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Progress Report

on

Nuclear Data Activities in Pakistan

1983/84

K. Gul
Pakistan Institute of Nuclear Science and Technology
P.O. Nilore Rawalpindi, Pakistan

Report on IAEA Contract No. 3310/RB

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REPORT ON THE

IAEA CONTRACT NO: 3310/RB

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Preface

The report contains the details of the research work being carried out under the IAEA Coordinated Research Program under the contract No. 3310/RB. Main efforts were devoted to investigate the structure in the neutron emission cross-section of iron on bombardment with 14.6 MeV neutrons. The present measurements are confined to demonstration of the existence of structure in the neutron time-of-flight spectra and have been written in a suitable form for publication in a Journal. The data on the precise energy measurements of gamma-rays has not been fully analysed. Only yields of the gamma-rays relative to the yield of 847 keV gamma-rays have been calculated. Further analysis of the data is in progress.

Scattering of 14.6 MeV Neutrons from Fe
(I) Investigation of structure in neutron emission spectra

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Structure in the spectra of neutrons emitted from iron on bombardment with 14.6 MeV neutrons has been investigated and explained in terms of excitation of levels in ^{56}Fe. The energies of scattered neutrons have been measured by the time-of-flight technique based on the associated particle method. The observed excitations have been correlated with the reported levels in a satisfactory manner. Evidence for new excitations at 8.8 ± 0.2, 9.8 ± 0.1, 10.2 ± 0.1, 12.44 ± 0.03 and 12.52 ± 0.03 MeV has been obtained. The excitation of possible components of M1 giant resonance in ^{56}Fe is discussed.

[NUCLEAR REACTIONS Fe(n,n'), E_n = 14.6 MeV, measured E_n (θ = 30°, 45°, 60°), ^{56}Fe energy levels, natural target.]

I. INTRODUCTION

In our previous measurements[1] on Fe we observed structure in the neutron emission cross sections which was attributed to the excitation of different energy levels in ^{56}Fe. Although the structure was clearly observed in the neutron emission cross sections, it was not distinctly clear in the neutron time-of-flight spectra. This was partly due to the low signal to background ratio and partly due to the poor energy resolution. The present measurements have been carried out with better energy resolution and improved signal to background ratio. The measurements have been aimed at precise energy rather than cross section deter-

mination. Energy levels upto 13 MeV have been excited and identified with the reported levels in ^{56}Fe. Evidence for the excitation of 5 new levels has been observed. The states which were excited through resonance scattering of electron bremsstrahlung and were proposed to be the components of giant magnetic dipole resonance[2] have also been seen in the present measurements. While the present work was in the process of publication, Takahashi et al[3] reported structure in the neutron emission cross sections of Fe.

II. EXPERIMENTAL METHOD

The neutrons were generated through the reaction $^{2}H(^{3}H,n)^{4}He$ by bombarding an air-cooled tritium target with 120 keV deuterons. The energies of scattered neutrons were measured by the time-of-flight technique using a 3.3 meters flight path. A NE213 liquid scintillator of size 12.7 cm diameter and 12.7 cm thickness coupled to a XP1040 photo-multiplier tube was used as a neutron detector. The gamma-rays background was suppressed by using an Ortec neutron gamma-rays pulse shape discrimination system. The scattering sample was 7.6 cm in thickness and 7.6 cm in height. In order to reduce general neutron background, the neutron detector alongwith its shielding of borated wax and lead was placed in a small room built within the experimental hall. The room was built of concrete bricks having 1.2 meter wall thickness. The scattered neutrons were well collimated over a flight path of about 2.5 meters. As the neutron detector was fixed the neutron generator was rotated about the vertical axis of the scattering sample for taking neutron time-of-flight spectra at different angles. The scattered neutron time-of-flight spectra at the laboratory angles of 30°, 45° and 60° were taken. The background spectra were taken at each angle for the same long counter counts and subtracted from the sample-in spectra. A typical background spectrum is shown in figure 1. The background subtracted neutron time-of-flight spectra at the three angles are shown in figures 2-4. The spectra were acquired on a 85 series Canberra Multichannel Analyzer and 3-point smoothing was carried out for the spectra.

III. ENERGY CALIBRATION AND ENERGY RESOLUTION

The timing calibration of multichannel analyser was done by using standard Ortec and Canberra delays. A time dispersion of 0.417 nano-second per channel was used. The incident energy of the neutrons was obtained from the kinematics of the neutron producing reaction and the neutron time-of-flight spectra of ^{12}C. The incident energy thus determined was 14.60 ± 0.03 MeV. The timing resolution of our system was about 7 channels amounting to 3.1 nano-seconds. The flight path being 3.3 meters, it amounts to about 0.9 nano-second per meter. As the incident energy of deuteron beam is 120 keV, the lowest limit of the energy dispersion is ± 60 keV for thick targets and it is less for thin targets. The energy resolution ΔE(MeV) is related to the timing resolution by the following expression:

$$\Delta E = \frac{E^{3/2}}{36.2} \times \frac{\Delta t}{d}$$

where E is the energy of a neutron in MeV, Δt is the timing resolution in nano-seconds and d is the flight path in meters.

