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DETECTOR

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S. Wald, and P.J. Countryman

February 1984

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A Two-Dimensional Position-Sensitive Phoswich Detector

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Abstract

A two-dimensional position-sensitive ΔE -E phoswich detector, 20 cm x 20 cm, was built using the fast plastic scintillator NE 102A for the thin (0.5 mm) ΔE element, and the new, slow plastic scintillator NE 115 (measured light output 35% of anthracene, decay time 225 nsec) for the thick (4.5 mm) E element. Natural light loss arising from multiple reflections at an irregular surface is responsible for the position dependence of the signals. The position resolution was found to be typically 10 mm (FWHM) in each direction. The detector is able to identify protons, deuterons and alpha particles, and exhibited an energy resolution of 5 to 6% (FWHM) and a time resolution of 580 psec (FWHM) in a test using 60 MeV alpha particles scattered from a gold target.

1. Introduction

Many experiments in heavy-ion physics involve coincidence measurements between heavy ions and light particles. In these experiments it is desirable to have detectors covering a large solid angle. Often a silicon telescope (with necessarily small area) is used for the heavy ions together with a large-area counter for the light particles (p,d,t,He). A recent example of this, and the reason for developing the present detector, is the "plastic box" [1], which consists of a cubical array of plastic scintillators covering nearly 4π solid angle, and which is presently used in conjunction with a $\Delta E - E$ silicon telescope for the projectile-like fragments. A wall of the cube consists of two independent scintillator paddles, 20 cm x 20 cm x 1 mm, positioned directly behind each other and 10 cm from the target. Identification of penetrating particles could be made in principle by recording the light output from each scintillator. The proximity of the paddles to the target and resultant large variation in energy loss for particles with different angles of incidence, however, hampered this identification. Furthermore, no information was available on the location of any incident particle and knowledge of the angle of emission was thus limited to knowing which of six walls detected the particle.

It was decided, therefore, to develop a scintillator detector with position sensitivity, as this would remedy simultaneously both of these problems. A boundary condition was that the new detector should replace one of the walls of the plastic box. This fixed the size to 20 cm x 20 cm.

The result, described in the following, is a ΔE -E "phoswich" detector having an xy position resolution of $\sim 1\text{cm}^2$, much improved particle identification, and energy and time resolutions of 5 to 6% and 580 ps, respectively, for 60 MeV α particles. Interesting features of this detector are the use of plastic scintillator material for both the ΔE and E elements of the phoswich, and position sensitivity derived from light losses arising naturally from multiple internal reflection. The detector, although designed for use with the plastic box, has a wide range of applications in coincidence experiments requiring a highly efficient detection and identification of light particles.

Section 2 describes the determination of the position of the incident particle. The design and construction of the phoswich are considered in section 3. The use of a newly available scintillator material, NE 115, is described there along with the light transmission, detection, signals, and electronic gating. Section 4 gives the results of test measurements with 60 MeV alpha particles. Following the summary in section 5, the appendix describes measurements of the light output and decay of NE 115.

2. Position sensitivity

There have been relatively few applications of scintillators in which position sensitivity is achieved with a small number of phototubes [2]. Two methods have been used and they are based on the time of flight for light signals to each end of a detector or on the ratio of light intensity received at each end of the detector. In the case of the time-of-flight method, position resolution has been limited to 2-3 cm.

While this method is well suited for detectors with the long dimensions [3] typically found in high energy experiments, the relatively small size (20 cm x 20 cm) of the present detector makes this method unsuitable.

Position sensitivity through light attenuation has been achieved by introducing a light absorbing material into the scintillator [4]. This additional attenuation, however, reduces the light output and results in poor energy and time resolution. Similarly, the surface of a scintillator may be treated to reduce internal reflection, increase light loss, and achieve position sensitivity [5].

We have observed that, for a thin sheet of scintillator, the light collected at a photomultiplier viewing the thin cross section depends sensitively on the distance from the light source to the photomultiplier.

Fig. 1 shows the light output (in photoelectrons) as a function of position for two strips, 20 cm x 2 cm x 1 mm and 20 cm x 2 cm x 5 mm. One end of each strip was coupled directly to a photomultiplier tube (RCA 8850). The theoretical maximum number of photoelectrons was estimated to be around 210, assuming (i) an initial production of 4800 photons by 5.5 MeV alpha particles stopping in NE 102, (ii) a value of 0.18 for the fraction of the light within the total reflection cone, and (iii) a mean quantum efficiency of 24% for the phototube. This is in good agreement with the measurements made with the alpha source positioned ~ 1 cm from the phototube.

