Date: FEB 24 1978

Royal Rostenbach
Engineering Energetics
202-632-5790

The following identification number has been assigned to your proposal:

ENG 7811042

In all future correspondence, please refer to the number shown above.

The Proposal has been referred for review and evaluation to the:

Division of Engineering

Consideration of proposals normally requires approximately six months, but more time may be needed on those involving special problems in which case you will be notified.

A separate acknowledgment is being sent to your institution's business office.

Central Processing Office
Administrative Services Office

.L. 24 (10-73)

lational Science Foundation
Washington, D.C. 20550

Official Business
PENALTY FOR PRIVATE USE, $300

Postage and Fees Paid
National Science Foundation

U.S.MAIL

Elizabeth Ralph
Museum Applied Science Ctr for Archaeology
University of Pennsylvania
Philadelphia, PA 19104

Museum Applied Science Center for Archaeology

Martin Biddle, Director — Elizabeth K. Ralph, Associate Director

THE UNIVERSITY MUSEUM • UNIVERSITY OF PENNSYLVANIA
33rd & SPRUCE STREETS • PHILADELPHIA, PENNSYLVANIA 19104
386-7400 (Area Code 215) — Cable Address "Antique"

31 January 1978

Anthony Merritt
Office of Research Administration
University of Pennsylvania

Dear Mr. Merritt:

The University Museum will contribute $5,000 towards the purchase of a Germanium Gamma-ray detector and associated electronics. This spectrometer system will be used primarily for research in thermoluminescence dating. The total price of the system is $24,000. The remaining fraction of the purchase price is being applied for from NSF under "Engineering Specialized Research Equipment." The principal investigators of this grant are Elizabeth Ralph and William Stephens.

Yours truly,

Martin Biddle
Director

UNIVERSITY of PENNSYLVANIA
PHILADELPHIA 19104

OFFICE OF RESEARCH ADMINISTRATION

(AREA 215) 243-7293
FRANKLIN BUILDING
3451 WALNUT STREET I6

January 31, 1978

Central Processing Section
National Science Foundation
Washington, D.C. 20550
Attn:
Division of Engineering
Engineering Equipment Grant Request

Re:
Research proposal entitled: "Germanium Gamma-ray Detector for Improved Precision in Thermoluminescent Dating"

Gentlemen:

Enclosed herewith are copies of a proposal for the above referenced project which is being conducted under the direction of

Dr. Elizabeth K. Ralph, Associate Director, Museum Applied Science Center, University Museum.

The proposal has been signed on behalf of the University by appropriate University officials.

The University agrees to cost share on this proposal in accordance with current National Science Foundation Policy.

Should you require any additional information, please do not hesitate to call me.

Sincerely

A. E. Paddock
Contracts Administrator

AEP:ekk
encl.

cc: Dr. Ralph

UNIVERSITY of PENNSYLVANIA
PHILADELPHIA 19104

The Faculty of Arts and Sciences
DEPARTMENT OF PHYSICS

July 31, 1978

Dr. John Yellen, Program Director
Division of Anthropology
National Science Foundation
Washington, D.C. 20550

Dear Dr. Yellen:

At the instruction of Dr. Marshall Lee, Division of Engineering, I have reduced the budget of our proposal ENG 7811042 from $19,000 to $9500.

The revised budget sheets are attached.

We appreciate your willingness to contribute $9500.

Sincerely yours,

Elizabeth K. Ralph

Elizabeth K. Ralph

EKR:mbp
cc: Mr. Anthony Merritt, Director
Office of Research Administration
University of Pennsylvania

UNIVERSITY of PENNSYLVANIA

PHILADELPHIA 19104

OFFICE OF RESEARCH ADMINISTRATION

(AREA 215) 243-7293
FRANKLIN BUILDING
3451 WALNUT STREET I6

August 3, 1978

Central Processing Section
National Science Foundation
Washington, D.C. 20550
Attn:

Re: Revised budget for proposal entitled: "Germanium Gamma-ray Detector for Improved Precision in TL-Dating"

Gentlemen:

Enclosed herewith are copies of a proposal for the above referenced project which is being conducted under the direction of Dr. Elizabeth K. Ralph, Associate Director, Museum Applied Science Center, University Museum.

The proposal has been signed on behalf of the University by appropriate University officials.

The University agrees to cost share on this proposal in accordance with current National Science Foundation Policy.

Should you require any additional information, please do not hesitate to call me.

