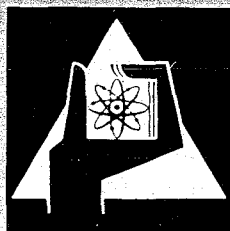# KERNFORSCHUNGSZENTRUM

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## On-Line Computer Systems for Experimental Nuclear Physics at Karlsruhe

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## Abstract

Characteristic features of two on-line systems namely a coupled
CDC 160 A-8090 computer system called MIDAS and a CDC 3100 system
are described. MIDAS in its present version is a data acquisition
and reduction system allowing on-line accumulation and totalizing
of 256 K channels on a disk and sequential accumulation on magnetic
tape. This system is shared by up to 10 experiments. For a typical
3-parameter experiment the handling of data will be discussed. The
CDC 3100 is used for cyclotron experiments. For this computer a
program controlled direct memory access for time-of-flight measure-
ments has been built. It allows 15 K totalizing with 100 K cycle
input rate. Electronical drifts are automatically controlled and
corrected. For 4 parameter (n,x)-experiments in the neutron energy
range 0.5 - 30 Mev with typical counting rates of 300 Hz the
computer identifies secondary particles reducing the number of
words to be stored.

Two on-line computer systems for experimental low-energy nuclear

physics are installed at Karlsruhe and have been working for

several years.

## 1. MIDAS

### a) Configuration

One system called MIDAS (Multiple Input Data Acquisition System) has been established to acquire and reduce the data of up to ten multiparameter experiments at the reactor FR 2. It was completed in several steps since the first approach in 1963 [1, 2]. At present, MIDAS 66 [3, 4, 5] is in operation.

As shown in Fig. 1, the center of this system is formed by the coupled CDC 160 A and CDC 8090 computers. Each processor has a memory of 8 K 12 bit words, 6.4 $\mu$sec cycle time. Both are coupled by a shared memory with 16 K (CDC 169), which can be addressed by each machine as a part of its internal memory. A channel-to-channel transfer of data is also possible. The system is equipped with an extended periphery consisting of two tape units, a disk storage, several display stations combined with command panels, a system and an input control, a real-time clock, and a multiplexer for ten input channels. The flow of data in the MIDAS system is demonstrated in Fig. 2. Data format at the input from the experiments is 20 or 38 bits. Including control bits this results in a 24 or 48 bit information for the system. Data format at the output is either i) a blocked sequential record of the data on tape, ii) a totalized record in the system or iii) a combination of both possibilities.

The disk is used as a storage for on-line totalizing up to 256 K channels with a length of 21 bits. This is done as follows. The disk is divided into 64 groups of 4 K each. The data are routed according to the upper 6 bits into one of 64 group buffers. If one of these buffers is filled with addresses, the corresponding group is read from the disk updated and rewritten on the disk. Precautions are taken to include the addresses which arrive during the read-in and updating time. In order to minimize the access time to the disk the most rapidly changing 3 lower bits at the channels are packed on the outer tracks. Overflows of

these bits are updated in another 6 bit subdivision of the channels. Finally the most significant 12 bits are handled in the same manner, thus resulting in a channel length of 21 bits.

The remaining capacity of the disk serves as a library of maintenance data and of experiment-oriented subroutines. Every experiment may have a set of such routines. One of them is loaded into the memory on the experimenter's command and is linked to the resident part of the operating system in order to control the handling and reduction of the experimenter's own data. 350 different commands are recognized by MIDAS, initializing, modifying, and stopping the flow of data and transferring them from one area to another. 10 K of the core storage are occupied by the operating system, 2 K by the experimenters' subroutines, 1 K by input buffers, 1 K by tape buffers, 4 K by the display array, 4 K by special purposes with high input rates and 10 K by the totalizing buffers.

Hardware buffering of the inputs allows instantaneous rates up to 800 kHz. The mean rate depends on what is to be done with the data. Sequential storage is limited by the speed of the tape ($\sim 10$ kHz 24 bits). On-line totalizing is restricted to 1200-500 counts/sec depending on the number of channels to be updated.

b)  Typical Procedure with MIDAS

Angular correlation measurements on $\gamma$-ray cascades following thermal neutron capture are picked out as an example of an experiment operated on-line to the computer.

A total of 68 K channels is available for this experiment and three subroutines are at the disposal of the experimenter. In the first subroutine the digital pulse height information is accumulated on the disk in a 256 x 256 channel matrix without any reduction. In addition, projection spectra are stored for

control purposes. Whenever the angle between the detectors is
changed, data are read out automatically on magnetic tape.
Further data processing is carried out on a large off-line
computer. Storage in full resolution allows the application
of a two-dimensional spectrum stripping procedure which has
been proven to be most suitable for off-line background elimina-
tion. Mostly, however, the double window technique has been
used. Sufficiently accurate results can be obtained easier and
faster. Fig. 3 demonstrates the application of the method. The
technique requires a second MIDAS subroutine. In order to reduce
data at an early stage of the measurement, digital windows are
set on the energy axes. The coincident pulses are routed into
subsections of the disk according to these window settings and
the angles defined by the detector positions. Thus, three-
dimensional measurements are possible. Window widths and posi-
tions can be fed into the computer on-line via punched paper
tape. Simultaneously, projection spectra are generated as in
subroutine one. The principal advantage of the digital gate
method of energy selection over conventional analog discrimina-
tion is due to the increased stability of the system, which is
important particularly if Ge(Li) detectors are used. Further
advantages are the simpler setting of the windows and the
possibility of easy control.
Each section or groups of sections of the disk can be displayed
during the measurements so that a full evaluation of the state
of the experiment is possible at any time. The presence of an
anisotropy is identified immediately (Fig. 4). The totalized
information can be dumped on magnetic tape or read out on
punched paper tape without interrupt of data accumulation.


c) Performance


Many efforts have been taken to make the system as reliable as
possible. The system control checks some basic functions of the
device. The stop of one processor, e.g., is signalled to the

other, or a missing reply of an external unit is generated in
an appropriate manner. In this case, the operating system tries
to connect another similar device or to reduce its task.
Experience has shown that an overload of the system is caused
usually by an unstable discriminator in one experiment. There-
fore, all counting rates are compared with preset limits and the
faulty experiment is disconnected.

