Testing a Neutron-Activated NaI Detector as a Low-Energy Calibration Device for SNO

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Following up on an idea from Queen's University, we have performed a series of tests to study the possibility of using a neutron-activated sodium iodide detector to serve as a low-energy calibration device for SNO. The basic idea of such a system is to use the decay of ^{24}Na ($t_{1/2}$ = 15 hours) inside a sodium iodide (NaI) detector to produce tagged gamma rays of 1369 and 2754 keV as energy calibration points for SNO. As can be seen from Figure 1, the ^{24}Na decay scheme consists almost entirely of a beta decay (endpoint energy = 1390 keV) followed by these two prompt gamma rays. If the ^{24}Na decay occurs inside a NaI crystal, then the beta particle will be detected with nearly 100% efficiency. The gamma rays will sometimes be absorbed in the NaI detector and will sometimes escape. The fraction of gammas that escape obviously depends on the size of the NaI crystal used. Under normal running conditions in SNO, it is expected that it would not be possible to see 1369- or 2754-keV gamma rays because of the large background rate in this energy range. However, if one were to place an activated NaI detector into the SNO water (either D_2O or H_2O) and use the signal from the NaI detector as a tag, then one could use the SNO photomultiplier tubes to measure the Cerenkov light produced in the water by the 1369- and 2754-keV gamma rays.

For our tests, we took a BICRON Corp. 7.62-cm x 7.62-cm NaI detector and placed it in a plastic bag. To the surface of this bag, we taped two 56 mCi ^{241}Am-Be neutron sources. Each of these sources emits approximately 1.7×10^5 neutrons/second. We allowed the neutrons to irradiate the NaI detector for a period of approximately 90 hours. After this time, we removed the neutron sources and set up the NaI detector for use with an ORTEC PC-based portable multichannel analyzer system.

From the NaI detector, we initially observed a very clean beta spectrum with an endpoint of approximately 2 MeV. This beta spectrum decayed away with a half-life of approximately 25 minutes. Thus (as expected), this activity was ^{128}I produced via the $^{127}I(n,\gamma)$ reaction inside the NaI detector. After waiting several hours, a spectrum with a much higher endpoint and a longer half life emerged. A spectrum accumulated from 24 hours of counting the activated NaI detector is shown in Figure 2. This spectrum is that of ^{24}Na produced via the $^{23}Na(n,\gamma)$ reaction inside the NaI detector. One can clearly see the beta spectrum extending up to about 1.3 MeV. Background gamma ray lines at 511 and 1461 keV are also seen. Above the beta endpoint, one sees peaks at 1369 and 2754 keV. These ^{24}Na gamma rays were obviously not detected in coincidence with beta particles. Hence they must be produced by ^{24}Na decays that occurred either near the edge of the NaI crystal or in the aluminum can of the detector where ^{24}Na can be produced via the $^{27}Al(n,\alpha)$ reaction. One also sees several continuous spectra with apparent endpoints near (a) 2.7 MeV , (b) 4.0 MeV , and (c) 5.5 MeV. These arise from ^{24}Na decays in which we caught the beta in the NaI detector and in addition (a) the 1369 keV γ ray, (b) the 2754-keV γ ray, (c) both the 1369- and 2754-keV γ rays.

We then set up a 110-cm^3 high-purity germanium detector and placed it up against the activated NaI detector. Figure 3 illustrates the types of events which can occur with such a system of detectors. By operating the germanium detector in singles mode, we clearly observed the 1369- and 2754-keV gamma rays escaping from the NaI detector. We then used a single-channel analyzer to set gates on different energy regions of the ^{24}Na spectrum observed in the NaI detector and measured the gamma-ray spectrum in coincidence in the germanium detector. Figure 4 shows the spectrum of γ rays observed in the germanium detector in coincidence with a signal in the NaI detector between 0.15 MeV and 1.0 MeV. Again, we clearly see both the 1369- and 2754- keV γ rays. Figure 5 shows the spectrum seen in the germanium detector in coincidence with a signal in the NaI detector above 2.8 MeV. The only way to get such a large amount of energy in the NaI detector is if both the beta and the 2754-keV γ ray are detected. Thus one should see only the 1369-keV γ ray in the coincident germanium spectrum . This is just what we see. Thus, one can vary the ratio of 1369-keV to 2754-keV γ rays observed in the germanium detector by changing the energy region in the NaI detector where the gate is set. Table 1 lists the values of this ratio observed as a function of the energy gate set on the NaI detector.