Light absorption in the material cannot be responsible for the decrease in signal as the distance increases. Since the maximum length of 20 cm is still more than an order of magnitude less than the attenuation length, the expected variation in output would be only a few

percent. Light attenuation through absorption will therefore be neglected in further considerations.

An ideal scintillator (fig. 2) would not attenuate light that is within the critical angle for total internal reflection and would have a light output independent of position. Actual scintillators, however, have a surface that is rough on a microscopic scale. Light can scatter out of the material, therefore, even if it is within the critical angle for a smooth surface. The angle of propagation with respect to the surface thus fluctuates, increasing the probability that light rays initially close to the critical angle will be lost. Since the number of internal reflections varies directly with the distance of the light source from the photocathode, the light collected is position dependent.

These considerations have been incorporated into a simple model for the dependence of light output on position. In this model the irregular surface of the scintillator is replaced with a smooth surface having a reflection coefficient R that varies with the angle of incidence. In an ideal scintillator the value of R would be unity for all angles between 0° and the critical angle of $\sim 50^\circ$. In the model, R varies linearly between 1 for 0° and $R = R_C < 1$ for the critical angle. At large angles, R is zero. Thus for a given ray with an angle of incidence θ , the light collected at the end of the scintillator is just $[R(\theta)]^{n(\theta)}$ where $n(\theta)$ is the number of internal reflections needed to reach the end. Since for a given light source, many angles of incidence will contribute to the total light collected, we expect the position dependence to be described by a superposition of exponential functions with different arguments. Calculations of the integrated light collection were made with the Monte Carlo method.

The results of these calculations are shown by the dashed lines in fig. 1. A value of $R_C = 0.8$ was used for both the thin and thick strips. Using different values for each strip would improve the agreement with the data. Since the value of R depends on the detailed nature of the surface it might be expected to vary with scintillator material and possibly from sample to sample. Nevertheless, the quantitative differences in the position-dependence of the thin and thick samples are well reproduced.

The present model is adequate for an understanding of the origin of position dependence and for use in optimizing the design of the mirrors at the edges (see section 3). Clearly, additional factors could be studied even with this very simple model: the effect of different light source geometries, the variation with position of the total light collected at both ends, and the addition of a light pipe between scintillator and phototube, for example. More sophisticated Monte-Carlo treatments of the irregular surface and the variation of R with θ can also be envisioned, but are beyond the scope of the present work.

The effect of adding a light guide between phototube and scintillator can be anticipated from fig. 1. The multiple reflections within the light guide are equivalent to displacing the origin of fig. 1 to the right. This reduces the position sensitivity, makes it more linear, and, of course, reduces the intensity of the light collected.

Changing any one dimension of a detector will in general change the dependence of the light collected on the source position. Thus, fewer reflections occur in the 5 mm thick test strip in comparison to the 1 mm test strip, and the position sensitivity in the former case is reduced

correspondingly (fig. 1). As long as light loss is due solely to reflective losses and not to absorption, any change in the detector that does not alter the number of reflections will result in an identical response. One such change is an identical scaling of all three dimensions of a rectangular scintillator.

The light collected depends not only on the position but also on the initial amount of light at the source. In order to derive a position indicator that is independent of particle energy, phototubes are placed at each end and the light output summed. For a two-dimensional detector the position indicators are

$$X = \frac{I_R}{I_R + I_L} \quad (1)$$

$$Y = \frac{I_U}{I_U + I_D} \quad (2)$$

where R,L,U and D denote respectively the right, left, up, and down edges of the phoswich when mounted in the vertical plane.

3. Design of the detector

3.1 The Phoswich

Previous phoswich detectors with a plastic scintillator element have had a thin slice of an inorganic crystal with a long decay time (typically CaF_2) as the first element ΔE counter [6]. Production limitations and cost restrict the size of the inorganic crystal and, therefore, the area of the whole detector. Larger phoswich detectors are possible using the new plastic scintillator NE 115, which has a long

decay time. The properties of this new material were measured and are described in the Appendix. Compared to NE 102 its decay time is 100 times longer (225 ns) and its light output is two times smaller (35% of anthracene).

