JAERI-M
6258

SDG-75016

PROGRESS REPORT
SEMICONDUCTOR DETECTOR GROUP

April 1, 1974 to March 31, 1975

September 1975

E. SAKAI, H. TERADA, M. KATAGIRI and H. ITOH

日本原子力研究所
Japan Atomic Energy Research Institute

JAERI-M 6258 SDG-75016

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April 1, 1974 to March 31, 1975

Eiji SAKAI, Hiromi TERADA, Masaki KATAGIRI, and Hiroshi ITOH

Division of Reactor Engineering, Tokai, JAERI

(Received September 9, 1975)

This report is an annual progress report of Semiconductor Detector Group and describes the work made during one year between April 1, 1974 and March 31, 1975. The related themes to the Group were " semiconductor detector development and application " and " fuel failure detector sodium in-pile loop test (III)(a contract study between Power Reactor and Nuclear Fuel Development Corporation and J.A.E.R.I.) ".

This includes a brief description of the results obtained in the following studies; portable Ge(Li) gamma-ray spectrometer fabrication,its application to gamma-ray spectrometry in Japan Research Reactor No.3 and to in-situ measurement of environmental gamma-rays, temperature cycling test of a hyperpure germanium detector, silicon detector fabrication by N^+ion implantation, PDP-8/L program development for an ND-50/50 multichannel analyser, X-ray spectrometry of Japan Fusion Tokamak No.2 plasma using a Si(Li) detector, sodium in-pile loop test of four types of fuel failure detection systems, and various kinds of technical service. The publications and lectures made in this period are also listed.

JAERI-M 6258　　SDG-75016

半導体検出器グループ・プログレス・レポート
（昭和49年4月1日～昭和50年3月31日）

日本原子力研究所東海研究所原子炉工学部
阪井英次・寺田博海・片桐政樹・伊藤　浩

（1975年9月9日受理）

本報告は，昭和49年4月1日から50年3月31日の1年間に原子炉計測研究室の半導体検出器グループが行なった研究のプログレス・レポートである。

可搬型 Ge（Li）ガンマ線スペクトロメータ試作，それを用いたJRR-3原子炉におけるガンマ線スペクトル測定，環境ガンマ線スペクトルの野外測定，高純度Ge検出器の温度サイクル試験，イオン注入によるシリコン検出器の試作，放射線データ処理装置ND－50／50用プログラム作成，Si（Li）検出器によるJFT-2プラズマからのX線スペクトルの測定，燃料破損検出装置のナトリウム・インパイル・ループ試験，各種技術サービスなどが主な内容である。この期間における論文，口答発表のリストを附した。

JAERI-M 6258 SDG-75016

PROGRESS REPORT - SEMICONDUCTOR DETECTOR GROUP
April 1, 1974 to March 31, 1975

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1. Summary

This report is an annual progress report of Semiconductor Detector Group and describes the work carried out during one year between April 1, 1974 and March 31, 1975. The related themes to the Group were " semiconductor detector development and application(# 437-01(2)) " and " F.F.D. sodium in-pile loop test (III) (contract study between Power Reactor and Nuclear Fuel Development Corporation and J.A.E.R.I.)!'

A brief description of the study is as follows:

1. A coaxial Ge(Li)detector having 33.4cm^3 sensitive volume and a closed-end coaxial Ge(Li)detector of 73cm^3 were fabricated and mounted in common-vacuum type cryostats of 7.5 liter liquid nitrogen, horizontally and vertically downward, respectively. The portable Ge(Li) spectrometers weighed 11Kg and their performance was measured.
2. Using those portable spectrometers, gamma-ray spectrometry at Japan Research Reactor No.3 and in-situ environmental gamma-ray spectrometry have been carried out.
3. A hyper-pure germanium detector manufactured by NRD was tested during temperature cycles between room temperature and 77K. It showed a stable performance.
4. Making of p-n junction type silicon detectors has been attempted by implanting N$^+$ions onto p-type silicon wafers.
5. Ge(Li)detector gamma-ray analysing programs have been developed using a PDP-8/L minicomputer combined with an ND-50/50 multichannel analyser.
6. X-ray spectra from plasma in JFT-2 have been measured using a Si(Li) spectrometer to deduce electron temperatures of the plasma.
7. A contract study " F.F.D. sodium in-pile loop test (III) " was carried out.
8. Some of the technical service made in this period were Ge(Li)detector repair, lending-out of a Ge(Li)detector, translation of IEC Publication 430 into Japanese, revising of terminology related to nuclear radiation research as a member of Working Committee of the Institute of Electrical Engineers of Japan, lectures at Reactor Engineering School and Radioisotope School.
9. During this period, one article in a journal, three JAERI-M reports, one JAERI-memo, and one text were published. Three oral presentations were also made.

In the following text, you may find that some sections were described roughly while the others in detail. The sections roughly described relate to the studies already published. Please consult with the publications listed in the last section when you need more information.

2. Staff

Professional Staff	Technical Staff
Eiji SAKAI	Hiroshi ITOH (2)
Hiromi TERADA (1)	
Masaki KATAGIRI	

Visitor

Seishiro SUZUKI (3)

Research Consultant

Yasukazu YOSHIZAWA (4)

(1) Transferred from Division of JMTR Project, Oarai Research Establishment, JAERI, on May 1, 1974

(2) Transferred temporarily to JPDR Project, Tokai Research Establishment, JAERI, from February 17, 1975

(3) September 6 to 27, 1974, as a student of Reactor Engineering School, JAERI; on leave from Japan Atomic Power Company, Tokaimura, Nakagun, Ibarakiken, Japan

(4) Professor of Low Energy Nuclear Physics, Faculty of Science, Hiroshima University, Higashi-senda-cho, Hiroshima, Japan

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3. Research and Development

3.1 Portable Ge(Li)gamma-ray spectrometer fabrication (E.Sakai, M.Katagiri, H.Terada, and H.Itoh)

Almost of all Ge(Li)detectors usually have liquid nitrogen dewars of about 30 liters to hold liquid nitrogen as long as possible; therefore, they are large, heavy, and sometimes inconvenient for use in the experiments in which mobility is very important. The need of small, light portable Ge(Li)detectors is increasing, especially in field applications such as safeguards measurements and environmental gamma-ray spectrometry. We fabricated and tested portable Ge(Li)spectrometers of smaller dewars of liquid nitrogen.

The first portable Ge(Li)spectrometer made use of a 7.5liter dewar (Cryogenic Associates SD-170J) from which a cold finger extended horizontally[L-1). An aluminum end-cap and a ring for fitting a preamplifier and a high voltage filter were designed. A coaxial Ge(Li)detector having 33.4cm^{3}sensitive volume was made by drifting a 2.85cm long Hoboken crystal of 4.0cm diameter. Figure 3.1.1 shows the construction of the detector. The spectrometer including the cryostat, 7.5liters of liquid nitrogen, a preamplifier Ortec 120-4F, and a high voltage filter Ortec 119B weighs only 11Kg. The consumption rate of liquid nitrogen was 1.05liters/day in an air-conditioned room, and 1.5liters/day in the outdoors, as shown in Fig.3.1.2. Liquid nitrogen was filled every four days for extra safety. As an electronics system, an Ortec 452 Spectroscopy Amplifier and an Ortec 459 Bias Voltage Supply put in a Minibin Ortec 401M/402M were used. The output of the Amplifier was connected to a multichannel analyser using a long cable.

The absolute peak detection efficiency for 1333keV gamma-rays measured at a source-to-detector distance of 25cm was 3.12×10^{-5}which corresponded to 2.6 % relative to that of 3" x 3" NaI(Tl)detector when 1200V was applied. The energy resolution was 3.5keV. This spectrometer was used in the measurement of gamma-ray spectra in the Japan Research Reactor No.3 (see Section 3.2) and in the in-situ environmental gamma-ray spectrometry (Section 3.3). It was also used in the neutron energy spectrum measurement based on Ag(n,n') reaction in Japan Material Testing Reactor Critical Facility (Section 3.10.2).

The spectrometer was assembled in June 1974 and used in the outdoors during the rainy season of June and July. The 7pin hermetic seal for connecting the detector signal lead to the preamplifier input (see Fig.3.1.1) was found to become wet with high humidity; one pin connected to the cold finger ground using a thick, short copper wire become cold enough to condense humidity. To avoid the

