906

OMB CONTROL NO. 1910-1400

U.S DEPARTMENT OF ENERGY
UNIVERSITY RESEARCH INSTRUMENTATION PROGRAM

8602 (R) 021

COVER PAGE
(THIS PAGE MUST BE THE FIRST PAGE OF THE APPLICATION) 712330

1. Name of Institution: ~~New York University Medical Center, Institute of Environmental~~ Medicine

Address: City Longmeadow Rd., Tuxedo 3. State New York 4. ZIP 10987

Principal Investigator: Dr. Norman Cohen

Department: ~~Environmental Medicine~~

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Title of Application: A Hyperpure Germanium (HPGe) Array Detection System

Area of Proposed Research (Select ONE) D *

A. Materials Characterization
B. Catalysis
C. Engineering Science
D. Health & Environmental Effects
E. Other

. Research Subcategory (See Section II of DOE/URI FY86 Announcement) In Vivo Measurement to Characterize Exposure

. Total DOE Funding for Research in Selected Area, (During the last two fiscal years): $ 211,000.00

2. Estimated Purchase Price of Equipment: $ 131,460

3. Amount Requested from DOE: $ 131,460

List all Federal agencies which are currently considering proposals from the institution involving the same or similar equipment.

4. Agency: U.S. DOE/OHER Agency Proposal Number: DE-AC02-77-EV04326
5. Agency: U.S. DOE/OHER Agency Proposal Number: DE-AC01-78-EV04957

NOTE: The institution is responsible for informing DOE if a proposal involving the same or similar equipment is submitted to a federal agency prior to the announcement of DOE's URI awards.

6. List any federal agency which has provided funds to the institution during the past two years for the same or similar equipment.

Agency: none Amount of Funds: none

17. Please check one of the following:

☒ I authorize outside peer review of this proposal.

☐ I do not authorize outside peer review of this proposal.**

Signature of Principal Investigator: [signature] Date: 12/2/85

Name and Title of Institutional Official (President or Designee)	Name and Title of Financial Officer
T.A. Fitzgerald, Director	Joanne M.J. Quan
Office of Grants Administration and Institutional Studies	Vice President for Finance
Signature: [signature]	Signature: [signature]
Date: 12/3/1985	Date: 12/4/85

* Note - The application will be evaluated by reviewers in this field.
** Note - May prevent full consideration of this application.

BOX No. B-41-4 Bldg. 2714-H
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1076537

Table of Contents

	Page
SUMMARY	3-4
BUDGET SHEET	5-6
DOE GRANT/CONTRACT SUMMARY.	7-8
NARRATIVE	9-35

Estimated Cost and Budget

Appendix

Faculty Resumes

Assurance of Compliance Form

1076538

Summary

The equipment proposed in this report is designated in toto as a Hyperpure Germanium (HPGe) Array Photon Detector. Basically, it is composed of a series of germanium diodes positioned in a geometry which approximates a planar surface scintillation detector to be placed over the body area which will be measured for radioactive contamination. Most often, this structure is the lung; however, the major interest at our Institute encompasses the bone structures of the skull and patella area as well. The output of the germanium detectors is routed through appropriate summing amplifier noise discrimination systems into a computer-based multichannel analyzer. The equipment has all of the advantages of germanium detection systems, i.e., low background and high resolution, and when several detectors are positioned in an array, can approximate the efficiency normally obtained by larger sodium iodide/cesium iodide detectors, i.e., the Phoswich.

It has been estimated that the acquisition of this detector system by the Institute of Environmental Medicine at New York University Medical Center will provide state-of-the-art technology and allow us to estimate internal body burdens heretofore undetectable by Phoswich systems. We also anticipate that it will be possible to accurately evaluate this new technology in terms of figure-of-merit comparison with the Phoswich detector and general parameters of accuracy and precision. This survey will enable the initiation of a multitude of new research avenues which could not have previously been explored. Since researchers at the Institute of Environmental Medicine have the facilities necessary to investigate the germanium array system in detail, it will be possible to explore and optimize this new technology for use in cases of routine internal contamination surveillance. Furthermore, we will be able to

1076539

explore a variety of new applications of this system since it holds promise for increased detection efficiency and a further decrease in our detection limits.

Some of the initial research experimentation which we anticipate performing with this new equipment includes the development of Poisson background estimation techniques using at least 50 human background subjects and the evaluation of the degree of interference observed by the new germanium systems due to multi-organ distribution of specific actinide elements. Finally, we will derive statistical methods and equations for the propagation of error to be used for a realistic determination of the lower limits of detection. We will then put this system to use in the practical application of determining environmental levels of lead-210 skeletal burdens and measuring the distribution and retention of internal contaminants in bone.

As shown in Table 2, there are currently 4 students present at the Institute of Environmental Medicine who will benefit from the acquisition of this equipment both academically, as a teaching system, and in their specific dissertation research programs. To date, there have been 7 students who have received their Ph.D. degrees in this specific area of research (over a 15-year period) and we expect an additional 4 students to graduate within the next 2 years.

1076540

OMB CONTROL NO. 1910-1400

U.S. DEPARTMENT OF ENERGY
UNIVERSITY RESEARCH INSTRUMENTATION PROGRAM

BUDGET PAGE

ESTIMATED COSTS

Instrumentation	Requested of DOE	Institution's Cost Sharing *(1)*	Other Federal Funds *(2)*	TOTAL
A. Purchase Price *(3)*	131,460		8,000*	
Subtotal:	131,460		8,000	139,460
B. Other Allowable Costs				
1. Shipping / Handling	X X X X X			
2. Installation	X X X X X	5,000		
3. Building / Laboratory Renovation	X X X X X	10,000		
Subtotal:		15,000		15,000
C. TOTAL	131,460	15,000 *(4)*	8,000	154,460

NOTES:

(1) Non-Federal funds only. (However, may be provided by a third party.)

(2) Estimate funds to be obtained from other Federal agencies for purchasing the instrument, etc.

(3) Only the purchase price of the instrumentation is eligible for DOE funding through this program.

(4) This amount represents allowable cost sharing. (See pages 7 and 8).