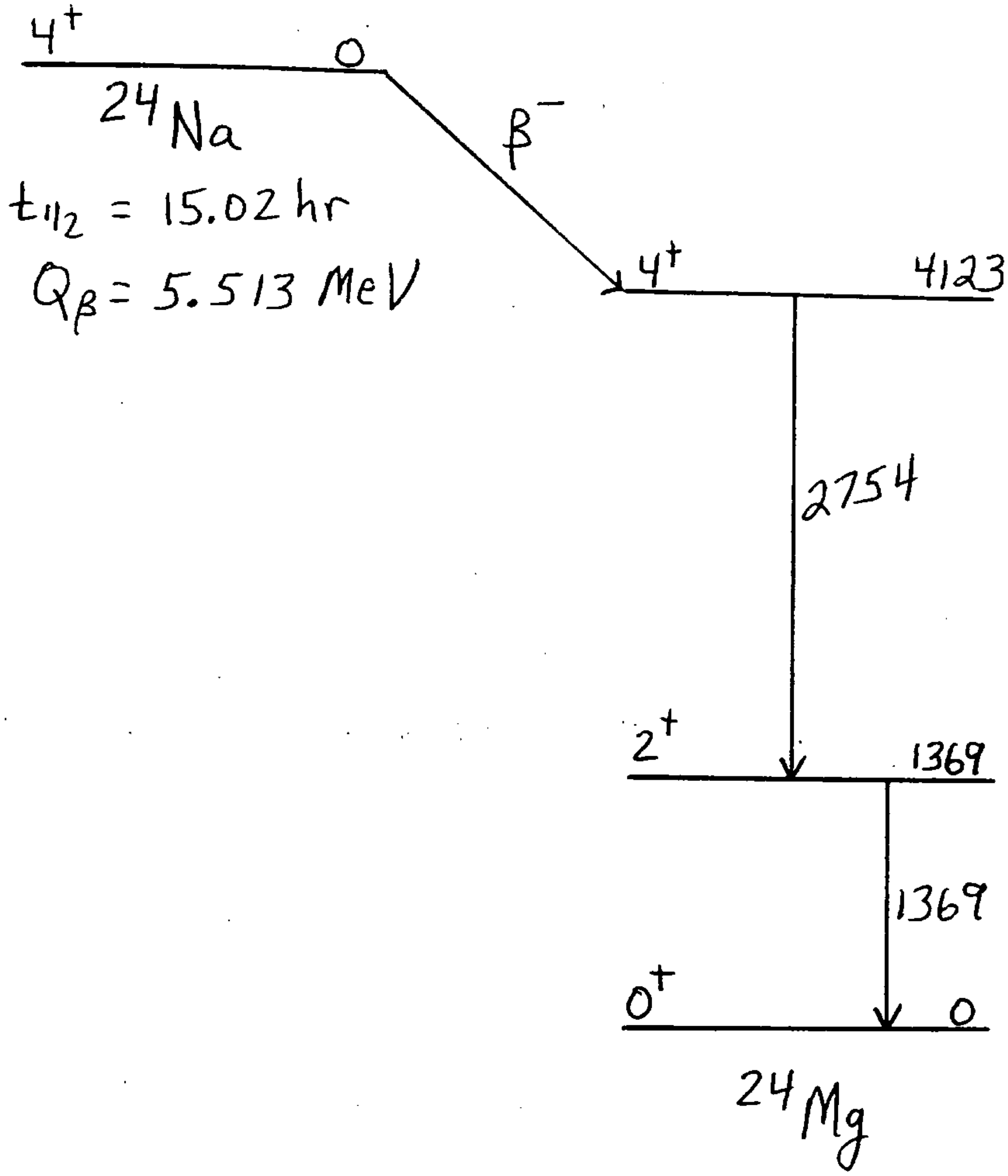
