror board.

The pentagon prism is used for fine adjustments of the mirror board. The prism reflects the laser beam 90 degrees independent of the elevation angle. However, the upper surface reflects a minor part of the beam back to the laser. A second reflection in the laser takes it back to the prism. Therefore, two spots can be seen on a white paper placed one or two meters from the prism. Adjust the mirror board until the two spots coincide for all azimuth angles. Actually, only four directions are needed, two for the adjustment and two as check points. It is practical to use the directions defined by the winged nuts.

3.2.3 Adjust the Height and the Centre Position of the Neutron Detector Bench

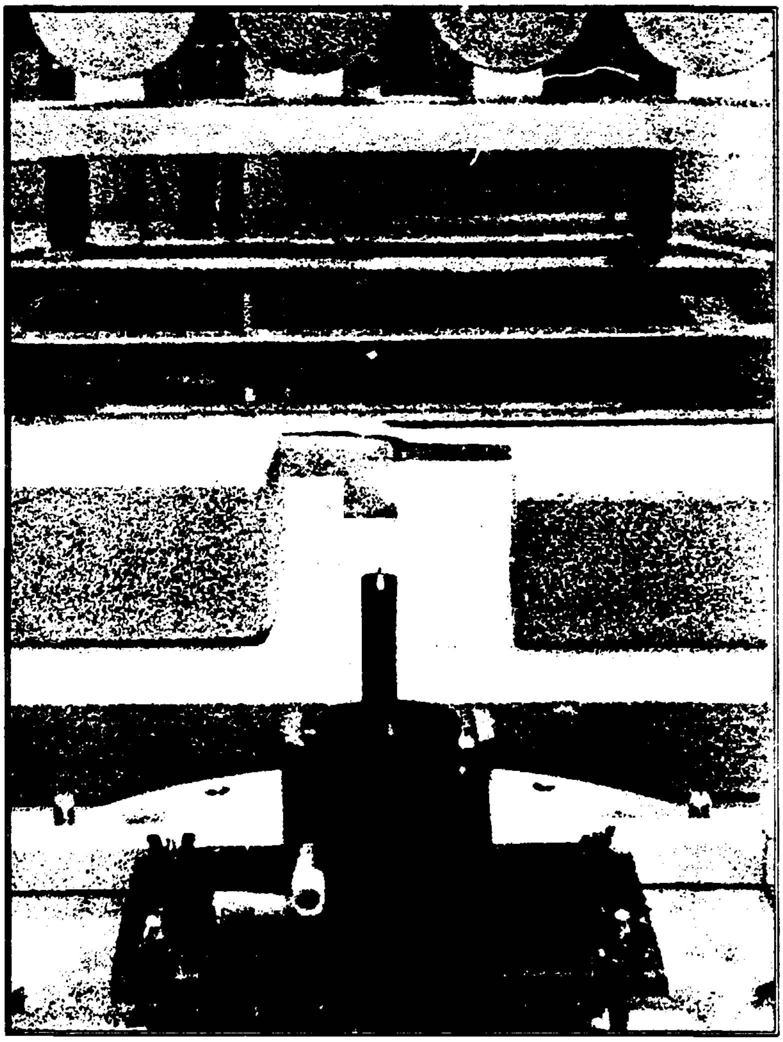

Fig.11. Adjustment of Neutron Detector Bench Height and Centre

Fig.12. Adjustment of a Leg

Mount the black pin, figure 7, "More Tools", page 10, {item 7}. Mount the pentagon prism and direct the beam to the top of the black pin as indicated in figure 11. Adjust the position of the neutron detector bench until the laser beam hits the drilled hole in the frame of the bench (in the figure the beam hits the frame at the edge of the hole and the pin in order to make it visible). The adjustments must be repeated at least once after the next step.

3.2.4 Adjust the Tilt and the Distance of the Detector Bench

Fig.13. Tilt Adjustment Points

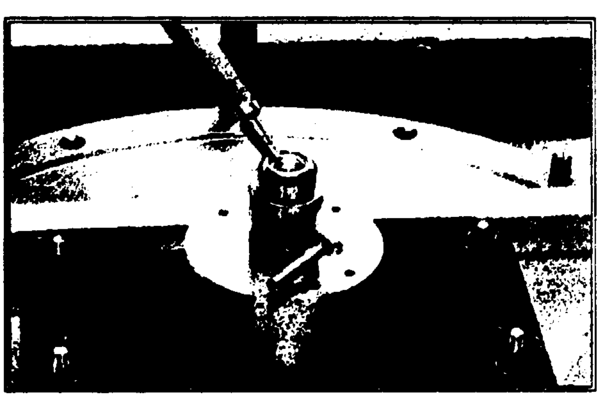

Fig.14. The Distance Arm

Remove the mirror holder and mount the 1034 mm distance arm. Use the four tilt adjustment points according to figure 13 (the points not shown in the figure are placed symmetrically) in order to adjust the tilt and the distance of the neutron detector bench.

3.2.5 Check the Detector Bench Position

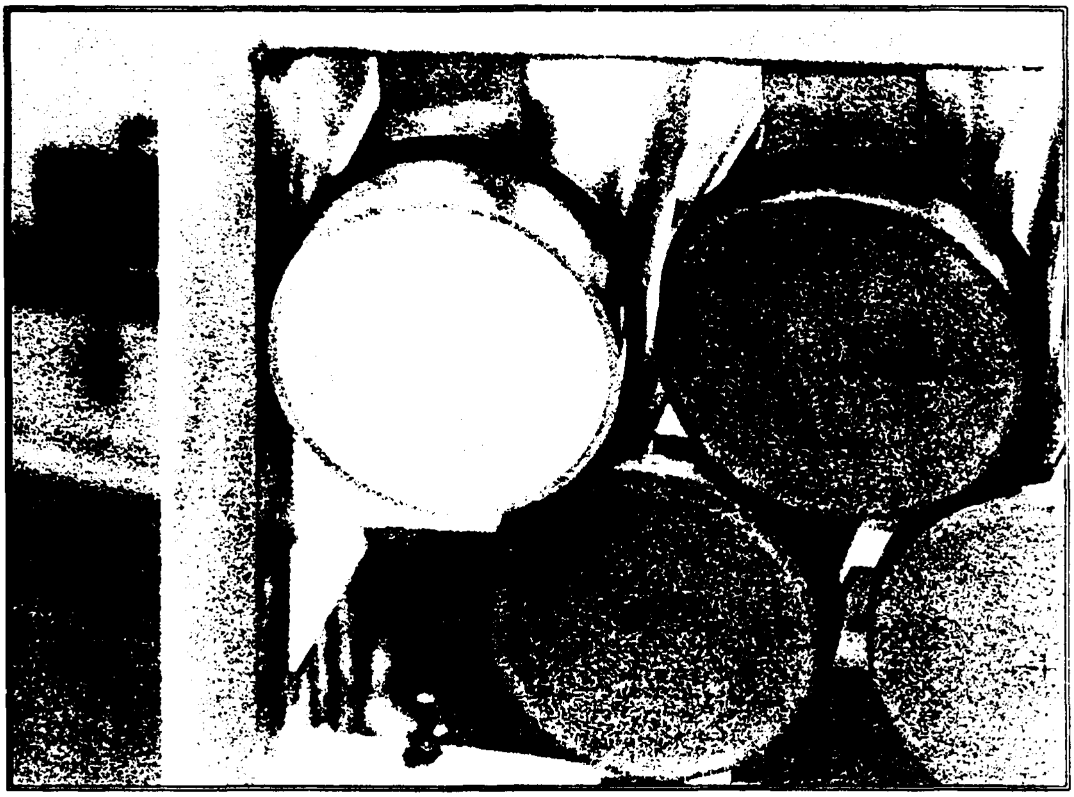

Fig.15. The Neutron Detector Dummy

The tilt of the individual detector holders may now be checked. Two detector dummies are supplied. They can be inserted in any of the detector positions. Use the reflected beam and direct it towards the centre hole of the dummy by the mirror in the mirror holder. A correct adjustment has been done if the laser beam goes through the hole in the plexiglass window and hits the centre of the rear of the dummy. A small deviation is acceptable.