* Service contract

1076541

A. Purchase Price (List components and unit prices.)

	Quantity	Description	Total Estimated Unit Price	Total
1)	10 ea.	Model GLP-36490/05 HP Ge Detectors	$9,690	$96,900
2)	10 ea.	Model 472 Ortec Spec Amps.	1,125	11,250
3)	2 ea.	Model 4001C/4002A Nim Bin and Power Supply	840	1,680
4)	3 ea.	Model 433A Dual Sum and Invert Amps	295	885
5)	1 ea.	Model 478 2 kV Bias Supply	745	745
6)	1 ea.	Automated Liquid Nitrogen Transfer and Fill System	10,000	10,000
7)	1 ea.	Model Ortec ADCAM MCA 150 Multi-channel Analyzer	10,000	10,000
	Subtotal:	26	32,695	131,460

1076542

OMB CONTROL NO. 1910-1400

DEPARTMENT OF ENERGY
UNIVERSITY RESEARCH INSTRUMENTATION PROGRAM
GRANT AND CONTRACT SUMMARY FORM

Grant/Contract/Subcontract No.	Principal Investigator	Title	Contract Dates FM MO	Contract Dates FM YR	Contract Dates TO MO	Contract Dates TO YR	Total Award Value	$ AMT Awarded for FY Period 1983 to 1985	DOE Technical Monitor/Location
DE-AC02-77-EV04326	Dr. N. Cohen	Professor and Director	12	83	2	85	$78,000		Dr. Wayne Lowder/ Germantown MD
			2	85	2	86	78,000	156,000	
DE-AC01-78-EV04957	Dr. G. Laurer	Research Professor	12	83	12	84	55.000	55,000	Dr. Wayne Lowder/ Germantown MD

Only provide information on research projects which are directly related to the selected principal research area.

1076543

RELATED FEDERAL AGENCY GRANTS AND CONTRACTS

Agency	Grant/Contract No.	Title	Grant/Contract Dates FROM MO YR	Grant/Contract Dates TO MO YR	Total Award Value
National Institute of Environmental Health Sciences	ES 00260	Research in Environmental Health Sciences	1/1/85	12/31/89	$7,219,952.00

Only provide information on research projects which are directly related to the selected principal research area.

1076544

Narrative

ABSTRACT

The original methodology, by which internal body burdens of various low-energy, photon-emitting radionuclides were determined *in vivo*, utilized the dual crystal NaI-CsI(Tl) detector developed at NYU Medical Center by Dr. Gerard Laurer in 1968. A complete list of the national and international laboratories utilizing this detection system at the present time is given in Table 1. A new detection system, which has recently been made commercially available and which is proposed for support under the URI program, makes use of an array of hyperpure germanium semiconductors which will surpass the NaI-CsI(Tl) detection system in terms of energy resolution and has recently been reported to have an overall "figure-of-merit" (due to its lower background count rate) which will exceed the current Phoswich system. As can be seen in Table 1, several national laboratories have purchased this new system without a detailed comparison to the Phoswich [i.e., NaI-CsI(Tl)] detector. As a university laboratory we do not have the time constraints and restrictions of an extensive routine surveillance schedule of nuclear plant employees as do the National Laboratories. Therefore, we are in the right position to examine in detail the many developmental details that are associated with making accurate *in vivo* measurements of internal body burdens with the new system and comparing it to the Phoswich system. We have, in fact, continued to receive support from the DOE to provide development and evaluation of whole-body counting systems for the last 25 years. Although we have repeatedly requested the purchase of the germanium array system for our own use, this instrument support has been unavailable. In an effort to begin the comparison, therefore, we have had to resort to sending our staff to various National

1076545

Laboratories where these systems were available for detailed measurements of bone phantoms, i.e., calibration structures that have been developed at New York University Medical Center. Although we have had the enthusiastic support of several investigators in various laboratories throughout the country in our meager beginning for this program, there is no doubt that this is a difficult way to accomplish the comparison. Our most recent evaluation and use of the germanium array system took place this past summer at the Battelle Pacific Northwest Laboratories and at the Rocky Flats Laboratory in Denver, Colorado. Much more could be accomplished in considerably more detail in the experimental programs we have planned if the germanium array system were available at our laboratory. This instrument would certainly enhance not only the scientific and technical excellence of our on-campus research program in the area of whole-body counting of nuclides which emit photons below 150 keV, but also provide the much-needed data for comparison of the new system to the Phoswich system.

Our research is particularly related to the area of nuclear energy insofar as we have continued to study the biokinetics and measurement of internal contamination that could result from radionuclides present in the nuclear energy fuel cycle. This includes "both ends" of the fuel cycle, insofar as our measurements include uranium and plutonium isotopes as well as those nuclides present in nuclear waste, i.e., plutonium, americium, curium, etc. We also have been involved with making measurements of lead-210 in vivo in uranium miners as a method for evaluating their cumulative past exposure to radon and radon daughters in uranium mines, as well as to residents of homes with abnormally high concentrations of radon/radon daughters due to implementation of procedures to guarantee increased energy efficiency, i.e., the general reduction in the number of air turnovers per unit time. We plan to

1076546

utilize our in vivo experience for developing new methodologies for accurately measuring and estimating internal body burdens so that we will be able to more accurately derive dose-response data. This includes the accurate estimation of nuclide distribution within the body, as well as its specific retention at various deposition sites. We are currently in the process of developing the advanced methodologies for determining how material deposited in bone might influence the estimate of activity present in the lung. This is an important aspect of our dose calculation procedures.

Dr. Laurer, who developed the original Phoswich system, continues to work on new developments here at the Institute and his ability to utilize state-of-the-art equipment in order to further his own research into imaging systems, as well as to further enhance existing in vivo measurement systems, requires that our Institute have the HPGe assay measurement system immediately available. It is difficult to proceed into more advanced areas of in vivo bioassay measurements systems without the use of the latest developments in this area.

It has been continually demonstrated that it is necessary to estimate quantitatively the amount of internal contamination in order to accurately estimate risk. Conventional bioassay techniques such as measuring activity in excreta can give erroneous results when material in insoluble and not excreted in a manner indicative of specific contaminant body burdens. For this reason it is essential to combine bioassay of excreta with in vivo measurements of the lung and various other tissue deposition sites. The importance and scientific merit of this area has been recognized by the DOE and we have therefore received continued support over the past 25 years.