Sincerely

Andrew G. McIlvaine
Contracts Administrator

AGM:ekk
encl.

cc: Dr. Ralph

PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

Cover Page Format

w/o CVs

FOR CONSIDERATION BY NSF ORGANIZATIONAL UNIT (please specify):

Research Proposal to:
NSF Division of Engineering
Engineering Equipment Grant Request

PROGRAM ANNOUNCEMENT/SOLICITATION NO.:	CLOSING DATE (IF ANY):
NSF 77-45	February 1, 1978

NAME OF SUBMITTING ORGANIZATION TO WHOM AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS)

Trustees of the University of Pennsylvania

ADDRESS OR ORGANIZATION (INCLUDE ZIP CODE)

Office of Research Administration 409 Franklin Bldg./I6
Philadelphia, PA. 19104

TITLE OF PROPOSED PROJECT

Germanium Gamma-ray Detector for improved precision in Thermoluminescent Dating

REQUESTED AMOUNT	PROPOSED DURATION	DESIRED STARTING DATE
19,000 ~~$16,000~~	Purchase time for equipment	August 1978

PI/PD NAME AND SOCIAL SECURITY NO. (SSN)*	PI/PD PHONE NO.
Elizabeth Ralph 002-14-7858	215-243-8168

PI/PD DEPARTMENT	PI/PD ORGANIZATION
Museum Applied Science Center for Archaeology (MASCA)	UNIVERSITY MUSEUM University of Pennsylvania

ADDITIONAL PI/PD AND SSN*	ADDITIONAL PI/PD AND SSN*
William E. Stephens	
ADDITIONAL PI/PD AND SSN*	ADDITIONAL PI/PD AND SSN*
FOR RENEWAL OR CONTINUING AWARD REQUEST, LIST PREVIOUS AWARD NO.:	

REMARKS: *Submission of social security numbers is voluntary and will not affect the organization's eligibility for an award. However, they are an integral part of the NSF information system and assist in processing the proposal.

PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR	AUTHORIZED ORGANIZATIONAL REP.	OTHER ENDORSEMENT
NAME: Elizabeth K. Ralph	NAME: Anthony Merritt	NAME: Arthur E. Humphrey
SIGNATURE	SIGNATURE	SIGNATURE
TITLE: .Associate Director of MASCA	TITLE: Director of Office of Research Administration	TITLE: Dean of Engineering
DATE: 31 January 1978	DATE: 31 January 1978	DATE: 31 January 1978

Note: Use of this standard proposal format is required by OMB Cir. A-110).

ABSTRACT

This equipment grant is for the purchase of a lithium-drifted germanium gamma-ray spectrometer to be used for radiometric analysis of uranium, thorium and potassium content in ceramic materials. This measurement is necessary for estimating the radiation dose-rate present in materials to be dated by thermoluminescence. Currently uranium and thorium concentrations are estimated by alpha counting. This procedure suffers from many inaccuracies due to the inefficiencies of -counting and the failure of several of the key assumptions in converting α-counts to uranium and thorium concentrations. Potassium concentration is currecntly measured by flame-photometry. Preliminary experiments using a Ge(Li) gamma detector show that potassium can be measured to a precision of the order of 1%. The precision of uranium and thorium concentration measurements are more difficult to estimate, but appear to be within 10%. If gamma-ray spectroscopy were coupled with neutron activation, measurements of uranium and thorium concentrations to better than 1% could be obtained.

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INTRODUCTION AND BACKGROUND

This equipment grant is for the purchase of a lithium-drifted germanium gamma-ray detector, Ge(Li) detector, to be used for individual radiometric analysis of uranium, thorium and potassium content in ceramic materials. This measurement is necessary for estimating the radiation dose-rate present in materials to be dated by thermoluminescence.

In 1959, Elizabeth K. Ralph started research directed toward the possibility of using thermoluminescence for dating pottery, a theory which had been suggested originally by Farrington Daniels in 1953. This work has been pursued actively at the MASCA research center by Mark Han since 1962.

During the past fifteen years, under the direction of Drs. E. K. Ralph (Associate Director) and W. E. Stephens (Associate Director for Research), improvements in the overall technique and a specific method of sample preparation have been developed independently here at MASCA.

Thermoluminescence dating is based upon the fact that particles emitted from traces of radioactive elements in the clays bombard the other constituents and raise electrons to metastable levels. When the clay is heated, enough extra energy is supplied to enable the electrons to return to normal states. In this transition, each one emits a photon of light. Thus, the firing or final heating of a ceramic is the starting point of the accumulation of metastable electrons.

The essential features of thermoluminescent dating of ceramics are the measurement of the inherent radioactivity, and the natural and artificial thermoluminescent glow curves, from which, ideally, the age (or date of last firing) can be determined. (cf. Fig. 1.)