In contrast to other detectors [6,7] the fast plastic scintillator is the first element of the phoswich (20 cm x 20 cm x 0.5 mm). Since the light output of NE 102 is higher than the slow plastic NE 115 a reduction in thickness for the ΔE element is possible and, most important, good timing properties are obtained even for particles that do not penetrate into the second element. The first element stops protons with $E < 6$ MeV and still gives a reasonable signal for 40 MeV protons. The second layer of the phoswich is the slow plastic NE 115 (20 cm x 20 cm x 4.5 mm), which stops protons up to 20 MeV. The sheets are glued together with optical cement along a thin line at all four borders to avoid a "dead layer" of glue for most of the surface area.

3.2 Light Collection and Readout

Since the detector is to be used in a 4π arrangement, the light guides and tubes must be located behind the phoswich itself (figs. 3 and 4). Two-dimensional position resolution requires light readout at all four edges of the detector. Thus, the edges were beveled at 45° , polished and aluminized. Each edge acts as a 90 degree mirror that reflects the light from the phoswich into the light guide (fig. 3). Systematic calculations with the Monte Carlo code led to the particular design of the mirror edge shown in fig. 3. The light collection efficiency for a normal coupling (shift = 0, offset = 0) was calculated

to be 66%. In the optimized design the calculated collection efficiency rose to 95% (assuming an ideal mirror). By conservation of area, the 5 cm diameter phototube (RCA 8575) limits the thickness of the twisted strip light guide to 9.5 mm.

Since the position determination depends on the intensity ratio at the ends, it was considered important to have stable photomultiplier gains. Every tube has a light emitting diode (LED), which enables monitoring of the gain during the experiment. Active voltage dividers were used to minimize gain changes with varying count rates. They consist of emitter followers in the last five stages and a first dynode voltage stabilized by a zener diode, a design similar to that described in ref. [8]. The divider draws a relatively large current and raises the temperature of the tubes, especially as they are operated in vacuum. A massive, water-cooled copper plate (not shown in fig. 4) was attached to all four tube bases. This plate also supports the light guides and provides easy mounting of the detector in the vacuum chamber.

3.3 Signals and Gating

The signal from the phoswich consists generally of a larger amplitude pulse of short duration superimposed on a lower amplitude pulse with a long decay time. Fig. 5 shows a typical signal at the anode of the photomultiplier. The anode signal was split and directed into two charge sensitive analog to digital converters (QDC's). The dynode signal was used to determine the gating of the QDC. In this test experiment the detector was operated in a stand-alone mode instead of being triggered by a heavy-ion telescope. Therefore, a coincidence of the four dynode

signals was used for a trigger. The coincidence started two different gates, a short one (30 nsec) for the ΔE component and a long one (600 nsec) covering both components and corresponding to the total light output. The variation in transit time in the phoswich is at most 1 nsec and introduced only a small time jitter in the gating of the analog pulse. There was no difficulty in setting common gates for all four signals. To obtain the full range in both QDC's, 1:4 attenuators reduced the charge into the QDC with the 600 ns gate. Eight parameters are thus obtained for each event.

In order to adjust the electronics, it is convenient to have a test pulse that duplicates that from the phoswich. The simple passive device shown in fig. 6 produces an output pulse with a suitable shape (see fig.5). By adjusting RC time constants any phoswich can be simulated. The input potentiometer allows some variation of the $\Delta E/E$ ratio.

4. Test of the detector

4.1 Position Resolution

A test was made with 60 MeV alpha particles from the LBL 88-Inch Cyclotron. The detector was positioned in vacuo in the angular range from 14° to 56° and was exposed to particles scattered by a gold foil. A mask having sixteen holes, 6.25 mm in diameter, spaced approximately 5 cm apart in a rectangular pattern was placed before the detector. Fig. 7 shows a two-dimensional scatter plot. The holes were numbered consecutively from top to bottom and left to right (see fig. 7). Positions 1 through 8 are in the region of intense elastic scattering, but holes 9 through 16 are beyond the grazing angle. The main