There is no doubt that there is continuing need to develop a relationship

1076547

between low dose radiation and its possible effects in order to set realistic guidelines and limitations upon which our nuclear energy program depends. It is only through accurate measurements of internal body burdens and their biokinetics that this goal can be achieved.

The Institute of Environmental Medicine has trained many advanced students at the Ph.D. level over the past 25 years, most of whom are now employed in major National Laboratories, the nuclear industry (including power reactor utilities) and in other academic institutions. Thus far the Laboratory for Radiological Studies has produced over 50 Ph.D. graduate students under a certified degree program which is part of our Department of Environmental Medicine. Our support from the Department of Energy has been responsible for providing the necessary tuition and Ph.D. dissertation topics for many of these students.

Operation and Maintenance Insurance

As previously described, there are several individuals on-site who have extensive electronic experience and who will therefore be able to guarantee a quality control program to assure effective and trouble-free operation. All of our electronic equipment is currently powered through an Elgar uninterruptable power supply which prevents transient power spikes and power failure problems. In addition, we maintain a series of computerized quality control and quality assurance checks on all equipment in an effort to monitor any changes in the efficiency, background, or data acquisition and readout that might normally occur. Finally, in addition to inhouse control, we would institute a service contract from the EG&G Ortec Company (at university expense) which would act as a warranty for the germanium array system and its associated electronics. In the past we have had several such service

1076548

contracts drawn with the EG&G Ortec Company and have found that their service is rapid and reliable.

Academic Eligibility

As previously described in the text of this proposal, the New York University Medical Center, Institute of Environmental Medicine is a well established and certified graduate program in health physics and radiation protection. In fact, we are a participating university in the Oak Ridge Tennessee Associated University Health Physics Fellowship Program that has recently been instituted. Thus far, we have been granted one fellowship for one of our students. In addition, we offer our own NIEHS and NIOSH fellowships, along with graduate assistantships which are usually supported by DOE-sponsored research. Our students have usually received employment in National Labs, in the nuclear industry, and in many cases with other universities at the faculty level.

Although the majority of our radiological health research support comes from the Department of Energy, our Institute has its basic core support with the National Institute of Environmental Health Sciences, the National Cancer Institute, and the American Cancer Institute. This latter funding covers the cost of salaries for the principal investigators and tenured members of the faculty, all utilities at the Institute of Environmental Medicine, and all general maintenance and stock supplies. In the past, we have had considerable interaction with almost all of the National Laboratories in the U.S. currently under DOE aegis. On a non-Federal level, we have received continued support from two nuclear utilities, the Consolidated Edison Company and the New York State Power Authority, both of which own and operate 1000-MWe power reactors within 50 miles of our Institute. In particular, we have performed whole-body counting measurements for a variety of employees who have operated at these

1076549

utility sites in cases of potential exposure and internal contamination with radionuclides.

As an Institute, the New York University Medical Center maintains a variety of major equipment in all of the various scientific disciplines involved in energy research pursuits. In particular, as relates to the present proposal, we have whole-body counters, X-ray fluorescence systems, a variety of multichannel analyzers, IBM and PDP computers and various crystal configurations for measurement of nuclear radiation. In addition, we have alpha/beta proportional counters, and high-pressure ion chambers for the measurement of background radiation. At the Institute level, of course, we maintain a variety of instruments of high quality, including mass spectrometers, scanning electron microscopes, etc., etc.

The qualifications of the major faculty that will be associated with this particular research area are described in the two attached CV's. Both of the principal investigators have had more than 25 years of experience in the nuclear radiation and measurement field, and teach various graduate-level courses as part of our Ph.D. program. Dr. Laurer, in particular, has been responsible for some of the major developments in the gamma spectrometry area, and has been the inventor/designer of the Phoswich system described throughout this proposal and utilized throughout the world.

INTRODUCTION AND OBJECTIVES

The *in vivo* measurement of uranium, plutonium, and other transuranic and heavy metal radionuclides which emit low energy photons is an extremely complex problem. Complexity is introduced into the measurement of these radionuclides by human variables such as source distribution (i.e., macro and micro-

1076550

nuclide distribution), chest wall thickness (cwt), organ and tissue interferences, and spectral distortions due to the presence of other radionuclides. Therefore, elaborate methods, instrumentation, and calibration techniques are required in order to properly access dose distributions within the body. Past developments in the in vivo measurement of transuranic and other heavy metal radionuclides have concentrated on measurement techniques and phantom construction for the dosimetry of lung tissues. Experience has shown that most intakes of transuranic and heavy metal radionuclides occur via inhalation, therefore lung tissue provides the most optimum site for the initial measurement of most intakes. While lung tissue usually receives the largest initial deposition due to inhalation of bone seeking radionuclides, the biological effects and long term dosimetry are moderate when compared with the dosimetry and carcinogenic effects incurred by bone/soft tissue interphase areas. In addition, the metabolism of these radionuclides, once they are transported out of lung tissue, is highly variable resulting in large uncertainties in the systemic deposition fractions for other organs.

For ^{239}Pu the risk from bone cancer is at least 1,000 times greater than the risk from lung cancer. For this reason, accurate estimates of bone depositions are needed and, to date, in vivo measurement is the most conclusive and accurate method for determining the magnitude of specific tissue and organ (especially bone) depositions. In order to perform accurate measurements of bone tissue, several confounding factors need careful study and practical solutions implemented which properly address these confounding factors.

Several complicating factors exist when attempting to measure bone-seeking radionuclides in vivo. An important variable in the measurement of these radionuclides is source distribution within and between tissues. Bone-

1076551

seeking radionuclides tend to initially deposit onto bone surfaces, thus trabecular bone tends to provide concentrated areas for in vivo measurement. Measurement of bone using thoracic skeletal areas leads to confounding factors involving cross contributions from liver and lung tissues. Methods developed at this Institute are currently being studied which will result in simultaneous determination of lung, liver, and bone depositions. In addition, the simultaneous solution of organ activities has been compiled within a computer program to facilitate its use and demonstrate its utility to other laboratories performing these types of measurements.