IV. DISCUSSION

A detailed information on energy levels of ^{56}Fe has been reported by Auble[4]. More states at 6.927, 7.212, 8.131, 8.243, 8.538, 10.479 and 11.133 MeV have been reported by Kumagai et al[2] through resonance scattering of electron bremsstrahlung and these states have been suggested to be components of giant M1($T_<$) resonance resulting from excitation of the particle-hole states of the form $[1f^{-1}_{7/2}\, 1f^{1}_{5/2}]_{1^+}$. Alford et al[5] have reported levels at 5.3, 6.55, 8.150 and 9.240 MeV through(^3He,n) reaction on ^{54}Cr which are in agreement with the energy levels reported by Evers et al[6]. These states are two proton excitations from the ground state of ^{56}Fe. Ahmad et al[7] have measured energies of several states through (p,γ) and (p,n) reactions on ^{55}Mn. These states have isospin value T = 3 and are analogue of the low lying states in ^{56}Mn. The first T = 3 state in ^{56}Fe which

is the analogue of the ground state of ^{56}Mn occurs at 11.509 MeV. In the region of high excitations, only selective states are picked up through different types of reactions. It is well established that 14.6 MeV neutron scattering takes place predominantly through direct nuclear reaction mechanism. The states which have wave functions similar to that of ground state are preferentially excited through direct inelastic scattering reaction because the contribution of the overlap integral to the DWBA cross section is significant. Therefore the T = 3 states in ^{56}Fe which are analogues of the low lying states in ^{56}Mn are expected to be preferentially excited. The direct excitation is also known to give an essential contribution to the reaction mechanism in neutron scattering on low lying collective states in the target nucleus[8]. Therefore the 4.51(3^-)MeV one phonon octupole state and one phonon states such as 3.12(4^+)MeV state in ^{56}Fe are expected to be selectively excited. For the convenience of the discussion we divide the entire region of excitation into the following three energy regions.

A. 0-8 MeV excitation region

This energy region contains a considerable number of levels. The energy resolution being poor, it is difficult to resolve energy levels completely. Moreover, due to rapid intensity variations of the angular distributions, different levels dominate at different angles. Therefore, an exact identification of levels at different angles is rendered difficult. However, it is possible to compare the present measurements with previously reported measurements based on nucleon scattering of about the same energy. Peterson[9] reported measurements of 17.5 MeV protons from iron at 65°. Takahashi et al[3] reported measurements of 14 MeV neutrons from iron at 45°. Peterson[9] observed strong excitation of the 4.51 MeV state which has a spin-parity value of 3^- and is regarded as one phonon octupole vibration. Takahashi et al[3] have reported an excitation of 4.59 MeV which they have identified with the 4.51 MeV state. We also see a strong excitation at 4.5

± 0.1 MeV that could be identified with the discussed 4.51 MeV state though contribution from the near by levels cannot be ruled out. Between the two prominent neutron groups that correspond to the ground state and the 4.51 MeV state, we see a neutron group that corresponds to 3.2 ± 0.2 MeV which is in good agreement with the 3.23 MeV neutron group reported by Takahashi et al[3]. The 3.2 MeV excitation observed by us possibly corresponds to the strongly excited 3.12 MeV state which has the spin parity value of 4^+ and is reported by Peterson[9]. At 30° where the intensity of neutron group corresponding to the 4.51 MeV state is low, we clearly see the presence of a neutron group that corresponds to an excitation of 5.3 ± 0.2 MeV which is in good agreement with the energy of 5.29 MeV reported by Takahashi et al[3]. This group of neutron may correspond to the unresolved groups of protons resulting from the excitation of 5.15 and 5.26 MeV doublet seen by Peterson[9]. The 6.1 MeV excitation observed by us is also in good agreement with the excitation of 6.09 MeV reported by Takahashi et al[3]. The 6.5 MeV excitation reported by Takahashi et al[3] is also in good agreement with the 6.5 MeV excitation observed in the present measurements and possibly corresponds to the 6.48 MeV state observed by Peterson[9]. We see neutron groups corresponding to excitations at 6.9 ± 0.1 and 7.3 ± 0.1 MeV which are not completely resolved. Takahashi et al[3] also see a neutron group that corresponds to 6.9 MeV excitation. Kumagai et al[2] have reported excited states at 6.927 and 7.212 MeV which could be identified with the 6.9 and 7.3 MeV excitations observed in the present measurements.

