BNWL-1178
UC-41

5-
7-70

THE USE OF SOLID STATE DETECTORS
FOR ORGAN COUNTING

D. McConnon

July 1970

AEC RESEARCH &
DEVELOPMENT REPORT

ROUTE TO	P.R. NO.	LOCATION	FILES ROUTE DATE

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00061 5155

BNWL-1178
UC-41, Health
and Safety

THE USE OF SOLID STATE DETECTORS FOR ORGAN COUNTING

D. McConnon

Radiological Sciences Department
Environmental and Life Sciences Division

July 1970

FIRST UNRESTRICTED
DISTRIBUTION MADE

JUL 15 '70

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

BNWL-1178

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

THE USE OF SOLID STATE DETECTORS FOR ORGAN COUNTING

D. McConnon

ABSTRACT

Results of in-vivo measurement of a complex mixture of gamma emitters with conventional whole body or organ counting systems are often unsatisfactory because of the poor resolution of the counting system. The possibility of eliminating this problem by the use of a counting system employing a high resolution solid state detector prompted study of such a system to determine its suitability in measuring amounts of radionuclides in individual organs. The response of a dual crystal Ge(Li) detector to gamma emitters contained in various organ compartments of an anthropomorphic phantom was measured. The study indicated that even though its sensitivity is poor relative to that of conventional organ counting systems, use of a solid state system may yield useful supplemental information for assessment of internal depositions, provided the amount deposited in the organ is sufficiently large, and that the background and counting geometry are controlled.

CONTENTS

INTRODUCTION.	1
SUMMARY AND CONCLUSIONS	2
DISCUSSION	2
Experimental Considerations	2
Results	5
Energy Response Measurements	5
Background Measurements	5
Organ Burden Measurements	8
Minimum Detectable Activities	10
REFERENCES	12
DISTRIBUTION	Distr-1

THE USE OF SOLID STATE DETECTORS FOR ORGAN COUNTING

D. McConnon

INTRODUCTION

High-resolution solid state detectors are becoming increasingly important for identification and measurement of complex gamma ray spectra from a wide variety of samples. Investigations have shown that, in many cases, the increased selectivity of a solid state counting system, when combined with proper sample preparation, allows much more precise analysis for many sample constituents than is possible with the rather elaborate NaI (Tl) detector systems because of the greater than 10-fold improvement in resolution available with solid state systems.⁽¹⁾

In spite of their high resolution and peak-to-Compton ratio, solid state detectors have found only limited application in whole body counting for in-vivo measurements of gamma emitters because of their low photopeak efficiency. However, a solid state detector system may have distinct advantages over conventional scintillation counting systems for some whole-body counter applications, particularly in cases where a complex mixture of gamma emitters such as a fission product mixture has been deposited.

The use of a solid state detector for in-vivo low energy X-ray measurements has been demonstrated. The capability of a Si(Li) detector to completely resolve the 13, 17, and 20 keV L X-rays associated with the decay of ^{239}Pu has provided a convenient method for estimating depth of deposition in ^{239}Pu wound cases.⁽²⁾ In another study, a Ge(Li) detector system was used to measure human thyroid uptake of ^{123}I , and to estimate the effective depth of the thyroid gland.⁽³⁾

The present study was undertaken to determine the feasibility of estimating organ burdens of gamma emitters by external measurement with a large volume lithium-drifted germanium detector.

SUMMARY AND CONCLUSIONS

Although solid state detectors offer the advantage of high resolution for gamma spectroscopy, their sensitivity is limited by small sensitive areas and volumes. As technical problems are solved and larger crystals become available, solid state systems will become increasingly important for in-vivo measurements of gamma emitters. At present, coaxial Ge(Li) detectors are being produced with sensitive volumes as high as 100 cm^3 . While these detectors are troubled with such problems as dead layers and nonuniform electric fields, steady improvement in their fabrication indicates that there is promise for their eventual routine use. In the meantime, solid state detectors may be useful for providing supplementary information in resolving complex mixtures of radionuclides following accidental intake, provided the activity is sufficiently high. This might be particularly true if a multiple detector system could be used to increase counting efficiency. Improvements in sensitivity may also be made by performing measurements in a shielded environment and locating the detector as close to the body as possible in a reproducible geometry.

DISCUSSION

EXPERIMENTAL CONSIDERATIONS

The detector consists of two trapezoidal lithium-drifted germanium crystals cooled to liquid nitrogen temperatures and placed side by side in a single stainless steel housing with the intrinsic regions facing the 0.020-in. beryllium window. Both crystals are coaxial in design and have a total volume of 25 cm^3 . The resolution (full width at half maximum) of

Neg 0684647-4

FIGURE 1. Photograph of REMAB Phantom About to be Inserted
under the Detector

each crystal is 2.5 and 2.7 keV for the 661.6 keV gamma ray of ^{137}Cs . The efficiency of each crystal for ^{60}Co relative to that of a 3 in. $\times$ 3 in. NaI(Tl) crystal is 1.75% and 1.9% while the peak/Compton ratio for 1332 keV of ^{60}Co is 14/1 and 10/1, respectively.