Another factor which is crucial to the in vivo measurement of bone-seeking radionuclides is the variability of human background levels. Background reduction is of limited usefulness if the variability of the background increases relative to the signal strength. New hyperpure germanium detection systems which have recently been employed by several laboratories for the routine measurement of radiation workers have demonstrated a significant reduction in human background levels relative to a photopeak signal. However, preliminary analysis of a set of 100 human background subjects has shown that the variability of background may be greater than that predicted using standard statistical and spectral extrapolation techniques. Methods for evaluating human background must be investigated to determine which method provides the least variable analysis. Several methods of background determination are applied to the routine measurement of radiation workers by various laboratories. These methods also need to be tested to determine which method provides the best and least variable answer to background determinations.

Calibration for various in vivo source distributions and bone deposition sites is critical to the accurate determination of skeletal deposition of

1076552

bone-seeking radionuclides. Calibration for low-energy X-rays (e.g., ~17 keV X-rays from plutonium and other actinide isotopes) is extremely difficult to perform due to the large attenuation cross sections of bone and soft tissue. The 17 keV photons have half value thicknesses of 0.07 cm and 0.54 cm for bone and muscle tissues, respectively. Construction of human surrogate structures used to calibrate in vivo measurement equipment must account for variances in tissue depth and source distributions within the organ, especially for transuranics in bone.

DESCRIPTION OF EQUIPMENT AND FACILITIES

The first dual crystal detection system was developed in these laboratories and was later marketed by Harshaw under the name of "Phoswich" detectors. Today the Laboratory of Radiological Studies maintains a significant inventory of these detectors, three of which are maintained in an 8'x8'x8' low-background whole-body counting room. The counting room is temperature and humidity controlled and is constructed of 15 cm of low background steel with graded Z lead-cadmium-copper lining to reduce low energy background. The detectors maintained in this room are 15.2 cm dual NaI-CsI(Tl) crystals used for simultaneous measurement of high and low energy photons. In addition, an 8"x4" NaI(Tl) detector is maintained within the room for 1 meter arc whole body count measurements. Daily quality control measurements are performed and computer analyzed for each detector and associated electronics. Electronics associated with the dual crystal detectors include pulse-shaping anticoincidence circuitry, a 4096 channel MCA, a 16K Byte Data General Computer, cassette data storage system, an HP7048A Plotter, IBM Computer Terminal, and Digital (LA120) Line Printer. Detector positioning is carefully controlled using specific engineering designs such that the detectors can be accurately

1076553

repositioned for all conceivable counting configurations.

Human surrogate "phantoms" have been designed and constructed to accurately simulate low energy photon escape and scattering processes within humans. These include an actual thoracic skeletal phantom labeled with ^{241}Am embedded in a tissue-equivalent thorax, real human skulls labeled with ^{241}Am, ^{238}Pu, and ^{210}Pb embedded in tissue-equivalent material and molded into human form, a Rando trunk phantom with removable tissue-equivalent lungs capable of being labeled with a variety of different radionuclides and a multipurpose phantom for use in the calibration of internally-deposited, high energy, gamma-emitting radionuclides.

METHODOLOGY AND DESCRIPTION OF SPECIFIC RESEARCH TASKS

Figure-of Merit Studies for Phoswich and Hyperpure Germanium Detection Systems

Germanium array detection systems are being used in several DOE and other nuclear facilities for *in vivo* measurement of employees. These facilities have high throughputs of personnel for *in vivo* measurement and consequently have minimal time and personnel to fully evaluate and optimize the use of new measurement systems. To date, limited research has been performed and a total of only six limited publications (Bem76, Ber81, Fa78, Go76, Ki77, Pal84) dealing with *in vivo* measurement of heavy metal radionuclides using germanium systems can be found. Initial studies show promise for Ge array measurement systems based on detection level studies using standard statistical techniques. However, measurements using hyperpure germanium measurement systems have been performed by members of this Institute at *in vivo* measurement facilities maintained by Rockwell International-Rocky Flats Plant and Battelle Pacific Northwest Laboratories and early results indicate that comparative measure-

1076554

ments and study of confounding factors are desperately needed. Determination of background and background variability needs proper and statistical analysis. Preliminary results of over 100 human subject background measurements show that conventional counting statistics may not be valid for these new systems. In fact, background variance may be a more complex functional characteristic of these new systems and more elaborate methods are needed to properly access the sensitivity of these systems. It has been shown (NCRP85) that the statistical variation of germanium detector response is reflected in the total charge collected (Q). The total charge is equal to qn where n is the number of interacting particles, and q is the charge released per particle. Using these considerations, it can be shown that the variation (σ_Q^2) of collected charge is equal to qQ. Finally, the variance is adjusted using the Fano factor correct for differences observed from experimental results. This method of variance determination may need to be incorporated into the routine statistical analysis and figure of merit of germanium measurement systems.

In addition to background variance determinations, research is needed concerning the measurement of bone and other tissues. Variation in measurement results can occur due to cross contributions from other organs or unequal distributions within an organ. Past research at this laboratory has concentrated on characterizing the response of dual crystal detectors to varying organ distributions, and matrix methods have been devised which eliminate interferences and provide accurate organ distributions. Methods to eliminate interferences from variable organ distributions must be developed for germanium array systems. The benefits as well as the limitations of these systems must be determined in order to assure accurate determination of organ depositions within DOE personnel.

1076555

Finally, the response of these systems for the measurement of bone depositions needs to be researched. The methods for accurate determination of bone depositions using dual crystal detectors and tissue-equivalent bone phantoms were developed at this laboratory. Over the past several years significant improvements in the determination of bone deposition activities have occurred at laboratories throughout the U.S. and Europe, largely due to innovative calibration efforts initiated by this Institute (Co77, Co81, Co83, La68, Wr72).

The method devised to research these new detector systems has been divided into two steps. A germanium system acquired by this laboratory would allow for full-time research and development of calibration and counting procedures for these systems. Computer programs will be compiled to demonstrate the feasibility of the methods developed. In conjunction with this initial step, NYUMC research personnel will, with the cooperation of DOE laboratories, perform related research and development at DOE sites and assist laboratories in establishing calibration and measurement methods for bone depositions. Areas of study using the germanium detector array will concentrate on determination of human background, human background variation, radionuclide distribution and associated interferences, mathematical and measurement method development, and computer development for the measurement of transuranics in bone and other organs.