B. 8.0 - 11.509 MeV energy region

In the 8.0 - 11.509 MeV energy region, the number of reported levels is small. We see a neutron group that corresponds to an excitation of 8.3 ± 0.2 MeV which could contain contributions from the 8.131, 8.243 and 8.538 MeV states reported by Kumagai et al[2]. The only other levels at 8.150 and 9.240 being formed by two protons excitation from the ground state of ^{56}Fe cannot

be expected to contribute significantly. We see a neutron group that corresponds to 9.1 MeV which probably corresponds to the level at 9.14 MeV reported by smith and Segeth[10]. We also see neutron groups that correspond to excitations at 10.5 and 11.13 MeV which could be identified with the only two levels at 10.478 and 11.133 MeV reported by Kumagai et al[3]. The excitation of different suggested components of giant M1($T_<$) resonance in the present measurements may be due to the prediction of Cecil and Peterson[11] for the enhancement of excitation of giant magnetic dipole resonance ($T_<$) through neutron scattering. In this energy region we see neutron groups which correspond to excitations at 8.8 ± 0.2 and 9.80 ± 0.1 and 10.2 ± 0.1 MeV that have not been reported so far.

C. The 11.509 - 12.8 MeV energy region

In this energy region several levels in ^{56}Fe which are the analogue of the low lying states in ^{56}Mn have been reported by Ahmad et al[7] through (p,γ) and (p,n) reactions. The energy resolution improves considerably for the lower energy neutron groups and we see clearly well resolved neutron groups. All the reported states that could be resolved have been identified and labelled with the energy values reported by Ahmad et al[7]. The expected positions of reported levels have been indicated through their energy values measured by Ahmad et al[7]. This has facilitated the correlation of the three spectra and the identification of observed levels with reported levels. Two new states in ^{56}Fe not reported before have been very clearly seen: The level 12.520 ± 0.03 MeV has been seen at the three angles whereas the level 12.440 ± 0.03 has been seen only at the angles 45° and 60°.

The Q-value for (n,2n) reaction on ^{56}Fe being 12.2 MeV, one would expect interference from neutron groups corresponding to different accessible excitations in ^{55}Fe, with those resulting from excitations above 12.2 MeV in ^{56}Fe. The contributions of neutron groups from the ground state and excited states at 0.411, 0.941, 1.317 and 1.408 MeV in ^{55}Fe have been taken into

account and the corresponding expected positions have been indicated in the neutron time-of-flight spectra. There is some contribution of the neutron group resulting from the excitation of 1.317 MeV state in ^{55}Fe to the observed neutron group that corresponds to the unreported level at 12.52 MeV. There is also a visible contribution from (n,2n) reaction on ^{56}Fe leading to the ground state of ^{55}Fe, to the neutron group of 11.133 MeV state in ^{56}Fe at 30°.

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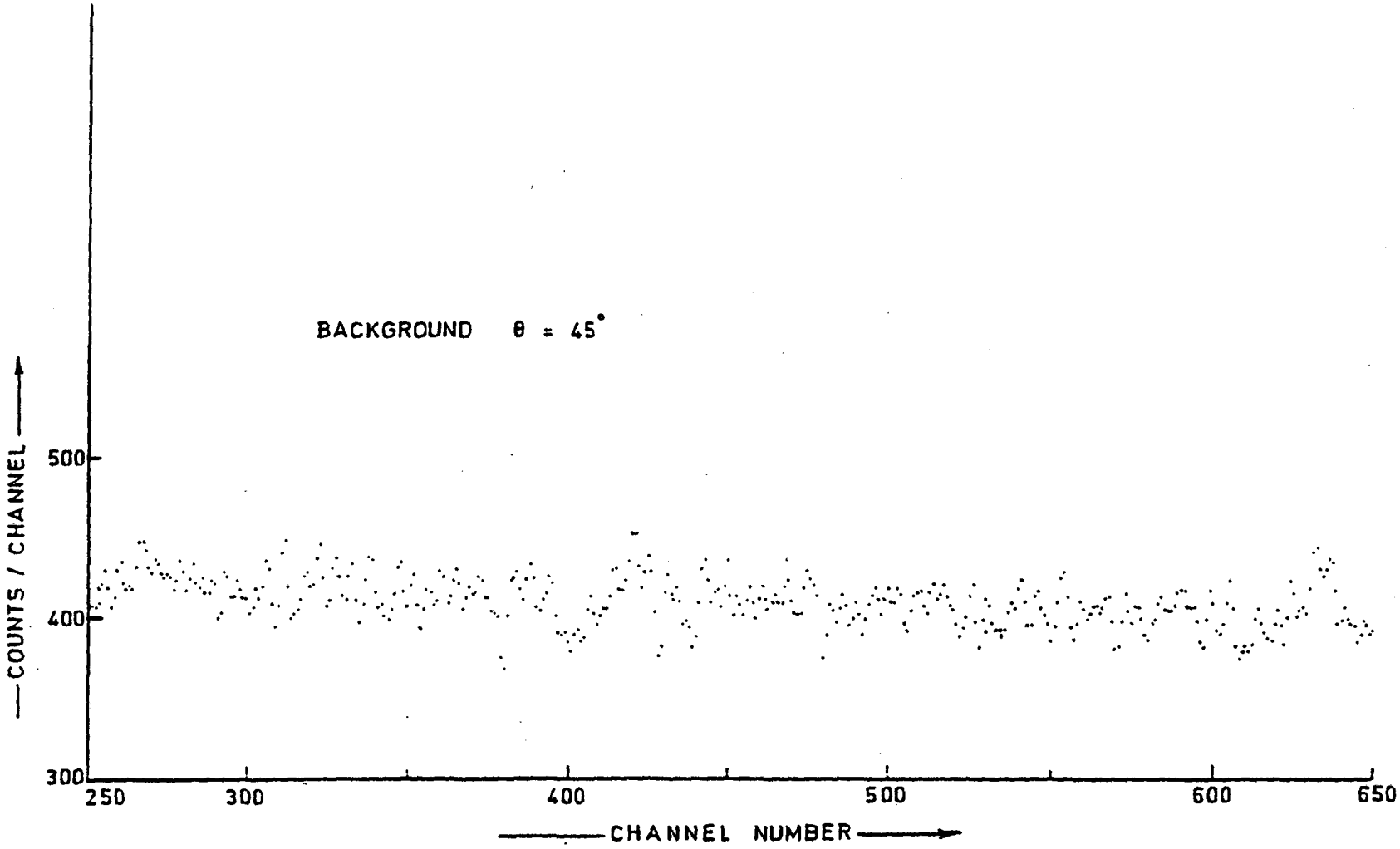