A check of the angular positions may also be done using the angle measurement procedures in "3.2.7 Measure the Azimuth Angles", page 18, and "3.2.8 Measure the Elevation Angles", page 19.

The neutron bench position should now be locked and its position should be marked for future reference. The adjustment procedure takes some time and could otherwise be spoiled by an accidental movement of the neutron detector bench.

3.2.6 Mount the Neutron Detectors and Adjust the Individual Detector Positions

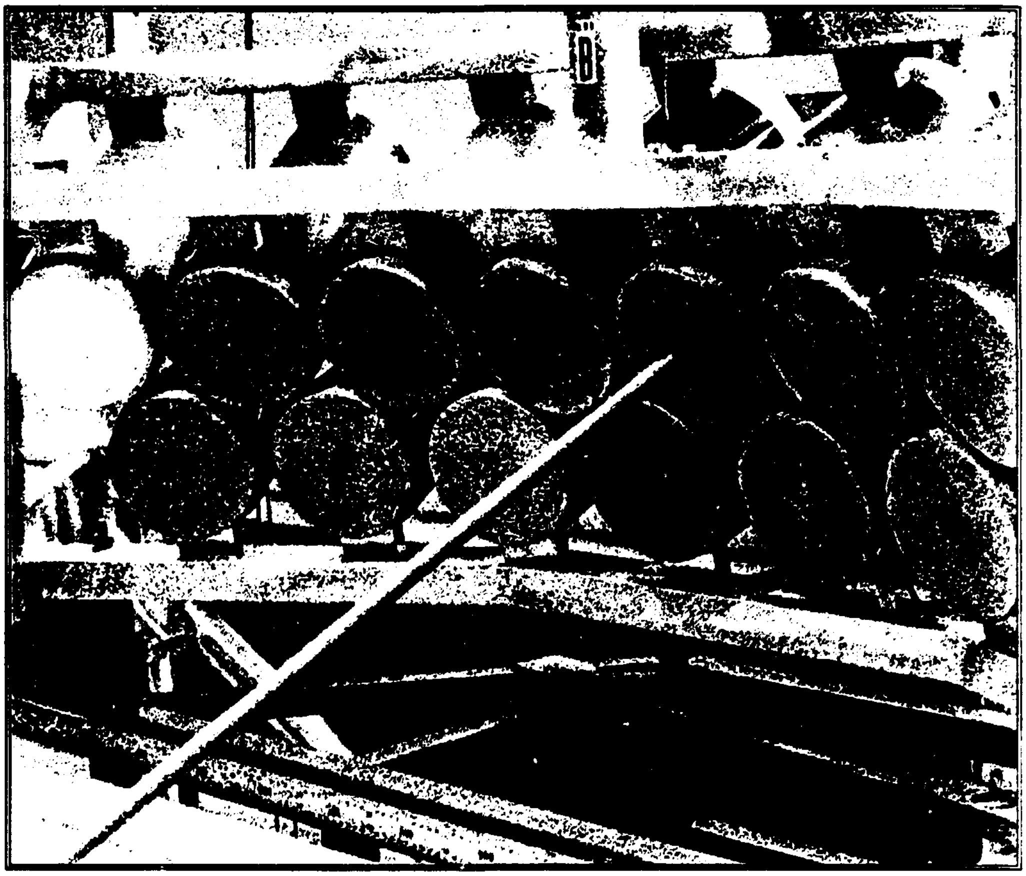

Fig.16. The Detector Distance

Insert the neutron detectors in the neutron detector holders. Set up the 1000 mm distance arm and use it for a precise adjustment of the distance between the reference point and the centre of the detector front surface.

The detectors can easily be moved in the holder by using a screwdriver to open up the holder. Place the screwdriver in the neutron holder slit. A small turn of the screwdriver will open the holder so that the neutron detector can smoothly be moved to the correct position.

3.2.7 Measure the Azimuth Angles

Fig.17. The Steel Ruler on the Neutron Detector Bench

Fig.18. Laser Beam on Ruler

There are scales on the mirror holder for the measurement of angles. However, the accuracy is not sufficient. Therefore, we have used rulers for the angular measurements. Denoting the ortogonal distance between the reference point and the ruler with R, the reading of the value at zero azimuth angle with H_r, and a reading at an angle corresponding to the azimuth angle of a detector position with H_i, we have

$$\varphi_i = \arctan\left[\frac{H_i - H_r}{R}\right]. \qquad (1)$$

3.2.8 Measure the Elevation Angles

Fig.19. The Vertical Scale

Place a vertical scale 2 or 3 meters from the reference point. Use the pentagon prism to get a reference reading V_r. Measure the distance from the reference point to the scale, R. Mount the mirror and direct the laser beam towards the centre of one of the detectors. Turn the mirror holder so that the beam hits the scale and read the position of the spot on the scale, V_i. Calculate the elevation angle from

$$\Theta_i = \arctan\left[\frac{V_i - V_r}{R}\right]. \qquad (2)$$

3.2.9 Insert the Neutron Detection Positions in the Data Base

Branch A			Branch B		
Detector #	**Elevation angle Θ degrees**	**Azimuth angle φ degrees**	**Detector #**	**Elevation angle Θ degrees**	**Azimuth angle φ degrees**
00	23.49	-37.19	00	23.64	-37.48
01	23.42	-27.05	01	23.60	-27.42
02	23.34	-17.16	02	23.57	-17.44
03	23.34	-7.30	03	23.54	-7.46
04	23.34	2.93	04	23.54	2.64
05	23.41	12.75	05	23.58	12.72
06	23.51	22.81	06	23.68	22.73
07	23.62	32.85	07	23.64	32.71
08	15.67	-32.31	08	15.93	-32.40
09	15.70	-22.35	09	16.06	-22.43
10	15.71	-12.41	10	16.06	-12.32
11	15.71	-2.36	11	16.14	-2.43
12	15.70	7.58	12	16.12	7.67
13	15.73	17.58	13	16.06	17.57
14	15.70	27.50	14	16.03	27.53
15	15.70	37.57	15	15.89	37.57

Table 2. Measured Angles during the Test Period

The measured angles should be inserted in the data base. They become a part of the JET pulse file and are used during the evaluation process.

The angles obtained during the test period are listed in table 2. The vertical scale was placed at about 2 meters from the reference point. The maximum errors were estimated to about 0.04 degrees for the elevation angles and 0.10 for the azimuth angles.

4. System Start-up

The Starburst starts automatically at power-up. It goes into the IDLE state [3] and is ready for use provided that the units are correctly mounted and interconnected [4]. The system should now be exercised and checked for any malfunctions[1]. Useful test instruments are the Ortec NIM modules: 448 Research Pulser, 462 Time Calibrator and P1010 Pulse Generator. They are considered to be standard laboratory tools and are not supplied with the instrument.

A proper way to do the exercise is to start with the kernel calibration states: Time Calibration and Amplitude Calibration. Pulse generators are used as inputs and the signals are checked [the signal shapes are shown in reference 4]. Proceed with manual control of the Measurement State.