The signal from each crystal was amplified separately through a low noise, charge-sensitive amplification system and then summed at the input of a multichannel analyzer. The system resolution (FWHM) was 4.0 keV at 661.6 keV.

A REMAB phantom filled with a tissue equivalent solution and containing a full skeleton and compartments for the kidneys, liver, lungs, and thyroid was used to make the organ burden measurements. Organ compartments were filled with solutions of various gamma emitters (approximately 10^7 d/m) and measurements were made with the dual crystal Ge(Li) detector placed directly over the organ and as close to the shell of the phantom as possible. Information on the radionuclides used is presented in Table 1 and the detector and phantom are shown in Figure 1.

TABLE 1. Radionuclides Used for Sensitivity and Energy Response Measurements

<u>Radionuclide</u>	<u>Gamma Ray Energy, MeV</u>	<u>Yield, Photons/Disintegration</u>
^{241}Am	0.060	0.38
^{141}Ce	0.145	0.48
^{203}Hg	0.279	0.815
^{137}Cs	0.662	0.859
^{54}Mn	0.835	0.995
^{22}Na	1.27	1.0
^{239}Pu	U L X-rays	

Special efforts were made to determine the sensitivity of the counting system for ^{239}Pu and ^{241}Am contained in the lungs and ^{131}I in the thyroid. The average density of the solutions used for the lung measurements was lowered to that of human lung tissue by the addition of polystyrene balls to the solutions.

RESULTS

Energy Response Measurements

The photon energy response of the dual crystal Ge(Li) system and a 9 3/8 in. diameter $\times$ 4 in. thick NaI(Tl) crystal was measured using a series of standard gamma emitting sources with well known gamma energies. The relative response of the two systems is shown in Figure 2. The data in Figure 2 indicate that above 60 keV, the maximum response of the NaI(Tl) crystal occurs at about 200 keV whereas the maximum response of the Ge(Li) detector occurs at less than 100 keV. Because of its relatively small size compared to the NaI(Tl) crystal, the energy response of the Ge(Li) detector falls off rapidly above 100 keV, decreasing by a factor of about 30 from 100 to 1000 keV. In absolute terms, the response of the Ge(Li) detector to 661.6 keV photons is about 0.3% of the response of the NaI(Tl) detector under identical geometrical conditions caused, for the most part, by the difference in volumes of the two detectors.

Background Measurements

Background measurements were made with the dual crystal Ge(Li) detector both inside an enclosure shielded by 4 in. of lead and lined with cadmium and copper, and placed inside an unshielded laboratory. The results of these measurements are presented in Figure 3. In the energy range of 0 to 1.4 MeV, the unshielded background count rate was reduced by a factor of about 50 within the lead shield. The peaks observed in Figure 3 in the shielded background spectrum may be attributed to natural radon and thoron daughter-product decay and lead K fluorescent X-rays. The peaks in the

Neg 0684647-2

FIGURE 2. Variation in Response of a NaI(Tl) and Ge(Li) Detector with Photon Energy

Neg 700996-1

FIGURE 3. Background Pulse Height Spectrum of Dual Crystal Ge(Li) Detector

unshielded background spectrum were probably induced by natural radioactivity and the decay of low level radioactive sources stored in the laboratory in which the background measurement was made.

Organ Burden Measurements

The response of the solid state system to radionuclides deposited in the kidney, liver, and lung compartments of the phantom are shown in Figure 4. The response or sensitivity is expressed as background corrected photopeak counts per photon emitted versus photon energy. In general, the curves follow the general pattern of the energy response curve shown in Figure 2. Of the three organs, the system had greatest sensitivity for gamma emitters in the kidney because this organ is closest to the surface of the phantom and it presents a more concentrated source to the detector. Even though the detector was positioned closer to the phantom for the liver measurements, the response was lower than in the case of the kidney because of the larger volume of the liver. Detector response in the case of the lungs was lowest because of the large volume source and the presence of overlying structures.

Using the 60 keV gamma ray of ^{241}Am , the solid state system has a detection capability of 0.275 ± 0.036 c/m/nCi or 3.3×10^{-4} photopeak counts per 60 keV photon emitted in the phantom lungs. The photopeak was summed over the energy range of 57.1 to 62.0 keV. The results of the plutonium lung measurements indicated that above 10 keV, the counting rate from 40 nCi of ^{239}Pu containing ~ 0.3 nCi ^{241}Am evenly distributed in the phantom lungs was not statistically above background. The detection capability of the system for ^{239}Pu in the lungs may be expected to be poor because of a combination of low X-ray yield, high absorption of low energy X-rays in the phantom, and the small sensitive area of the detector.

Neg 0684647-3

FIGURE 4. Sensitivity of the Dual Ge(Li) Detector for Radionuclides in the Lung, Liver, and Kidney

The sensitivity of the solid state system was determined for ^{131}I in the thyroid of the phantom. Because of the rigidity of the phantom, this measurement was made with the detector positioned 10 cm from the thyroid. The sensitivity of the system using the 364 keV gamma ray of ^{131}I was 0.716 ± 0.032 c/m/nCi or 3.9×10^{-4} photopeak counts per 364 keV photon emitted in the thyroid.