Figure 1. Neutron time-of-flight background spectrum at angle 45°.

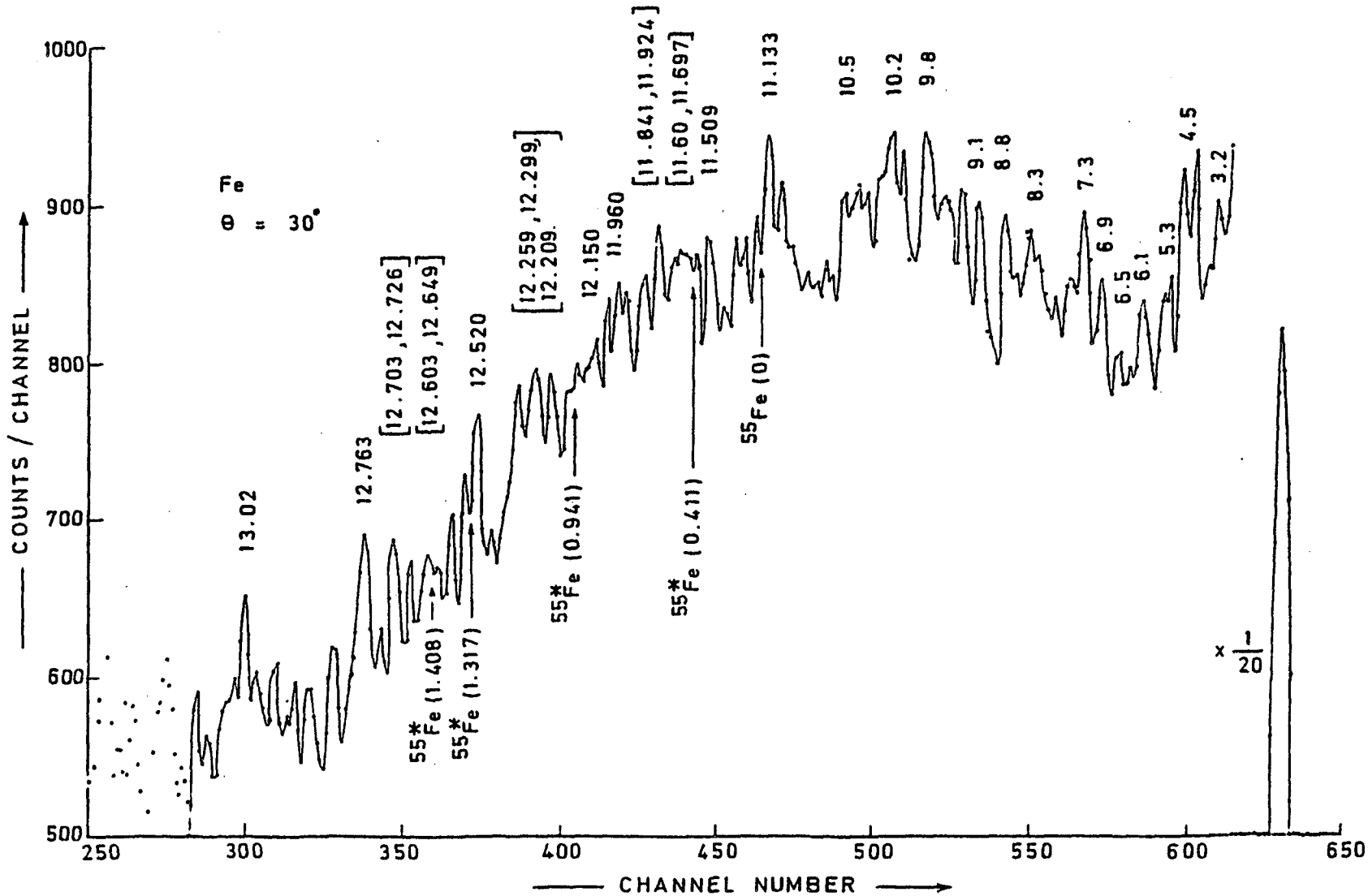

Figure 2. Background subtracted neutron time-of-flight spectrum at angle 30°.