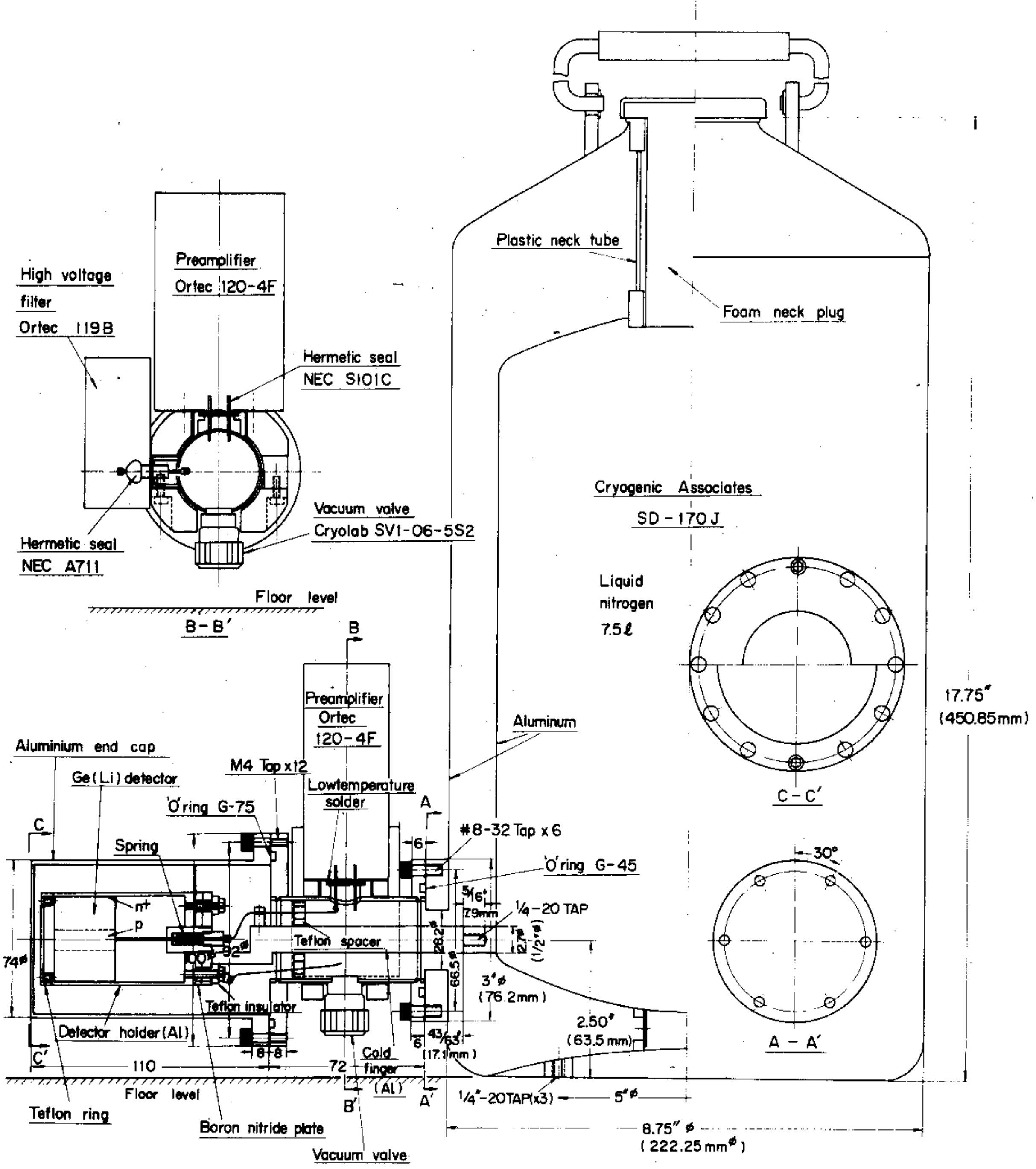

Fig.3.1.1 Portable Ge (Li) detector assembly

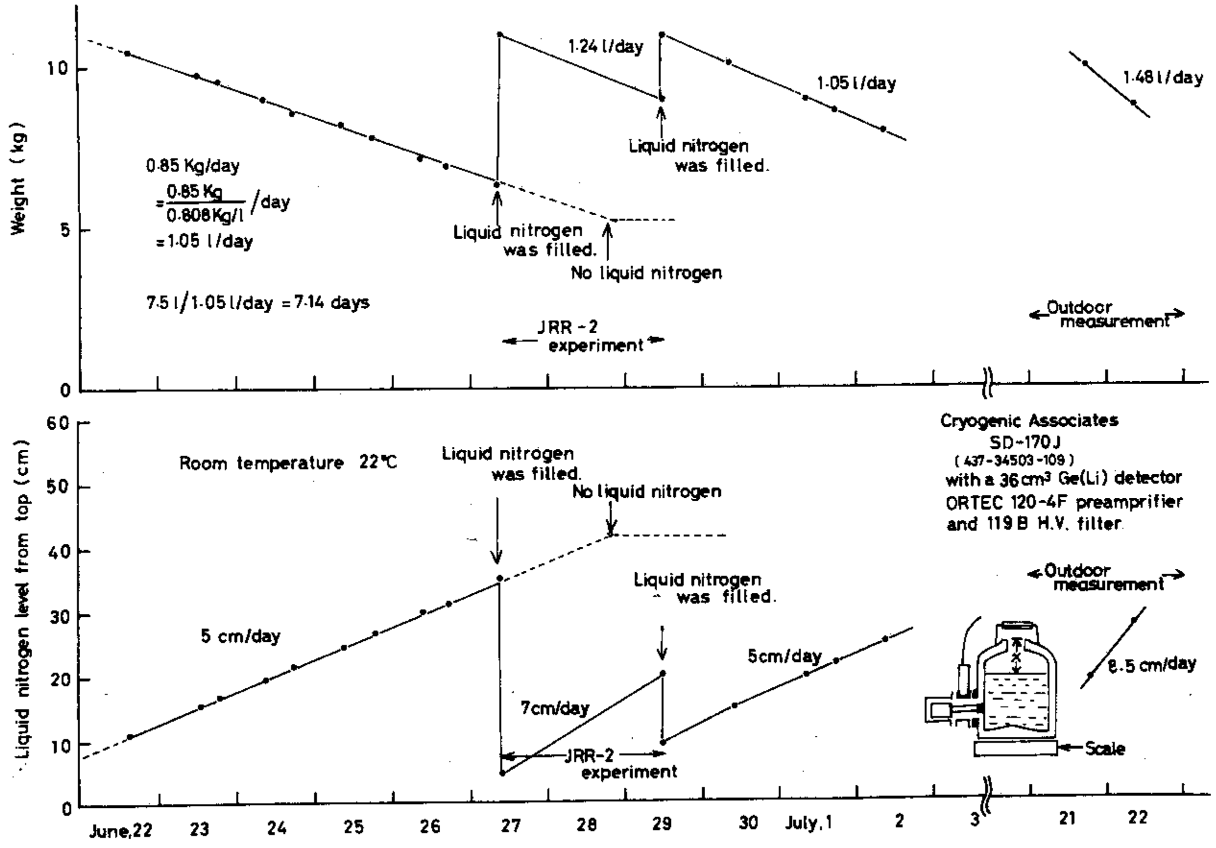

Fig.3.1.2 Liquid nitrogen consumption of cryostat with 33.4 cm³ Ge(Li)detector and preamplifier

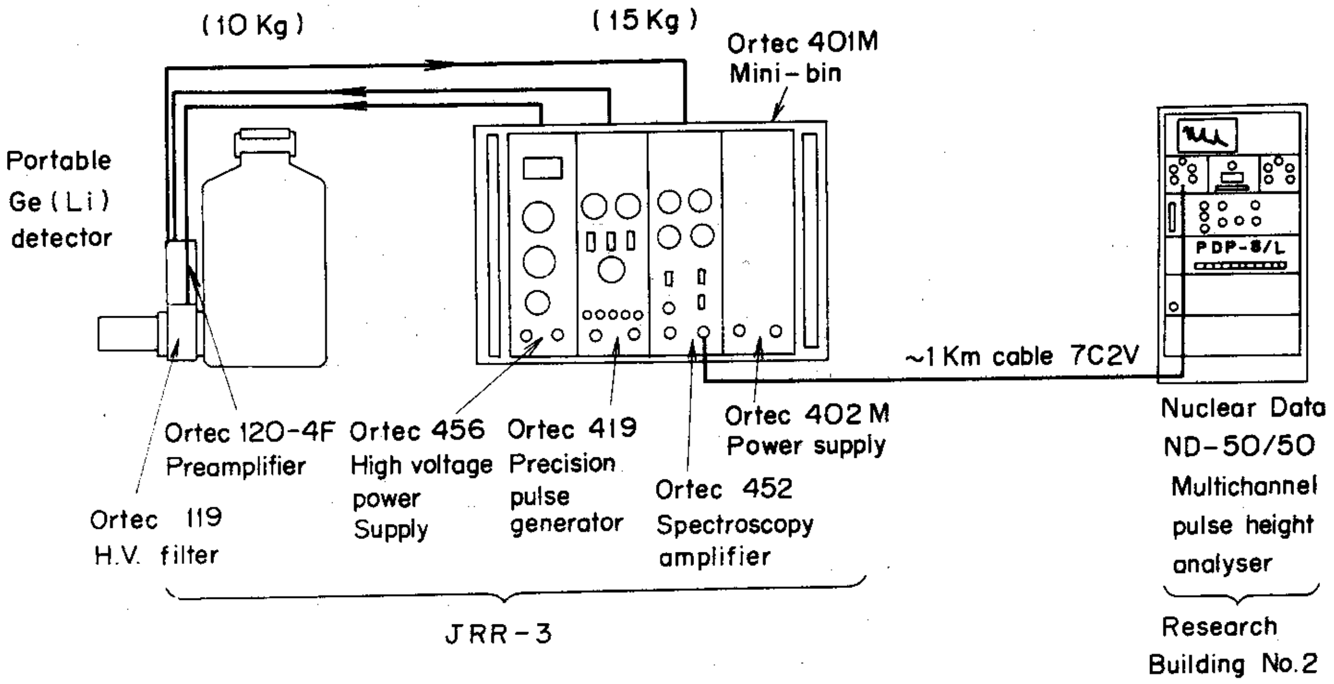

Fig.3.1.3 Schematic diagram of portable Ge(Li) detector system

condensation, silica gel was enclosed in the preamplifier case. The leakage current of the detector started to increase in December and the spectrometer was disassembled to etch and to clean up the detector. The thick copper wire between the hermetic seal and the cold finger was replaced with a thin manganese wire. As a result, humidity condensing problem was solved. The detector performance was improved to 2.1keV energy resolution and 6.4% peak detection efficiency for 1333keV gamma-rays when 4000V was applied. In February 1975, the leakage current started to increase again and only 1700V could be applied. The reason of the increase in leakage current is not clear.

The second portable Ge(Li)gamma-ray spectrometer as shown in Fig.3.1.4 was primarily designed for in-situ measurement of environmental gamma-rays. The cryostat has a 7.5liter liquid nitrogen dewar (Cryogenic Associates SD-170J) with a cold finger vertically extended downward. A tripod was used to support the center of the detector at one meter height from the ground. A 44.5mm long germanium crystal of 48mm diameter was lithium-drifted to make a closed-end coaxial Ge(Li)detector; the detector has 73.2cm^3 sensitive volume calculated from the observed diameter of the p-core, 12.2mm. The detail of the detector mounting is shown in Fig.3.1.5.

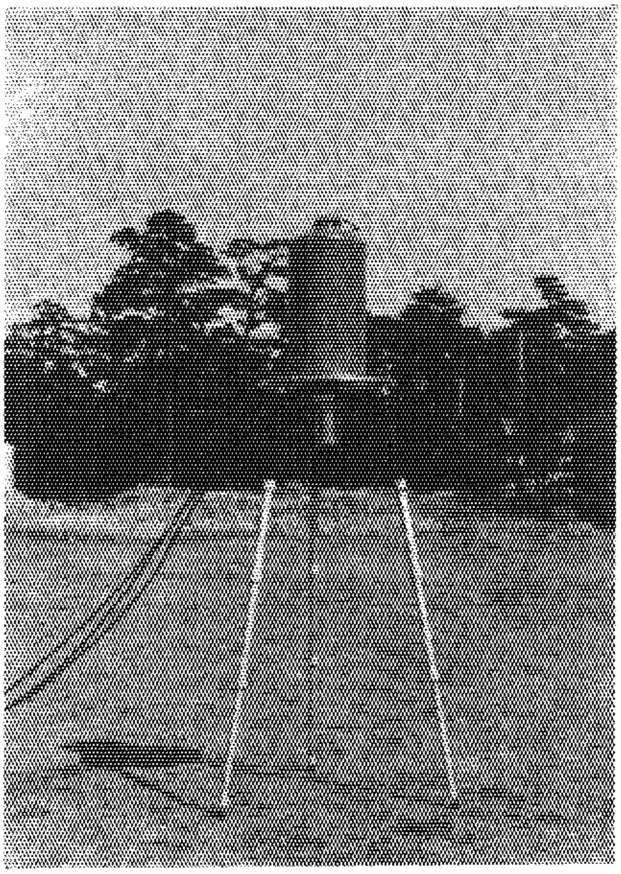

Fig.3.1.4 73cm^3 closed-end coaxial Ge(Li)detector for in-situ environmental gamma-ray spectrometer

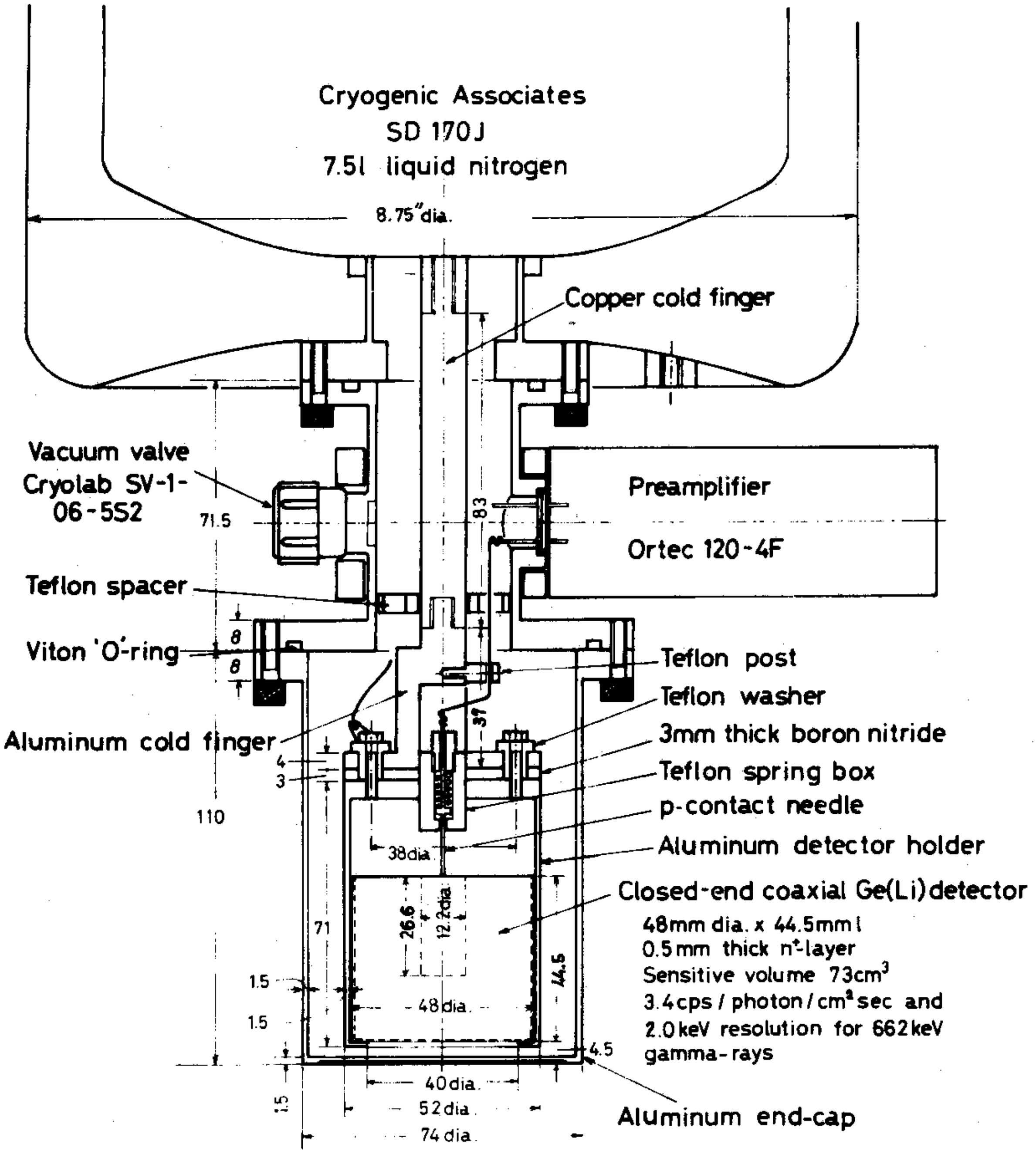

Fig. 3.1.5 Mounting detail of 73cm^3 closed-end coaxial Ge(Li) detector for in-situ gamma-ray measurement

The detector exhibited an absolute peak detection efficiency of 2.1 x 10^{-4} (17.5% relative to 3" x 3" NaI (Tl) detector) and 2.5keV energy resolution for 1333keV gamma-rays at a source-to-detector distance of 25cm when 2500V was applied. The cryostat consumes liquid nitrogen at a rate of 0.78liter/day; this rate is smaller than that of the firstly-made spectrometer. Examples of the environmental gamma-ray spectrometry using Ge(Li)detectors will be described in Section 3.3.