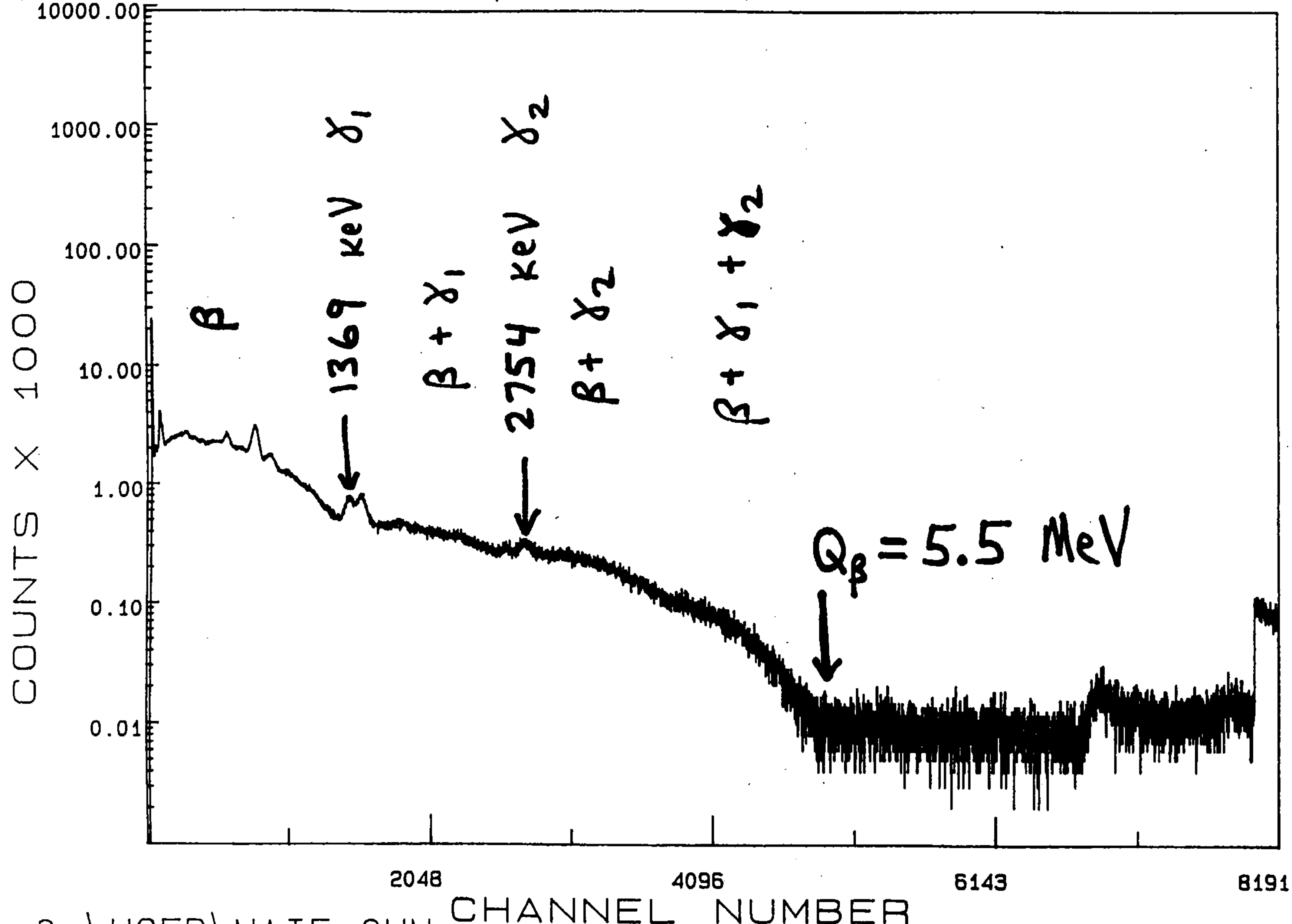


