AD733398

NOLTR 71-215

EVALUATION OF PLASTIC SCINTILLANTS FOR USE IN HIGH SENSITIVITY MEASUREMENTS OF LOW ENERGY GAMMA OR X-RAYS

By
David F. Covell
Herman I. Cordova

8 NOVEMBER 1971

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NAVAL ORDNANCE LABORATORY, WHITE OAK, SILVER SPRING, MARYLAND

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NOLTR 71-215

10

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Ordnance Laboratory White Oak, Silver Spring, Maryland	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

EVALUATION OF PLASTIC SCINTILLANTS FOR USE IN HIGH SENSITIVITY MEASUREMENTS OF LOW ENERGY GAMMA OR X-RAYS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

David F. Covell, Herman I. Cordova

6. REPORT DATE 8 November 1971	7a. TOTAL NO. OF PAGES 9	7b. NO. OF REFS 0

8a. CONTRACT OR GRANT NO. b. PROJECT NO. NSSC Work Request 10005, 19 May c. 1971 pertaining to ARPA Order 1798 of 11 March 1971 d.	9a. ORIGINATOR'S REPORT NUMBER(S) NOL TR 71-215 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency Washington, D.C.

13. ABSTRACT

(U) Evaluation and engineering data are presented regarding the applicability of plastic scintillants for low energy gamma and x-ray detection with special application to delayed-coincidence counting.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Delayed Coincidence Counting						
Gamma Ray Spectrometry						
Plastic Scintillants						
Radioactivity in Seawater						
Low-Energy Gamma Rays						

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CHEMISTRY RESEARCH DEPARTMENT
NUCLEAR CHEMISTRY DIVISION
NAVAL ORDNANCE LABORATORY
SILVER SPRING, MARYLAND

NOLTR 71-215 8 November 1971

Evaluation of Plastic Scintillants for Use in High Sensitivity Measurements of Low Energy Gamma or X-Rays

Several radionuclides decay by a process known as delayed coincidence, in which two gamma-rays are emitted with a short time delay (on the order of nanoseconds) between them. It is possible to establish counters with time and energy restraints such that gamma-rays emitted in delayed coincidence can be uniquely detected. Such a procedure is known as delayed-coincidence counting and has the advantages of (1) a very low background and (2) a high degree of uniqueness for the determination of specific radionuclides. Special problems arise when the gamma-rays are low in energy, or are highly converted so that only x-rays are observed, and when large area counters are required. This report describes an evaluation which has been made of plastic scintillants for possible use in large-area detectors for low energy gamma or x-rays in delayed coincidence.

This work has been supported by the Advanced Research Projects Agency, NSSC work request 10005, 19 May 1971, to NOL pertaining to ARPA Order 1798, 11 March 1971.

ROBERT WILLIAMSON II
Captain, USN
Commander

Albert Lightbody

ALBERT LIGHTBODY
By direction

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ILLUSTRATIONS

INTRODUCTION

To make in situ determinations of radionuclides present in trace amounts in the ocean, special techniques for concentration, detection, and pulse counting have been proposed. Certain radionuclides of interest have decay characteristics such that the technique of delayed-coincidence counting can be used. The advantages of this technique, where applicable, are that it greatly reduces background and greatly improves the specificity of response so that a substantial improvement in sensitivity is potentially realizable. For the present problem, it is proposed to achieve high sensitivity by combining the technique of delayed-coincidence counting with the use of large area detectors and with techniques for the concentration of elements of interest. Presented in this report are some preliminary data from the evaluation of detector concepts appropriate to this problem.

DETECTOR DESIGN CONSIDERATIONS

Because of the requirement for large area detectors, plastic scintillators are being considered. Compared to sodium iodide (NaI(Tl)), plastic scintillators have poorer energy resolution, generally poorer detection efficiency, and poorer light quantum conversion efficiency. Their advantages are (1) low cost, (2) availability in various sizes and shapes, (3) much shorter flourescent decay time (compared to NaI(Tl)), and (4) ruggedness.

The fact of poorer resolution is not expected to be troublesome since complex spectra are not anticipated, and in addition, the technique of delayed-coincidence counting, combined with electronic gating techniques, results in substantial simplification of the gross gamma-ray spectral response. The fact of poorer detection efficiency is not expected to be troublesome because the radionuclides of interest for which the proposed techniques would be applicable, all have low-energy gamma rays or highly converted gamma rays which result in the emission of low energy x-rays. Over the energy range of interest, which extends from approximately 10 keV to 40 keV, the detection efficiency of plastic is expected to be fairly high.