3.2 Gamma-ray spectrum measurement in Japan Research Reactor No.3 using a portable Ge(Li)spectrometer (E.Sakai, H.Terada, Seishiro Suzuki*, M. Katagiri, and Eiji Shirai#)

Gamma-ray spectra at various positions in the Japan Research Reactor No.3 have been measured using a portable Ge(Li)spectrometer (see Section 3.1). The peak detection efficiency and the energy resolution for 1333keV gamma-rays were 2.6% relative to 3" x 3" NaI(Tl)detector and 3.5keV,respectively. At all the measured points in JRR-3, gamma-rays from natural radionuclides such as K-40, Tl-208, Bi-214, and from Co-60 which was one of the induced radionuclides of the reactor-constructing-materials were observed. During the reactor in operation, gamma-rays from Ar-41, the induced radionuclide of argon in air, were observed also at all the points. High energy gamma-rays from the neutron capture reaction in iron and from N-16 induced by O-16(n,p)N-16 reaction of oxygen in heavy water coolant were found in the first floor of the reactor room; the former seems to originate around the monochrometer crystals of the neutron diffractometers. Gamma-rays from noble gas fission products were observed in helium cover gas of the F.F.D.system. In JAERI-M 6024[P-5)], pulse height distributions and counting rates of those gamma-rays are listed; the detail of the spectrometer as well as a brief description of JRR-3 are given. The results were presented at 1974 Fall Meeting on Reactor Physics and Engineering of the Atomic Energy Society of Japan on 17 October 1974 at Kyushu University[L-1)].

One of the coworkers (Seishiro Suzuki) cooperated the measurement as a trainee of the Reactor Engineering School during 6 to 27 September 1974.

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* Student of the Reactor Engineering School, J.A.E.R.I.; on leave from Japan Atomic Power Company, Tokaimura, Nakagun, Ibarakiken, Japan

\# JRR-3 Operation Section, Division of Research Reactor Operation, J.A.E.R.I.

3.3 In-situ gamma-ray spectrum measurement using portable Ge(Li)spectrometers

(E.Sakai, H.Terada, M.Katagiri, and H.Itoh)

The measurement of the environmental gamma-ray spectra has been carried out in the outdoors using the portable Ge(Li)spectrometers described in Section 3.1. The 33.4cm^3 Ge(Li)spectrometer(2.6% detection efficiency relative to 3" x 3" NaI(Tl)detector) was placed at one meter above the ground. Figure 3.3.1 shows the gamma-ray pulse height distribution obtained by a 10hr measurement made on the lawn between the Research Laboratory Building No.2 and the Reactor Engineering School Building. Gamma-rays from natural radionuclides in the soil such as K-40; Tl-208, Ac-228 (daughters of Th-232), and Bi-214 (daughter of U-238) were observed as well as Cs-137 (one of the fallout nuclides) and Ar-41 (originated by nuclear reactors). A similar measurement made at the Parking Lot near the Research Laboratory Building No.3 showed a smaller gamma-ray peak of Cs-137; this means that Cs-137 does not stay because of the disturbed surface of the soil by a blast of wind or traffic, or, new sand covered the soil surface to hinder the gamma-radiations from Cs-137. On the contrary, the soil under the lawn is not disturbed at all and keeps the fallout nuclides undisturbed. The fact that a very weak peak of Ar-41 could be observed in Fig. 3.3.1 suggests that the in-situ Ge(Li)spectrometer is a powerful tool to distinguish gamma-rays of man-made radionuclides from those originated by naturally-occurring radionuclides$^{L-1)}$.

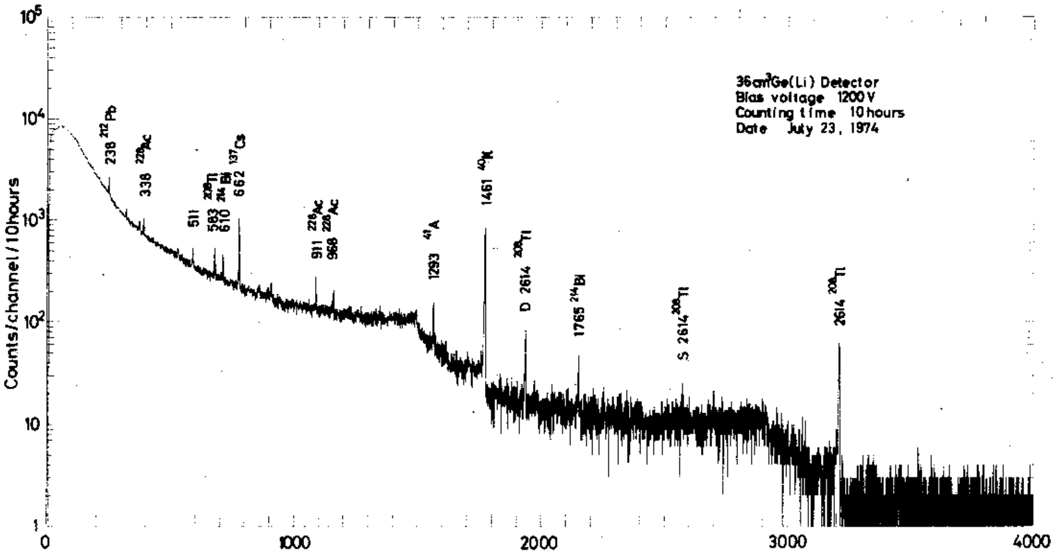

Fig.3.3.1 Outdoor measurement of background gamma-ray spectrum near the laboratory building NO. 2 in JAERI

The 2.6% detection efficiency of the 33.4cm^3 Ge(Li)detector is very small so that a 10hr measurement is needed. The secondly-made 73cm^3 Ge(Li)detector gave 17.5% detection efficiency relative to 3" x 3" NaI(Tl)detector and only a 2hr measurement was enough to obtain almost the same counts as those shown in Fig.3.3.1. Gamma-ray spectrometry at the L-Pit of the Waste Disposal Area showed that the main radiations came from CO-60 and Cs-137 and also the presence of Ag-110m; this measurement was required from the health physics point of view to confirm the safety of the workers who entered into the Pit.

The measurement of the peak detection efficiency of the detector as a function of the direction of incident gamma-rays will be performed and the concentrations of the radionuclides in the soil and the exposure rates at the detector position will be deduced by analysing the pulse height distributions.

3.4 Temperature cycling test of a hyper-pure germanium detector (E.Sakai, H.Terada, M.Katagiri, and H.Itoh)

A hyper-pure germanium detector manufactured by NRD (PHYGE model 0500 5B serial no. 100P5P3) was tested during temperature cycles. The detector specification shows 50mm^2 entrance window, 5mm thickness, and 3.5keV energy resolution for 625keV electrons. The detector has a construction shown in Fig.3.4.1; the p-contact (Ni-evaporated) of the detector is pressed

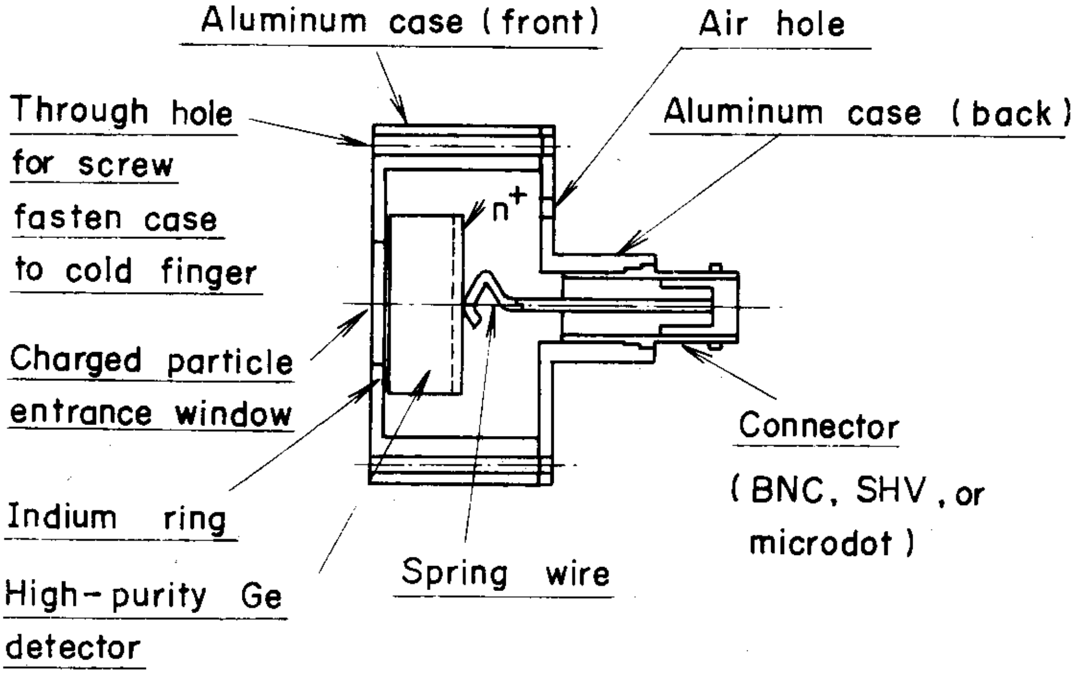

Fig.3.4.1 NRD PHYGE detector construction

through an indium ring to an aluminum case which has an open entrance for charged particles. The n^+-contact (Li-diffused) is pressed by a spring soldered to the center lead of a microdot connector. The detector case has a small diameter hole by which air can enter into the case.

The detector was mounted on a cold finger in a cryostat (Cryogenic Associates SD-170J), then an aluminum end-cap was fastened, evacuation started, and the vacuum valve was closed off. The leakage current and capacitance dependence on bias voltage, and energy resolution and peak detection efficiency for gamma-rays were measured after every temperature cycle from room temperature to 77K. The temperature cycling test was performed as shown in Table 3.4.1; liquid nitrogen was filled firstly at 11:00 on December 4, 1974 and various characteristics of the detector at 77K were measured. The detector started to warm up to room temperature at 17:00 on December 12, 1974

Table 3.4.1 Time schedule of temperature cycling

No. of temperature cycling	Cooling cycle		Duration (hr)	
	Start	Terminate	at 77K	at room temperature
Initial	11:00 Dec. 4	17:00 Dec.12	208	16.5
1	9:30 Dec.13	16:30 Dec.14	31	41.0
2	9:30 Dec.16	18:30 Dec.16	9	22.5
3	17:00 Dec.17	18:10 Dec.19	49	22.0
4	16:00 Dec.20	14:00 Dec.21	20	25.0
5	15:00 Dec.22	14:30 Dec.23	23.5	20.5
6	11:00 Dec.24	10:00 Dec.27	71.0	192.5
7	10:30 Jan. 4	9:00 Jan.22	430.5	893.5
8	14:30 Feb.28	15:00 Mar. 8	192.5	143.0
9	14:00 Mar.14			
		Total	1034.5hr	1376.5hr

and left there for 16.5hr until liquid nitrogen was filled at 9:30 on December 13, 1974. Then, the detector characteristics were measured, and so on ------. The experimental results obtained before the seventh cycle had been reported in JAERI-M 5988$^{P-3)}$. The results of the experiments including the eighth and the ninth temperature cycles were reported at 1975 Annual Meeting on Reactor Physics and Engineering of the Atomic Society of Japan on April 3, 1975$^{L-3)}$.

A summary of the results is as follows: The leakage current vs.applied voltage characteristics exhibited a variation in a small range, as shown in Fig.3.4.2, but, the magnitude of the leakage current itself was about 10pA which did not effect the energy resolution of the detector. The capacitance vs. applied voltage characteristics did not change until the seventh cycle, but, at the eighth cycle, the capacitance at applied voltages lower than 300V increased; this might mean an increase in the net carrier concentration in the depleted region near the n^+-layer (Li-diffused) of the detector. The capacitances at applied voltages larger than 300V did not change during the temperature cycles. Figure 3.4.3 shows the leakage current, capacitance, absolute peak detection efficiency(source-to-detector distance 10cm) and FWHM energy resolution for 356keV gamma-rays from Ba-133 as a function of the duration of the detector at room temperature. It shows that the detector performance except the leakage current did not change during 1376.5hr at room temperature; the change in the leakage current was not large enough to degrade the energy resolution of the detector. The detector had been at room temperature for more longer duration than 1376.5hr if one considers the fact that NRD tested the detector on October 21, 1974.

From the results explained above, it can be said that the hyper-pure germanium detector we tested is very stable against the temperature cycling in vacuum between room temperature and 77K. The possibility of a change in the depleted region near the n^+-layer (Li-diffused) during room temperature period can not be excluded. The detector is at present exposed to the air at room temperature and tests will be continued.