contribution in holes 9 to 16 is made by lower energy particles (evaporation alpha particles, inelastically scattered alpha particles or protons) and shows the decreasing position resolution expected with lower energy particles. Positions 13 and 16 are at the corners of the detector near the borders having optical cement and show an associated distortion. The position coordinates x and y are not linear since the light attenuation is not linear. Figs. 8a and 8b show position plots for the x and y axes. The position resolution for the 60 MeV α elastic component is ~ 10 mm FWHM. The peak areas in the x -position plot in fig. 8 for positions 2,6,10, and 16 reflect the angular distribution for elastic scattering. The y position plot in fig. 8b, covering positions 5,6,7 and 8, shows smaller changes in the elastic scattering cross section. Note that the positions 5 and 8 are at slightly larger polar angles. The position resolution is found to be worst in the center region of the detector since light coming from there has the highest attenuation. Also, lower energy particles in positions 10 and 14 show lower resolution due to decreased photon statistics. The best position resolution is found towards the edges of the detector.

It was shown in section 2 that the position dependence varies with the thickness of the scintillator sheet. Since the total light intensity for the phoswich contains contributions from scintillators of two different thicknesses, the position calibration depends in principle on the relative amount of light generated in the ΔE and E portions. Should this prove to be an important factor in an actual experiment, it is possible to measure separate position calibrations for the ΔE and E portions, and to determine the position of a given event independently for each portion.

The square symmetry of the present detector makes it possible to define the position either by using equations (1) and (2) or by interchanging right with left and up with down. If the light guides and phototubes at each corner have similar characteristics, then the response of the detector in each quadrant should be the same.

Since the position information depends on the amplitudes of the signals, small gain shifts in the phototubes will cause the position resolution to deteriorate. Although the phototubes were equipped with LED's for gain monitoring, this was not done in the test experiment. Spectra of short runs (30 min.) showed position resolution of typically 8 mm, 20% better than observed over a longer period of time. To obtain the optimum resolution of the detector, therefore, it appears necessary to monitor the gains during an experiment.

4.2 Particle Identification

It was found that adding the signals of the four tubes resulted in an improvement of more than a factor of two in the energy resolution. E and ΔE light intensities are given by

$$I = I_L + I_R + I_U + I_D \quad (3)$$

$$\Delta I = \Delta I_L + \Delta I_R + \Delta I_U + \Delta I_D \quad (4)$$

and are evaluated at each position. Fig. 9 shows the ΔI - I scattering plot for particles in position 3. Area 1 corresponds to neutral particles (n, γ) for which the efficiency of the detector is below 1.

Area 2 contains protons that bend back after a maximum corresponding to the punch-through energy of 22 MeV. Area 3 contains deuterons and tritons that can be resolved from protons and alpha particles, but not from each other. Area 4 contains alpha particles and the elastic peak. The inelastic part of the alphas shows a tail towards lower ΔI that represents some ^3He events. A separation of ^4He and ^3He is not possible. Area 5 represents events that stop in the ΔE detector. Note that there are two parallel lines; this is an electronic artifact caused by an inoperative lower significant bit in one of the QDC's.

4.3 Energy Resolution

The total light output for alpha particles in the central region of the detector is shown in fig.10. To obtain the energy of a particle a number of corrections must be applied. First the summed light intensity I is slightly dependent on the position as light collected from the center region is attenuated relative to that from the border region. Table 1 gives a map of the total light yield for different positions. The gain matching of the phototubes is very important in this respect. Equal gains for the individual tubes minimizes the position dependence of the energy signal and gives the best energy resolution. Before the test a rough matching was made using an alpha source in the center of the detector. Gain shifts in the tubes during the experiment made it necessary to match the gains with software in the post-run analysis. An additional LED was attached in the center of the detector afterwards to enable better control of the gains in future experiments.

A second correction is due to the general non-linear response of the scintillator for particles of different energies. A simple formula connecting light output I and incident energy E for particles stopped in a scintillator is [9]

$$I = N(ZA)^{-0.63} E^{1.62} \quad (5)$$

where the factor multiplying the energy has the values 4.0, 2.6, 2.0 and 1.1 for protons, deuterons, tritons and alpha particles, respectively, for NE 102.