Determination of the optimum detection system for measurement of radionuclides is a function of the figure of merit. The highest value of the figure of merit indicates the best measurement system available for the specified measurement conditions. Over the past few years more and more DOE laboratories have begun to alter their <u>in vivo</u> measurement systems in an attempt to

1076556

optimize this figure of merit. While this optimization represents apparent improvement in sensitivity, there are several peculiarities concerning these newer in vivo measurement systems which have not been studied. Currently (or within the near future) at least four major DOE laboratories are reported to be utilizing these newer in vivo detectors for routine measurements of DOE and DOE contractor personnel without a complete foreknowledge of the inherent differences between these newer detection systems and previously used in vivo monitors. The purpose of this justification is to request funding to obtain the necessary equipment to perform vital studies of these newer in vivo measurement systems, provide comparison to systems used in the past, quantitate data perturbations due to anthropometric differentiation of internally-deposited nuclides, and provide DOE laboratories utilizing these newer systems with modification methodology and supplemental information which can be used to account for differential deposition and anthropometric variability.

FIGURE OF MERIT

When choosing "the best" detection system, a quantitative value must be determined to assure optimum sensitivity for the complete measurement system. This value has been termed the "figure of merit" and, in very simple terms, is the ratio of the total signal to the overall variability. Without anthropometric interferences, the figure of merit can be reduced to:

$$\frac{S}{[(S + B) + B]^{1/2}}$$

where: S = signal counts and

B = background counts.

For radioactivity measurements, the net signal count is equal to the

1076557

detector efficiency multiplied by the number of disintegrations being measured. Thus, as the net signal count approaches the background count for a detection system (i.e., low disintegration rates), the highest ratio of the efficiency to the background variability will provide the optimum figure of merit. This means that the capability of spectrometry systems (as used for *in vivo* measurement) to achieve the optimum figure of merit is correlated directly (proportionately) with the ability of the detector to produce a significant peak rise above the continuum under the peak (background).

When a comparison is performed between high resolution germanium arrays and conventional *in vivo* detectors [NaI(Tl) or NaI-CsI(Tl)] without taking into account anthropometric interferences, it is easily proven that germanium arrays possess superior sensitivity. However, the figure of merit, by definition, requires that the signal count be divided by the *overall* variability. This overall variability must include the variability in count-rate introduced by the size and shape of the human subject and the distribution of radionuclides within the human subject. Therefore, human variability must be taken into account, as well as efficiencies and backgrounds, before finally selecting an optimum *in vivo* measurement system.

IN VIVO MEASUREMENT EXPERIENCE WITH GERMANIUM ARRAYS

Publications addressing the possible advantages and uses of germanium (Ge) detectors for the *in vivo* measurement of internally-deposited radionuclides can be traced back to 1976. Oak Ridge National Laboratory (ORNL) was the first to present preliminary studies utilizing Monte Carlo calculations to predict efficiencies for *in vivo* measurement of radionuclides utilizing Ge detectors. These studies showed that efficiencies using Ge detectors could vary by over a factor of 10^2 depending on detector positioning and source

1076558

distribution.

The first recorded use of Ge arrays for routine in vivo measurement of radiation workers started in October 1976 at the DOE Rocky Flats Plant. The detectors were and still are used to measure internally-deposited radionuclides, principally consisting of plutonium and americium isotopes. When first installed in 1976 the system cost approximately 91,000 dollars and provided a calculated lower limit of detection (LLD) of 0.19 nCi of ^{241}Am for an average subject who was counted for approximately one-half hour. Current LLD values for ^{241}Am using NaI-CsI(Tl) dual crystal detectors are approximately 0.3 nCi. Figure-of-merit considerations taking into consideration the dynamic nature of human source geometries were not studied prior to implementation of this system, however measurements of LLD and relative uncertainties for maximum permissible lung burden (MPLB) measurements were determined.

In 1977 a simplified comparison of LLD's between NaI detectors and high purity germanium (Ge) detectors was published. The Ge detector was a four crystal array and the source geometry consisted of uranium isotopes plated onto metal disks of unspecified size. This comparison also estimates for tissue absorption using six centimeters of pressed wood and an increased source-to-detector distance. Like the 1976 Monte Carlo studies, these studies only considered detector efficiencies as a basis for determining the optimum detector.

Later in 1983, a summary was published which described the use of a Ge array for routine in vivo measurement of several different radionuclides including ^{238}Pu, ^{241}Am, ^{144}Ce, and ^{210}Pb. This study determined detection levels for these radionuclides, but as with previous studies did not provide a study of the detector system's figure of merit. In addition, results from the

1076559

^{238}Pu measurements have been the subject of controversy for several reviewers of the article. Sequential measurements performed using the Ge array during the first 15 days in which dynamic lung clearance mechanisms are most noticeable had to be summed in order to make a final determination of ^{238}Pu content. Since publication of this study, it has also been revealed to several reviewers that simultaneous measurements utilizing a Phoswich detection system resulted in in vivo estimates of ^{238}Pu which were 2 to 3 times higher than the final estimate determined by the Ge array. Likewise, the Ge and Phoswich measurements exhibited vastly different retention functions over the first 15 days of measurement. These results can be explained by the first ORNL study cited in this review. During the first 15 days of in vivo measurement, dynamic alterations of source distribution and quantity are occurring and because of these alterations there can be geometry effects which are not corrected wnen utilizing a Ge array.

Germanium arrays are being used in several DOE and other nuclear facilities for in vivo measurement of employees. These facilities have high throughputs of personnel for in vivo measurement and subsequently have minimal time and personnel to fully investigate new measurement systems. Initial studies do show promise for Ge array measurement systems based on detection level studies and figure-of-merit determinations utilizing simple counting statistics. Study of the variations encountered for in vivo measurement data when differing radionuclide distributions are encountered have not been studied, nor has an appropriate figure of merit, taking into account overall variability of the measurement, been considered. Based on published information, extremely limited study has been performed on Ge arrays for in vivo measurement and yet these systems are routinely being utilized for in vivo measurement of personnel. It is projected that the use of these systems, based on

1076560

the limited number of studies to date, will increase substantially.