3.5 Silicon detector fabrication by N^+ ion implantation (M.Katagiri, H.Itoh, and E.Sakai)

Some of diodes, transistors, and I.C.s are manufactured using ion implantation technique by several manufacturers. This technique can be applied to make thin, rugged contacts on semiconductor detectors. Ions of B, Al, Ga, In

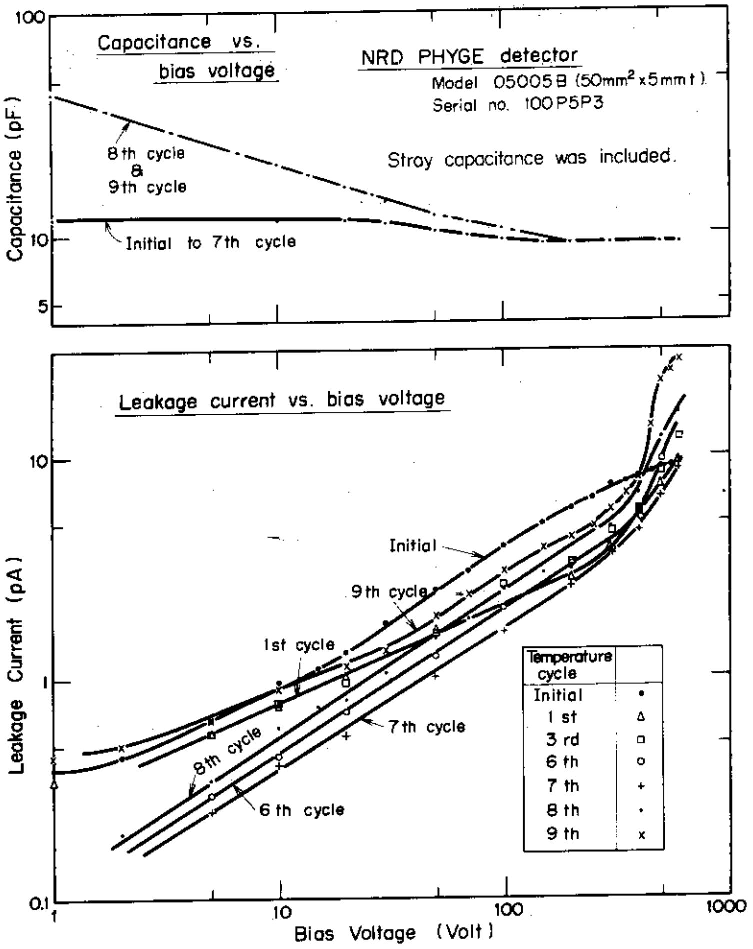

Fig.3.4.2 Capacitance and leakage current vs. bias voltage characteristics of PHYGE model 05005B detector

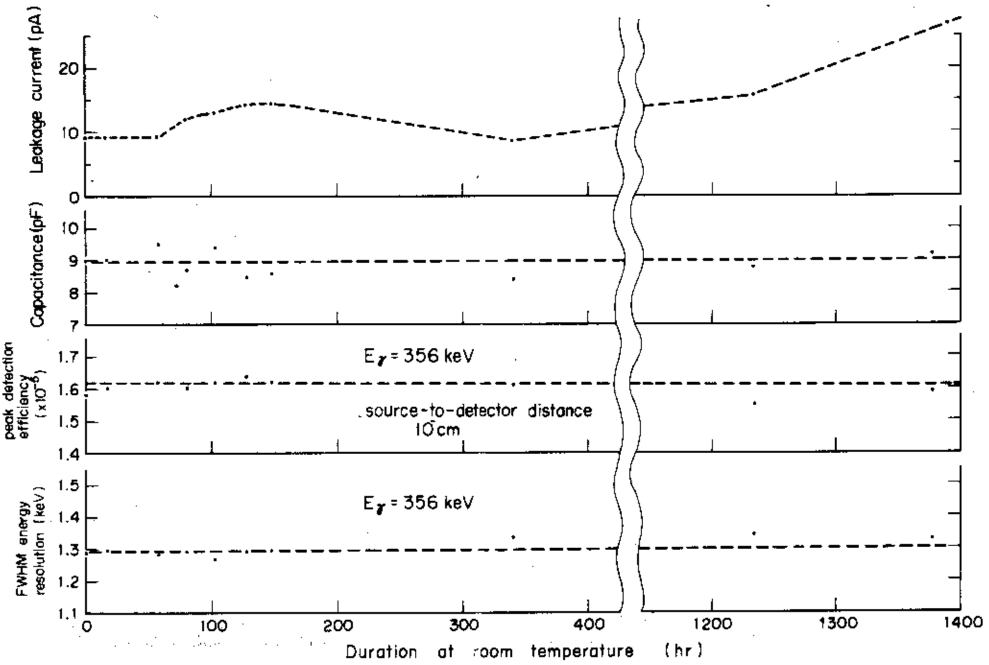

Fig.3.4.3 Detector performance at 600V bias vs. duration of detector at room temperature

can be implanted to make p^+-contacts and Li, N, P, As, Sb ions to make n^+-contacts. We tried to determine whether N^+ion implantation onto p-type silicon wafers could make p-n^+ junction or not using 2MeV Van de Graaff accelerator of the Physics Division of J.A.E.R.I.; the accelerator can accelerate only N^+ and Ar^+ ions at present.

One mm thick boron-doped p-type silicon wafers (200ohm cm) of 25mm diameter were etched with etchant HNO_3(2) + HF (1), attached onto an irradiation mount (irradiation window area 0.5cm^2), and irradiated by 1.1MeV N^+ions of 1.5μA. Some of the wafers were irradiated by 2 x 10^{16}ions/cm^2 and the others by 6 x 10^{16}ions/cm^2. The temperature of the irradiated wafers might reach about 100°C.

A thin gold film (10μg/cm^2) was evaporated onto a 0.3cm^2 area of the irradiated surface to confirm a good surface conductivity. As an ohmic contact to the p-type silicon, indium was pressed to the lapped surface of the silicon.

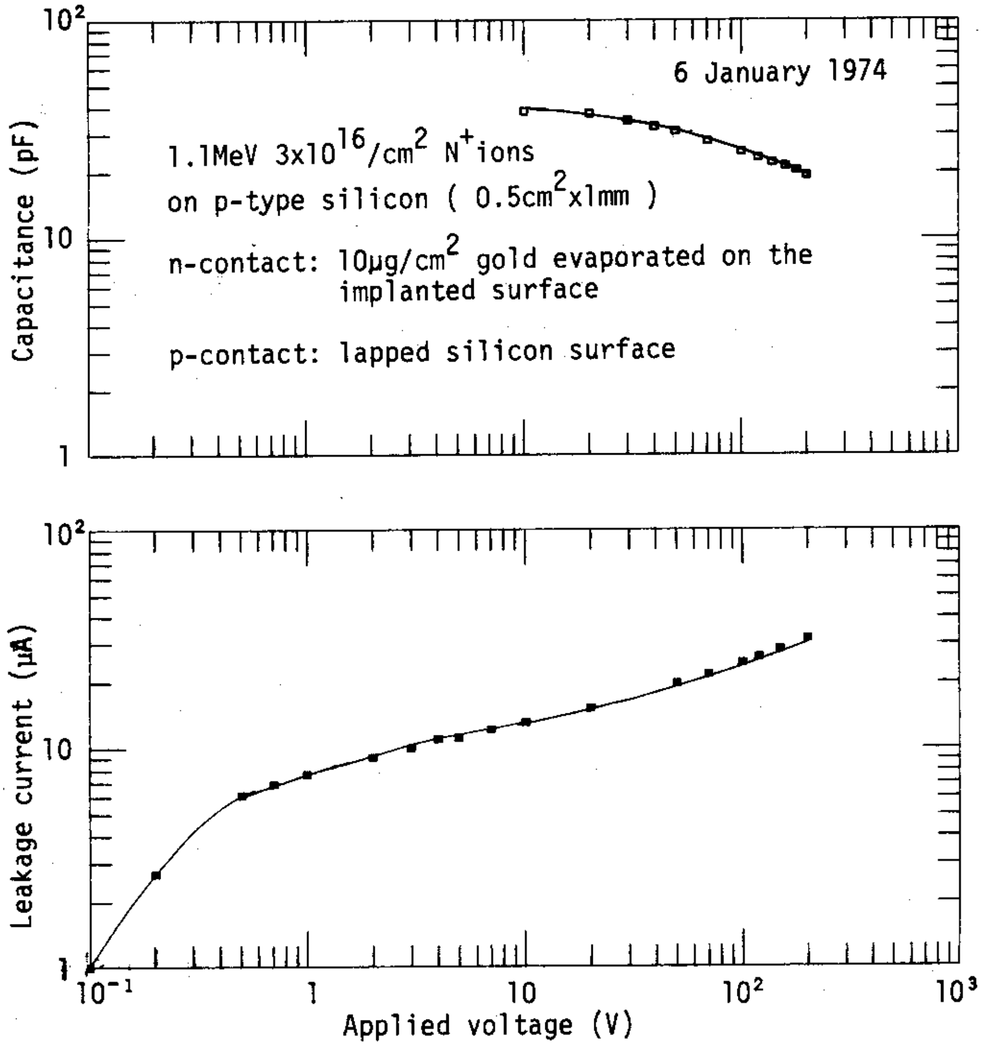

Fig.3.5.1 Capacitance and leakage current vs. applied voltage characteristics of 1.1MeV N^+ion implanted silicon detector

The leakage current and capacitance vs. bias voltage characteristics of the detector made by 3 x 10^{16} N^+ ions/cm^2 implantation are shown in Fig.3.5.1; the leakage current at 100V bias was 20μA. The pulse height distribution of alpha-particles from Am-241 obtained by the implanted detector is shown in Fig.3.5.2. The FWHM energy resolution of the alpha peak reached 700keV whereas good silicon detectors shows FWHM less than 20keV. The degradation of the energy resolution seems to be caused by the large leakage current and thick window of the detector. For the 6 x 10^{16} ions/cm^2 implanted silicon, the leakage current at 100V was 50μA and larger than 20μA of the 3 x 10^{16} ions/cm^2 implanted silicon detector.

From the results described above, it was found that the implantation of 1.1MeV N^+ions into p-type silicon could make p-n junction detectors. The effect of the energy and dose of the ions and annealing on detector performance will be investigated. Boron implantation will be also tried to make thin p^+-contacts on hyper-pure germanium crystals.

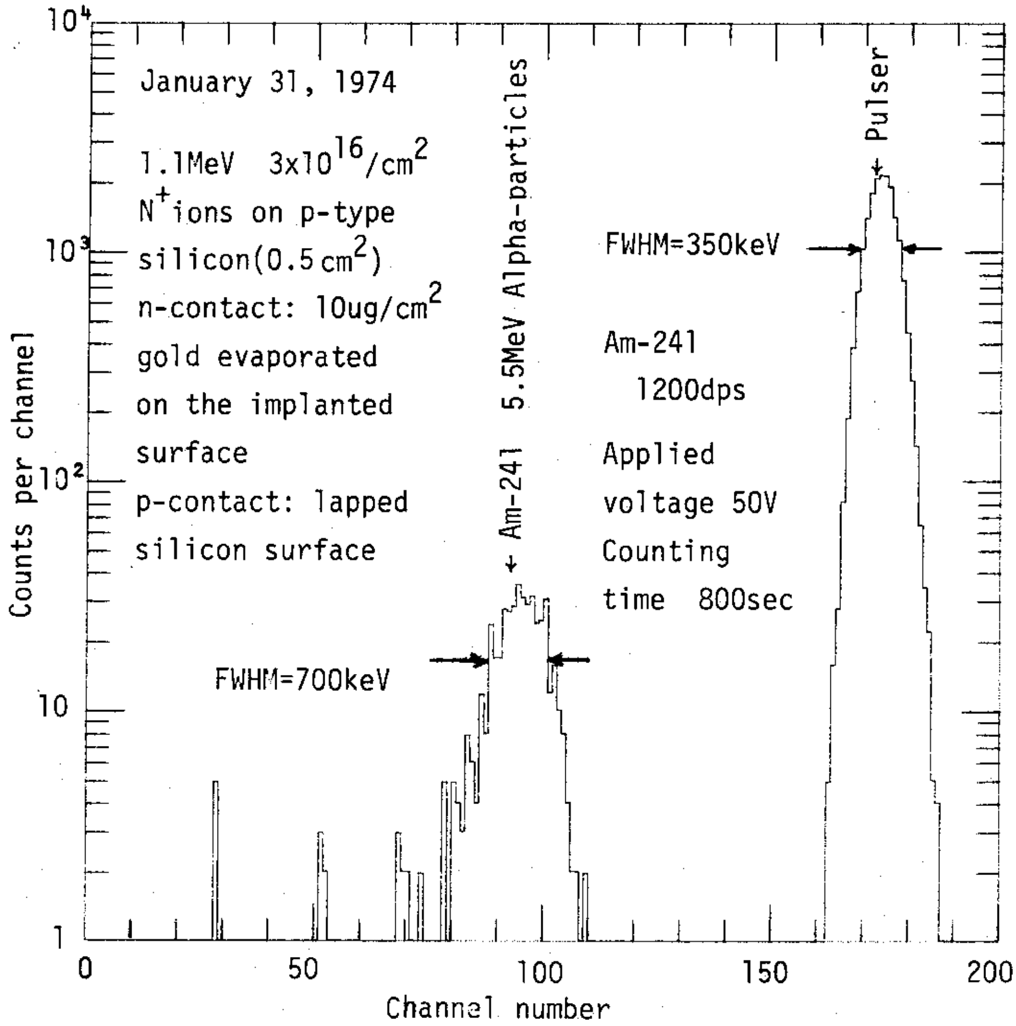

Fig.3.5.2 5.5MeV alpha-particle pulse height distribution obtained by N^+ion implanted silicon detector

3.6 PDP-8/L program development for ND-50/50 multichannel analyser (M.Katagiri)

ND-50/50 multichannel analyser has a minicomputer PDP-8/L (memory capacity 8K). The following programs have been developed for data processing of Ge(Li)gamma-ray spectrum analysis.