In principle, the method is straight-forward, but in practice, there are many problems and uncertainties. The primary causes of these problems are the lack of understanding of the behavior of various complex ceramic systems and the effects of pottery-manufacturing technologies on that behavior. Our experiments have shown that the thermoluminescent responses of different types of clay, in addition to the responses of various crystalline inclusions, are highly dependent upon the previous thermal history and chemical composition, and on the type of radiation applied.

It has been our intention to focus our experimentation upon these problems which are poorly understood, in order to obtain the knowledge needed to improve the reliability of the thermoluminescence method as a tool for the dating of fired earthen objects. During the past ten years, this laboratory has processed approximately 700 pottery samples, which represent 133 major sites from 35 countries.

Current experiments are directed toward the development of a new technique of sample preparation, namely, the deposition of the fine clay grains by the evaporation of a volatile liquid, such as acetone, in which they are suspended. The main purpose of this new approach is to eliminate large crystalline inclusions that may be present in coarse-grained sherds. Similar techniques have been employed at Oxford (Aitken, et al., 1968; Zimmerman, 1968 and 1971). The cores of large crystalline inclusions are known to have been subjected to a lesser amount of alpha particle radiation, from uranium and thorium contained in the clay, than have the finer sized grains, because of the short

range of alpha particles in clay. Previously, except for various experiments, we have ground whole sherds regardless of their particle size and measured the resultant powder.

Among the other experiments currently under investigation which should prove valuable in elucidating some of the factors having direct effects upon the thermoluminescence method are the following:

1. Identification of the type of clay by means of X-ray diffraction.
2. Determination of the original firing temperature of the sherd by techniques such as thermogravimetric analysis (TGA) and differential thermal analysis (DTA).
3. Investigation of a direct method for the determination of the true effective radiation damage of alpha particles. To do this, we plan to mix a calibrated liquid ^{210}Po source with the sample, and measure the resultant thermoluminescence.
4. Use of a beta source (^{36}Cl) for the irradiation of samples, to compare the effects of alpha, beta and X-ray doses.

PROBLEMS AND OBJECTIVES

As noted in the introduction, one of the essential features of thermoluminescence (TL) dating is the measurement of the inherent radiation contained within the sample under study. Currently, the total energy deposition from radioactive decays is estimated by alpha counting. To calculate the total energy deposition, one must make assumptions about the numerical value of the Th/U ratio and assumptions about the equilibrium within each decay family. In addition, measurement of total potassium content with a flame photometer allows an estimate to be made of ^{40}K, which must be measured independently since it produces no alphas.

Though it would appear that alpha counting would have a significant advantage over gamma counting by virtue of its possible better counting statistics (cf. Table 1), it is plagued with many difficulties. Alpha measurements are made by recording the photons produced from a ZnS screen exposed to radiation from a thick layer of finely ground ceramic material. Although the geometry of the counting apparatus is tightly controlled, it is difficult to make allowances for fluctuations in particle size and density within this layer. These fluctuations are dependent upon the composition and firing history of the ceramic material. Alpha radiation has a short range in clay, typically less than 45 microns, so that variations in uranium and thorium distribution within the sherd also have a major effect on the efficiency with which the alphas are counted. Consequently, one must make strong assumptions about the similarity of sherds to be dated and those used for calibration. TL-dating at Penn is considered a relative dating technique. TL-dates are calculated using an empirical constant, K, determined by measuring the specific TL for a number of samples of known age (Michael and Ralph, 1971):

$$\text{Age} = K\left[\frac{\text{Natural TL}}{\text{Artificial TL} \cdot R(\alpha)}\right]$$

where: factor in square brackets is called the "specific TL".

$R(\alpha)$: the α-particle count- rate of pottery sample.

Natural TL: measured TL from sample on first heating.

Artificial TL: measured TL after sample exposed to X-rays.

One must be certain of the physical similarity of the calibration samples and the dated samples if TL is to be reliable. These assump-

tions are not always justifiable. If the samples to be dated are very different in age from the calibration samples, it is also possible that they differ in ceramic technology and source of raw materials.

Another problem involved in the conversion of alpha counts to radiation dose is the assumption concerning the ratio of thorium to uranium in the sample. Typically, uranium occurs in a concentration of about 3 ppm and thorium in a concentration of about 12 ppm (by weight). Recently with the aid of a Ge(Li) detector owned by the Tandem Accelerator at Penn, measurements have been made of the Th/U ratio. It was found to vary markedly from sample to sample. The range encountered was from 4.1 to 0.5. The assumed value for this ratio is 3.9 (based both on a solar system estimate, and the ratio of lead isotopes). Though explicitly we never calculate this ratio (since we calibrate our TL with known age samples), variation of this order would produce an error of about 5% in the dose-rate as estimated from alpha counting (cf. Table 2).