Extensive studies of Ge array measurement systems are necessary. These studies should not only determine the appropriate figure of merit for these systems but must provide DOE laboratories currently utilizing these systems with methods for proper data interpretation. Study of distribution effects in bone, lung, liver, and other interfering organs must be performed in order to insure proper dose estimates for internally-deposited radionuclides. These studies must be performed by a laboratory that does not have the pressures of a routine *in vivo* measurement program so that a complete and detailed study can be performed.

New York University Medical Center's Institute of Environmental Medicine has the experience and facilities necessary for these types of studies. Since the Institute is an educational and research facility, it is ideally suited for developmental studies of Ge arrays without the pressures of a routine *in vivo* monitoring program. Likewise, being part of the University's Medical Center provides access to anthropometric materials which will allow for the proper determination of human variability and variable radionuclide distributions.

Specifically, we plan to develop background estimation techniques for the new germanium systems using at least 50 human background subjects. These background estimation techniques will incorporate the unique Poisson character of these systems. In addition, we plan to evaluate the degree of interference observed by the new germanium systems due to multi-organ distributions of actinide elements. This project will utilize the Humanoid Systems thorax phantom and bone phantoms developed at this Institute. Finally, we will derive statistical methods and equations for the correct propagation of error

1076561

to be used for the realistic determination of lower limits of detection. Thus, the proposed research will provide an accurate determination of the figure of merits for germanium and NaI-CsI(Tl) systems which take into account the unique statistical distributions of each system. This figure-of-merit study and associated research will assist laboratories in defining the proper counting system for various *in vivo* measurement applications.

Development of a Spectral Library for Low Energy Photon Emitters

Introduction of high resolution Ge arrays for the *in vivo* measurement of low energy photon emitters has resulted in display of rarely seen spectral lines. While these spectral lines are described in tables of isotopes, little graphic information exists for *in vivo* measurements. This Institute has, and continues to construct, a radionuclide library which provides spectral plots and technical data for low energy photon emitters measured *in vivo* using dual crystal detectors [NaI-CsI(Tl)]. This library has been published in NYUMC progress reports in an effort to assist other laboratories in identifying unknown spectra. Equivalent information does not exist for *in vivo* measurement of low energy photon spectra using Ge array systems. As an aid to laboratories employing these new detection systems for the routine *in vivo* measurement of personnel, and as a part of the research performed at this laboratory, a low energy spectral library for *in vivo* measurement will be developed for Ge array systems. These spectra will display the unique energy lines encountered when using Ge arrays for *in vivo* measurement of radionuclides which emit low energy photons and multiple X-rays. In addition, technical data for each nuclide will be attached to spectral plots in order to provide a single source of technical information for the *in vivo* measurement of low energy photon emitters.

1076562

Determination of Environmental Exposures to Radon Progeny Using In Vivo Measurements

The successful use of ^{210}Pb skeletal burdens as a means of estimating the lung dose from the cumulative exposure to short-lived radon progeny was first demonstrated with *in vivo* measurements of U.S. uranium miners in 1967 (Ei69). New York University Medical Center was the first research facility to propose the *in vivo* measurement of ^{210}Pb to be performed along with the bioassay of ^{210}Po as a means of deriving the total skeletal content of these nuclides which are subsequently employed to derive a cumulative lung dose. This technique was first made possible by the development of the dual crystal (Phoswich) detector which suppresses the majority of the Compton background in the low energy region of the photon spectrum, and allows for the measurement of the 47 keV photon emitted by ^{210}Pb. Based on this methodology, it is estimated that an amount of ^{210}Pb equivalent to a cumulative exposure of 300 Working Levels Months (WLM) of radon progeny exposure can be detected with the dual crystal technology.

New hyperpure germanium (HPGe) arrays are beginning to supplement the dual crystal technology in many laboratories. It is estimated and has been shown by Palmer *et al.* (Pal84) that the HPGe arrays are more sensitive (optimally by a factor of 2) than the Phoswich system in measuring ^{210}Pb skeletal burdens. This would increase capabilities to measure cumulative radon exposure levels by a factor of 2, to approximately 150 WLM. Other than the few measurements performed by Palmer, no research of this new technology for the measurement of low levels of radon progeny exposure has been performed. In addition, existing HPGe systems are limited in available time for the research of ^{210}Pb skeletal burdens due to commitments to perform routine

1076563

surveillance of laboratory personnel contamination.

The HPGe array detection system will be an excellent system for monitoring environmental exposures to radon progeny in homes known to contain elevated levels of radon and radon progeny. Recent newspaper articles in the northeastern portion of the country have been reporting levels of radon progeny as high as 10 to 15 WL in homes built over the Reading Prong. The Reading Prong is a geological Precambrian structure (consisting of schists and granite gneisses) in the northeast which contains elevated uranium deposits and extends from southeastern portions of New York State into New Jersey and Pennsylvania. Assuming an individual spends 50% of their time inside a house with 10-15 WL, a cumulative exposure of 250 WLM will occur after one year of residence. While this exposure level is too low to detect using dual crystal detection systems, it is far above the estimated lower limits of detection for the HPGe detection system.

If current estimates are correct, the HPGe system proposed in this study will allow for the measurement of cumulative exposures to environmental levels of radon progeny. This has far reaching implications relative to being able to determine those individuals who have incurred elevated exposures to radon progeny through their natural environment.

The research performed at this Institute provides a training center for personnel which eventually enter the nuclear field. Many of the graduates of this program currently work at DOE facilities and have provided significant accomplishments in the nuclear field. There are very few institutions capable of providing training for the <u>in vivo</u> measurement of low energy, photon-emitting radionuclides, and this Institute is one of these training centers. A list of students which have been directly or indirectly supported by this

1076564

research and the equipment maintained by this research is provided in Table 2.