1) Modified FOCAL program (MACAL)

A modification was made on "FOCAL" program to control the ND-50/50 multichannel analyser. "FOCAL" is an interpreter-type program developed by Digital Equipment Corporation(DEC). The main modified part of the program is FUNCTION; the other parts such as COMMAND and OPERATION were not modified. The modified program was named as "MACAL". The "MACAL" has two types, Type A and Type B.

Type A MACAL can do the following functions;

(1) read out from and write into the memory of ND-50/50
(2) on and off of ADC
(3) skip COMMAND when ADC is off
(4) read out of the intensified memories of ND-50/50
(5) selection of data output devices (teletype or punch)
(6) command for plotter (pen vertical movement, horizontal movement, diagonal movement, and pen up-down)

A part of the FUNCTION of FOCAL, for example, FSIN, FCOS, FRAN, etc., can not be used because of the shortage of the momory capacity; the functions (1) to (6) require almost of all the 8K memory.

Type B program can operate all the FUNCTIONs of FOCAL plus the functions (1) and (6). The other functions (2) to (5) can not be used in Type B. Type B program is required when a sine or cosine curve is to be plotted.

2) Ge(Li)gamma-ray spectrum analysis program

This program automatically detects peaks in gamma-ray distributions obtained by Ge(Li)detectors, fits Gaussian functions to the peaks, and calculates the peak areas. The commands and functions of the program are as follows;

(1) memory division (upto 64 division of 4096channel memories. The region number can be identified.)
(2) data print (When one types the channel numbers of start and stop, then, the contents of the memories will be printed out with a format of 10 channels in one line with identifying the channel number in every 20 channels.)
(3) data punch (When one types the channel numbers of start and stop and the data number, then, those numbers will be punched out by ASCII I7 format.)

(4) paper-tape read-in program (The data in the region specified by (1) are read in from the punched paper tape to the memories of ND-50/50 using a high-speed punched tape reader. For example, one can transfer the contents of 512channels in the punched tape into one specified region of the ND-50/50 memories.)

(5) energy calibration (One can calibrate the energy of the peaks using a linear equation from the two sets of the typed-in combinations of the gamma-ray energy and corresponding peak channel number.)

(6) peak channel calculation (The peak channel number (integer) as well as its corresponding energy of the intensified peak are calculated using Covel's method.)

(7) data analising program

When one types an approximated FWHM (FWHM= , less than 9channels) and the permissible error (ERROR= , in %) in FWHM and peak area calculation, the program automatically detects peaks, fits Gaussian functions to the peaks, and types out the following items;

(i)	NO	data number
(ii)	ENERGY	peak channel energy (keV)(seven digits)
(iii)	CHANNEL	peak channel number (seven digits)
(iv)	FWHMC	peak FWHM in channel number (four digits)
(v)	FWHMK	peak FWHM in keV (four digits)
(vi)	PEAKARE	peak area (seven digits)
(vii)	ERROR	square root of the area (less than five digits)
(viii)	ESDEV	error in % in peak area (four digits)
(ix)	COUNTRAT	peak area counting rate in cps (seven digits)
(x)	CNTERROR	error in peak area counting rate in cps (seven digits)
(xi)	CK	operation conditions of the program in calculation; for example, C = 1,2, and 4 means that the calculated FWHM, peak channel, and area does not meet the input conditions, respectively. C = 7 (1 + 2 + 4) for the condition that all the calculated FWHM, peak channel, and area does not meet the input conditions. C = 8 for the calculated FWHM larger than 9channels, and C = 9 for the case in which the area calculation can not be performed because of the presence of doublet peaks. K is the number of the turns in which the fitting program circulates in the calculation.

Alternatively, the same calculation can be performed by typing approximate channel numbers which must be close to the true peak channels within a specified FWHM channel number.

Figure 3.6.1 shows an example of the input and output of the calculation.

```
 D 31

DATA KAISEKI PROGRAM 3

FWHM=4
ERROR=2   %


COUNT TIME=     309

 NO  ENERGY CHANNEL FWHMC FWHMK PEAKARE ERROR ESDEV COUNTRAT CNTERROR CK

  1 31.1749 79.3737 2.978 1.215    4887   181 83.78 15.81450 13.24910 75

  2 35.9200 91.0000 4.000 1.633-   4904   198 4.507-15.86900-0.715245 98

  3 81.0758 201.639 3.929 1.604   25936   196 6.987 83.93500 5.864490 75

  4 161.126 397.776 3.377 1.378    1436   104 9.806 4.646740 0.455663 75

  5 223.567 550.765 4.533 1.850    1067    79 7.663 3.451270 0.264481  2

  6 276.897 681.433 4.046 1.651   11022   120 2.275 35.66990 0.811490  2

  7 303.362 746.276 3.909 1.596   25496   168 2.106 82.51050 1.737430  1

  8 356.516 876.515 4.021 1.641   72428   274 2.036 234.3940 4.771170  2

  9 384.347 944.705 4.150 1.694    9386    99 2.263 30.37530 0.687369  2


*
```

Fig.3.6.1 Example of input and output of gamma-ray peak analysing program (D 31 DATA KAISEKI PROGRAM 3)

3) Ge(Li)detector performance analysing program

The program is to be used in the experiments to measure Ge(Li)detector performance. Information on standard gamma-ray sources can be typed in. The commands and functions of the program are as follows;

(1) all the items except (2) and (7) described in the previous section 2)

(2) performance analysing program

By typing an approximate FWHM (FWHM = ,less than 9channels), an assigned error in % in FWHM and area calculation (ERROR =), the names of the standard sources (SOURCE =), and the numbers of the elapsed days after the source calibration (KEIKA BI =), then, the following items will be typed out;

(i)	COUNT TIME	the live time of the measurement
(ii)	NO	data number
(iii)	ENERGY	gamma-ray energy in keV (six digits)
(iv)	EFFICIENCY	gamma-ray peak detection efficiency (E format, six digits)
(v)	EFFICI.ERROR	absolute error of gamma-ray peak detection efficiency (six digits)
(vi)	ESDEV	% error of gamma-ray peak detection efficiency (nine digits)(the total of the statistical error of the peak area, fitting error, and standard source error)
(vii)	FWHMK	energy resolution in keV (four digits)
(viii)	TOTALEF	peak-to-total ratio (The total counts integrate all the counts above 8keV)(five digits)
(ix)	COMPTON	peak-to-Compton ratio (the maximum count of the fitted Gaussian peak devided by the averaged count in the energy range of (0.75 to 0.8) times of the Compton edge energy)(six digits)
(x)	CK	conditions of the calculation as explained in the previous section 2)-(7)-(xi)

Standard sources normally used in the experiments are Am-241, Co-57, Ba-133, Hg-203, Na-22, Cs-137, Mn-54, Y-88, and CO-60. One can type the radioactivity (μCi), halflife (sec), gamma-ray energy (keV), gamma-ray branching ratio, and standard deviation of the radioactivity (%) as the input data of the standard sources.

Figure 3.6.2 shows an example of the input and output of the calculation. In this example, ENERGY = 662 and ACTIVITY = 345751 had been already stored in the memories.

4) Plotting program

A program which can plot curves of the results obtained using the programs described in sections 2) and 3), for example, peak detection efficiency, FWHM energy resolution, peak-to-total ratio, peak-to-Compton ratio as a function of gamma-ray energy is under development; log-log, linear-linear, or, log-linear plot of the curves fitted by the least-square-fitting taking account of the standard deviation will be developed.

```
 D 10

TOKUSEI SOKUTEI

G.N.=  0   G.D.=  1

FWHM=4
ERROR=2  %

SOURCE= CS137
KEIKA BI=255

ENERGY=  662   ACTIVITY= 345751

COUNT TIME=      300

 NO  ENERGY   EFFICIENCY   EFFICI.ERROR ESDEV FWHMK TOTALEF COMPTON CK

  1 662.094 0.177207E-03 0.442948E-05 2.500 1.885 0.08665 46.7487  1

*
```

Fig.3.6.2 Example of input and output of gamma-ray detecting performance measurement program (D 10 TOKUSEI SOKUTEI)

3.7 JFT-2 plasma X-ray spectrum measurement using Si(Li) X-ray spectrometer

(E.Sakai, H.Terada, M.Katagiri, Norio Suzuki*, Katsuki Maeno*, and Noboru Fujisawa*)

Electron temperature measurements had been carried out using a technique to detect the Thomson-scattered laser beam by electrons in the plasma of the Japan Fusion Tokamak No.2 (medium-beta-value torus experimental apparatus) (see,for example, T.Matoba, A.Funahashi, and G.Ando;"Thomson scattering apparatus for JFT-2", JAERI-M 5515 (Jan. 1974)). The electron temperatures in plasma can be alternatively deduced from the slope of the X-ray spectrum radiated from the plasma. The JFT-2 Group had a plan to deduce the slope of the X-ray spectrum using the absorber method in which two sets of the X-ray absorbing film - scintillator combination were to be used. Our group in cooperation with the JFT-2 Group planned to measure X-ray spectra directly using Si(Li)

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* JFT-2 Group, Thermonuclear Fusion Laboratory, Tokai Research Establishment, J.A.E.R.I.

detectors recently developed. A Si(Li) X-ray spectrometer specifically designed for the JFT-2 experiment was bought in FY 1973. The first experiment was performed in April, 1974 and the second in February, 1975. In the period between the two experiments, the experiment could not be made because a modification was made to increase the toroidal magnetic field of JFT-2 from 9KGauss to 18KGauss.

A damage of the Be window of the spectrometer was found a few months after the first experiment had completed. The damage seems to be caused by the fatigue of the Be window itself or the adhesives of the window brought by the pressure cyclings between vacuum and air atomosphere. The spectrometer was sent back to the manufacturer to repair.

A schematic diagram of the spectrometer system is shown in Fig.3.7.1. The spectrometer was manufactured by Canberra Industries, Inc.; it is one of 7300 series Si(Li)detector systems which includes a Si(Li)detector of 30 mm^2 area and 3mm thickness, an optoelectronic feedback preamplifier with a cooled FET input, a model 1713 X-ray spectroscopy amplifier, and a model 1763 spectrum enhancer. The output of the enhancer was analysed by a multichannel analyser Hewlett Packard 5401B (1024channel, 200MHz ADC). The Si (Li)detector has an entrance window of 1/3 mil (8.38um) thick beryllium. The energy resolution (FWHM) for 5.9keV X-rays from Fe-55 was 167eV at 12μsec timeconstant of the amplifier. The dewar of the spectrometer was an integral vacuum type of 30 liter liquid nitrogen and specially designed to meet the limited space for the spectrometer in JFT-2 experiments. A flange was prepared on the middle of the aluminum end-cap to make vacuum connection with JFT-2 plasma. In order to measure X-rays emitted within a predetermined period (for example, 10msec) in one plasma sustaining period (about 100m sec), a trigger signal from JFT-2 was passed through a gate and delay generator and a function generator to determine the time width and its biggining, and gates the multichannel analyser. The amplifier output was also fed to a single channel analyser to be counted by a scaler. The flange of the end-cap of the detector was fitted to a flange of a 54cm extension tube which was connected to a gate valve of one of the observation ports of JFT-2; this avoids the effect of the strong magnetic field of JFT-2 on the detector and at the same time prepares the space for the detector. A teflon insulator was sandwitched between the gate valve and the extension tube to confirm an electrical insulation of the detector from JFT-2 apparatus. The inside of the extension tube was evacuated to avoid an absorption of low energy X-rays. Near in the