Fig. 1

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
REALTIME = 86512.22 SECONDS, LIVETIME = 86400.00 SECONDS
DATA COLLECTED AT 12: 15: 16 ON 08-Sep-93

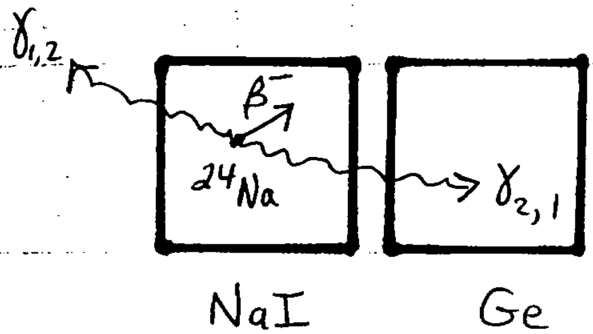
Spectrum of ^{24}Na observed in activated NaI detector



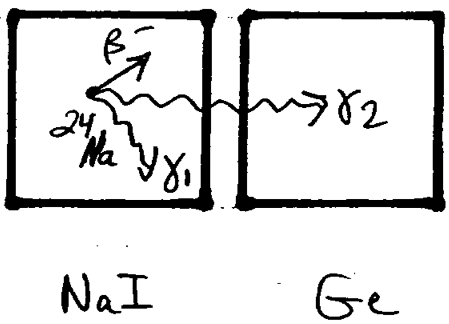
C: \USER\NAI5.CHN

Fig. 2

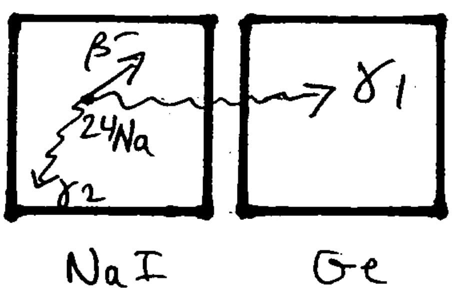
Neutron-Activated NaI Detector



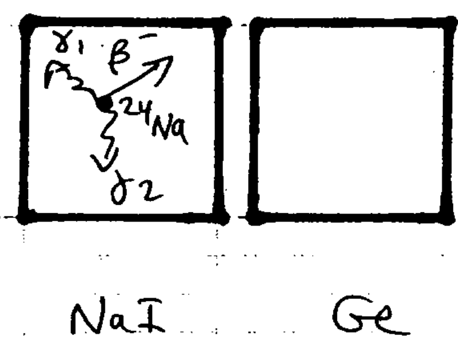
See *either* 1369 or 2754 in coincidence in Ge