The fast component I_F and the slow component I_S add to the total light as

$$I_F = N(ZA)^{-0.63} [E^{1.62} - (E - \Delta E)^{1.62}] \quad (6)$$

$$I_S = r N(ZA)^{-0.63} (E - \Delta E)^{1.62} \quad (7)$$

$$I = I_F + I_S = N(ZA)^{-0.63} [E^{1.62} - (1-r)(E - \Delta E)^{1.62}] \quad (8)$$

The quantity r is the ratio of the light output of NE 115 and NE 102, and E and ΔE are the total energy and the energy lost in the thin scintillator, respectively. A correction must also be applied for the portion of the slow signal from the thick detector that is contained in the short gate T_1 . This correction can be calculated from the known decay time of the NE 115 and the known values of T_1 and T_2 (see fig. 5). The component of light from the slow scintillator contained in gate T_1 is given by

$$\Delta I_{NE115} = (I - \Delta I) \frac{\int_0^{T_1} e^{-t/\tau} dt}{\int_{T_1}^{T_2} e^{-t/\tau} dt} \quad (9)$$

A precise evaluation of ΔI_{NE115} would require the use of a decay constant τ that is a function of time (see Appendix).

$$\text{Thus } I_F = \Delta I - \Delta I_{NE115} \quad (10)$$

The ΔE signal will be position dependent since the particles have different angles of incidence. Inversion of equations 6-8 and 10 for each position enables one to obtain the energy for a particle stopped in the second scintillator. The energy resolution obtained in this manner varied from 5 - 6% over the entire detector. (See Table I)

4.4 Time Resolution

To measure the time resolution of the detector one tube provided the start signal, another tube gave the stop signal. The position used for this measurement was located in the more central region of the detector at a distance of approximately 75 mm from each of the tubes used for the timing. The FWHM of the time peak was 820 psec, which corresponds to an intrinsic time resolution of 580 psec. A correction for time walk of the signals was not applied. It is possible to improve the time resolution by averaging the times obtained from each of the four tubes. However, this technique cannot be used without a separate time signal from a trigger detector.

5. Conclusion

A position-sensitive phoswich detector has been designed and successfully tested. It offers a large area, 400 cm^2 , and position sensitivity in two dimensions with a resolution of $\sim 1 \text{ cm}^2$. Position sensitivity is attained without the introduction of additional light attenuation beyond that already inherent in the scintillator as supplied by the manufacturer. An important feature is the use of a new plastic scintillator NE115 having a long decay time ($\tau \sim 225 \text{ ns}$) for the second element of the phoswich. This reserves the scintillator material with the fast decay time, NE 102 ($\tau = 2.4 \text{ ns}$) for the first element and permits fast timing to be done on particles stopping in the first element. The introduction of position sensitivity enables the use of the detector at short distances from the target without sacrificing energy resolution or, most important, particle identification. An energy resolution of $\sim 5\text{--}6\%$ for $60 \text{ MeV } \alpha$ particles was obtained, and identification of protons, deuterons and alpha particles was possible. The intrinsic time resolution was $\sim 0.6 \text{ ns}$. Only four phototubes are needed and there are eight signals to be digitized. The detector geometry is suitable for a wide range of experiments in which the probability of two particles entering the detector at the same time is not too large. Thus, the detector described here offers an economical solution to the problem of measuring and identifying light charged particles in coincidence experiments.

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Appendix

The New Scintillator, NE 115

NE 115 is a new plastic scintillator manufactured by Nuclear Enterprises, Edinburgh, Scotland. The light output is smaller and the decay time is much longer in comparison with standard plastic scintillators.

The specifications supplied by the manufacturer were

- light output; 25% of anthracene
- decay time; 375 ns
- wavelengths of maximum emission; 375,385,395 nm
- refractive index; 1.58.

We measured somewhat higher values for the light output, approximately 35% of anthracene, and the decay time was found to be shorter, 225 nsec.

The decay time was measured with the single photon method [10]. A ^{241}Am source irradiates the scintillator, which is coupled directly to an RCA 8850 Phototube. A second RCA 8850 tube, selected for low dark current, was coupled loosely, giving a pulse for approximately every 40th count. The time spectrum is shown in fig. 11. A decay time of 225 ± 20 ns is indicated by the dashed line.

The light output was measured with two different methods. First, a variable gain, linear shaping amplifier was used to integrate the anode signal. The digitized signal could be calibrated in terms of the number of photoelectrons. Second, the dynode signal gated a QDC that integrated the anode signal current.