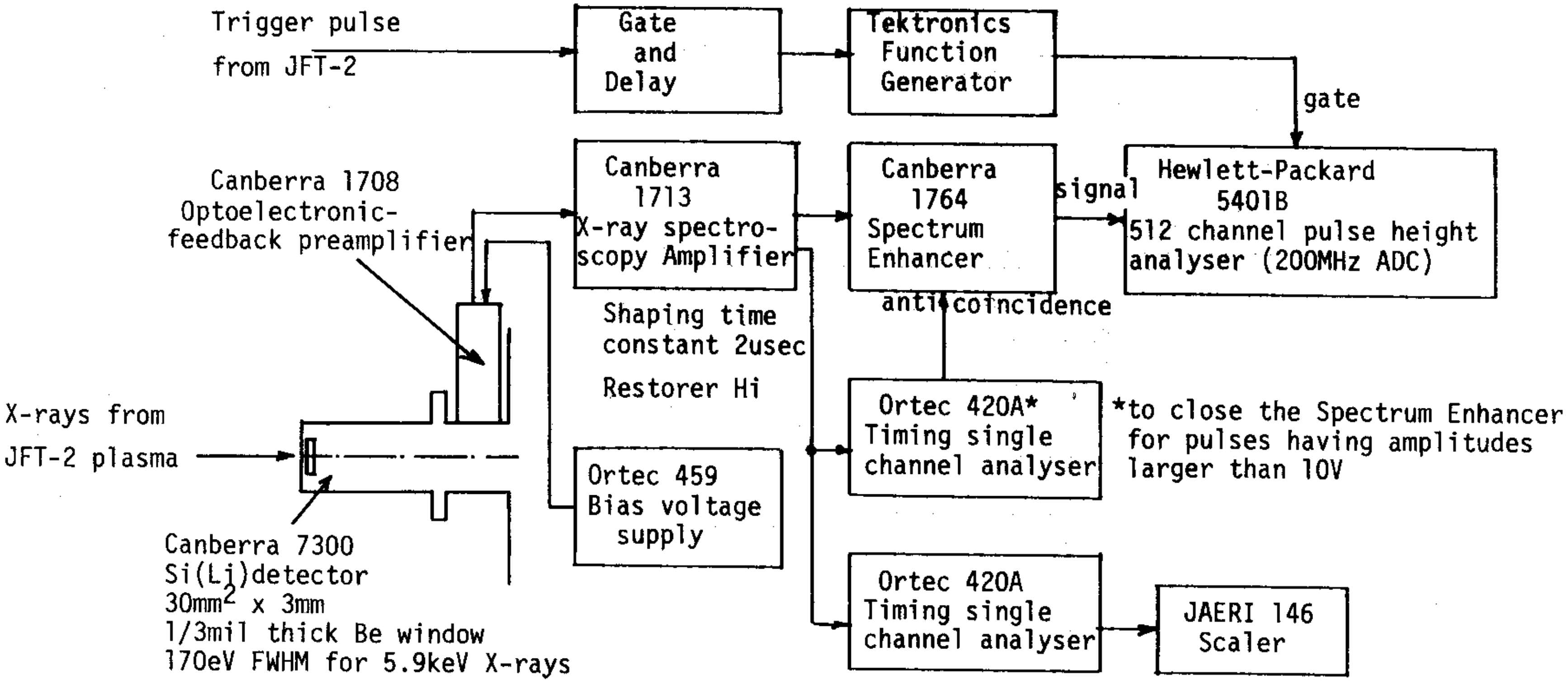

Fig.3.7.1 Schematic diagram of Si(Li) X-ray spectrometer for JFT-2 plasma experiment

both ends of the tube two slits were installed to adjust X-ray beam collimation and counting rate; the slit near the detector can be changed as 0.2, 0.4, 0.8, 1.0, and 1.2mm. The other slit has 1.0mm diameter.

An example of the X-ray spectra obtained in the first experiment is shown in Fig.3.7.2. The dark dotts show the X-ray pulse height distribution (sum of 10 discharges) obtained in the period between 40 and 60msec after the discharge started while the circles show the X-ray spectrum obtained after the correction due to the absorption of the 8.4μm thick Be as well as energy coefficient was made. From the slope of the spectrum (circles), the electron temperatures deduced are 390eV from the spectrum above 1keV, and 120eV from that below 1keV. The electron temperature varied as shown in Fig.3.7.3. Circles show the temperatures obtained from the slopes above 1keV, and crosses below 1keV. The origin of the two components of the measured temperatures seems to be caused by an inadequate correction made on the absorption by the Be window of 1/3mil thickness which may differ from the actual thickness when one considers that the second experiment gave only one component of the electron temperatures and also that the fatigue of the Be window might make it more thinner than the initial thickness. The values of the electron temperatures obtained from the X-ray spectra above 1keV are found to be not inconsistent with those from the laser scattering.

The second experiment started in February 1975 after the toroidal coil modification of JFT-2 had completed. In this experiment, a model ND-50/50 4096 channel pulse height analyser instead of the Hewlett Packard model 5401B was used. The output of the amplifier was carried to the ND-50/50 by a 400m cable (RG-62/U) from the JFT-2 Building to the Room No.109 of the Research Laboratory Building No.2 as shown in Fig.3.7.4. The ND-50/50 was modified to operate as a two-dimensional analyser of (8 x 512) channels; the eight channels correspond to the predetermined periods, $\Delta t_1, \Delta t_2, \ldots, \Delta t_8$, which is about 1/8 of the plasma sustaining period of about 100msec. Each 512channel records each X-ray pulse height distribution obtained in each of the predetermined periods.

A schematic diagram of a one-width NIM module which includes a control circuit for the two-dimensional analysis of the ND-50/50 is shown in Fig.3.7.5. A trigger pulse from JFT-2 sets "0" bit in a binary counter, makes the 512 channel ADC in operation and, thus , pulses are stored in the core-memories # 1 to # 512. When a predetermined period Δt, for example, Δt = 20msec (Δt can be set between 10μsec and 10000sec.) has elapsed, an ADC off signal appears and passes a pulse-shaper and gate to advance the binary counter by one. Therefore, ADC

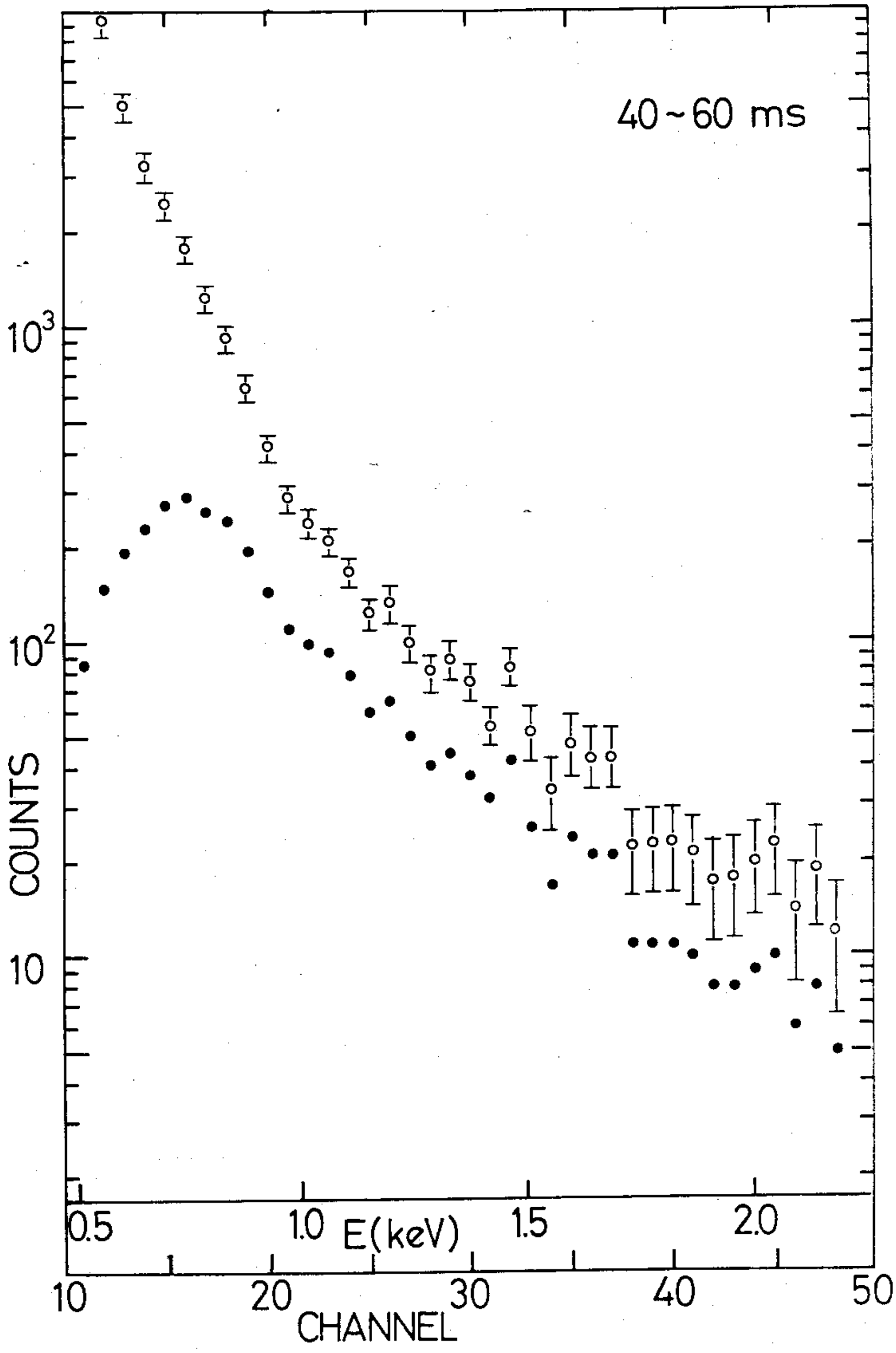

Fig.3.7.2 X-ray pulse height distribution (●) and corrected X-ray spectrum (○) from which plasma electron temperature was deduced

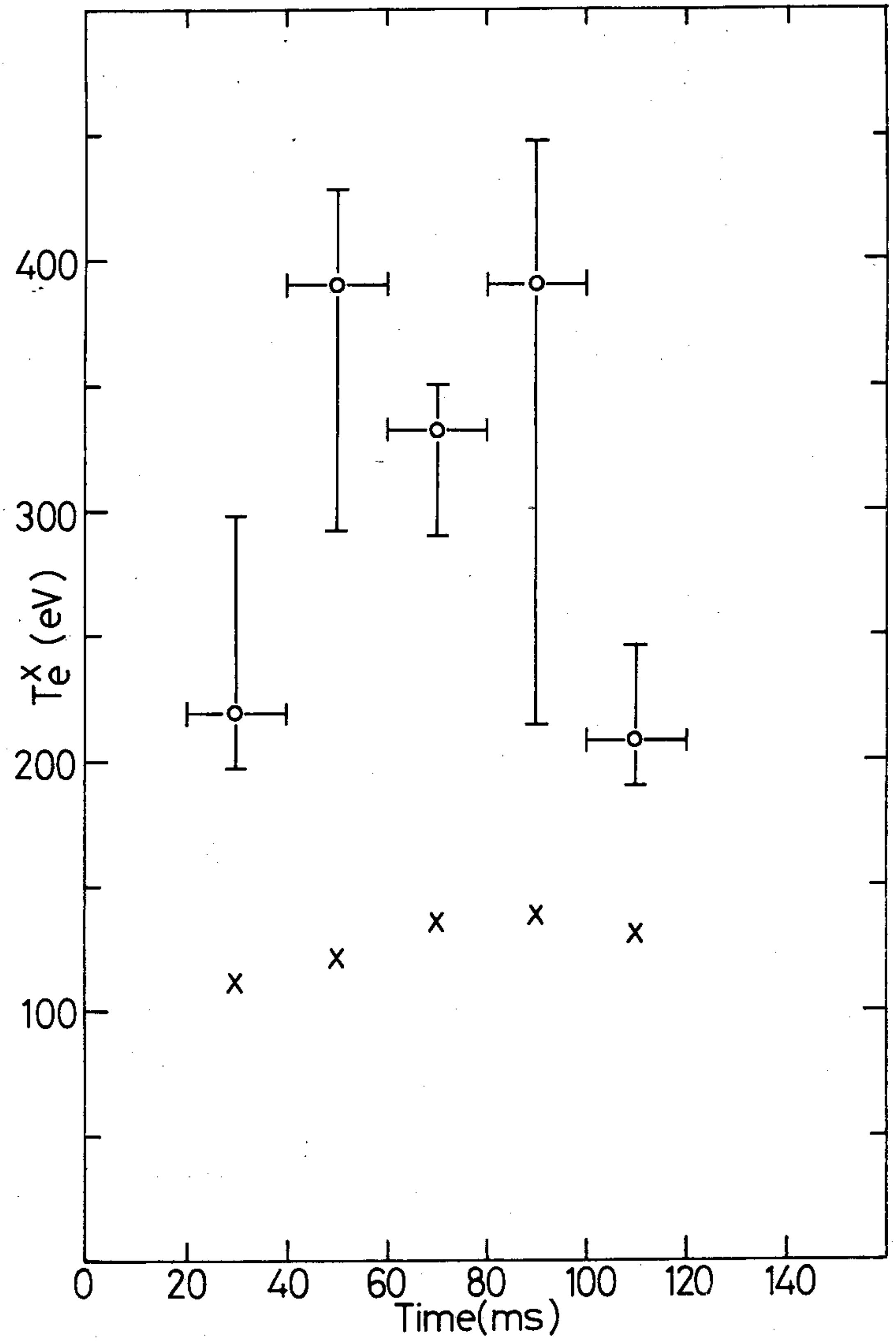

Fig.3.7.3 Results of plasma electron temperature measurement using Si(Li) X-ray spectrometer