The Starburst may be controlled by a direct terminal or the host computer. The parameter settings should be those given in "Data Collection Program for TANSY-KM5".

The internal settings are listed in the appendices to "Technical Description of the Tansy Spectrometer". All modules were trimmed during the laboratory test period and no further action is necessary unless the modules have been used and adjusted for other purposes. Readjustment can be done by anyone familiar with the electronic modules. Here we will only shortly discuss two details, the walk adjustment of the constant fraction discriminator and the adjustment of the timing window of the TDCs.

4.1 Constant Fraction Discriminator Walk Adjustment.

No proper radioactive source is available for the adjustment of the proton line constant fraction discriminator. The discriminator is normally used at an energy of about 12 MeV. During time calibrations the discriminator level is lowered to about 1 MeV.

The module can not handle the full energy interval properly. Therefore, it is adjusted to give the best possible behaviour only at the interval used for protons during the measurements. A timing shift is accepted at low energies.

The EG&G Ortec 448 research pulser can be used for the adjustments. The trigger signal is shaped by an adequate fast shaping amplifier. We have used the Ortec 579 Fast Filter Amplifier with a clipping time of 2.5 ns. The amplifier output is delayed 300 ns and used as a stop signal in one of the neutron detector lines. The main signal is given a risetime of 50 ns and a decay time of 20 μs and is connected to the test inputs of one of the proton detector preamplifiers. The values are chosen to be as close as possible to the values observed for proton interaction. The signal amplitude is varied by the attenuators in order to avoid any changes in the trigger signal. The same number of attenuators should be used for all the measurements in order to get the best result. The Time-Amplitude calibration program is used for the collection of data. Note that a full time histogram is collected in the Starburst memories as a help for the positioning of the 20 ns long time-amplitude interval [5].

The adjustments are tedious. The walk of the constant fraction discriminators was carefully adjusted before the delivery of the instrument.

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[1]All modules worked satisfactory during the test period except the TDCs CTD1-007 and CTD1-009.

4.2 The TDC Time Window.

The blocking signal from the constant fraction discriminators is used as a gate signal defining the time measurement interval of the TDCs. A proper setting of the position and the length of the time interval minimizes the time shielding effect. The time interval of the collected events is defined by software parameters.

The time position of the interval is given by the difference in the length of the cables for the start signal and the gate signal. It can not easily be changed.

The length of the time interval can be adjusted to cover only the interval of interest. It is adjusted by a potentiometer in the constant fraction discriminator.

Figure 16 in reference [4] gives an example of a proper setting of the time window.

4.3 The ADC Gate Signal

The signal for the ADC gate is produced by the Gate Keeper module. Potentiometers are available for the start time and the length of the gate. The gate is easily adjusted using a two-channel oscilloscope. An example of a proper setting is given in reference [4], figure 17.

5. Calibrations

The calibrations involves the energy calibration of the neutron detectors, the energy calibration of the proton detectors and the time calibration, the time synchronization of the neutron detectors and the proton detectors.

5.1 The Energy Calibration of the Neutron Detectors

The energy of the scattered neutrons ranges from about 0.5 MeV to 4 MeV. The corresponding electron energies are 100 and 1400 keV, respectively. The sensitive energy interval of the neutron detectors is defined by the voltage of the photomultiplier supply and the lower and upper levels of the discriminators.

The calibration of the neutron detectors is based on the equation

$$A = \frac{E}{E_0} \cdot k \cdot V^n \tag{3}$$

where

- A = an amplitude normally at the place of the discriminators in units of the discriminator setting,
- E = particle or gamma ray energy in electron energy units,
- E_0= a reference energy, normally for cobalt giving a peak maximum at 781 keV,
- k = an amplification factor,
- V = the high voltage supply to the photomultiplier, and
- n = an exponent giving a relation between the photomultiplier voltage and amplification.

Equation 3 is transformed to its logarithmic equivalence,

$$\ln(A) = K_0 + n \cdot \ln(V) + \ln(\frac{E}{E_0}). \tag{4}$$

where K_0 is the natural logarithm of k.

We use the scalers in the calibration process. They are connected to the coincidence unit which easily can be set to transfer all signals above the lower discriminator or all signals above the upper discriminator. The pulse generator (CPG3) can be used for the control of the measurement times. As the high voltage of the neutron detector can be controlled by the CAMAC crate it is possible to scan a voltage interval in predetermined steps in an automatic measurement sequence. In each step we measure the number of pulses above the discrimination level D which corresponds to an energy E_1. From equation 3 we have a connection between D and E_1

$$E_1 = \frac{D.E_0}{k} \cdot V^{-n} \tag{5}$$

The number of pulses recorded is given by

$$P(V) = \int_{E_t}^{\infty} P(E)dE \qquad (6)$$

This is a function which will grow with increasing voltage over the whole interval. We need a well defined point on the curve. Such a point can be found if we differentiate equation 6.

$$\frac{dP(V)}{dV} = -P(E_t)\frac{dE_t}{dV} = P(E_t)\frac{nE_t}{V} \qquad (7)$$

It can be shown that this function has a maximum which is defined by the relation

$$P(E_{vm}) = const \cdot E_{vm}^{-\left(\frac{n+1}{n}\right)} \qquad (8)$$

where E_{vm} is connected to V as A in equation 3. This is a well defined point. However, it is not the same point as the maximum point in a normal amplitude distribution. If the energy distribution contains a peak with a gaussian shape we can get an estimate of the difference,

$$\frac{E_{vm}-E_m}{E_{vm}} = \frac{n+1}{n}\left[\frac{\sigma}{E_{vm}}\right]^2, \qquad (9)$$

where σ is the standard deviation and E_m the maximum point of the gaussian distribution. The difference is some percent. Therefore, the maximum point in the voltage scan is a point usable for the calibration process. However, the reference energy E_0 should be determined from the linear amplitude distribution.

Going back to equation 4 it is now possible to use the maximum point for the determination of the parameters. The voltage scan is repeated for a number of discriminator settings. The discriminator level is plotted as a function of the voltage at the maximum intensity and the parameters K_0 and n are determined for every neutron detector in the system. The calibrations must be done for both the lower level and the upper level discriminators. The parameters of the two levels are not equal as different amplification factors are used for the two levels.

The final discriminator and voltage settings are determined as follows. The lower discriminator level has been determined to 150 mV. The level is chosen in order to use the signal interval as well as possible. The voltage settings are then calculated from equation 4 using 100 keV for E. The energy of the upper level has been chosen to 1400 keV. This value together with the obtained voltages define the settings of the upper level discriminators.

The method has been carefully investigated [6,7,8]. The results of the calibrations are given in "5.1.5 Neutron Detector Calibration Data", page 26. In the next chapters we will describe procedures to check, recalibrate and add a new detector to the system.

The voltage scan is done in steps of 5 volts. The voltages are scanned from 1000 volts to 1800 volts in order to cover the voltage range of interest. Each step is measured 1 second. A waiting time of 5 seconds must be included after each change of the voltage and before the measurement in order to let the voltages be stabilized. In the most interesting region we then obtain about 10,000 pulses per step which is sufficient for the analysis. The whole procedure takes about 4 hours.

Several programs have been written for the handling of the calibration. Listings of the programs and the corresponding command files are presented in appendix 1.

5.1.1 A Quick Check of the Neutron Detector Calibration

The calibration is sensitive to the position of the cobalt source. During the calibrations in the laboratory it was placed in the system reference point, see figure 4, "TANSY Arranged for Mechanical Adjustments and Measurements", page 8. However, in order to do a quick test the source may be placed on the flange outside the vacuum vessel.