The magnetic tape is used not only as a storage for all data
routed to it but also as a record of all relevant changes of
system's state. In addition, core and disk storage are dumped
automatically every four hours (check-point). After a possible
breakdown of the system, reading the last dump and including all
subsequent changes by a little program assure complete restora-
tion of the system without the presence of the experimenters and
with a minimum loss of good data.
MIDAS has run now for more than 28,000 hours for data acquisition
purposes. Though we do not call our maintenance during the night
time, an efficiency of more than 97 % was achieved in the past
two years.


2.  CDC 3100


The CDC 3100 On-line Computer System is used for neutron time-of-
flight experiments with the Karlsruhe Isochronous Cyclotron (the
block diagram of the on-line data acquisition system is shown in
Fig. 5). The cyclotron produces bursts of neutrons with instantaneous
neutron intensities of $6 \times 10^{17} - 6 \times 10^{18}$ n/sec at 20 - 200 kHz
repetition rate. The time-of-flight of neutrons over a 200 m light
path is measured in 1 nsec intervals from a few hundred nsec up to
about 25 $\mu$sec. The events due to neutron interactions in liquid
scintillators used appear in bursts so that the instantaneous rate
of time-of-flight events is up to 6 MHz at which the data acquisi-
tion system may accept data words. Thus, a four-word fast buffer

derandomizer memory is installed to regulate the flow of data. For randomly distributed detector pulses the dead time of the total system is about 50 nsec at present. Data are processed by a CDC-3100 central unit with a 16 K word memory, 24 bits per word and 1.8 $\mu$sec cycle time. For on-line work the unit has 1 direct memory channel and 4 communication channels (two are to be coupled in the 24 bit mode) with 32 external interrupts. The direct memory channel is used for the program controlled direct access input of experimental data. Two tapes, a disk, command and display units, and the paper tape read and punch unit are connected to one channel. Another channel is still free and reserved for intercommunication with central computers. For real time operations, a specialized operating system is available which allows the use of the machine in the time-shared mode by up to 8 experiments. The complete data acquisition system is fully operational and has been used for about two years with the exception of the direct memory channel.

The direct memory channel designed by us allows high input speed and maximum channel operation. Typically, 15,000 time channels can be used from a total of 16,383 with a maximum of more than $10^5$ events per sec (time averaged). As shown in Fig. 6 this system can also execute a number of on-line operations, such as spectrum compatibilization, peak stabilization and automatic regulation of the cycle time during measurements for sample "in" and sample "out" and excerts a great deal of on-line control of the overall reliability of the time-of-flight apparatus.

Another application of the data acquisition system is for the measurement of the neutron induced reactions generating charged particles. In these experiments four parameters are registered:

1) E -information      10 bits
2) dE-information      9 bits
3) time of flight      9 bits
4) angular position    4 bits

The data acquisition system is used for on-line operations on the four parameter informations, such as particle identification and time-of-flight correction etc., and for storage of the reduced data. Summing up of the data will be done off-line because of the large multiplicity of parameter combinations.

For particle identification one needs the total energy E as well as the energy loss of the corresponding particle dE passing through the semiconductor detector of a counter telescope. Fig. 7 shows one method of displaying the data. The axes represent the total energy E and the energy loss dE. The straight line on the left represents particles that stop within the thin detector while the curves represent protons, deuterons, tritons, alphas, and He 6 nuclei, respectively. Data reduction is done on-line as follows. Over a large energy region the particle range is proportional to $(E - 2 \text{ Mev})^{1.75}$. Taking the difference $D = (E_{total} - 2 \text{ Mev})^{1.75} - (E_{total} - dE - 2 \text{ Mev})^{1.75}$ and comparing D with specific limits for each type of particle the dE information is reduced to only one identification number for each kind of particle. Elimination of the dE parameter by using the product dE x E is not sufficient because of a large loss of mass resolution.

Fig. 8 indicates what can be obtained with the method mentioned above. It is a plot of the intensity of charged particles versus the square root of D for particle energies between 4 and 40 Mev from the (n, charged particle) reactions on $Be^9$. The five well separated peaks are due to protons, deuterons, tritons, alphas, and He 6 nuclei generated by neutrons of energies between 8 and 35 Mev.

A second on-line operation done in this experiment is the evaluation of the neutron time of flight. The measured time is the difference between the time of generation of the neutrons and the time of registration of the charged particles in the detectors. This time is to be corrected by the on-line calculated time of flight of the charged particles from the target to the detector.

Another on-line operation is the correction of the particle
energies due to the energy loss within the target of a finite
thickness.


3. **Aspects**

In order to overcome the exponentially increasing demands for
data acquisition and processing at the Karlsruhe Center, new
efforts are needed. MIDAS, e.g., is a very comfortable but
early approach of data acquisition. It is loaded to capacity
by existing experiments. Therefore, two new systems are being
installed, both of them incorporating TELEFUNKEN TR 86 A
computers. One of them handles scaler oriented data in reactor
science and chemistry (gas chromatography, mass spectrometry),
the other is to process event oriented nuclear experiments.
At the moment, the first one is used for both lines of appli-
cation.
Another approach is the development of a computer network ordered
in a hierarchy including a IBM 360/91 located at Munich. The
main purposes of this system are i) backing up small computers
with the computing power and mass storage facilities of the
central general purpose machines ii) speeding up the turn
around time between data acquisition and their evaluation.
The computer network is now under construction and will come
in operation in 1969/70.

## References

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        On-Line Computer, Proc. EANDC Conf. on Automatic Acquisi-
        tion and Reduction of Nuclear Data, Karlsruhe 1964, p. 149

/ 2 /   DIMMLER, G. and KRÜGER, G.:
        A Display System for Use with an On-Line Computer, ibd.p. 393

/ 3 /   KRÜGER, G.:
        Ein Doppelcomputersystem zur integrierten Datenverarbeitung
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        durch ein Vielfachzugriffssystem, Proc. on Teilnehmer-
        Rechensysteme, Oldenbourg Verlag Munich and Vienna (1968)
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        MESPRØ 66, Internal report Karlsruhe 1968

Figure captions

Fig. 1    Configuration of MIDAS 66

Fig. 2    Flow of data through MIDAS 66

Fig. 3    Application of the double window technique for background
          elimination using a Ge(Li)-NaI(Tl) coincidence apparatus.
          Neutron capture $\gamma$-radiation from the reaction $^{57}$Fe(n,$\gamma$)$^{58}$Fe.
          Settings of the digital windows on the NaI(Tl)-detector
          spectrum are shown in the insert. The coincidence spectra
          taken with the Ge(Li)-detector correspond to the following
          energies of photopeak pulses in the windows (from above):
          810 + 864 kev, 810 kev, 864 kev.