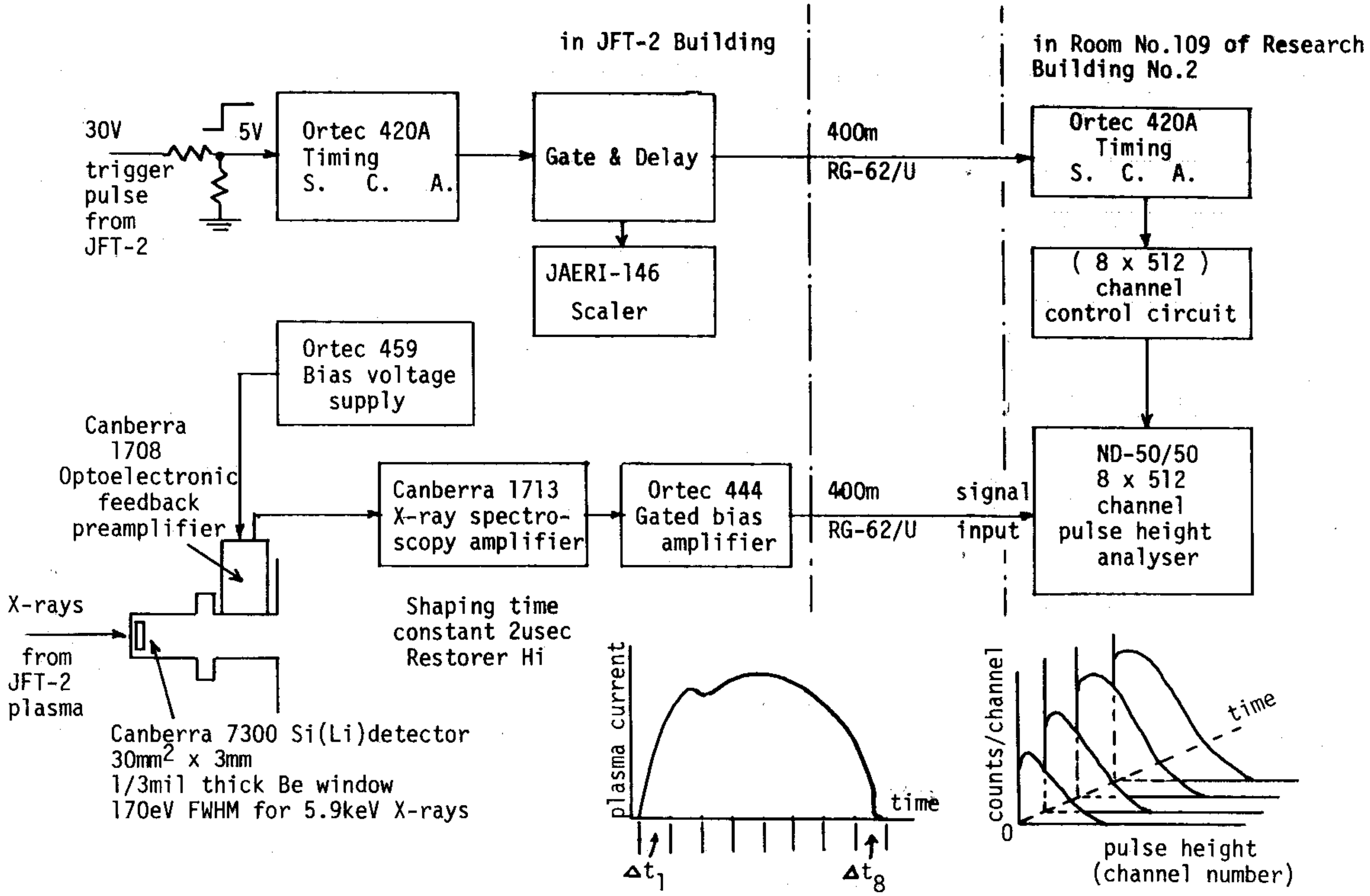

Fig.3.7.4 Schematic diagram of the electronics used in data-handling of Si(Li) X-ray spectrometer system for JFT-2 plasma electron temperature measurement

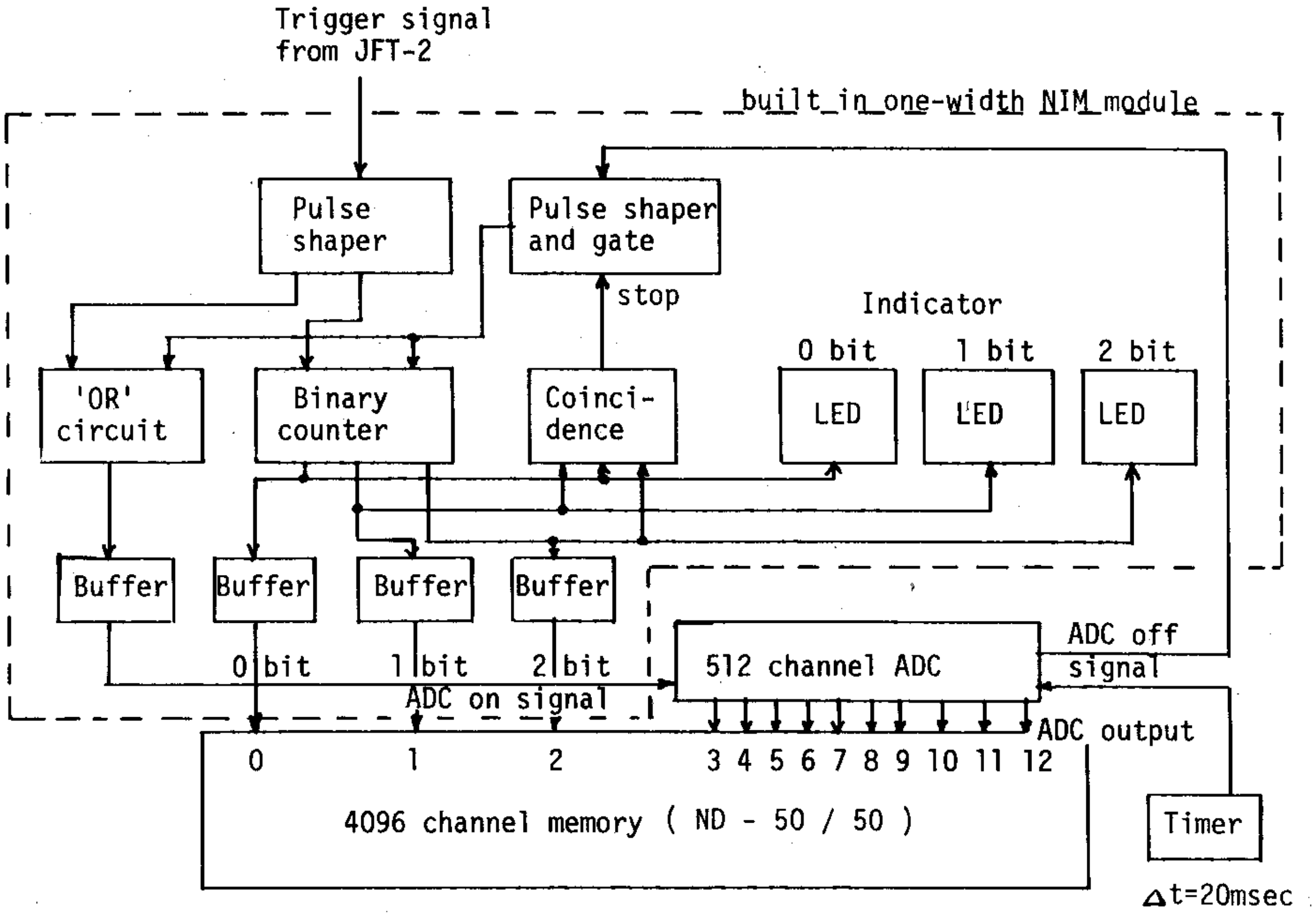

Fig.3.7.5 Schematic diagram of (8 x 512) channel control circuit

output pulses are stored in # 513 to # 1024 core memories in the next Δt sec. When the counting in the last period Δt_8 has completed, an ADC off signal appears, but this signal does not advance the binary counter anymore, because the pulse-shaper and gate is closed by the coincidence output. Then, the data stored in the ND-50/50 is read out as described in the following text. The system will wait until the next trigger pulse arrives from JFT-2.

JFT-2 is operated at one discharge in every 10min. The two-dimensional data of 8 x 512 channels are read out after every discharge has completed. Only the data obtained from the discharges of the same plasma conditions will be selected when analysis is to be made; this is necessary because of a problem of the reproducibility of the plasma conditions in every discharge. The data read-out was programmed by a minicomputer PDP-8/L used in the ND-50/50 in the time sequence shown in Fig.3.7.6; i.e., after an X-ray spectrum measurement has made, the data stored in the core memories of the ND-50/50 are plotted by a CAL COMP-565 plotter in the form of eight pulse height distributions for eight periods. Then, each of the summed counts in each of the eight pulse height distributions is calculated and typed out. Then, a sum of all the counts in the eight pulse height distributions is typed out. Then, all the data are punched out on paper tape by a Fujitsu model 465 puncher. Then, one is added to the run number and the system will wait the next discharge of JFT-2.

The punched data are analysed to make correction of the absorption and energy coefficient using large computers in the Computing Center; electron temperatures are deduced from the slopes of the corrected X-ray spectra. An example of experimental results is shown in Fig.3.7.7; the above picture shows an oscilloscope trace of the plasma current and one-turn voltage. The below shows the electron temperatures deduced from X-ray spectrum obtained by the Si(Li)detector measurement. The electron temperatures from the Si(Li)detector and from the laser scattering are not inconsistent with each other while the former measurement gave averaged values in space and the latter gave the values for the center of the plasmas. The future experiments are planned to compare the results obtained by the two methods.

A part of the measurements was reported at the 30th Annual Meeting of the Physical Society of Japan held at Kyoto University on April 2, 1975$^{L-2)}$.

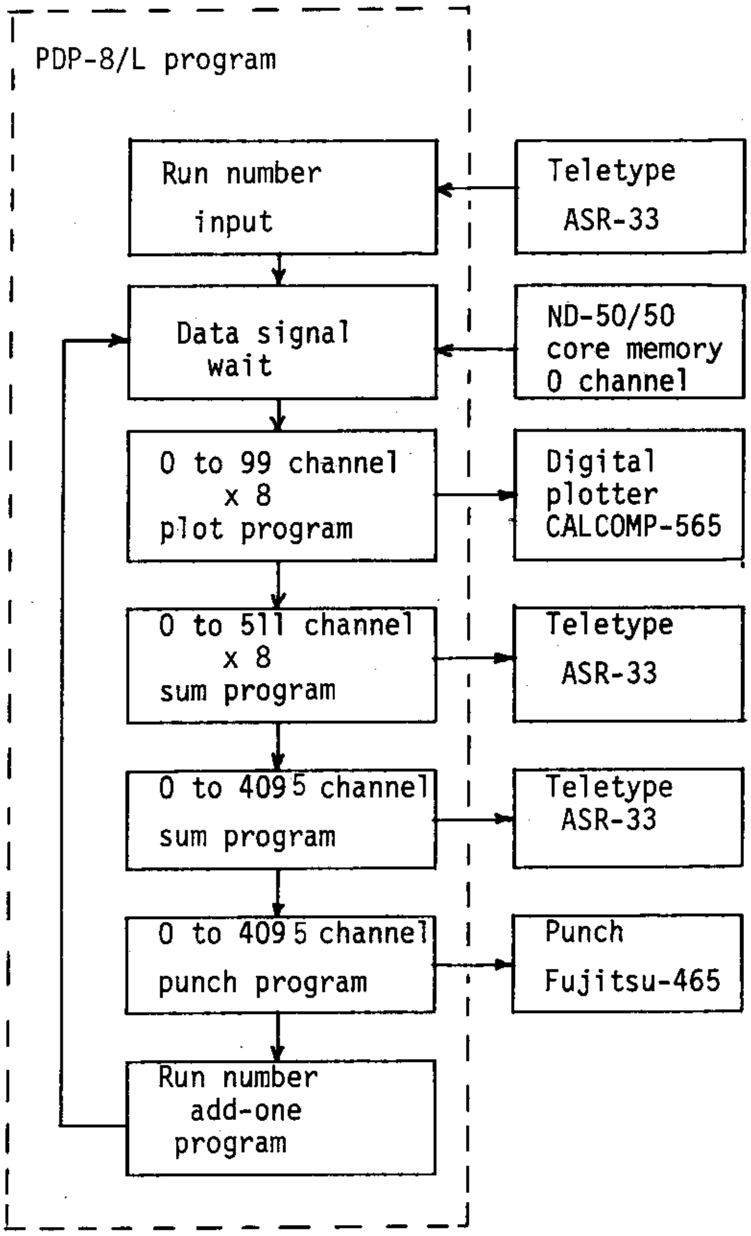

Fig.3.7.6 Flow chart of data readout of eight 512 channel X-ray pulse height spectra stored in ND-50/50 core-memory