A voltage scan measurement is done and the points with maximum derivative are determined. The corresponding values can be calculated from the parameters given in table 3, "Neutron Detector Calibration Parameters for Branch A", page 27 and table 4, "Neutron Detector Calibration Parameters for Branch B", page 27.

The two sets of voltages are compared. From the laboratory tests it has been found that differences up to 7 V are acceptable. The obtained values should not be used for a recalibration. If it is decided to change the calibrations a more accurate method should be used.

5.1.2 A Careful Check of the Neutron Detector Calibrations

For a more careful check of the calibrations it is necessary to open the vacuum vessel and place the cobalt source at the system reference point. The proton detectors should be removed as they are not used.

Prior to the calibration the baseline photomultiplier bases should be recalibrated. The DC-level of the output of the bases is adjusted to zero. During the measurement of the DC-level the normal output should be connected to the discriminator and the second output should be terminated with 50 ohm. It is possible to adjust the DC-line to zero with an accuracy of .4 mV.

The lower level discriminators are set to 150 mV. This is the normal setting of the discriminators. The values should be checked and adjusted if necessary.

The upper level discriminators are disconnected from the coincidence unit. However, the setting of the coincidence unit should not be altered.

A voltage scan is run and the positions of the peaks are determined. The positions of the peaks are compared to those obtained from the old calibration parameters. A deviation of 5 V is accepted. It might happen that this test has a positive outcome in spite of the fact that the quick test failed. The system has been improved by the baseline adjustment and the check of the discriminators. Furthermore, the cobalt source is in the reference point.

5.1.3 Recalibration of the Neutron Detectors

The results obtained in the previous chapter can be used for a readjustment of the calibration parameters. It has been found during the laboratory test period that the exponent n, which determines the photomultiplier tube multiplication factor, is very stable. Therefore, any deviation in the calibration depends probably on changes in other parts of the amplification chain. Therefore, using the obtained peak voltage as V, only the parameter K_0 is updated according to the relation

$$K_0 = \ln(D) - n \cdot \ln(V) \qquad (10)$$

The obtained parameters are used for the determination of a new voltage or, in the case of the upper level, a new discriminator setting.

A check and recalibration can be done also for the upper level discriminators. The procedure is the same as above but the lower level discriminators are disconnected from the coincidence unit and the unit is set to accept only signals with amplitudes higher than the upper level discriminators. However, it should be emphasized that the final result of TANSY is not as sensitive to the upper level as to the lower level discriminators. Therefore, it is possible to use the result of the low level measurement in order to update the parameters for the upper level discriminators. The factor n is kept and a new parameter K_{0Unew} is obtained from the old parameter K_{0Uold} by

$$K_{0Unew} = K_{0Uold} + (K_{0Lnew} - K_{0Lold}) \qquad (11)$$

5.1.4 Calibration Parameters for a New Neutron Detector

A rigourous calibration of a new neutron detector is tedious. However, it is possible to use the experiences from the calibrations in the laboratory to get fairly good parameters. The basic observation is that the exponent of the photomultiplier amplification factor does not vary very much between the different photomultiplier tubes. Therefore, it is possible to use the mean value of the exponents as an exponent for the new detector. However, note that we have different exponents for the lower and the upper level.

The procedure is the same as the above recalibration procedure. A voltage scan is done and the peak voltage is found. The new K_0 values are obtained from equation 10 and 11.

5.1.5 Neutron Detector Calibration Data

The final parameters for the neutron detectors are summarized in the following three tables. The reference source is Co-60 giving a reference energy estimated to 781 keV.

The parameters are obtained for a lower level discrimination at 100 keV and an upper level at 1400 keV electron energy. These values correspond to the neutron energies of 0.5 MeV and 4 MeV, respectively.

	Lower Level Discriminator		Upper Level Discriminator	
Detector #	K_0	n	K_0	n
00	-95.59770	13.9199	-95.93807	13.8552
01	-92.98448	13.6593	-97.03045	14.1008
02	-92.67700	13.6140	-94.83014	13.7963
03	-94.71216	13.9067	-96.51661	14.0441
04	-94.02595	13.7617	-94.33855	13.6972
05	-94.15124	13.7548	-93.86630	13.6082
06	-95.71883	13.9254	-93.99732	13.5837
07	-95.37336	13.8737	-97.10278	14.0017
08	-89.64796	13.3720	-92.16994	13.6088
09	-94.05767	13.8962	-92.76257	13.6038
10	-92.60953	13.6415	-92.78299	13.5531
11	-93.63454	13.7802	-94.57716	13.7974
12	-94.35622	13.8519	-97.09632	14.1143
13	-95.02723	14.0444	-95.59081	14.0087
14	-96.64515	14.1437	-98.74255	14.3156
15	-90.92054	13.3984	-92.85490	13.5530

Table 3. Neutron Detector Calibration Parameters for Branch A

	Lower Level Discriminator		Upper Level Discriminator	
Detector #	K_0	n	K_0	n
00	-94.32612	13.7845	-97.53858	14.1077
01	-94.69771	13.8778	-96.95764	14.0739
02	-95.20302	14.0554	-93.84972	13.7565
03	-91.35313	13.5781	-94.32944	13.8779
04	-93.16808	13.8366	-94.18201	13.8629
05	-93.91614	13.7961	-96.26985	14.0069
06	-85.90939	12.9904	-85.23893	12.7811
07	-92.92239	13.6960	-92.48105	13.5235
08	-85.10455	12.9348	-80.74310	12.2098
09	-96.38091	14.1114	-97.91914	14.2092
10	-93.43744	13.8595	-91.37764	13.4656
11	-101.54265	14.6917	-106.64184	15.2696
12	-94.26544	13.9245	-94.83786	13.8927
13	-93.53030	13.8722	-93.36443	13.7377
14	-92.13696	13.7060	-93.20802	13.7402
15	-92.13000	13.5939	-94.02959	13.7413

Table 4. Neutron Detector Calibration Parameters for Branch B

Det. #	Branch A			Branch B		
	Lower Level mV	Upper Level mV	High Voltage V	Lower Level mV	Upper Level mV	High Voltage V
00	150.	927.	1596.	150.	911.	1565.
01	150.	932.	1517.	150.	923.	1530.
02	150.	927.	1520.	150.	923.	1445.
03	150.	945.	1508.	150.	941.	1406.
04	150.	957.	1550.	150.	922.	1400.
05	150.	949.	1570.	150.	934.	1510.
06	150.	943.	1605.	150.	918.	1283.
07	150.	959.	1610.	150.	927.	1481.
08	150.	935.	1384.	150.	939.	1244.
09	150.	913.	1447.	150.	924.	1527.
10	150.	925.	1490.	150.	947.	1410.
11	150.	928.	1492.	150.	918.	1624.
12	150.	926.	1513.	150.	940.	1447.
13	150.	922.	1436.	150.	935.	1410.
14	150.	909.	1529.	150.	922.	1391.
15	150.	940.	1500.	150.	921.	1476.