See *only* 2754 in coincidence in Ge



see *only* 1369 in coincidence in Ge

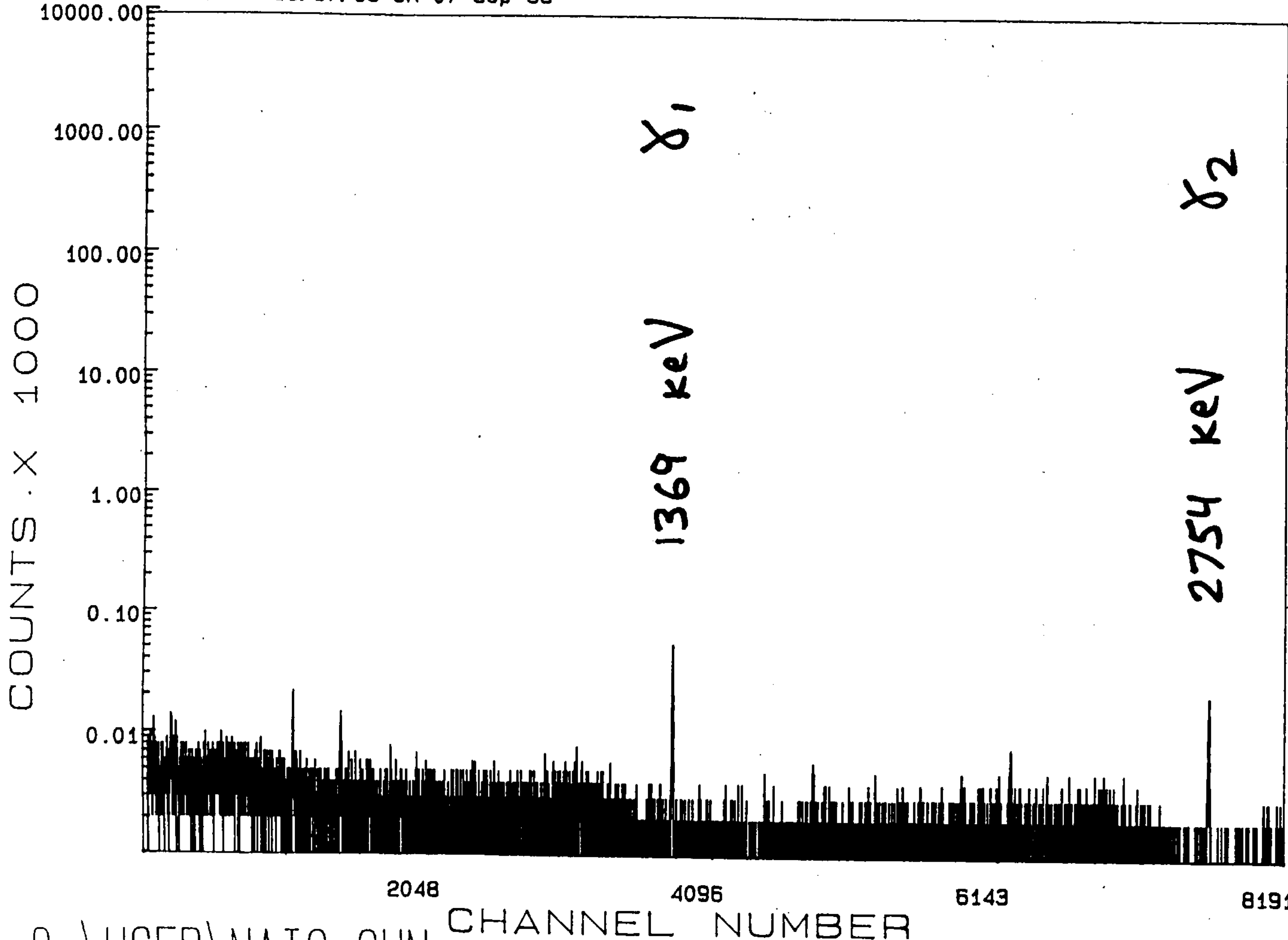


see *no coincidences*

$$E_{\beta_{max}} = 1390 \text{ keV}$$

Fig 3

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
REALTIME = 3718.50 SECONDS, LIVETIME = 3600.00 SECONDS
DATA COLLECTED AT 15: 17: 18 ON 07-Sep-93