SIGNIFICANT PAST ACCOMPLISHMENTS

Some of the most significant accomplishments which have resulted from the continuing support of our research endeavors in this area include:

1) The original design of the dual crystal [NaI-CsI(Tl)] detector which provides for low-background, high-efficiency detection of photons with energies below 150 keV.

2) Development of calibration structures for bone-seeking nuclides which have deposited in or on the skull, thorax and knee (patella and ends of the femur, tibia and fibula) areas. These phantoms have been employed by several laboratories which are responsible for the routine measurement of possible internal contamination by important actinide nuclides.

3) Development of a methodology for determining the contribution of material which has deposited in the thoracic skeleton to material which may be present in the lung. This correction is essential for calculation of the correct radiation dose which has been delivered to the lung.

4) Development of an optimum configuration, e.g., using three Phoswich detectors, for determining the amount of activity associated with the skull bones.

5) Determination of both low and high energy photon-emitting nuclide contamination by a technique whereby signals are simultaneously removed from both the CsI(Tl) and the NaI(Tl) (in coincidence with the CsI) from the same detector. By this technique it is possible to make both high and low energy measurements in the same geometry, simultaneously, without the

1076565

requirement for additional measurement time or repositioning.

6) Development of a least-squares regression computer program for analysis of *in vivo* low energy measurements of mixed nuclides in man.

7) Compilation of a library of important radionuclides which are routinely measured using the dual crystal detector. These include the major actinides and alkaline-earth materials and includes important information regarding spectral shape for point source vs. material homogenously distributed in the lung, as well as decay scheme and important spectral characteristics for each nuclide.

8) Development of a matrix calculation method which allows for the simultaneous determination of radionuclide content within any number of specified organs. This methodology is easily computed, allows for the separation of organ activities *in vivo*, and provides a basis for direct comparison of measured organ burdens with internal dose standards.

The above accomplishments in crystal development and counting methodology have resulted in the following important applications:

1. Determination of organ specific activities and follow-up of many inadvertent actinide exposures in man.

2. Use of ^{210}Po in uranium miner skeletal tissues to estimate depositions in skeleton and cumulative lung doses from ^{222}Rn daughters.

3. Comparison of human *in vivo* data with nonhuman primate measurements after exposure to similar chemical and physical isotope forms.

1076566

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1076568

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1076569

TABLE 1

Phoswich and Germanium Detection Systems Utilized at Laboratories for *In Vivo* Measurement of Low-Energy Photon-Emitting Contaminants[1]

United States Laboratories	Type(s) of System(s) Used NaI-CsI(Tl)	Ge
Argonne National Laboratory	X	
Battelle Pacific Northwest Laboratories	X	X
Idaho National Ecology Laboratory	X	X
Lawrence Livermore National Laboratories	X	
Los Alamos National Laboratory	X	
Mound Laboratories	X	
New York University Medical Center	X	
Oak Ridge National Laboratories	X	X
Reynolds Electrical & Engineering Co.	X	
Rocky Flats Plant	X	X
Savannah River Plant	X	X
University of Pittsburgh	X	
Foreign Laboratories		
Atomic Energy Establishment (England)	X	X
Atomic Energy Research Establishment (England)	X	
Centre d'Etudes Nucleaires (France)	X	
Comissao National de Energia Nuclear (Brasil)	X	
Dept. of National Health & Welfare, Radiation Protection Division (Canada)	X	X
Environmental Radioactivity Laboratory, CNEN-CSN (Italy)	X	
Bhabha Atomic Research Center Hospital, Health Physics Division (India)	X	

[1] This data was collected from the scientific literature and personal communications and may, therefore, not represent a complete account of the types of detection systems utilized by these laboratories.

1076570

TABLE 2

Students Who Have Received Advanced Degrees from New York University Medical Center in the Last 10 Years as a Direct or Indirect Result of Research Using In Vivo Counting Systems

Raymond Guilmette -	[redacted]
Henry Spitz -	[redacted]
Thomas Lo Sasso -	[redacted]
James Neton	[redacted]
Mark Maiello	[redacted]
Lowell Ralston	[redacted]
David Hickman -	[redacted]

* To be awarded.

1076571

Estimated Cost and Budget

Hyperpure Germanium (HPGe) Array

Detection System-Cost Breakdown*

1)	10 ea.	Model GLP-36490/05 HP Ge Detectors ($9,690 ea.)	$96,900
2)	10 ea.	Model 472 Ortec Spec. Amps ($1,125 ea.)	11,250
3)	2 ea.	Model 4001C/4002A Nim Bin and Power Supply ($840 ea.)	1,680
4)	3 ea.	Model 433A Dual Sum and Invert Amps ($295 ea.)	885
5)	1 ea.	Model 478 2 kV Bias Supply ($745 ea.)	745
6)	1 ea.	Automated Liquid Nitrogen Transfer and Fill System ($10,000 ea.)	10,000
7)	1 ea.	Model Ortec ADCAM MCA 150 Multichannel Analyzer ($10,000 ea.)	10,000
		Subtotal	$131,460
8)	Service Contract		$8,000
9)	Installation		5,000
10)	Building Renovation		10,000
		Subtotal	$23,000
		Grand Total	$154,460

* Note that the $8,000 cost of the EG&G Ortec Service Contract will be assumed by our National Institute of Environmental Health Sciences Center Grant # ES 00260, whereas $15,000 in installation and renovation charges will be supplied by the New York University Medical Center as a cost-sharing contribution.

1076572

Curriculum Vitae

Name: Norman Cohen, Ph.D. Born [redacted] N.Y.

Educational Background:

[redacted]

Employment:

Professor and Director, Laboratory of Radiological Studies, New York University Medical Center, Tuxedo, New York (9/84-present)

Employment Description:

Teaching and research investigator for various studies involved with radiobiology, radiochemistry and radiation physics of the biokinetics, metabolism and toxicology of the heavy metals -- current interest: Pb-210, Po-210, Am-241, Pu-238/239, Cm-243/244, Th-232/230/228, Np-237/239, Pa-233, Ra-226, Fe-55, various essential trace metals and stable lead in man and nonhuman primates.

Present Federal Government Public Advisory Committees:

National Academy of Sciences, National Research Council, Member, Uranium Mill Tailings Study Panel (1984).