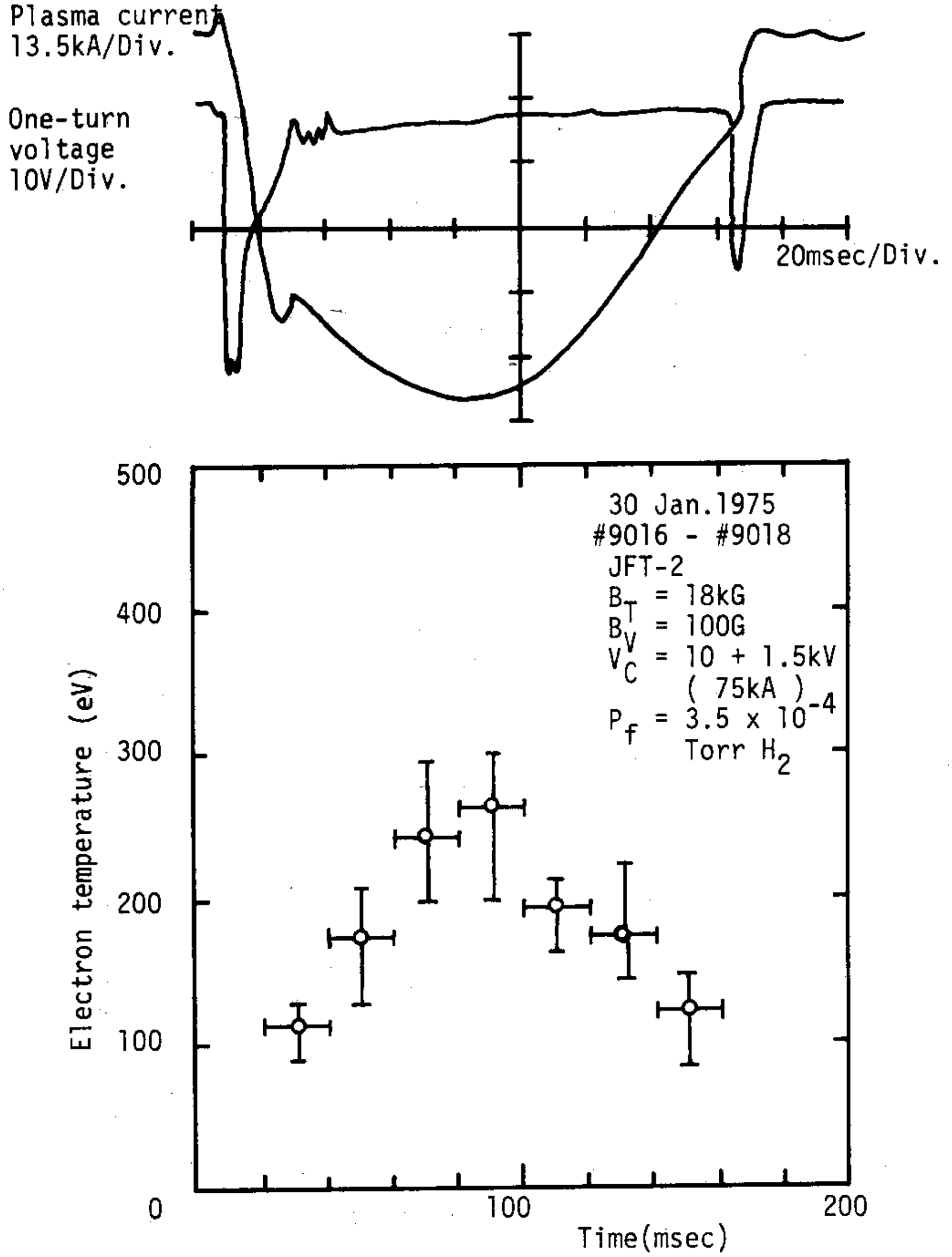

Fig.3.7.7 Plasma current waveform and electron temperature deduced from X-ray spectra

3.8 Test of four types of fuel failure detection systems using Sodium In-pile Loop (Contract study between Power Reactor and Nuclear Fuel Development Corporation and J.A.E.R.I.)(E.Sakai, M.Katagiri, H.Terada, H.Itoh, Tomohide Sukegawa* and Kenmei Hirano*)

We had been entrusted with a contract study " FFD sodium in-pile loop test (III)" from the Fast Breeder Reactor Development Project of the Power Reactor and Nuclear Fuel Development Corporation (Persons in charge are Drs. Yasuhide Mimoto and Kazutake Imani.) in the period between May 1, 1974 and 30 April 30, 1975. The study consisted of the preparation and out-of-pile test of the fuel failure detection systems for the Sodium In-pile Loop. The S.I.L. is scheduled to operate with uranium oxide fuels in its irradiation section at the end of 1975.

A polyethylene moderator system was designed as a delayed neutron monitor placed on the lid of the S.I.L. and its detection efficiency of neutrons from an Am-Be source was measured. A simulated polyethylene moderator was experimented to measure the neutron detection efficiency as a function of the position of the Am-Be neutron source. The thickness of the paraffin covered on the source was varied to change the neutron spectrum. The neutron detection efficiency thus obtained simulates the detection efficiency of delayed neutrons existed in the sodium in the expansion tank of the S.I.L. A secular change in the characteristics of BF_3 counters and B-10 counters manufactured by Mitsubishi Electric Company,Ltd. were tested and no change was observed.

A precipitator manufactured by Hitachi Limited was installed in the basement of the reactor room of JRR-2.

In order to measure gamma-ray spectra of fission products in cover gas, a gas reservoir whose inner volume can be changed between $100cm^3$ and $1000cm^3$ and a coaxial Ge(Li)detector of $54cm^3$ sensitive volume had been constructed. The detector has an energy resolution of 2.4keV and a peak detection efficiency of 9% relative to 3" x 3" NaI(Tl)detector measured at a source-to-detetor distance of 25cm for 1333keV gamma-rays. Two kinds of on-line digital subtract units by which a peak area in the pulse height distributions could be counted had been designed and tested. A multichannel pulse height analyser, Canberra Industries model 8100, was accepted.

Some of the data analysing codes for the fuel failure detection systems of the Sodium In-pile Loop were developed.

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* Reactor Safety Laboratory II, Division of Reactor Safety, J.A.E.R.I.

Those results were reported in JAERI-memo 6118 (April 1975)[P-6]. Messrs. Naoaki Wakayama and Hideshi Yamagishi of the Reactor Instrumentation Laboratory are deeply acknowledged for their help in the polyethylene moderator simulation experiment; Mr. Tsunemi Kakuta for his help in the B-10 counter characteristics measurement.

3.9 Dr. Yasukazu Yoshizawa (Research Consultant)'s lecture

Dr. Yasukazu Yoshizawa, Professor of Faculty of Science, Hiroshima University,has been a research consultant of our group. He gave a lecture on " the precise energy determination of gamma-rays and related problems " on February 24, 1975. The contents of his lecture can be summarized as follows;

1) It is important for the precise determination of gamma-ray energy to calibrate Ge(Li)detector systems. This calibration is not easy because Ge (Li)detectors have the following characteristics. The peak position in a gamma-ray pulse height distribution may change when the gamma-ray source position moved; this is considered to be caused by charge collection characteristics of the detector and also by the field increment effect (see R.G.Helmer, et al; Nuclear Instruments and Methods, 123 (1975) 51-59). The latter field increment effect is not yet well understood and needs more experiments.
2) The shape of 511keV annihilation gamma-ray peak in the pulse height distributions depends on the material in which positron-electron pairs annihilate . The fundamental structures of the material can be deduced from the measurement of the peak shape of 511keV gamma-rays; for example, whether the positrons annihilate with conduction electrons or with inner-shell electrons can be determined.

The above two problems were reviewed including the experimental results recently obtained by his group in Hiroshima University. The future plan of the experiment to be undertaken was also discussed.

3.10 Technical service

3.10.1 Ge(Li)detector repair (M.Katagiri)

Pepair of a coaxial Ge(Li)detector owned by the Reactor Engineering School was asked. The detector was manufactured by Elscint, Israel, and caused a trouble of vacuum leak probably due to a degradation of vacuum-sealability of the indium seals used between flanges. The cryostat was modified, the detector mount renewed, and the detector was remounted. The initial performance of the detector was recovered; the leakage current was less than 0.1nA, the capacitance 45pF, the energy resolution 3.5keV (with an Ortec 120-3B preamplifier), peak detection efficiency measured at 25cm 2.5×10^{-5} for 1333keV gamma-rays when 1000V was applied.

3.10.2 Lending-out of Ge(Li)detector

A 33.4cm^3 Ge(Li) portable gamma-ray spectrometer was lend out to Mr. Ikuo Kondo, Project Engineering Section, Division of JMTR, Oarai Research Establishment, J.A.E.R.I. He used the detector to measure gamma-rays from Ag (n,n'gamma) reaction at Japan Material Testing Reactor Critical Facility. His experimental results were reported at 1975 Annual Meeting on Reactor Physics and Engineering of the Atomic Energy Society of Japan (Paper B35 " A trial of reactor neutron spectrometry making use of the excited levels of Ag-107/109 ", at Tokyo Institute of Technology, April 3, 1975).

3.10.3 Japanese version of IEC Publication 430 (E.Sakai, H.Terada, and M.Katagiri)

The Japan Industrial Standard Committee had asked to translate IEC Publication 430 published by the International Electrotechnical Committee, Geneva, Switzerland into Japanese as a reference for discussions. The IEC 430 describes a standard on various procedures to test germanium gamma-ray detectors. Our report, JAERI-M 5914$^{P-1)}$, includes a faithful Japanese translation of IEC 430 in which some errors were corrected; it also includes a description of the history of the Publication and a comparison with IEEE Std 325-1971 (ANSI N42.8-1972) published by the Institute of Electrical and Electronics Engineers, Inc. This translation will be discussed at the Subcommittee on prepairing an original draft of the Japanese industrial standard of germanium radiation detector in 1975.

A brief content of the IEC Publication 430 was introduced in a quarterly journal " Hoshasen (Ionizing Radiation)" published by the Hoshasen Subcommittee of the Japan Society of Applied Physics.

3.10.4 Working Committee of the Institute of Electrical Engineers of Japan on revising terminology of ionizing radiation research (E.Sakai)

As a member of the Working Committee of the Institute of Electrical Engineers of Japan, E.Sakai worked on revising the terminology related to the ionising radiation research, mainly that related to semiconductor detectors. This work will terminate in 1975 and publish a standard dictionary of terms related to the ionizing radiation research.

4. Publications and lectures

4.1 Publications

P-1 TEST PROCEDURES FOR GERMANIUM GAMMA-RAY DETECTORS (A JAPANESE VERSION OF IEC PUBLICATION 430)
E.Sakai, H.Terada, and M.Katagiri
JAERI-M 5914 / SDG 75001 (Jan. 1975) (in Japanese)

P-2 TEST PROCEDURES FOR GERMANIUM GAMMA-RAY DETECTORS (SUMMARY OF IEC PUBLICATION 430)
E.Sakai
Hoshasen (Ionizing Radiation) Vol.2 No.1 pp.83-89 / SDG 75004 (Jan. 1975) (in Japanese)

P-3 TEMPERATURE CYCLING TEST OF A HYPER-PURE GERMANIUM DETECTOR
E.Sakai, H.Terada, M.Katagiri, and H.Itoh
JAERI-M 5988 / SDG 75003 (Feb. 1975) (in Japanese)

P-4 SEMICONDUCTOR RADIATION DETECTOR
E.Sakai
Text for Radioisotope School cource " Radioisotope application and instrumentation " / SDG 75008 (Mar. 1975) (in Japanese)

P-5 GAMMA-RAY SPECTRUM MEASUREMENT IN JAPAN RESEARCH REACTOR NO.3 USING A PORTABLE Ge(Li) SPECTROMETER
E.Sakai, H.Terada, S.Suzuki, M.Katagiri, and E.Shirai
JAERI-M 6024 / SDG 75005 (Mar. 1975) (in Japanese)

P-6 PERFORMANCE OF FUEL FAILURE DETECTION SYSTEM IN SODIUM IN-PILE LOOP EXPERIMENT (III) - Preparation and out-of-pile test of fuel failure detection system -
E.Sakai, M.Katagiri, H.Terada, H.Itoh, T.Sukegawa, and K.Hirano
SJ 250 75-04 / SDG 75010 (Apr. 1975) (in Japanese)

4.2 Lectures

L-1 PORTABLE Ge(Li) GAMMA-RAY SPECTROMETER FABRICATION AND APPLICATION
E.Sakai, H.Terada, M.Katagiri, and H.Itoh
1974 Fall Meeting on Reactor Physics and Engineering of Atomic Energy Society of Japan, Paper C-17, at Kyoshu University, 17 October 1974 (in Japanese)

L-2 SOFT X-RAY MEASUREMENT IN JFT-2
N.Suzuki, K.Maeno, N.Fujisawa, E.Sakai, M.Katagiri, and H.Terada
The 30th Annual Meeting of Physical Society of Japan, Paper 2pC6, at Kyoto University, 2 April 1975,/ SDG 75007 (in Japanese)

L-3 TEMPERATURE CYCLING TEST OF A HYPER-PURE GERMANIUM DETECTOR
E.Sakai, H.Terada, M.Katagiri, and H.Itoh
1975 Annual Meeting on Reactor Physics and Engineering of Atomic Energy Society of Japan, Paper B 43/ SDG 75002, at Tokyo Institute of Technology, 3 April 1975 (in Japanese)