The poorer light quantum conversion efficiency results in a reduced light output, so that more amplification is required. The requirement for increased amplification could result in a serious noise problem in the low-energy region. New high-gain phototubes are available, however, with very low dark-current characteristics. These excellent phototubes, combined with coincidence techniques of very short time-resolution (made possible by the short fluorescent decay characteristic of the plastic scintillant) are expected to provide sufficient control of noise so that it will not be the limiting factor in determining sensitivity.

EXPERIMENTAL

Several pieces of Pilot B* plastic scintillant were obtained, and some evaluation studies were made in regard to their suitability for sensitive low-energy gamma-ray measurements. The principal qualities of Pilot B which contribute to its usefulness in this application are (1) its excellent transparency to its own emission spectrum (transmission characteristic: 0.01 cm^{-1} at 4070 Angstroms); (2) density = 1.02; and (3) decay time constant = 1.7 x 10^{-9} seconds. Studies are being made of the noise continuum, the photopeak resolution and the photopeak counting efficiency over the energy range of interest. For these studies, the response to gamma- and x-rays from ^{57}Fe (6 keV, 14 keV), ^{119m}Sn (3 keV, 25 keV), and ^{80m}Br (12 keV and 37 keV) is being observed, with detectors functioning singly and in coincidence.

The multiplier phototubes used for these studies are Type 8850, manufactured by RCA. These are referred to by RCA as "Quantacon" phototubes, characterized as having an extremely high-gain gallium-phosphide first dynode and a high quantum efficiency bialkali photocathode. Dynodes subsequent to the first dynode are copper-beryllium. These tubes have excellent gain vs. dark-current characteristics and should be ideally suited to this problem of low-energy scintillation counting.

The electronic instruments used (e.g., high-voltage supplies, linear amplifiers, timing single channel analyzers and coincidence units) are modular (NIM-BIN) in design. The units used were mostly manufactured by Ortec Corporation. The pulse-height analyzer was manufactured by Technical Measurement Corporation, and has a total channel capacity of 16,384. For this work, spectra of 1,024 channels only are used.

RESULTS

Studies of the noise and background characteristic of 2 in. dia. by 1 in. long and 2 in. dia. by 2½ in. long plastic scintillators in conjunction with the Type 8850 multiplier phototubes, show the noise continuum ends at an equivalent gamma-ray energy of approximately 10 keV, and that only a normal background is observed above this energy region. Because of poor resolution, the gamma-ray photopeak response in the 10-15 keV region would tail into the noise, and thus the

*Manufactured by Pilot Chemicals Division of New England Nuclear Corporation.

noise response in the ungated mode would be detrimental to sensitivity in this energy region. The ungated integrated noise and background spectrum (over the energy range of 0-50 keV) for the 2" x 2½" Pilot B detector was observed to be approximately 800,000 counts per minute; when operated in coincidence with the NaI(Tl) detector (over an energy range of 0-250 keV) and a coincidence resolution time of 0.1 μsec., the integrated noise and background spectrum for the Pilot B detector dropped to approximately 30 counts per minute, and most of these counts were less than 10 keV in energy equivalence. Further improvement in the noise and background spectrum could be achieved by narrowing the energy ranges of the detectors (by electronic gating), and by using a shorter coincidence resolution time.

The resolution of these two plastic scintillators and of the 2" x 2" NaI(Tl) (with 0.005" beryllium window) detector, also mounted on a Type 8850 phototube, was measured. For these measurements the 25 keV photopeak of ^{119m}Sn was used. For NaI(Tl), the observed resolution (FWHM) was 32% whereas the resolution for the 2" x 1" and the 2" x 2½" plastic scintillators was 75% and 72%, respectively.

The relative efficiencies of these three detectors were determined by integrating the counts per unit time in the 25 keV photopeak of ^{119m}Sn. Relative to NaI(Tl), the efficiencies of the 2" x 1" and the 2" x 2½" plastic scintillators were 22% and 36% respectively.

CONCLUSIONS

These preliminary studies show an excellent potential for plastic scintillators as detectors for delayed-coincidence measurements in the energy range of 10-40 keV. The tube noise can be satisfactorily controlled by gating techniques which can also be used to reduce background in the energy range of interest by several orders of magnitude. Resolution is substantially poorer than for NaI(Tl) but, in view of the relatively simple spectra which are anticipated, the loss of resolution is not expected to be troublesome. The detection efficiency relative to NaI(Tl) is poorer, at least over part of the energy range of interest, but it is expected that the improved sensitivity that will result from the proposed gating techniques will compensate for this lack of efficiency. If necessary, an improved efficiency could be achieved by using thicker plastic detectors. In Figure 1 is shown the thickness of Pilot B plastic scintillant which would be required for 90% absorption of photons as a function of photon energy. From the figure, it is seen that a thickness of approximately 11 cm. would be required for 90% absorption of a 40 keV photon.