Table 5. Neutron Detector Discriminator and Voltage Settings

5.2 The Energy Calibration of the Proton Detectors

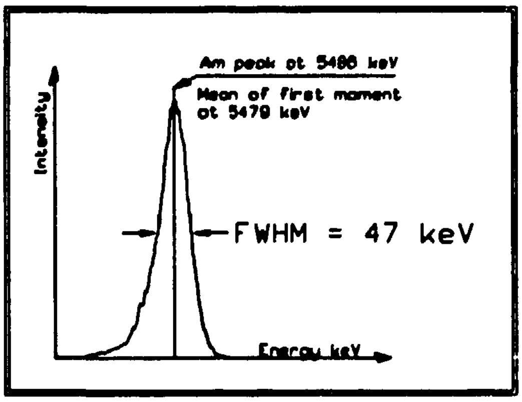

Fig.20. The Americium Peak

The energy calibration of the proton detectors is based on two peaks. The first is the peak created by one of the two americium sources in the vacuum vessel. The second is a peak coming from the built-in pulse generators. The position of this peak must be determined and included in the data file. Simultaneously, we determine the amplification and the energy offset. Finally, energy windows should be determined for the automatic calibration done during the measurements.

For the calibration we need an external good pulse generator such as the Ortec 448 Research Pulser. The Starburst auxiliary crate controller is run in the amplitude calibration state. The resulting three 8192-channel spectra are consecutively stored in the first part of the first memory. A host computer program should be available for the fetch and analysis of these spectra.

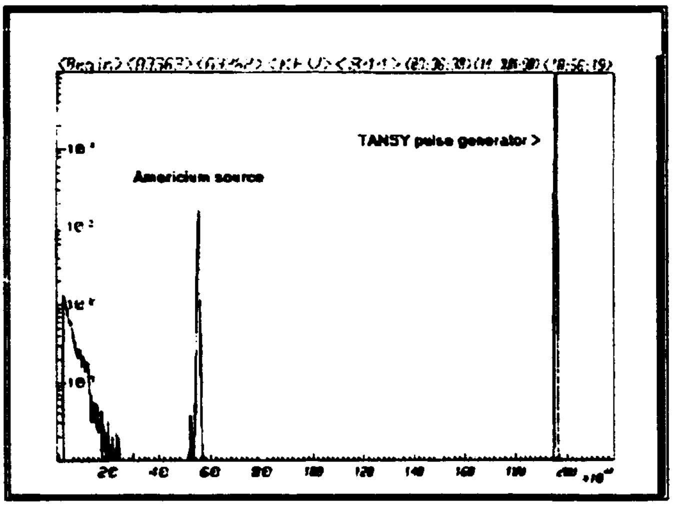

Fig.21. The Position of the Americium Peak and the TANSY Pulse Generator Peak

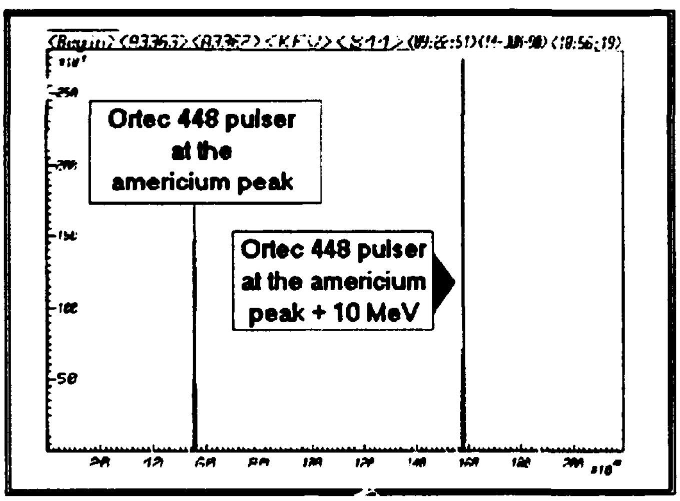

Fig.22. The Position of the Peaks of the Calibration Pulse Generator

Prior to the calibration the amplifier DC-level should be set to zero and the amplification adjusted so that the Am-peak is approximately in channel 2100. The pulse generator peak should be placed at about channel 7500. It is important that it is well above the expected amplitude of the protons. An example of the settings is given in figure 21.

The calibration can now be done according to the following steps:

1. Do an overnight measurement. The resulting spectra should then look like the spectrum presented in figure 21. The shape of the Am-peak is shown in figure 20, "The Americium Peak", page 28. An overnight measurement is needed as the count rate of the Am-peak is only one count per second.

2. Connect the Research Pulser 448 to the test input of one of the preamplifiers . Set the energy of the pulse generator pulse to 5479 keV. The peak value of Americium is 5486 keV. However, there are more peaks close to the main peak. The mean value evaluated with the moment method is 5479 keV. Adjust the normalization of the pulse generator so that the channel number obtained by the moment method is equal to the channel number obtained from the Am-peak.
3. Set the energy of the pulse generator at 15479 keV and determine the corresponding channel number.
4. Calculate the energy amplification and the energy offset from

$$dE = \frac{10000}{C_{10} - C_{Am}} \qquad (12)$$

$$E_0 = C_{Am} \cdot dE - 5479 \qquad (13)$$

where C_{Am} is the channel number at the Am-peak and C_{10} is the channel number at the Am-peak + 10 MeV.

5. Repeat 2 to 5 for all the six proton detector lines.

6. Measure the positions of the TANSY pulse generator peaks and calculate the corresponding energies:

$$E_p = E_0 + dE\, C_p \qquad (14)$$

where C_p is the position of the pulse generator peak in channels and E_p is the corresponding energy.

The obtained data should be inserted in the data file. The data used during the test period are collected in table 6.

Branch A					
Parameter	Name in Starburst	Unit	**Detector 0**	**Detector 1**	**Detector 2**
E_0, Energy offset	PE0	eV·10	-3610	-4344	-4035
dE, Energy per channel	PDE	eV/10 channels	26017	26144	25917
Energy of americium peak	PEA	keV	5479	5479	5479
E_p,,Energy of pulse generator peak	PEP	keV	19201	18982	18916
Amplitude intervals common to all detectors, only region 0 and 1 are used			**Region 0**	**Region 1**	**Region 3**
Lower limit	CLL	Channels	2000	7200	0
Upper limit	CLH	Channels	2200	7500	0

Branch B					
Parameter	Name in Starburst	Unit	Detector 0	Detector 1	Detector 2
E_0, Energy offset	PE0	eV·10	-0658	-3408	-0751
dE, Energy per channel	PDE	eV/10 channels	26113	26662	24717
Energy of americium peak	PEA	keV	5479	5479	5479
E_p.,Energy of pulse generator peak	PEP	keV	19190	19674	18220
Amplitude intervals common to all detectors, only region 0 and 1 are used			Region 0	Region 1	Region 3
Lower limit	CLL	Channels	2000	7200	0
Upper limit	CLH	Channels	2300	7500	0

Table 6. Calibration Parameters for the Proton Detectors

5.3 Time Calibrations

A cobalt gamma source is used for the time calibration. The source is placed in the reference point and the proton detector discriminators are set to about 50 mV in order to accept the gamma ray interactions in the proton detectors. The time calibration option of the Starburst controller is used. It collects the time distributions in the three CAMAC memories and the amplitude distributions in the Starburst memory.