National Council on Radiation Protection and Measurements (NCRP), Chairman, Task Group on Xenon Isotopes in the Atmosphere - Accumulation, Biological Significance, and Control Technology (SC-38) (1982-present).

National Council on Radiation Protection and Measurements (NCRP), Member, Task Group on Neptunium (SC-57) (1982-present).

Publications:

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Curriculum Vitae

NAME: Gerard R. Laurer, [redacted] N.Y.

Employment: New York Univ., Dept. Environmental Medicine
550 First Avenue, N.Y., N.Y. 10016 Sept. '59 - present

Position: Research Professor, 1983 - present

Education: [redacted]

Research Areas: Design/application of systems and techniques for in vivo detection and measurement of radionuclides in man; design/application of XRF systems for analysis of stable elements in the environment and man.

Publications

1. Laurer, G.R., M. Eisenbud, and N. Cohen, A Detection System for the Localization and Measurement In Vivo of Small Amounts of Photon Emitters, Proc. of the Workshop on Measurement of Heavy Elements In Vivo, Battelle Seattle Research Center, June 24-25, 1976, BNWL-2099/UC-41, pp. 207-218 (Sept. 1976).

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1076574

December 3, 1985

U.S. DEPARTMENT OF ENERGY

ASSURANCE OF COMPLIANCE

Nondiscrimination in Federally Assisted Programs

(Hereinafter called the "Applicant")

(Name of Applicant)

HEREBY AGREES to comply with Title VI of the Civil Rights Act of 1964 (Pub. L. 88-352), Section 16 of the Federal Energy Adminstration Act of 1974 (Pub. L. 93-275), Section 401 of the Energy Reorganization Act of 1974 (Pub. L. 93-438), Title IX of the Education Amendments of 1972, as amended, (Pub. L. 92-318, Pub. L. 93-568, and Pub. L. 94-482), Section 504 of the Rehabilitation Act of 1973 (Pub. L. 93-112), the Age Discrimination Act of 1975 (Pub. L. 94-135), Title VIII of the Civil Rights Act of 1968 (Pub. L. 90-284), the Department of Energy Organization Act of 1977 (Pub. L. 95-91), and the Energy Conservation and Production Act of 1976, as amended, (Pub. L. 94-385). In accordance with the above laws and regulations issued pursuant thereto, the Applicant agrees to assure that no person in the United States shall, on the ground of race, color, national origin, sex, age, or handicap, be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity in which the Applicant receives Federal assistance from the Department of Energy.

Applicability and Period of Obligation

In the case of any service, financial aid, covered employment, equipment, property, or structure provided, leased, or improved with Federal assistance extended to the Applicant by the Department of Energy, this assurance obligates the Applicant for the period during which Federal assistance is extended. In the case of any transfer of such service, financial aid, equipment, property, or structure, this assurance obligates the transferee for the period during which Federal assistance is extended. If any personal property is so provided, this assurance obligates the Applicant for the period during which it retains ownership or possession of the property. In all other cases, this assurance obligates the Applicant for the period during which the Federal assistance is extended to the Applicant by the Department of Energy.

Employment Practices

Where a primary objective of the Federal assistance is to provide employment or where the Applicant's employment practices affect the delivery of services in programs or activities resulting from Federal assistance extended by the Department, the Applicant agrees not to discriminate on the ground of race, color, national origin, sex, age, or handicap, in its employment practices. Such employment practices may include, but are not limited to, recruitment, recruitment advertising, hiring, layoff or termination, promotion, demotion, transfer, rates of pay, training and participation in upward mobility programs, or other forms of compensation and use of facilities.

Subrecipient Assurance

The Applicant shall require any individual, organization, or other entity with whom it subcontracts, subgrants, or subleases for the purpose of providing any service, financial aid, equipment, property, or structure to comply with laws cited above. To this end, the subrecipient shall be required to sign a written assurance form, however, the obligation of both recipient and subrecipient to ensure compliance is not relieved by the collection or submission of written assurance forms.

1076575

Data Collection and Access to Records

The Applicant agrees to compile and maintain information pertaining to programs or activities developed as a result of the Applicant's receipt of Federal assistance from the Department of Energy. Such information shall include, but is not limited to, the following: (1) the manner in which services are or will be provided and related data necessary for determining whether any persons are or will be denied such services on the basis of prohibited discrimination; (2) the population eligible to be served by race, color, national origin, sex, age and handicap; (3) data regarding covered employment including use or planned use of bilingual public contact employees serving beneficiaries of the program where necessary to permit effective participation by beneficiaries unable to speak or understand English; (4) the location of existing or proposed facilities connected with the program and related information adequate for determining whether the location has or will have the effect of unnecessarily denying access to any person on the basis of prohibited discrimination; (5) the present or proposed membership by race, color, national origin, sex, age and handicap, in any planning or advisory body which is an integral part of the program; and (6) any additional written data determined by the Department of Energy to be relevant to its obligation to assure compliance by recipients with laws cited in the first paragraph of this assurance.

The Applicant agrees to submit requested data to the Department of Energy regarding programs and activities developed by the Applicant from the use of Federal assistance funds extended by the Department of Energy. Facilities of the Applicant (including the physical plants, buildings, or other structures) and all records, books, accounts, and other sources of information pertinent to the Applicant's compliance with the civil rights laws shall be made available for inspection during normal business hours on request of an officer or employee of the Department of Energy specifically authorized to make such inspections. Instructions in this regard will be provided by the Director, Federally Assisted Programs Division, Office of Equal Opportunity, U.S. Department of Energy.

This assurance is given in consideration of and for the purpose of obtaining any and all Federal grants, loans, contracts (excluding procurement contracts), property, discounts or other Federal assistance extended after the date hereto, to the Applicant by the Department of Energy, including installment payments on account after such date of application for Federal assistance which are approved before such date. The Applicant recognizes and agrees that such Federal assistance will be extended in reliance upon the representations and agreements made in this assurance and that the United States shall have the right to seek judicial enforcement of this assurance. This assurance is binding on the Applicant, its successors, transferees, and assignees, as well as the person whose signature appears below and who is authorized to sign this assurance on behalf of the Applicant.

December 4, 1985
(Date)

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1076576