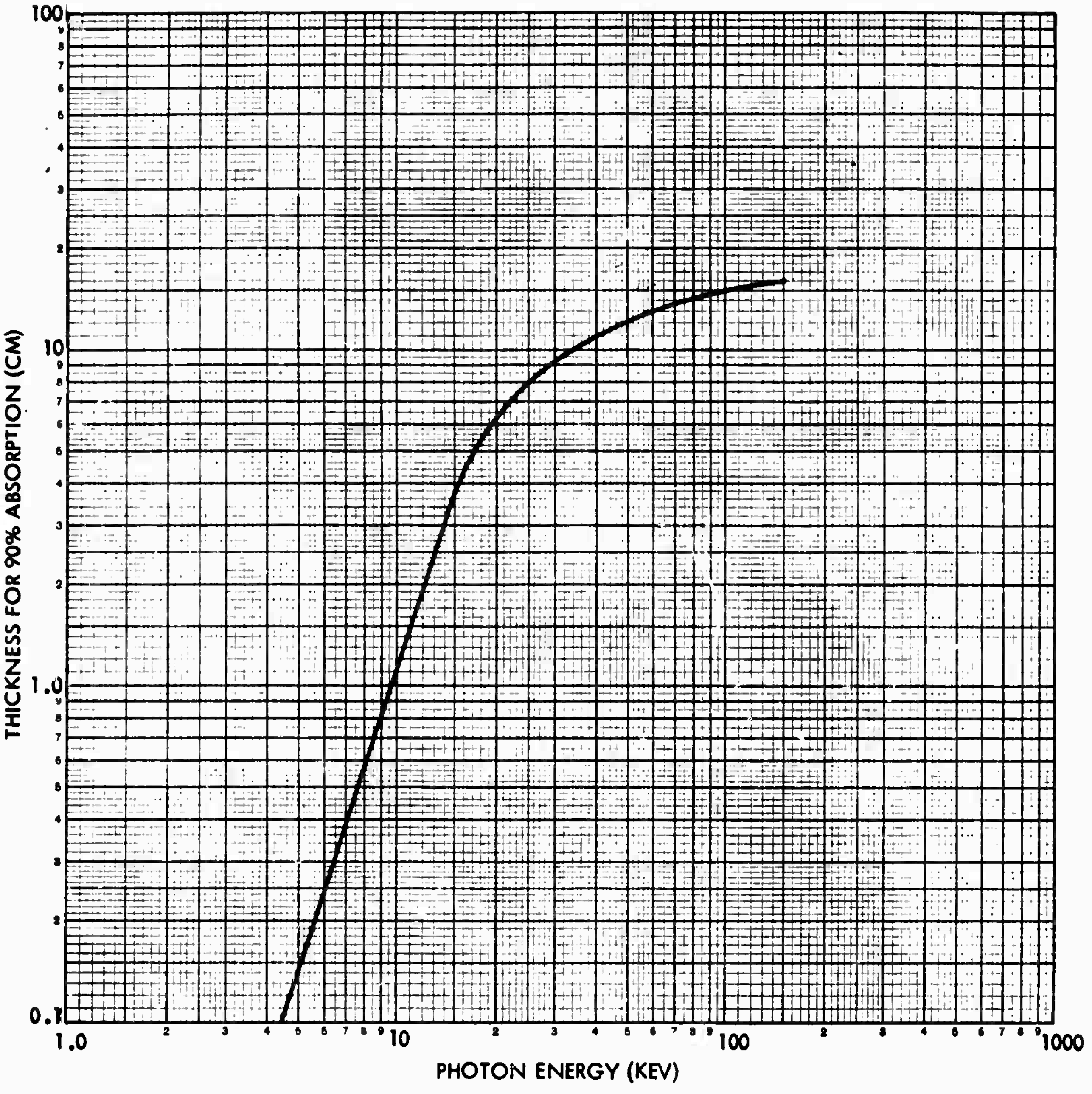

FIG. 1 THICKNESS OF PILOT B PLASTIC SCINTILLANT REQUIRED FOR 90% ABSORPTION OF PHOTONS AS A FUNCTION OF PHOTON ENERGY