Fig. 4    Angular correlation of the 850 - 778 kev $\gamma$-ray cascade from
          the reaction $^{96}$Mo(n,$\gamma$)$^{96}$Mo displayed on CRT. NaI(Tl)-
          detector spectra taken at $90^\circ$, $120^\circ$, $150^\circ$, $180^\circ$, $210^\circ$,
          $240^\circ$ and $270^\circ$. Digital window settings in the spectrum
          of the second detector at 850 kev. Part of the $^{96}$Mo decay
          scheme is shown in the insert.

Fig. 5    Data Acquisition System at Isochronous Cyclotron

Fig. 6    Simplified flowchart for the direct access mode of the
          CDC 3100

Fig. 7    Particle identification in Be$^9$(n,x) reactions, schematic
          drawing of the total energy range in the insert

Fig. 8    Data reduction according to different kinds of particles
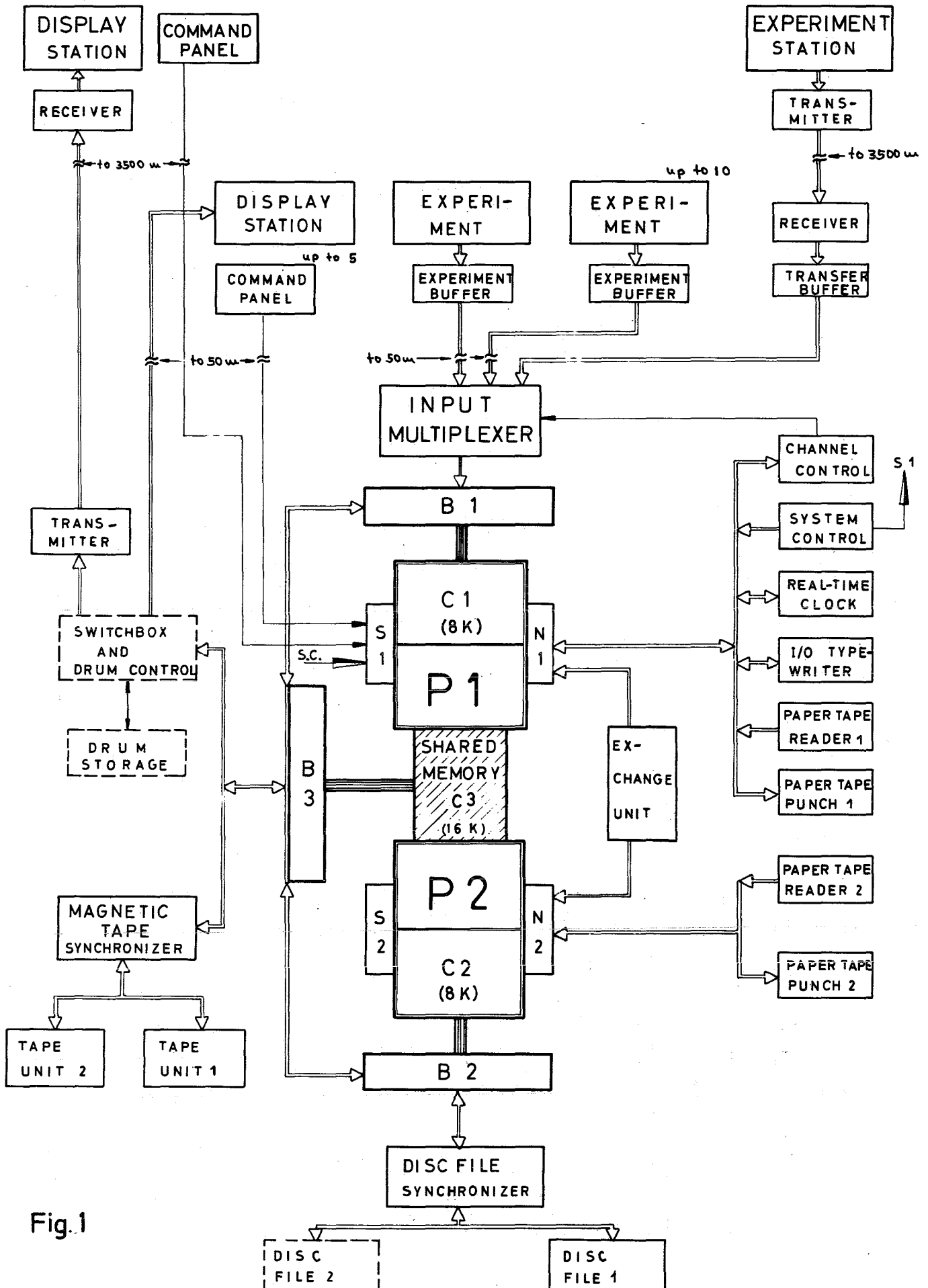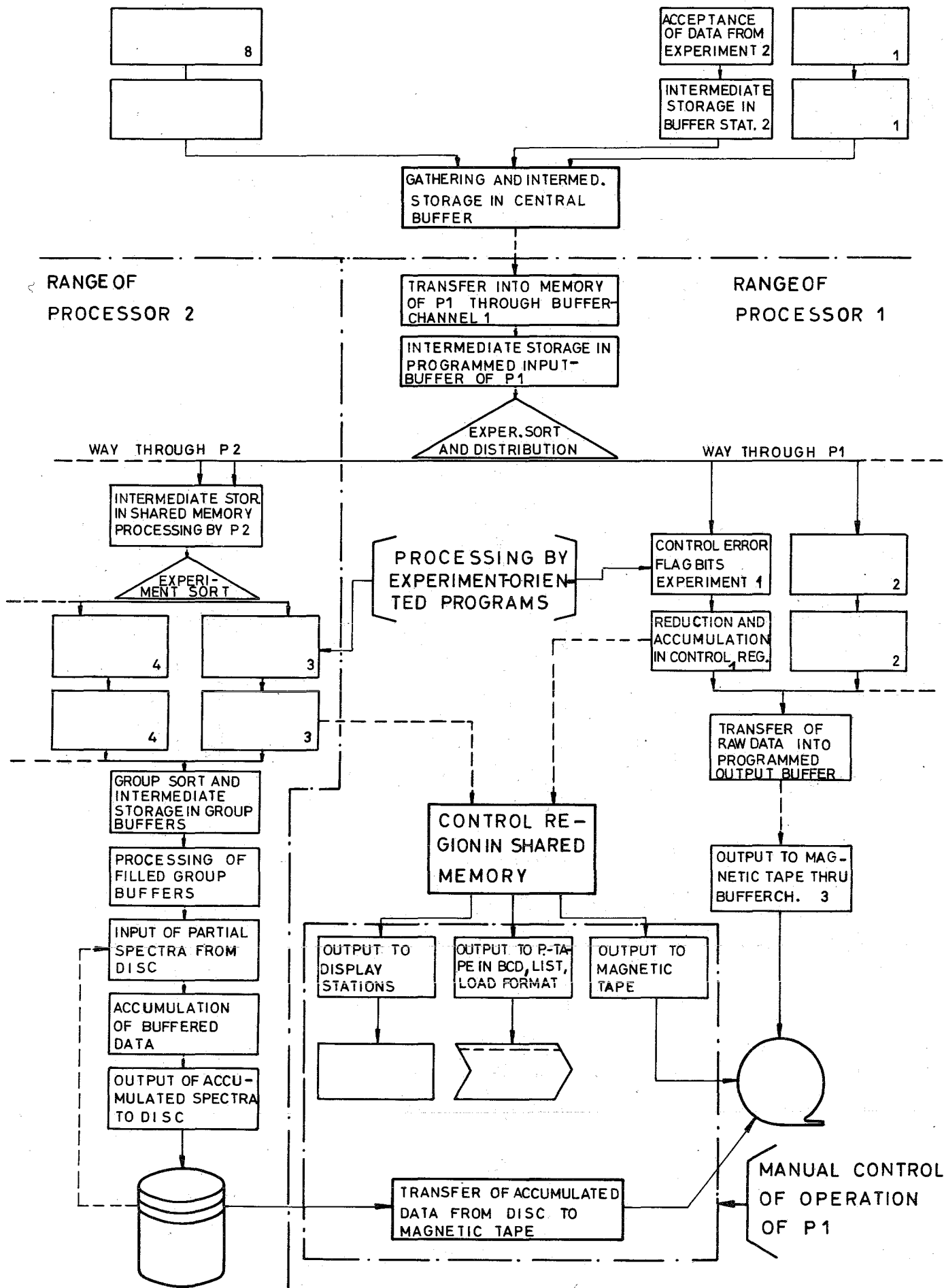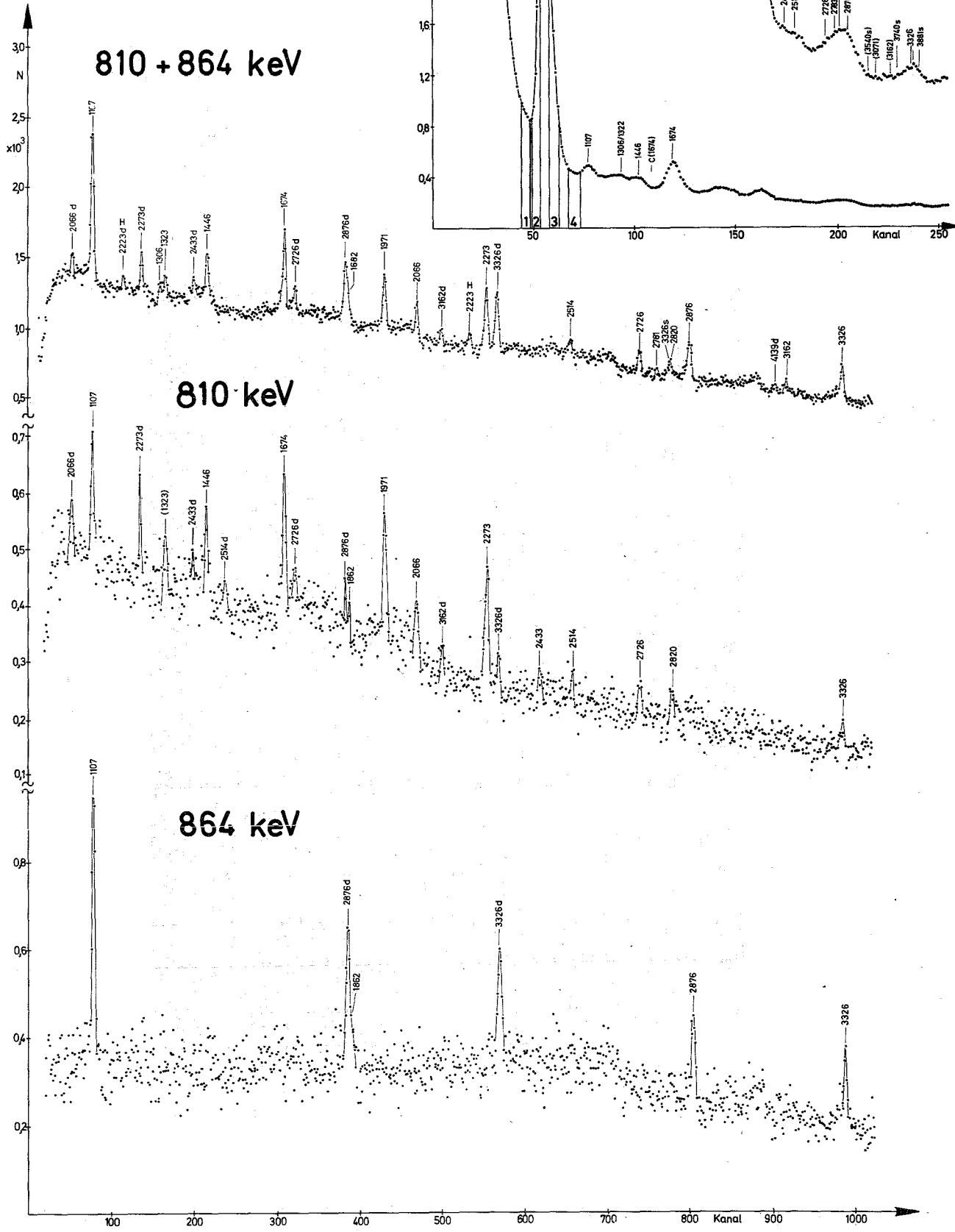          with energies between 4 - 30 Mev