Minimum Detectable Activities

From the work of Altshuler and Pasternack,⁽⁴⁾ one may calculate a "minimum significant measured activity," defined as the smallest measurement which is interpreted as meaning there is activity in the sample, and a "minimum detectable true activity," defined as the smallest amount of activity required to be in a sample, in order that a measurement can be expected to imply correctly the presence of activity with a predetermined degree of confidence. These calculations were made with the background data presented in Figure 3 and the sensitivity measurements referred to above for ^{241}Am in the lungs and ^{131}I deposited in the thyroid. The results of the calculations are presented in Table 2. In the calculations, the probabilities of judging true activity as background and true background as activity were set at 2.5%.

The minimum detectable true activity of ^{241}Am in the lungs for a 20-min counting period in a low background environment may be compared with the detection capability of conventional lung counters. The present detection level for ^{241}Am of the Hanford lung counter is $0.32 \text{ nCi}^{(5)}$ which is approximately 20 times lower than the detection capability of the dual crystal Ge(Li) detector. Assuming a Pu/Am ratio of 13, then the solid state system is capable of detecting about 80 nCi of plutonium uniformly deposited in the lungs.

The minimum detectable true activity of ^{131}I in the thyroid with the solid state system for a 20-min counting period in a

TABLE 2. Minimum Significant Measured Activities and Minimum Detectable True Activities of ^{241}Am in the Lungs and ^{131}I in the Thyroid as measured with a Dual Crystal Ge(Li) Detector

<u>Counting Time, min</u>	<u>Shielding</u>	<u>Minimum Significant Measured Activity, nCi</u>	<u>Minimum Detectable True Activity, nCi</u>
<u>^{241}Am in the Lungs</u>			
20	none	19	39
40	none	13	27
20	4 in. Pb	2.6	6.1
40	4 in. Pb	1.9	4.2
<u>^{131}I in the Thyroid</u>			
20	none	2.8	5.8
40	none	2.0	4.0
20	4 in. Pb	0.4	1.0
40	4 in. Pb	0.3	0.7

low background environment is about 1.0 nCi. Conventional thyroid monitors employing NaI(Tl) crystals can detect at least 0.020 nCi of ^{131}I in the thyroid under similar conditions. Similar results may be quoted for the other radionuclides studied. As the photon energy increases, the detection capability of the solid state system decreases more rapidly than that of a NaI(Tl) system because of the smaller size of the Ge(Li) crystals. As larger Ge(Li) crystals become available, counting efficiencies will approach those of conventional NaI(Tl) systems.

REFERENCES

1. J. A. Cooper, N. A. Wogman, H. E. Palmer, and R. W. Perkins. "The Application of Solid State Detectors to Environmental and Biological Problems", Pacific Northwest Laboratory Annual Report for 1967 to the U.S.A.E.C. Division of Biology and Medicine, Volume II: Physical Sciences, Part 2. Radiological Sciences, BNWL-715, pp. 119-122. Battelle-Northwest, Richland, Washington, 1968.
2. H. E. Palmer, N. A. Wogman, and J. A. Cooper. "The Determination of the Depth and Amount of ^{239}Pu in Wounds with Si(Li) Detectors," Proceedings of the Symposium on Diagnosis and Treatment of Deposited Radionuclides, held in Richland, Washington, May 15-17, 1967.
3. V. J. Sodd, H. N. Wellman and B. M. Branson. " ^{123}I Thyroid Measurements with a Ge(Li) Detector," Journal of Nuclear Medicine, vol. 10, no. 3, pp. 136-139, March 1969.
4. B. Altshuler and B. Pasternack. "Statistical Measures of the Lower Limit of Detection of a Radioactivity Counter," Health Physics, vol. 9, no. 3, pp. 293-298. March 1963.
5. K. R. Heid and J. J. Jech. Assessing the Probable Severity of Plutonium Inhalation Cases, BNWL-SA-1595. Battelle-Northwest, Richland, Washington. July 1968.

DISTRIBUTIONNo. of
CopiesOFFSITE

- 1 AEC Chicago Patent Group
 G. H. Lee
- 2 AEC Division of Technical Information Extension

ONSITE-HANFORD

- 2 AEC Assistant Director for Pacific Northwest Programs
- 1 AEC Chicago Patent Group
 R. K. Sharp (Richland)
- 1 AEC Richland Operations Office
 C. L. Robinson
- 3 Battelle Memorial Institute
- 32 Battelle-Northwest
 B. V. Anderson
 P. E. Bramson
 J. P. Corley
 F. T. Cross
 G. W. Endres
 A. J. Haverfield
 J. F. Honstead
 H. V. Larson
 D. McConnon (10)
 I. C. Nelson
 J. M. Nielsen
 H. E. Palmer
 F. L. Rising
 J. K. Soldat
 C. M. Unruh
 N. A. Wogman
 Technical Information (5)
 Technical Publications (2)