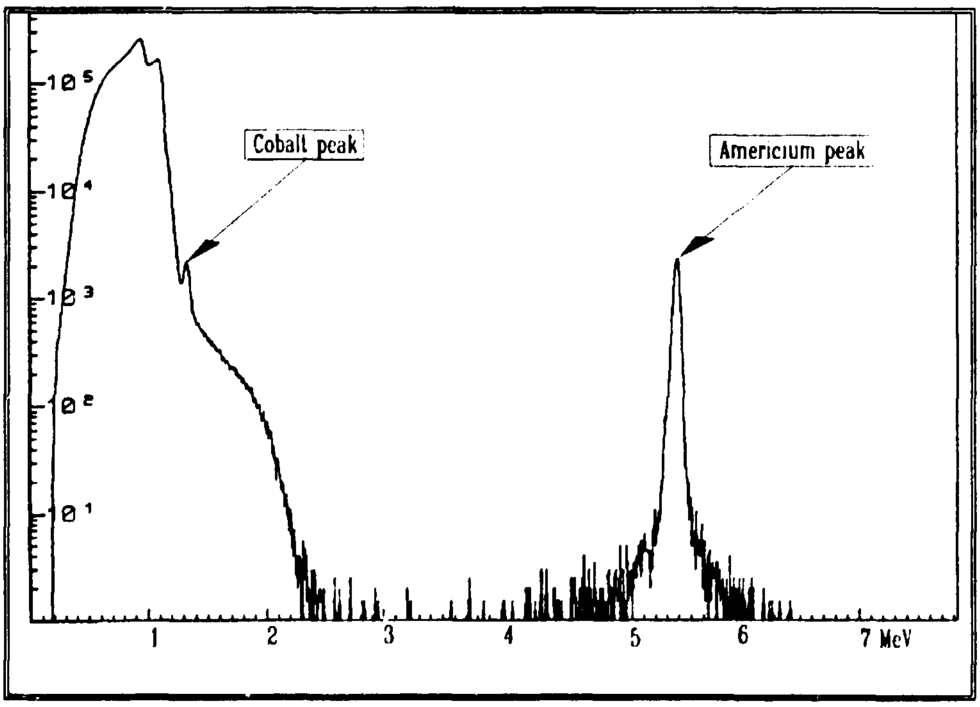

Fig.23. The Cobalt Calibration Amplitude Distribution

The amplitude distribution is seen in figure 23. The americium peak and one of the cobalt peaks can readily be seen. The choice of discrimination level can be based on this distribution. A higher discriminator level gives a better time resolution but the efficiency decreases and hence the measurement time of the calibration increases. Another application of the amplitude distribution is to use it as a check of the performance of the diodes and the energy calibration. During a normal test with two americium sources another peak will appear. It has a lower peak energy than the americium peak. It is created by the α-particles penetrating the foil. See figure 33, "The Secondary Americium Peak", page 38.

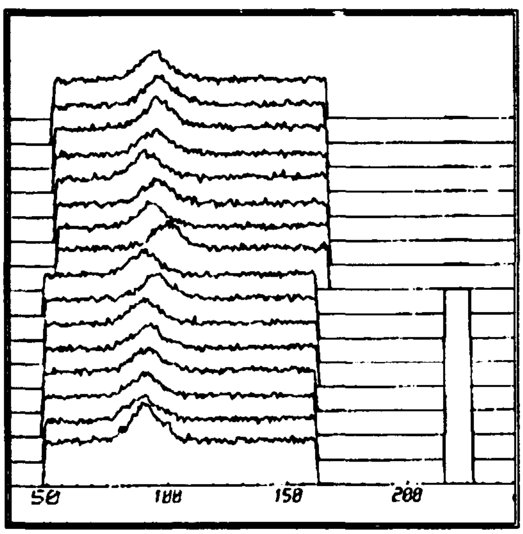

Fig.24. Time Distributions from a Cobalt Calibration

A time distribution result of an overnight measurement with a cobalt source is shown in figure 24. A gate about 200 ns long has been used. The delay in the proton line was set to 32 ns.

The lowest curve in figure 24 represents neutron detector number 0 and the uppermost number 15. The peak at the end of the time trace is caused by the stop pulse internal to the TDC.

The cobalt peaks at about 100 ns have widths of about 10 ns and the signals contain a lot of statistical noise. Therefore, it is not easy to find a good definition of the timing directly from the signals. We have used a correlation method to find the relative positions of the peaks. The correlation coefficient at a time channel k is given by

$$\rho(k) = \frac{\sum_{m=0}^{n} P_i(k+m)\, P_i(k+l+m)}{\sqrt{\sum_{m=0}^{n} P_i^2(k+m) \sum_{m=0}^{n} P_j^2(k+l+m)}} \qquad (15)$$

where $\mathbf{P}_i$ and $\mathbf{P}_j$ are the deviations of the channel contents from the mean value of the interval and n is the number of channels used. The correlation is 1 for a complete correlation.

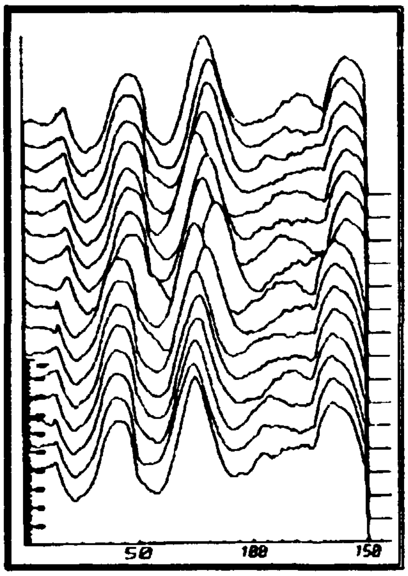

Fig.25. An Example of a Correlation

The result corresponding to the correlation in figure 25 is:

Detector	0 Corr. coef.	1.0000	at time	70.00	ns.
Detector	1 Corr. coef.	0.7131	at time	69.92	ns.
Detector	2 Corr. coef.	0.7341	at time	70.47	ns.
Detector	3 Corr. coef.	0.7130	at time	72.03	ns.
Detector	4 Corr. coef.	0.7124	at time	70.94	ns.
Detector	5 Corr. coef.	0.7266	at time	70.16	ns.
Detector	6 Corr. coef.	0.7464	at time	74.38	ns.
Detector	7 Corr. coef.	0.7513	at time	69.84	ns.
Detector	8 Corr. coef.	0.7194	at time	78.91	ns.
Detector	9 Corr. coef.	0.7323	at time	73.75	ns.
Detector	10 Corr. coef.	0.7273	at time	75.47	ns.
Detector	11 Corr. coef.	0.7414	at time	71.17	ns.
Detector	12 Corr. coef.	0.7169	at time	75.39	ns.
Detector	13 Corr. coef.	0.7648	at time	76.56	ns.
Detector	14 Corr. coef.	0.7625	at time	76.02	ns.
Detector	15 Corr. coef.	0.7632	at time	74.69	ns.

The correlation coefficient varies very much over the time interval. Three main peaks can be observed in figure 25. The first comes from the step at the beginning of the hardware defined time interval. The last comes from the end of the time interval. These peaks have correlation coefficients lower than the coefficient for the cobalt peak. Therefore, it is easy to write an algorithm which finds the correlations and the times of the cobalt peak. The program used during the test is listed in appendix 2.

In the example above we have used detector number 0 as the reference detector. The first correlation is then an autocorrelation and gives a correlation coefficient of 1. The time given is the time of the beginning of the correlation interval. All times may be referred to this time.

The result of the cobalt measurement is used for the determination of time delays for the different proton-neutron detector combinations. The procedure is illustrated in the figures 26, "The Start and Stop Times in the Real Time Frame", page 34, to figure 29, "Calibration of the Proton Detector Times", page 35.