Fig.1

**Fig. 2**

The diagram contains the following labeled blocks:

Top right:
- ACCEPTANCE OF DATA FROM EXPERIMENT 2
- INTERMEDIATE STORAGE IN BUFFER STAT. 2
- (box labeled 1)
- (box labeled 1)

Top left:
- (box labeled 8)

Center top:
- GATHERING AND INTERMED. STORAGE IN CENTRAL BUFFER

**RANGE OF PROCESSOR 2** | **RANGE OF PROCESSOR 1**

- TRANSFER INTO MEMORY OF P1 THROUGH BUFFER-CHANNEL 1
- INTERMEDIATE STORAGE IN PROGRAMMED INPUT-BUFFER OF P1
- EXPER. SORT AND DISTRIBUTION

WAY THROUGH P 2 | WAY THROUGH P1

- INTERMEDIATE STOR. IN SHARED MEMORY PROCESSING BY P2
- EXPERIMENT SORT
- (box labeled 4)
- (box labeled 3)
- (box labeled 4)
- (box labeled 3)

- PROCESSING BY EXPERIMENT-ORIENTED PROGRAMS

- CONTROL ERROR FLAG BITS EXPERIMENT 1
- (box labeled 2)
- REDUCTION AND ACCUMULATION IN CONTROL REG.
- (box labeled 2)

- GROUP SORT AND INTERMEDIATE STORAGE IN GROUP BUFFERS
- PROCESSING OF FILLED GROUP BUFFERS
- INPUT OF PARTIAL SPECTRA FROM DISC
- ACCUMULATION OF BUFFERED DATA
- OUTPUT OF ACCUMULATED SPECTRA TO DISC

- CONTROL REGION IN SHARED MEMORY

- TRANSFER OF RAW DATA INTO PROGRAMMED OUTPUT BUFFER
- OUTPUT TO MAGNETIC TAPE THRU BUFFERCH. 3

- OUTPUT TO DISPLAY STATIONS
- OUTPUT TO P-TAPE IN BCD, LIST, LOAD FORMAT
- OUTPUT TO MAGNETIC TAPE

- TRANSFER OF ACCUMULATED DATA FROM DISC TO MAGNETIC TAPE

**MANUAL CONTROL OF OPERATION OF P1**
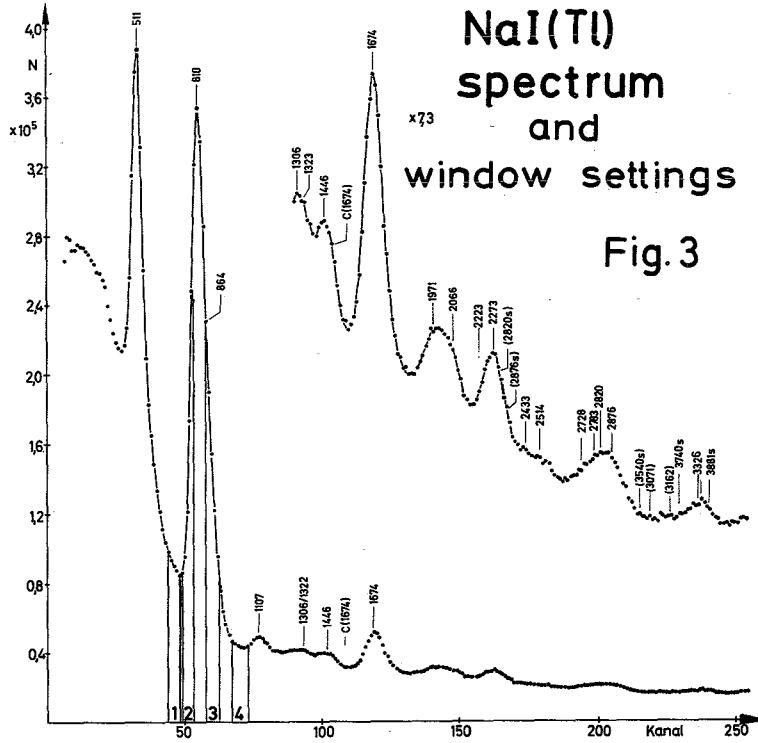
$^{57}Fe(n,\gamma)^{58}Fe$
Ge(Li) spectra
concident with