The assumption of secular equilibrium is the source of yet another uncertainty in the conversion of alpha count rate to total dose-rate. Secular equilibrium implies radioactive equilibrium, i.e., the activity (rate of decay) of each member of a series is precisely the same as for any other member. This is important for two reasons: (1) Since the half-lives of ^{238}U, ^{235}U and ^{232}Th are long, about 10^9 years, the concentration of parents does not change appreciably during the time period over which the TL is accumulated. Consequently, assuming equilibrium, a measurement of the present dose-rate is a good estimate of what it has been throughout the life of the sherd. This makes it possible to estimate the total radiation dose received by the sherd since its time of manufacture. (2) It is only with some assumption

about the relative concentrations of daughters in a decay series that a measurement of one kind of radiation ($\alpha, \beta,$ or γ) can be used to predict the amounts of the other two. If the relative concentrations of the daughters changes substantially from sherd to sherd, calibration even with known age samples is of limited value. In particular, radon (^{222}Rn) and thoron (^{220}Rn) are noble gases. Tanner (1964) quotes migration distances of 200 cm for radon in unfired dry clay during its 3.8 day half-life (thoron should travel one one-hundredth of this distance). This can be a cause of serious disequilibrium within the decay families. It is particularly serious with regard to radon, not only because of the greater possibility of its leakage, but also the greater effect when it does(cf. Table 3). If radon were to leak away during alpha counting of the ground sherd but had not escaped from the intact sherd, the radiation dose estimated may be less than the actual dose received by 30% (cf. Table 4). This calculation assumes that the alpha efficiency in producing TL is a small fraction of the beta efficiency (as it is in quartz, an important TL material). It is important, therefore, that one be able to test in the intact sherd the assumption of radon loss. This can be done with a gamma detector by testing for the daughters of radon disintegration.

Another disequilibrium-producing condition may result from ion-exchange of UO_2 (Hedges and McLellan, 1976). Alterations of the original uranium concentration by as much as 10% could occur over the burial period if the sherd were buried in ground waters containing twice the concentration of uranium as in the parent clay of the sherd. Such concentrations are not unlikely (Miyake, et al, 1964). A similar exchange may occur for thorium and potassium.

This is a difficult phenomenon to detect by conventional means. One could measure the residual ion-exchange ability of the sherd material and the uranium concentration of the ground waters, but this would only give a rough estimate of the possible uranium uptake during the burial period. A much better check could be made by coupling neutron activation techniques with gamma-ray spectrometry. ^{239}Np and ^{233}Pa are convenient isotopes to use in measurements of U and Th concentrations. Both have short half-lives and consequently high specific activities. When bombarded with thermal neutrons, ^{238}U and ^{232}Th have cross-sections of 2.73 and 7.4 barns respectively (Adams and Gasparini, 1970). Both Np and Pa have strong γ-ray peaks that can be used for quantitative analysis of U and Th down to concentrations of the order of parts per billion (Reed, et al, 1958).

PRELIMINARY EXPERIMENTS

The Ge(Li) detector of the Tandem Accelerator Laboratory has been used to make an initial set of measurements to test the usefulness of gamma-spectrometry as an aid in TL research (cf. Fig . 2). Measurements of ^{40}K (the peak at 1.46 MeV) give values which correspond with those from flame-photometry to within 5%, and to those from mass spectrometry to within 1%. The Oxford Standard, containing 10 ppm each of uranium and thorium, has also been measured. The agreement appears to be within 10%. Samples of monazite in which the equilibrium of the decay families is assured, have been measured yielding encouraging results.

Many of these experiments were completed before the Archaeometry Conference in March 1977, at which time we discussed them with Martin Aitken of the Research Laboratory for Archaeology and the History of

Art at Oxford. He considered the results so significant that he subsequently has ordered an intrinsic germanium well detector of his own. The cost of his detector,without supporting electronics, was over $19,000. Though Prof. Aitken has opted for a well detector because of its greater sensitiviy and larger solid angle, we feel that the advantages of an end-detector (viz. its lower cost, its ability to do gamma spectrometry on unaltered sherds (the hole in the well detector is only 15 mm in diameter) and its general usefulness in other experiments external to the detector), make it a more reasonable acquisition for our laboratory.