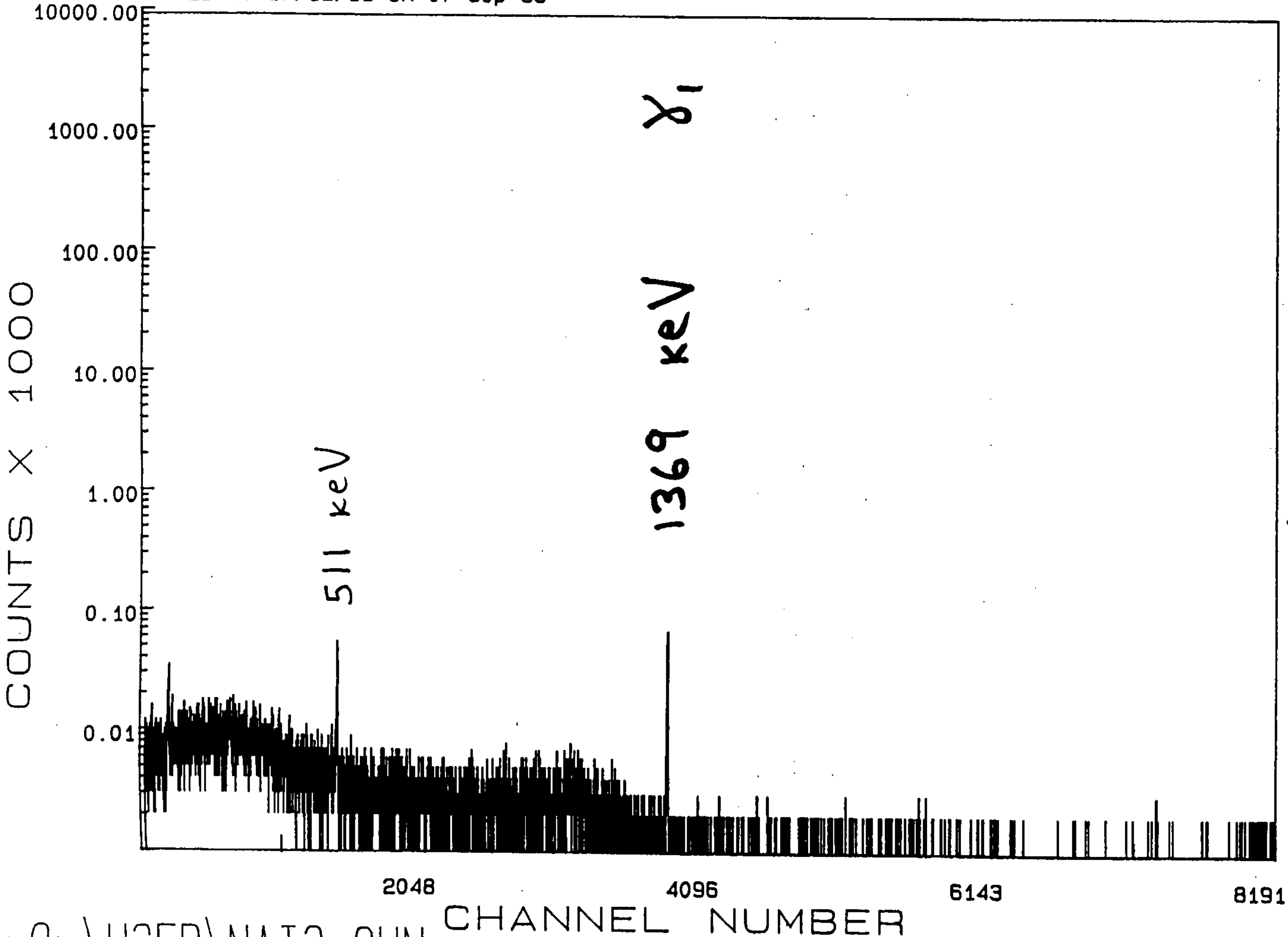


Spectrum of 24 Na observed in external germanium detector in coincidence with signal 0.15 ≤ E ≤ 1.0 MeV in NaI detector

C:\USER\NAI2.CHN

Fig 4

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
REALTIME = 57117.86 SECONDS, LIVETIME = 52068.78 SECONDS
DATA COLLECTED AT 17:12:53 ON 07-Sep-93



Spectrum of ^{24}Na observed in externa germanium detector in coincidence with signal ≥ 2.8 MeV in NaI detector

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Table I.

NaI Gate Condition	$\frac{N_\gamma(1368)}{N_\gamma(2754)}$ Seen in Ge Detecto
No Gate (ie. Ge singles only)	1.80 ± 0.10
$0.15\ \text{MeV} \leq E_{NaI} \leq 1.0\ \text{MeV}$	1.69 ± 0.14
$1.0\ \text{MeV} \leq E_{NaI} \leq 2.8\ \text{MeV}$	1.97 ± 0.24
$2.8\ \text{MeV} \leq E_{NaI}$	≥ 277