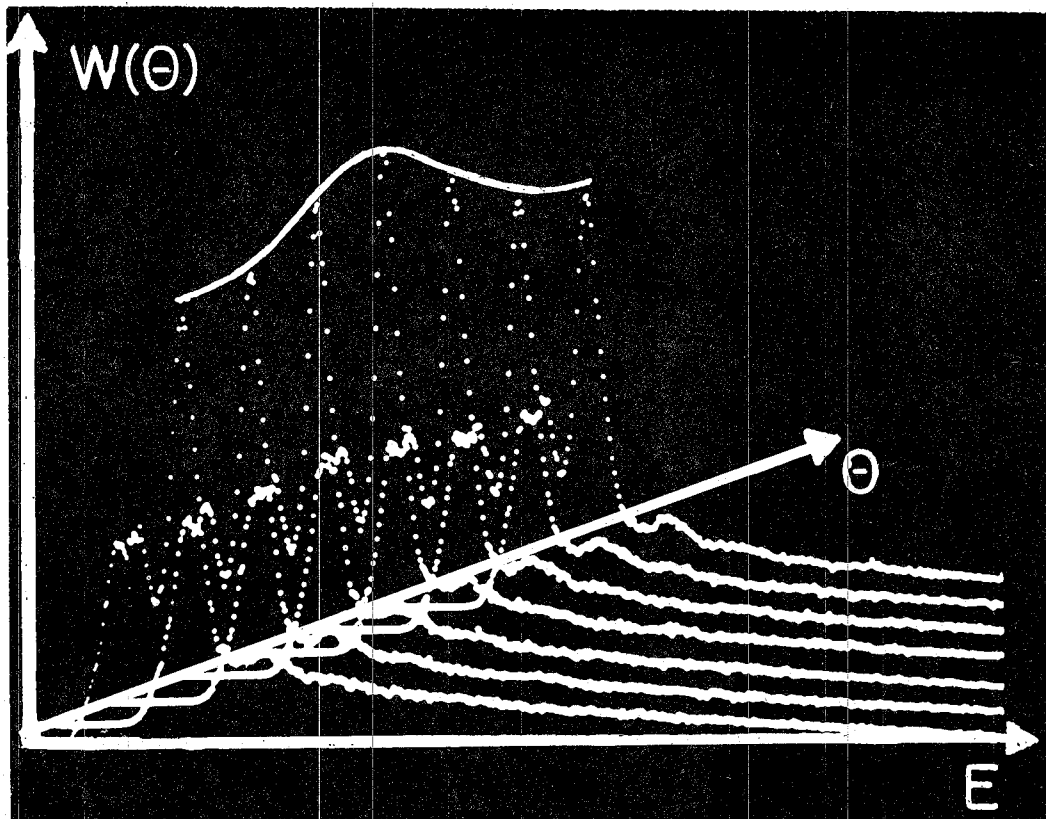810 + 864 keV
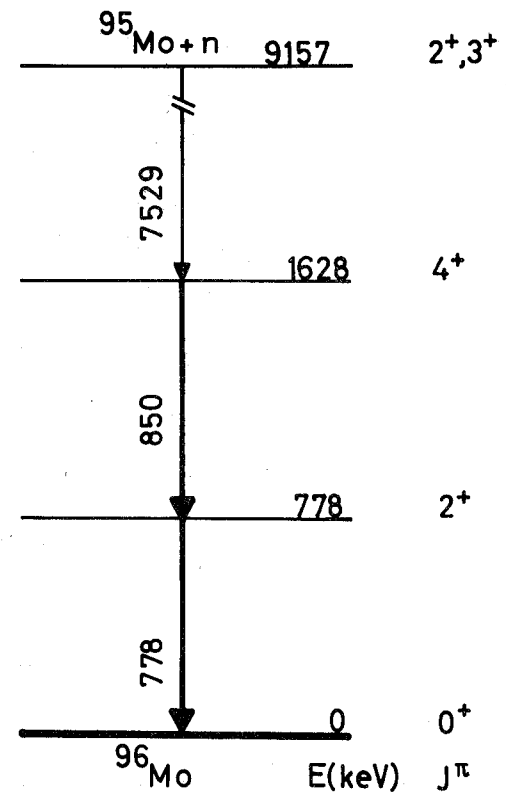
NaI(Tl)
spectrum
and
window settings