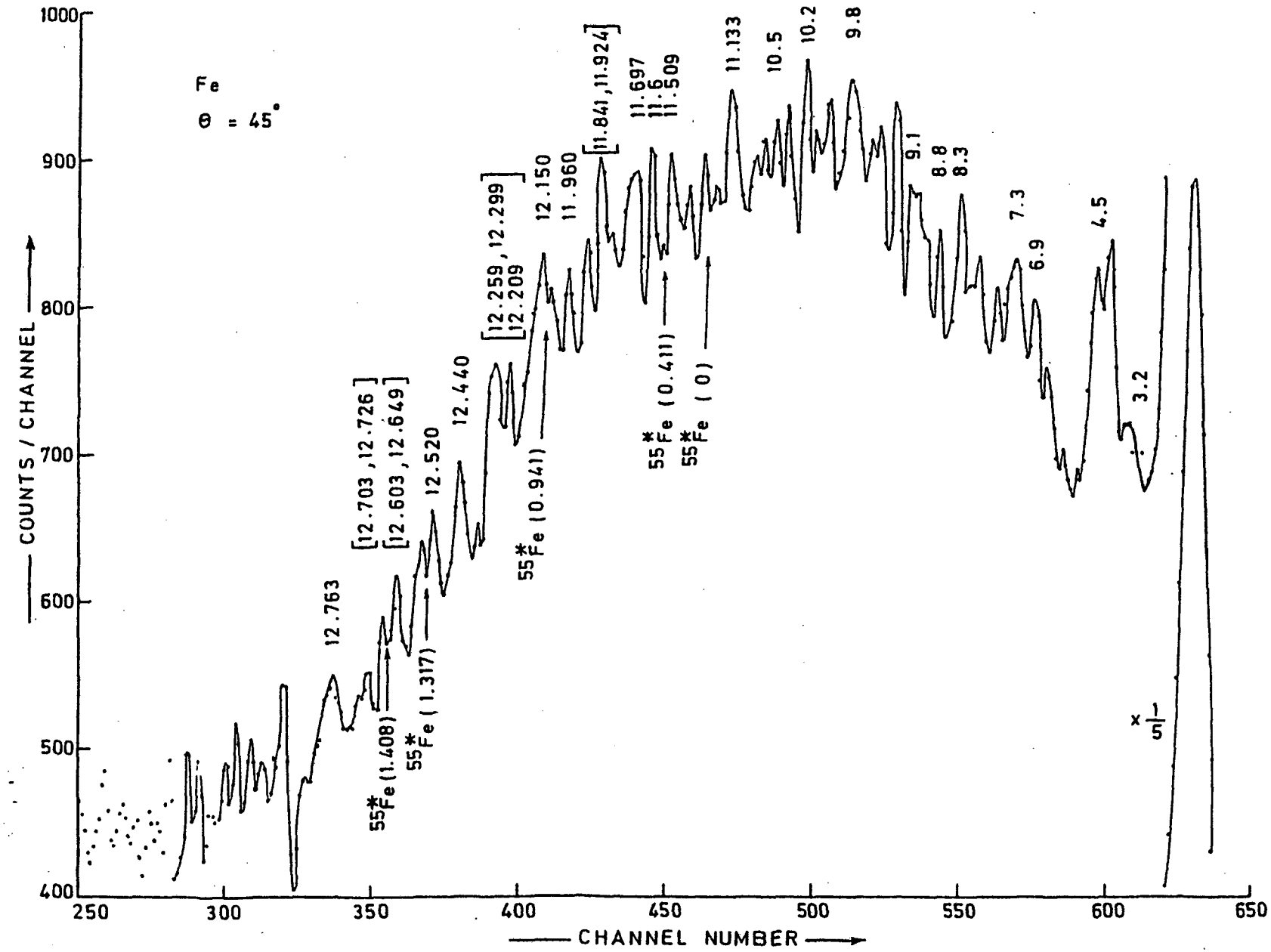

Figure 3. Background subtracted neutron time-of-flight spectrum at angle 45°.