OTHER APPLICATIONS

The Ge(Li) detector is generally useful for gamma spectrometry from about 50 KeV to 10 MeV. At 1.332 MeV (^{60}Co) the detector's resolution (including all front end electronics) is 2.0 KeV.

There is some interest at the Laboratory of Research into the Structure of Matter (LRSM), a facility jointly associated with the departments of chemistry, physics and metallurgy, in neutron activation analysis. The primary application would be in trace element analysis in metals, which would be useful in determining the provenience of materials of archaeological interest. Samples could be irradiated either at Brookhaven National Laboratory or the Tandem Accelerator at Penn. Brookhaven has the advantage of a greater neutron flux, but irradiation at Penn has the advantage of simultaneous analysis of the gamma rays, and therefore the potential of studying isotopes with shorter half-lives.

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Miyake, Y., Sugirama, Y., and Tsubota, H., 1964, in The Natural Radiation Environment, Adams and Lowder, eds. , Chicago.

Reed, G.W., Hamaguchi, H., and Turkevich, A., 1958, The Uranium Content of Iron Meteorites, Geochim. Cosmochim. Acta. 13 : 248-255.

Tanner, A.B., 1964, Radon Migration in the Ground: A Review, in The Natural Radiation Environment, Adams, J.A.S. and Lowder,W.M., eds., University of Chicago Press.

Zimmerman, D.W., 1968, Dating of Ancient Pottery by Thermoluminescence, in Second International Conference on Luminescence Dosimetry, Auxier, J.A., Becker, K., and Robinson, E.M., eds., : 858-867.

Zimmerman, D.W., 1971, Thermoluminescent Dating using Fine Grains from Pottery, Archaeometry 13(1) : 29-52.

EQUIPMENT

The major budgetary item is the lithium-drifted germanium (Ge(Li)) gamma-ray detector. It's energy resolution is roughly ten times better than a NaI(Tl) scintillator (cf. Fig. 3). At 1.332 MeV (^{60}Co), the resolution of a Ge(Li) gamma-ray detector is about 2.0 KeV.

Lithium drifted detectors require constant maintenance at liquid nitrogen (LN_2) temperatures. If they are allowed to come to room temperature, they must be sent back to the factory for remanufacture. Assuming average evaporative losses and transfer efficiencies, it will cost about $1200/year to maintain the detector at LN_2 temperature. This sum will be provided by the Radiocarbon laboratory budget. The detector will be housed in the Radiocarbon laboratory and its staff will maintain the crystal, since the Radiocarbon laboratory operates seven days a week.

Two additional advantages of keeping the detector in the Radiocarbon laboratory are the Radiocarbon laboratory's better shielding from cosmic-radiation (hence lower background) and its nearness to the Tandem Accelerator - valuable, if neutron activation experiments are undertaken.

The other items on the budget are the front-end electronics for data handling, including a pulse height analyzer, a teletype for hard copy, and magnetic cassette interface and recorder. Because of the large number of samples to be analyzed, it is necessary that the pulse height analyzer be capable of spectrum stripping for subtraction of background. It will not be possible, as is often done, to accumulate backgrounds for each sample in the subtract mode, as this would double

the required counting time. This unfortunately means a considerably more expensive analyzer ($8,500 as opposed to $5,000).

There is a strong possibility that we may be able to reduce the cost of the front-end electronics by about $3,000 by custom designing the pulse height analyzer and data processing equipment ourselves.

The cassette recorder will allow the collected data to be further processed either on the PDP 11-34 or IBM-360 owned by the physics department.

BUDGET

Ge(Li)-gamma-ray detector (Princeton Gamma Tech)	$10,800.00

1. Configuration: cylindrical closed ended coaxial.
2. Core Diameter: 12 mm.
3. Performance:
   a. Efficiency: 12% relative ro a 3 X 3 NaI for the 1.332 MeV peak of ^{60}Co at a source-detector distance of 25 cm.
   b. Resolution: 2.0 KeV FWHM @ 1.332 MeV
      1.0 keV FWHM @ 122 keV
      FWTM/FWHM 2.
   c. Peak to Compton Ratio : 35.0 @ 1.332 MeV
   d. Count rate: 2000 cps

Pulse Height Analyzer (Tracor Northern 1710)	8,500.00
Teletype (DEC Writer)	1,700.00
Cassette Recorder and Interface	1,000.00
Other	2,000.00

Amplifier
HV power supply for detector bias
NIM Assembly
NIM Power Supply

Total Cost	$24,000.00

Support

University Museum	5,000.00
~~Laboratory for Research into the Structure of Matter~~	~~3,000.00~~
	~~$8,000.00~~
	$ 19,000.00
TOTAL REQUESTED	~~$16,000.00~~