Table 2 gives the results for a number of materials and samples. All samples were discs 25 mm in diameter. Reference samples were of NE 102, NE 102A, and Pilot F. The results were reproducible within 1% for the same method and sample. A deviation of about 10% is observed between the methods, which might be due to the rise time of the shaping amplifier. In the case of NE 115, the value for the light output was corrected for the gate length not covering the entire signal. Since the relative light outputs of the reference materials were slightly different from their literature values, the mean NE 115 output was determined with respect to the mean value of the reference materials. This gives a light output of 35% of anthracene. These measured values were used in the data analysis described in section 5.

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Table 1

Light Intensity and Energy Resolution for Different Positions

Position	Measured Relative Light Intensity	Deviation from Mean	Energy Resolution (FWHM) %
1	643	1.11	5.4
2	575	1.0	5.4
3	554	0.96	5.7
4	618	1.07	5.8
5	574	1.0	6.3
6	533	0.93	5.7
7	524	0.91	6.0
8	569	0.99	6.0
10	591	1.03	5.5
11	573	1.0	5.6
<hr/>			
Mean	575 $\pm$ 34		

Table 2

Comparison of the light output of NE 115 with
standard plastic scintillators.

Material, (Sample No.)	Shaping Amplifier (Measured Photoelectrons)	Camac QDC (Channels)
NE 102 (1)	695	253
NE 102A (1)	717	262
NE 102A (2)	727	272
Pilot F (1)	787	287
Pilot F (2)	760	277
NE 115 (1)	429	-
NE 115 (2)	448	144
NE 115 (3)	443	142
Mean light output of NE 115 (%of anthracene)	39	35

Figure Captions

- 1) The light collected (in units of photoelectrons) at one end of a thin strip 20 cm long and 2 cm wide. Results for two thicknesses, 1 mm and 5 mm are given as a function of source distance along the strip. Solid lines guide the eye to the experimental data points. The dashed lines are the results of a calculation described in the text.
- 2) Schematic illustration of light transmission by internal reflection in an ideal thin scintillator (no light loss) and a real scintillator. The irregular surface of the real scintillator causes light loss at some of the reflections because the critical angle for internal reflection is exceeded.
- 3) Detail of the coupling of the light guides to the phoswich. The calculations described in the text were used to find the indicated optimum values of the shift and offset for the aluminized surfaces comprising the mirror.
- 4) A sketch of the entire phoswich detector, including the light guides, phototubes and bases. The plate for cooling the tubes and mounting the detector is not shown.
- 5) Anode signals obtained for reaction products from the reaction of 60 MeV alpha particles with Au nuclei (left panel). The right panel shows the pulse-form obtained from a pulser, the passive shaping circuit shown in fig. 6 and a LED. The gate signals used for the two QDC's were $T_1 = 30$ ns and $T_2 = 600$ ns.

- 6) Schematic of the passive shaping circuit used to provide a light source having the two time components of the phoswich scintillators.
- 7) A scatter plot showing the results obtained for alpha particles passing through the 16 holes in a mask (described in text). Holes 9-16 are beyond the grazing angle.
- 8a) The x-position signal for alpha particles passing through holes 2, 6, 10 and 14. The counts in holes 2 and 6 are from elastic scattering, whereas the events in position 14 are entirely low-energy alpha particles from inelastic scattering and evaporation.
- b) The y-position signal for holes 5, 6, 7 and 8. Positions 5 and 8 show fewer counts because they are at larger polar angles.
- 9) The fast signal, corrected for the slow signal contained in the fast gate, versus the total light output, for position number 3 on the mask. The labelled areas contain mainly: 1, gamma rays and neutrons; 2, protons; 3, deuterium and tritium; 4, alpha particles; 5, low-energy particles stopping in the first element.
- 10) Spectrum of the total light output for alpha particles. The range of events is from about 10 MeV to 60 MeV at the elastic peak.
- 11) The decay time spectrum of Ne 115 obtained with the single photon method. One channel is equivalent to 0.36 ns. The dashed line corresponds to a decay time of 225 ns.

XCG 8311-4914

Fig. 1

XBL 8311-7378

Fig. 2

XBL 8311-3449

Fig. 3

XBL 8312 - 6917

Fig. 4

XBB 830-11074

Fig. 5

XBL 8311-3448

Fig. 6

XBL 8312-6919

Fig. 7

XBL 8311-7388

Fig. 8a

XBL 8311-7379

Fig. 8b

XBL 8312-6918

Fig. 9

XBL 8311-7387

Fig. 10

XCG 8311-4916

Fig. 11

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