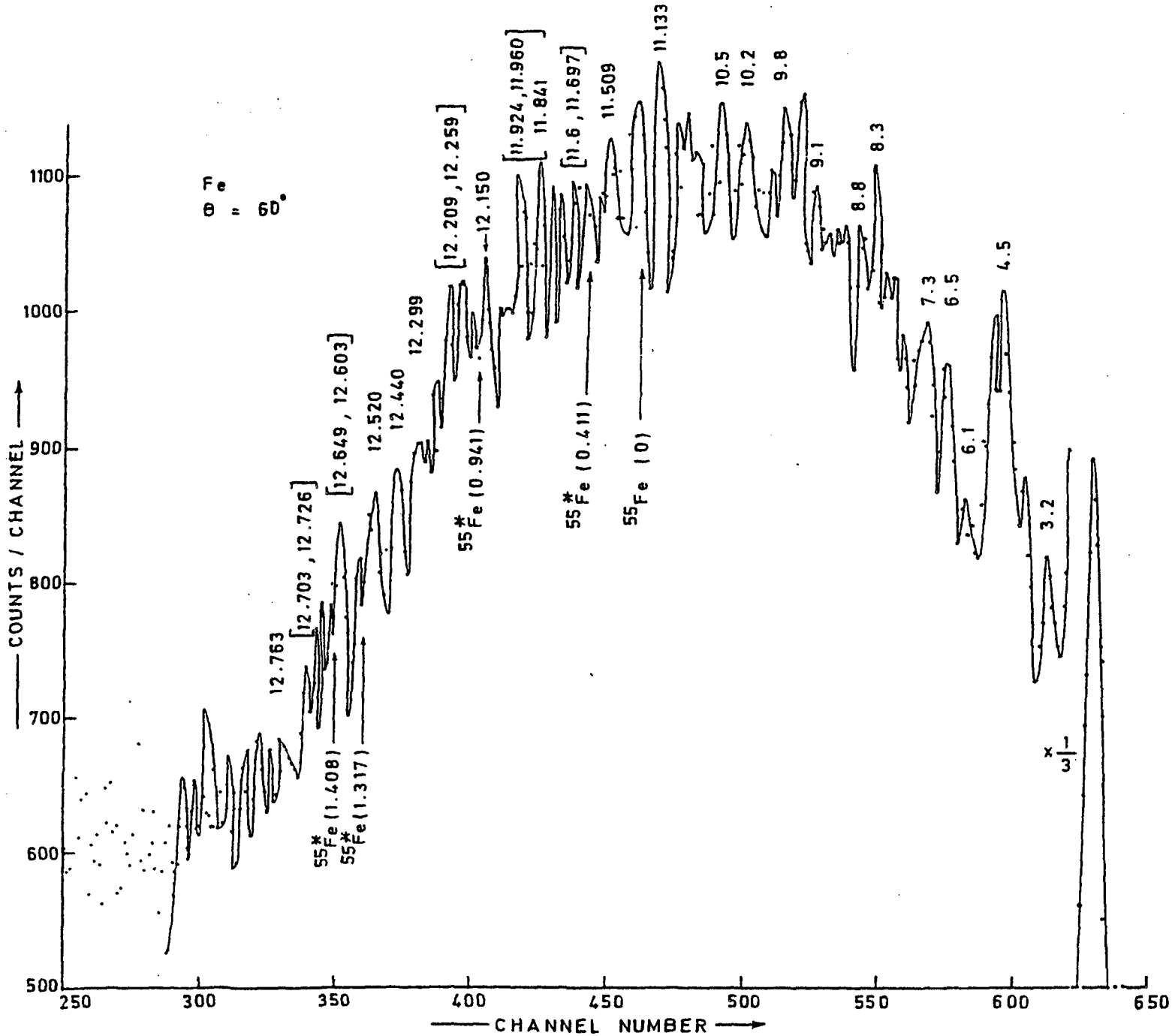

Figure 4. Background subtracted neutron time-of-flight spectrum at angle 60°.

MEASUREMENT OF YIELD OF GAMMA-RAYS EMITTED FROM IRON ON BOMBARDMENT WITH 14.7 MeV NEUTRONS

K.Gul, M.Ahmad, S.M. Saleem, M.Anwar and Naeem A. Khan

Introduction

The knowledge of production of gamma-rays from Fe on bombardment with 14.7 MeV neutrons is desirable both from nuclear physics and applied point of view. Iron is to be used as a structure material in Fusion reactors which involve interaction of 14.6 MeV neutrons. Moreover the precise knowledge of gamma-rays and their yields also helps in knowing the energy levels and their decay scheme. The present work describes the measurements of energies of gamma-rays and their yields from Fe relative to the yield of 847 keV gamma-rays emitted from the deexcitation of 847 keV (2^+) level in ^{56}Fe.

Experimental Details and Results

The energies of gamma-rays were measured by a 100 cc Ge(Li) detector. The detector was placed in an apartment of 1.2 meters thick wall constructed of concrete bricks. All Gamma-rays in the energy range 400 keV to 10 MeV were recorded on a 85 series Canberra multichannel analyser. Gamma-rays background was taken by removing the sample and subtracted from the sample-in spectrum. A part of the spectrum is shown in figure 1. The yield of gamma-ray alongwith the energies is shown in Table 1. The efficiency of the Ge(Li) detector was measured[1)] in a seperate experiment on the 5 Mega-Watt research reactor at Pinstech using the reaction $^{35}Cl(n,\gamma)^{36}Cl$, and $^{14}N(n,\gamma)^{15}N$ and (n,γ)reaction on Cr. The yield of the gamma-rays have been corrected for the attenuation of emitted gamma-rays in the iron sample. For comparison the

reported measurements of Lachkar et al[2)] are also given in the table 1. The agreement between the present measurements and the reported measurements is quite satisfactory. Further analysis of the data is in progress.