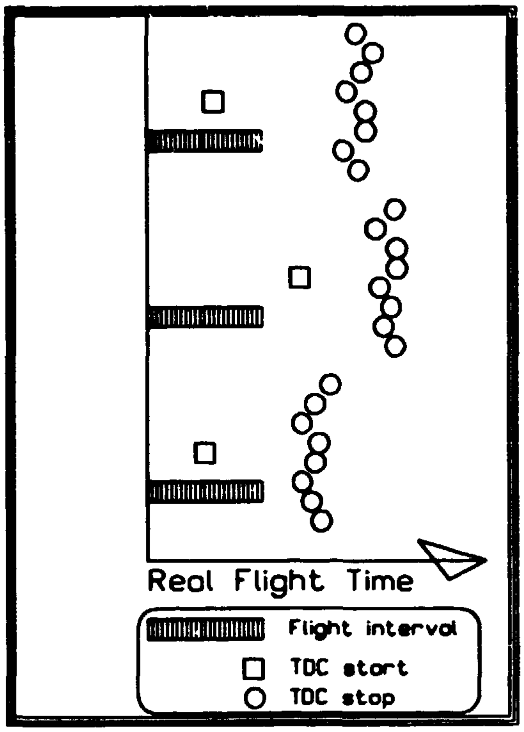

Fig.26. The Start and Stop Times in the Real Time Frame

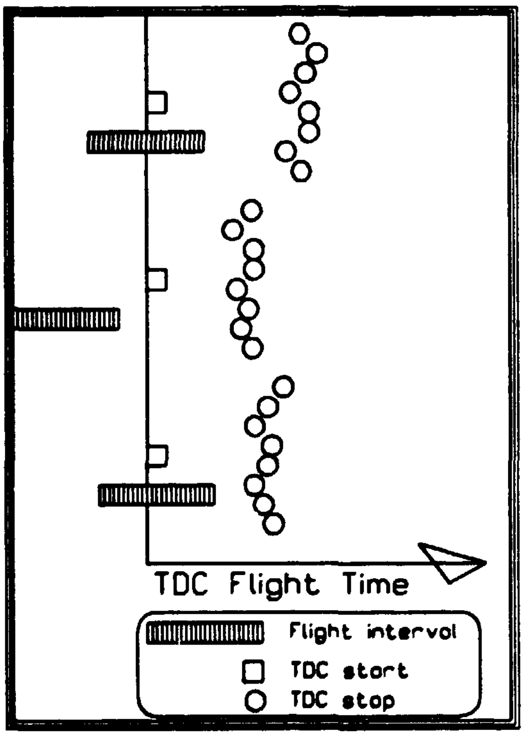

Fig.27. Start and Stop Times in the TDC Time Frame

The positions of the start and stop times in the real time frame are illustrated in figure 26. Only 8 of the 16 neutron detectors are shown in the figure. One case is illustrated for the three proton detector lines. The real start and stop time is the same for all the lines. The start times created by the proton detectors are scattered around. They are illustrated by boxes in the figure. To each proton detector time belongs 16 stop times. The delays are unique for each proton-neutron detector combination.

The TDCs do not know anything about the event before the arrival of the start pulse. Therefore, the positions of the real time-of-flight intervals appear at different positions in the TDC time frames. This is illustrated in figure 27. It is a picture of the times delivered by the system to the JPF data file.

The measured times include only a part of the time scale in the figure. Three factors decrease the time interval. The first is the maximum measurement time of the TDC. The second is the hardware gate set by the proton discriminator blocking signal and the third is the software time limits set by the parameters TLL and TUL [3].

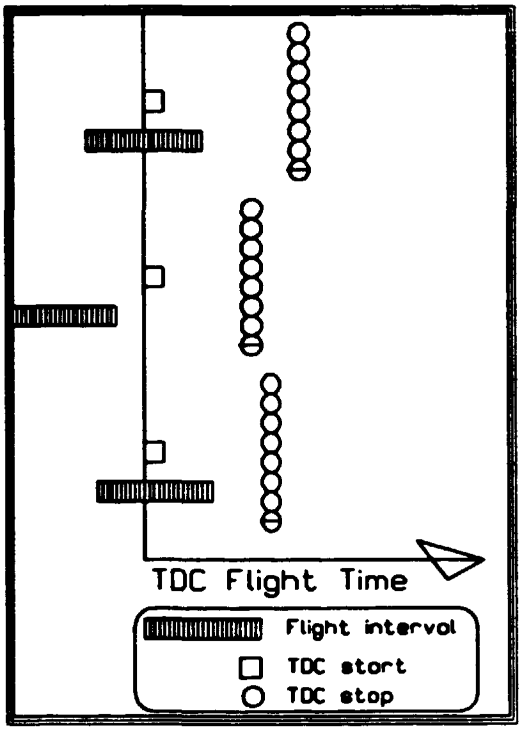

Fig.28. Calibration of the Neutron Detector Times

In the first step in the calibration we use the correlation method described above in order to place all the neutron detectors on a straight line. This is illustrated in figure 28. The neutron detector time used as a reference is marked with a bar. Normally detector number 0 is used for this purpose.

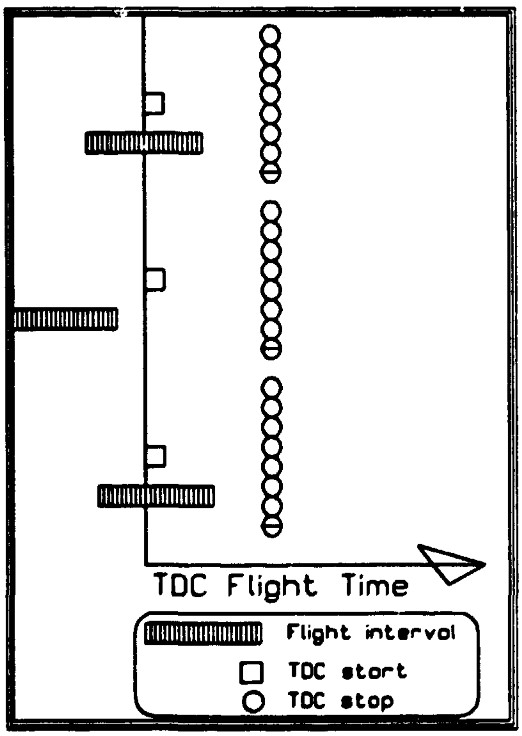

Fig.29. Calibration of the Proton Detector Times

It is possible to use the result of the cobalt measurement for another step in the calibration. The position of the reference detectors marked with a bar in the figures can be used to adjust all the neutron detector times and get a common time base for a complete branch. This is illustrated in figure 29.

The real flight time can now be found from the following equation:

$$T = T_{adj} + T_p + T_{p,n} \qquad (16)$$

where T_p is the calibration time for the proton detector line and $T_{p,n}$ is the calibration time for the neutron detector in that line. T_{adj} is a final adjustment calibration time. Although the cobalt calibration can give a guidance for this adjustment time common to the whole branch, it is not possible to get a reliable value of acceptable accuracy. Another method must be used. This is a part of the evaluation process and will be described in a document dealing with those topics [9]. T_{adj} may be included in T_p.

The values used during the laboratory tests are given in table 7 and table 8, page 36. T_p corresponds to the parameter PDT in the JPF data file and $T_{p,n}$ corresponds to NT0, NT1, and NT2.