SPECIALIZED RESEARCH EQUIPMENT CERTIFICATION FORMAT

UNIVERSITY	BRANCH/CAMPUS
University of Pennsylvania	
COLLEGE OR DIVISION	**DEPARTMENT**
Faculty of Arts and Sciences	Physics, Radiocarbon Laboratory

1. EQUIPMENT REQUESTED (List only major items costing $10,000 or more)

GERMANIUM GAMMA-RAY DETECTOR (LITHIUM -DRIFTED) Ge(Li) $10,800

2a. SIMILAR EQUIPMENT PRESENTLY IN DEPARTMENT (Include very brief description; date of purchase; original purchase price; source of funds (university, private grant, Federal grant - specify agency))

Ge(Li) Detector

dia: 43.3mm
length: 46.0mm
drift depth: 17.0mm
nominal active volume 65cm^3
resolution: 2.4 KeV at 1.332 MeV

purchased June 1972
$11,500
NSF funds

2b. PRESENT USE (For what purpose; hours used per week; if equipment considered to be obsolete, state reason)

Used for analysis of gamma radiation produced in conjunction with the Tandem Accelerator.

In use on average 20 hrs/wk.

2c. REASON THIS EQUIPMENT CANNOT BE USED IN PLACE OF EQUIPMENT REQUESTED FROM NSF

Not enough time is available on this detector for the large number of tests planned. We've only been able to use it for exploratory research.

3. SIMILAR EQUIPMENT PRESENTLY LOCATED IN ANOTHER DEPARTMENT OF THE SAME COLLEGE (DIVISION) OR IN A DIFFERENT COLLEGE (DIVISION) OF APPLICANT UNIVERSITY

NONE

I CERTIFY: (1) THAT NO EQUIPMENT WHICH COULD BE USED EFFECTIVELY FOR THE PURPOSES SPECIFIED IN MY PROPOSAL IS AVAILABLE FOR USE BY ME IN MY DEPARTMENT OR IN ANOTHER DEPARTMENT, DIVISION, OR COLLEGE OF MY INSTITUTION, (2) THAT IF FUNDED BY NSF, EQUIPMENT WILL BE SUBJECT TO (a) REASONABLE INVENTORY CONTROLS AND MAINTENANCE PROCEDURES, AND (b) GRANTEE POLICIES FOR ENHANCED MULTIPLE OR SHARED USE ON OTHER PROJECTS IF SUCH OTHER USE DOES NOT INTERFERE WITH THE WORK ON THIS PROJECT PROPOSED.

NAME AND TITLE OF PERSON COMPLETING THIS CERTIFICATION (Principal Investigator)	SIGNATURE	DATE
Elizabeth K. Ralph		31 Jan 1978

FACILITIES

MASCA Laboratories, University Museum

MASCA has adequate laboratory and office space. This includes seven rooms for the regular staff plus a large well-equipped laboratory for visiting scientists, volunteers, and for conferences. With funds from NSF Grant GS 36308X, all of the rooms are now air-conditioned by means of a central water-cooled system.

EQUIPMENT

Equipment purchased with NSF grants GS-566, 1028, 1568, 2716 and 36308X is available in MASCA. This includes two sets of glow-curve apparatus with linearly controlled heating programmers, nine functional alpha counters, and a photon counting system. X-ray apparatus is available in the Department of Physics. Beta and gamma sources are available through the cooperation of Dr. Suntharalingam at Jefferson Medical College. However, for convenience we are purchasing a ^{36}Cl beta source, and two more ^{210}Po sources per year to continue the alpha experiments. Grinding equipment, dosimeters, and other minor components have also been purchased.

RADIOCARBON LABORATORY, PHYSICS DEPARTMENT

The Radiocarbon Laboratory consists of two rooms 20 x 20 feet and a third room 20 x 50 feet. All of the rooms are air-conditioned by means of two central water-cooled systems.

Equipment

After the establishment of the radiocarbon laboratory in 1951, it was moved to the "new" Department of Physics in 1956. At that time equipment was purchased to convert from solid carbon to carbon dioxide gas proportional counting. We now have the following components for routine and experimental ^{14}C dating:

Two fume hoods for the pretreatment of samples with HCl and NaOH, nitrogen pyrolysis, and other projects.

One CO_2 combustion and purification train, as shown diagrammatically in Figs. 3 and 4.

Two counter-filling trains and vacuum systems. (One of these is used routinely for our standard ^{14}C counting; the other is available for experimental purposes.)

Three CO_2 gas proportional counters (two 8-liters and one 1-liter capacity), with surrounding shielding and associated electronic components.