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Table 1: Yield of gamma-rays relative to 847 keV gamma-ray from Fe on bombardment with 14.7 MeV neutrons and their comparison with reported values[1].

Energy (keV)	Present measurement	Reported measurement
438	1.6 + 0.4	
475	1.9 + 0.5	
567	1.0 + 0.4	
698	9.4 + 0.6	
847	100.0 + 0.8	100
931	10.7 + 0.6	
1010	1.3 + 0.4	
1038	10.4 + 0.9	10.5 ± 1.6
1175	1.1 + 0.4	
1238	50.1 + 2.5	49.3 ± 12.1
1310	16.5 + 0.5	
1360	1.2 + 0.3	
1408	3.1 + 0.3	
1581	0.5 + 0.3	
1670	3.8 + 0.3	
1728	0.4 + 0.3	
1775	1.3 + 0.2	
1811	9.3 + 0.7	7.6 ± 1.2
1861	0.4 + 0.3	
2035	2.4 + 1.2	
2113	1.7 + 0.3	
2217	2.5 + 0.3	
2273	1.2 + 0.3	
2374	0.5 + 0.3	
2425	0.8 + 0.3	
2469	0.6 + 0.2	
2526	2.4 + 0.3	
2599	4.6 + 0.6	4.6 ± 0.9
2759	1.5 + 0.4	
2956	0.9 + 0.3	
2985	0.8 + 0.2	
3063	0.8 + 0.2	
3203	1.0 + 0.4	
3254	1.5 + 0.4	
3450	1.2 + 0.3	
3554	0.4 + 0.3	
3612	1.6 + 0.3	
3663	1.0 + 0.4	
3835	1.0 + 0.5	
5095	0.9 + 0.4	
6747	0.9 + 0.4	
7091	0.7 + 0.4	
8800	0.6 + 0.3	

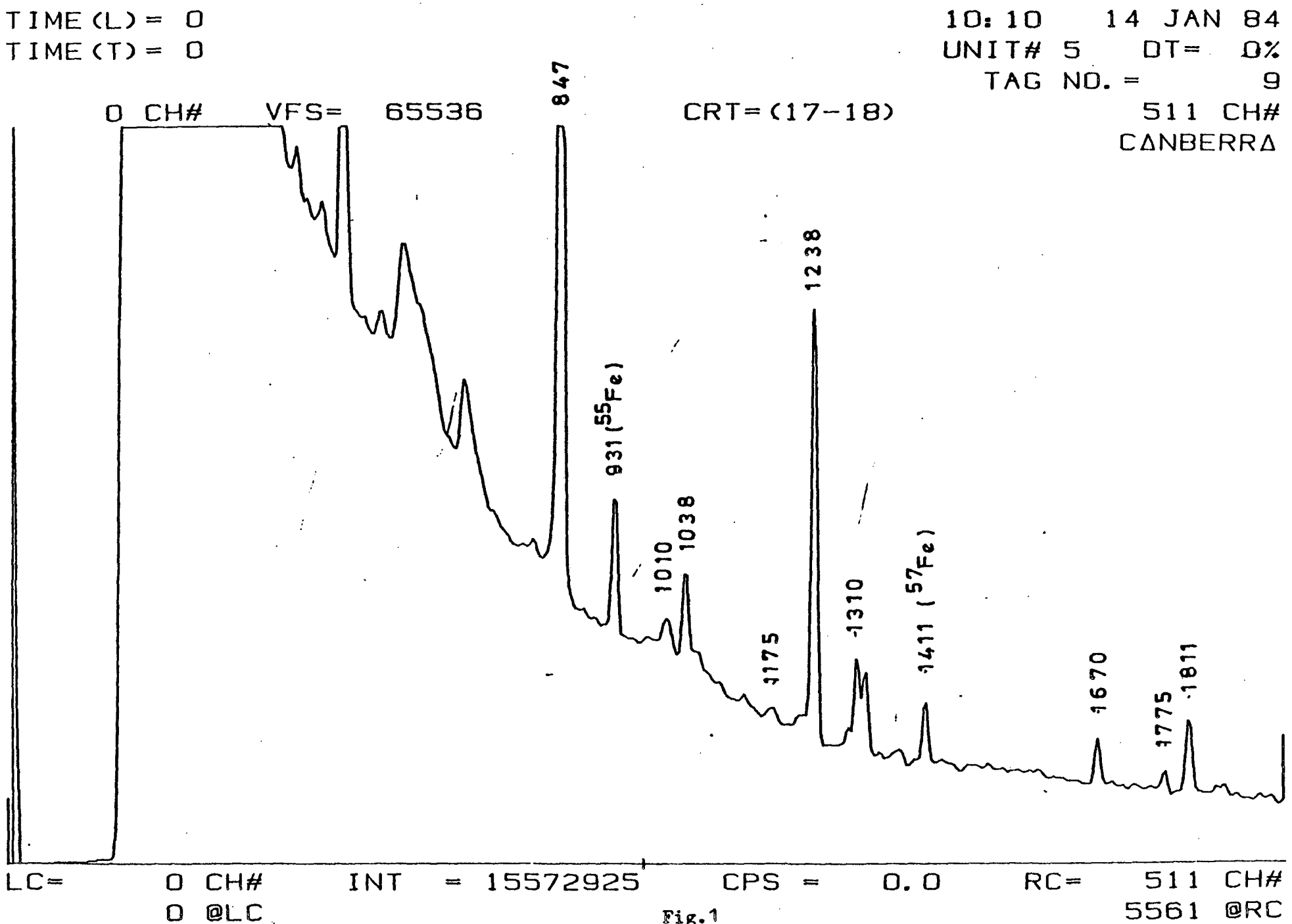
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Fig.1