Branch	T_{adj}	T_0	T_1	T_2
Unit	ns	ns	ns	ns
A	-20	02.00	06.64	02.68
B	-21	09.63	10.16	08.98

Table 7. Calibration Times used for the Proton Detector Lines during the Laboratory Tests

Detector #	Branch A			Branch B		
	$T_{0,n}$	$T_{1,n}$	$T_{2,n}$	$T_{0,n}$	$T_{1,n}$	$T_{2,n}$
Unit	ns	ns	ns	ns	ns	ns
00	30.00	30.00	30.47	70.00	65.00	65.00
01	32.58	32.34	33.44	69.92	65.31	66.09
02	33.05	34.06	34.22	70.47	66.09	66.95
03	33.83	34.84	35.08	72.03	67.34	68.20
04	32.89	34.37	36.02	70.94	67.66	67.73
05	32.50	32.89	35.16	70.16	66.02	67.42
06	33.20	37.66	35.16	74.38	71.09	70.86
07	33.98	37.03	35.55	69.84	66.33	66.48
08	32.42	33.44	35.00	78.91	75.86	76.17
09	32.97	34.61	35.47	73.75	69.84	70.00
10	30.86	32.19	33.67	75.47	71.80	72.19
11	30.94	31.72	32.73	71.17	67.58	67.97
12	31.09	32.34	33.44	75.39	71.09	71.72
13	35.55	37.03	36.88	76.56	72.50	72.42
14	33.28	35.31	34.77	76.02	72.81	73.75
15	32.97	33.83	34.06	74.69	70.86	71.56

Table 8. Neutron Detector Calibration Times Used During the Laboratory Tests

6. Run-Time Considerations

TANSY is a complex instrument and must be looked after during operation. As far as possible the instrument has been prepared for automatic operation routines. However, the calibrations must be checked from time to time in order to obtain reliable results.

The neutron detectors have been very stable during the laboratory tests. Small deviations of the calibrations give only a marginal influence on the final result. We suggest that the calibrations should be checked once every month at the beginning of the operation of TANSY. Experience will then show the necessity of changing this routine.

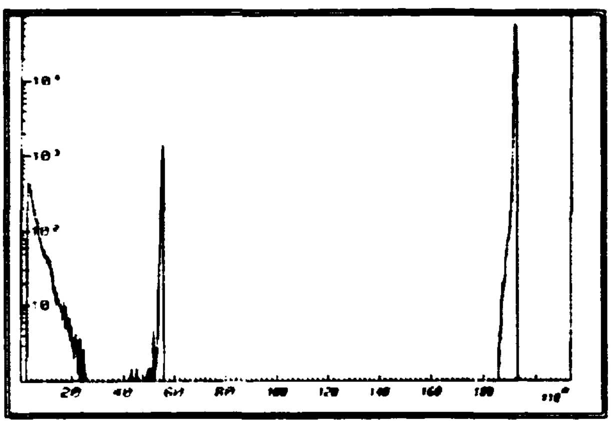

Fig.30. A Full Calibration Spectrum

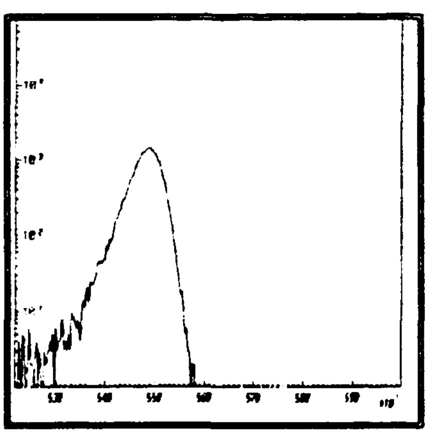

Fig.31. Americium Peak Calibration Window

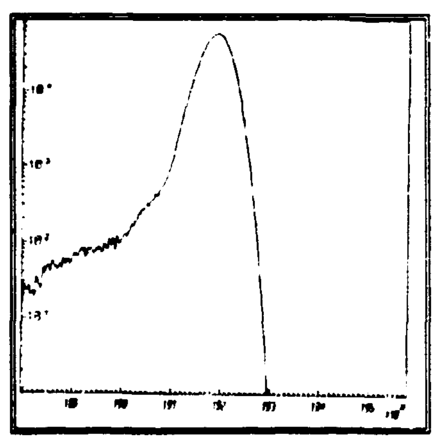

Fig.32. Pulse Generator Peak Calibration Window

The proton detectors will sooner or later be deteriorated because of radiation damage. The lifetime of one set of proton detectors has been estimated to one year for a normal operation of JET. However, this estimate is very uncertain. Therefore, the proton detectors should be checked at least once a day. Calibration data for the proton detectors are included in the JPF data file for energy calibrations. These data should also be used for checks of the detectors.

Figure 30 shows the full calibration spectrum from one of the test measurements. During the normal operation of TANSY only three parts are included in the JPF data file. Two parts were used during the test measurement. These are illustrated in figure 31 and 32. The peaks are used for an energy calibration during the evaluation process [9]. However, a special program should be included and run every day. The peak positions and the widths should be followed. An increased width of the americium peak indicates problems because of radiation damage.

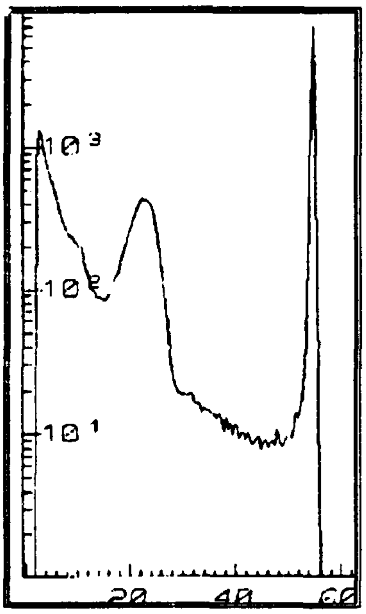

Fig.33. The Secondary Americium Peak

During the test period we used only one americium source. It could not be placed at the final position because a special shield had to be inserted for the protection of the proton detectors. Therefore, the above figures do not tell the full story.

One special run was done with two americium sources at the positions to be used at JET. One of the results is shown in figure 33. A second peak can be observed. It has a width of 485 keV FWHM and appears at 2.27 MeV. It is caused by those α-particles that penetrate the foil. The foil thickness was 0.95 mg/cm^2.

This peak may be used as a further check on the conditions in the vacuum vessel. Any failure of the foil should be detected because the energy loss of the α-particles depends on the foil thickness.

A good test of the proton detector condition is the magnitude of the leakage current. During the test period it was on the order of 5 μA. It can be read on the proton detector bias supplies. However, at JET it should be digitized and brought to e.g. the MIMIC.

Another quantity of interest is the vacuum. Arrangements have been done for a manual reading. Again, it would be valuable to have the information available in the control room.

References

1. Gudmar Grosshög, Dan Arorsson, 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, Magnus Hoek, Ryszard Rydz, Lennart Norberg, and Lasse Urholm, Technical Description of the Tansy Spectrometer, TANSY-KM5, Report **CTH-RF-81,** Chalmers University of Technology. 1991.

5. Dan Aronsson, Selection and Calibration of Proton Detectors for Use in the TANSY Neutron Spectrometer, Report **CTH-RF-73,** Chalmers University of Technology. 1990.

6. Krzysztof Drozdowicz, Remote Control of LeCroy HV4032/2132 High Voltage System, Report **CTH-RF-61,** Chalmers University of Technology. 1988.

7. Magnus Hoek, Krzysztof Drozdowicz, and Dan Aronsson, Method of Energy Calibration of the TANSY Neutron Detectors, Report **CTH-RF-68,** Chalmers University of Technology. 1990.

8. Krzysztof Drozdowicz, Magnus Hoek, and Dan Aronsson, Measurement for the Energy Calibration of the TANSY Neutron Detectors, Report **CTH-RF-72,** Chalmers University of Technology. 1990.

9. Gudmar Grosshög, Dan Aronsson, Magnus Hoek, Ryszard Rydz, Lennart Norberg, and Lasse Urholm, Control and Evaluation Programs for TANSY-KM5, Report **CTH-RF-85,** Chalmers University of Technology. 1991.