Oscilloscopes, voltohmmeters, thermocouples, potentiometers, and many other auxiliary components that are required to maintain the operation of the laboratory and to conduct new experiments.

MASCA PERSONNEL INCLUDING RADIOCARBON LABORATORY

Director
Martin Biddle

Associate Director for Research
William E. Stephens

Associate Director
Elizabeth K. Ralph

Associate Director for Development
F. Otto Haas

RADIOCARBON LABORATORY
Dept. of Physics

U. of Pa. Support - Physics - Museum
Radiocarbon Budget (7/1/77-6/30/78)
$59,934.00

Elizabeth K. Ralph

Barbara Lawn

Jeffrey Klein (G.S.)

NSF Support, Earth Sciences Division
EAR 74-22233-A01,
Elizabeth K. Ralph, Principal
Investigator (1/31/77-7/31/79)
$90,018.00

Henry N. Michael (5 months)

Anne Meulengracht-Madsen (G.S.)

William Penn Foundation
(3/1/77 - 2/28/78) $6,729

Bernard Fishman (G.S.)

MASCA - UNIVERSITY MUSEUM

NSF Support - Special Projects
Division of Social Sciences
(SOC 75-04203-A02)
7/1/77 - 6/30/78
$129,035

Thermoluminescent Dating of Pottery

Mark Han

Stephen Epstein (G.S.)

Nicholas Hartman (G.S.)

Patrick McGovern (G.S.)

Information Center

Kathleen Ryan

Hamish Forbes (G.S.)

Interdepartmental and Volunteers

Mud-brick and Stone Preservation

Darrel Butterbaugh

Potassium Analyses

Margaret Vandereau

VALLEY FORGE PARK SERVICE GRANT
(9/30/77-1/31/79)
$99,994.00

Helen Schenck)) Historical Archaeologists
Joseph Hall)
Nicholas Hartmann, G.S.) Aerial and
Diana Bermingham, G.S.) geophysical survey
Lin Foxhall, G.S. Part-time Admin Asst.

Bruce Bevan, volunteer consultant MASCA
John Cotter, consultant archaeologist

NOTES: 1) G.S. = Graduate Student

2) The U. of Pa. and NSF grants include funds for supplies, equipment, services, etc. as well as for salaries.

CURRENT SUPPORT AND PENDING APPLICATIONS

Current Support

Radiocarbon Laboratory

University of Pennsylvania-Physics — $59,934.00
Radiocarbon Budget (7/1/77-6/30/78)

Elizabeth K. Ralph, Principal Investigator
6 man-months

NSF Support, Earth Sciences Division — 90,018.00
EAR 74-22233-A01 (1/31/77-7/31/79)

Elizabeth K. Ralph, Principal Investigator
2 man-months

MASCA Laboratories

NSF Support, Special Projects — 129,035.00
SOC 75-04203-A02 (7/1/77-6/30/78)

Martin Biddle, Principal Investigator
1.2 man-months

National Park Service, Valley Forge Project — 99,994.00
(1/10/77-12/31/78)

Elizabeth K. Ralph, Principal Investigator
2 man-months

Pending Support

MASCA grant proposal (7/1/78-6/30/80)