Fig. 3

810 keV

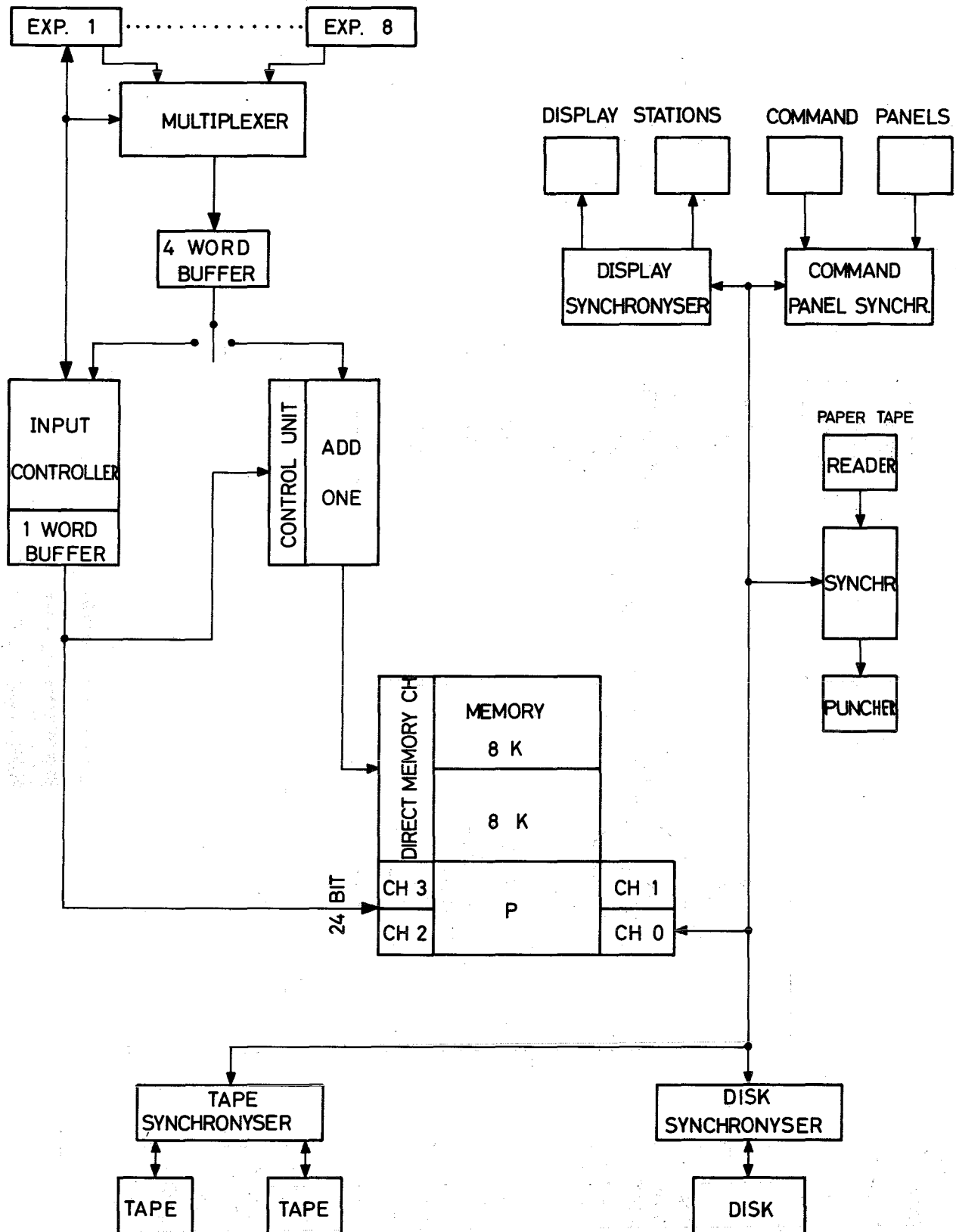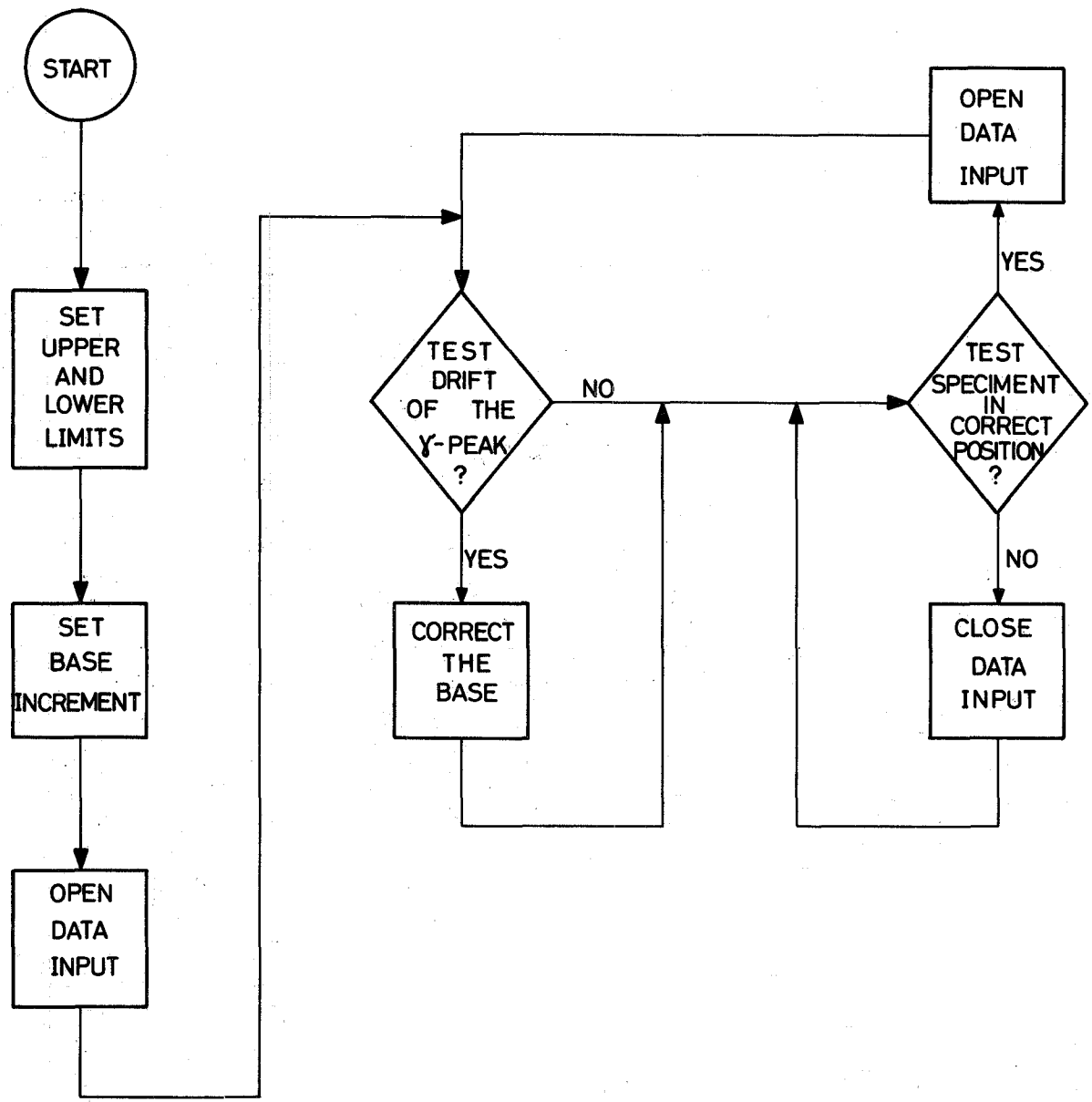864 keV