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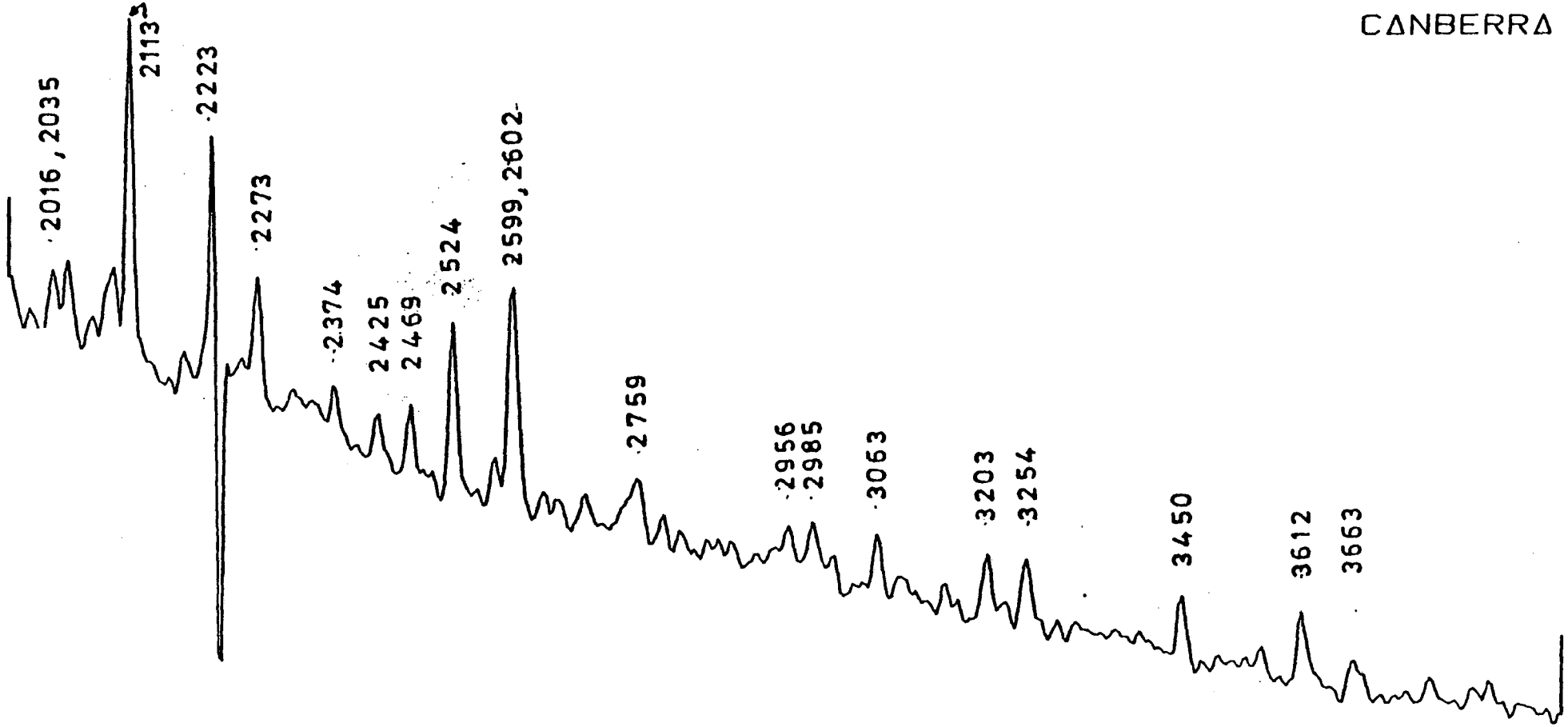

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Fig.1 (continued)