Fig. 4

Fig.5 DATA ACQUISITION AT THE ISOCHRONOUS CYCLOTRON
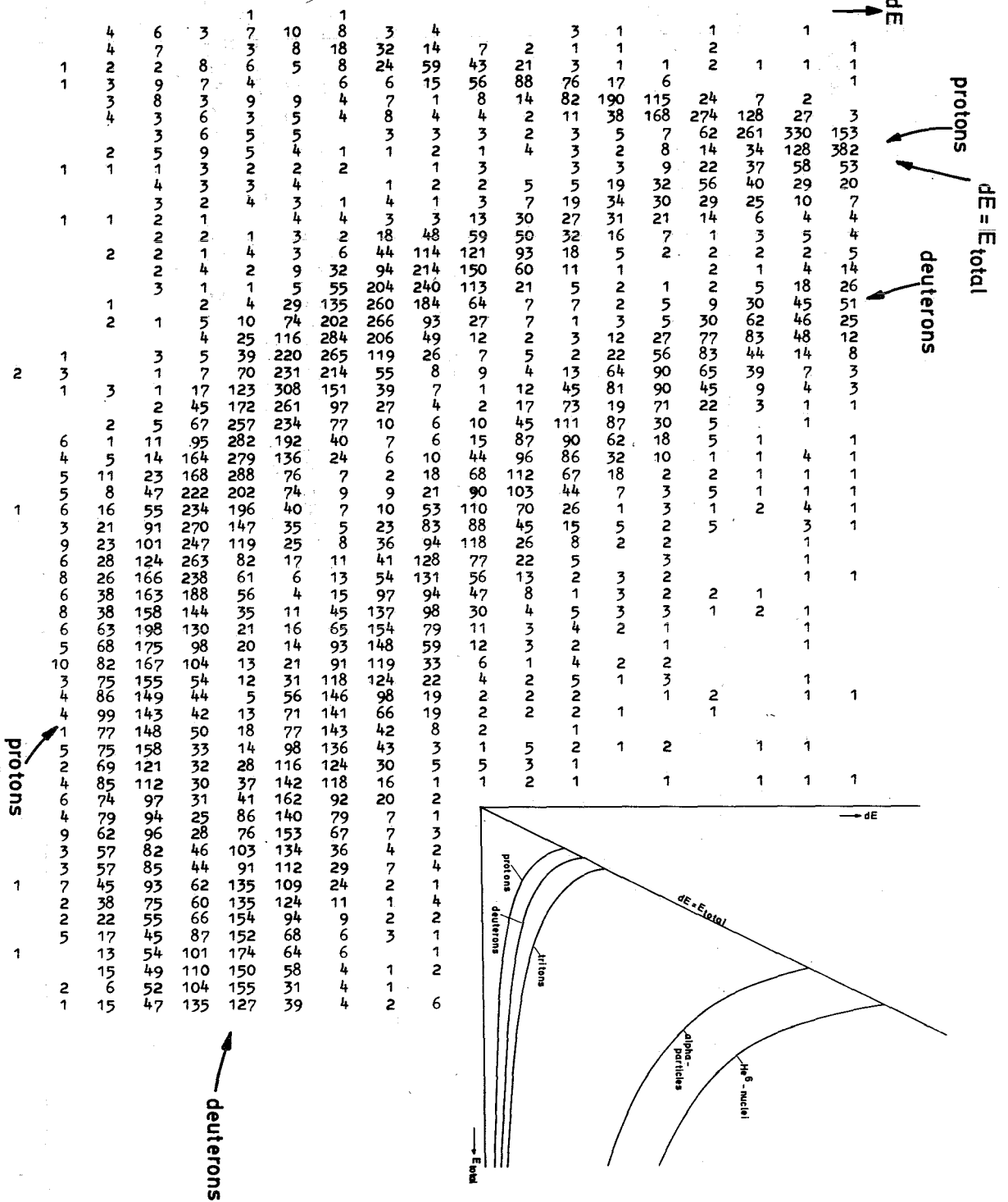
Fig.6   SIMPLIFIED   FLOWCHART FOR THE PROGRAM  CONTROLLED    DIRECT   ACCES   MODE   OF   THE    CDC 3100
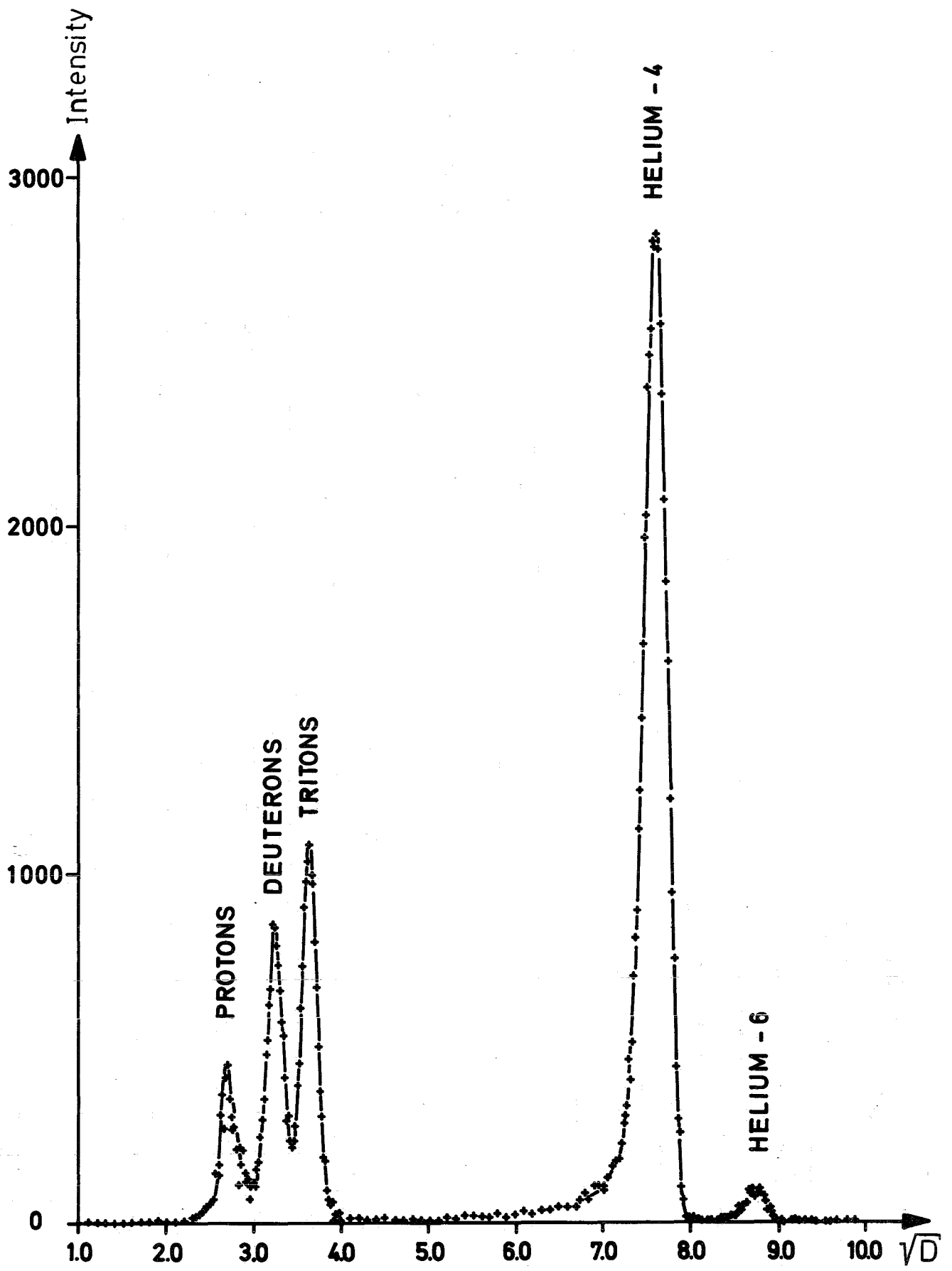
Fig. 7

dE

dE = E total

protons

deuterons

protons

deuterons

E total

(inset diagram labels: dE; dE = E total; protons; deuterons; tritons; alpha-particles; He6-nuclei; E total)

Fig. 8