APPENDIX

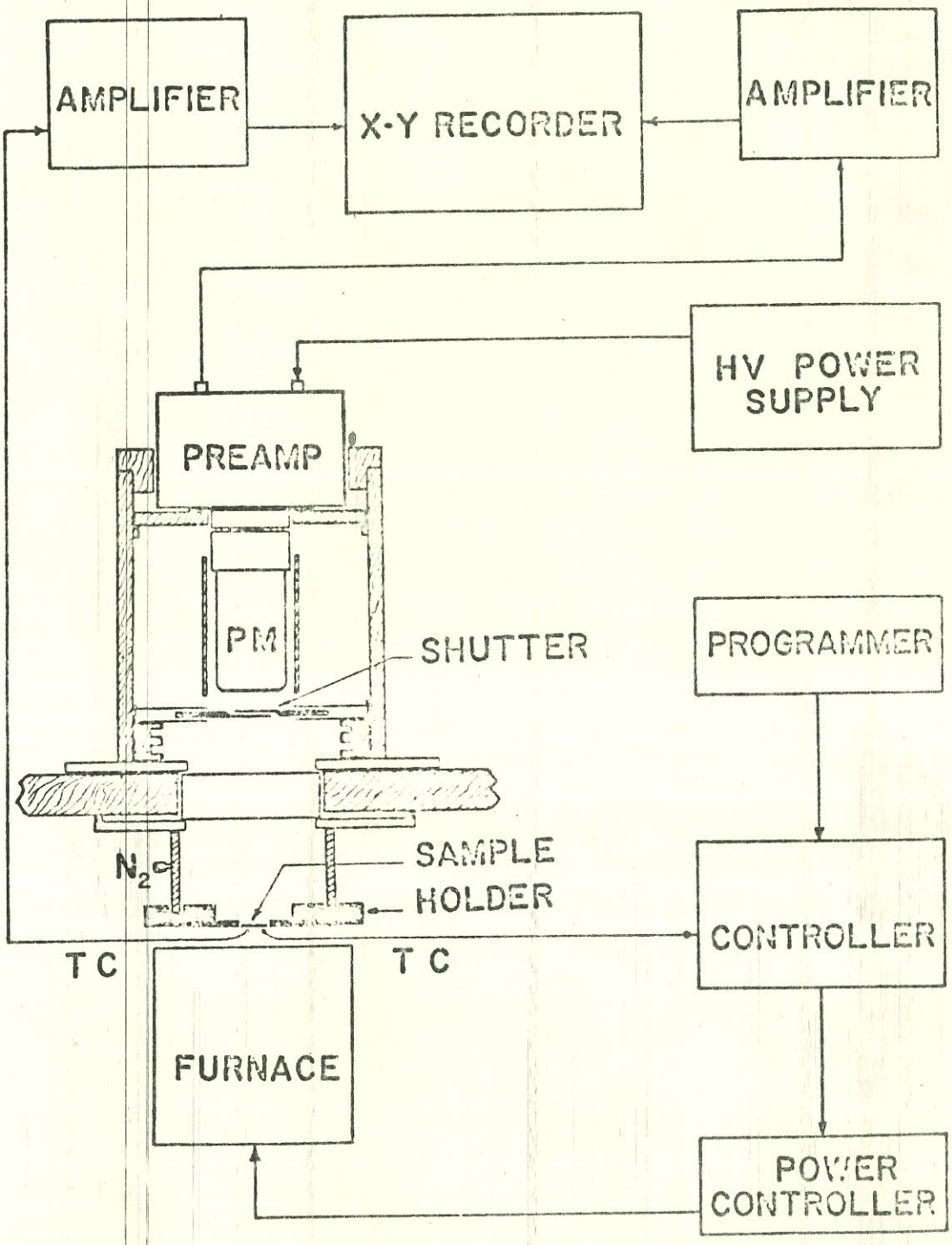
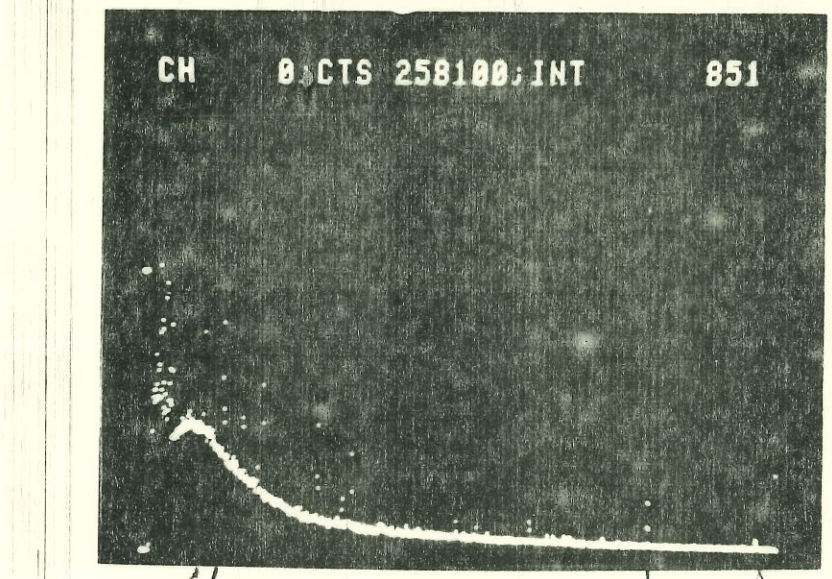


Figure 1. Block diagram of TL glow curve apparatus and programmer, which provides a linear rate of temperature increase for heating the sample.



186 239 1460 1764 keV

Figure 2. Photograph from CRT of Pulse Height Analyzer connected to Ge(Li) Detector. (TL sample # PT 175)

Peak at	186 keV	Ra
	237 keV	ThB
	1.46 MeV	^{40}K
	1.76 MeV	Bi

vertical scale ~ 500 counts/div
horizontal scale ~ 200 keV/div

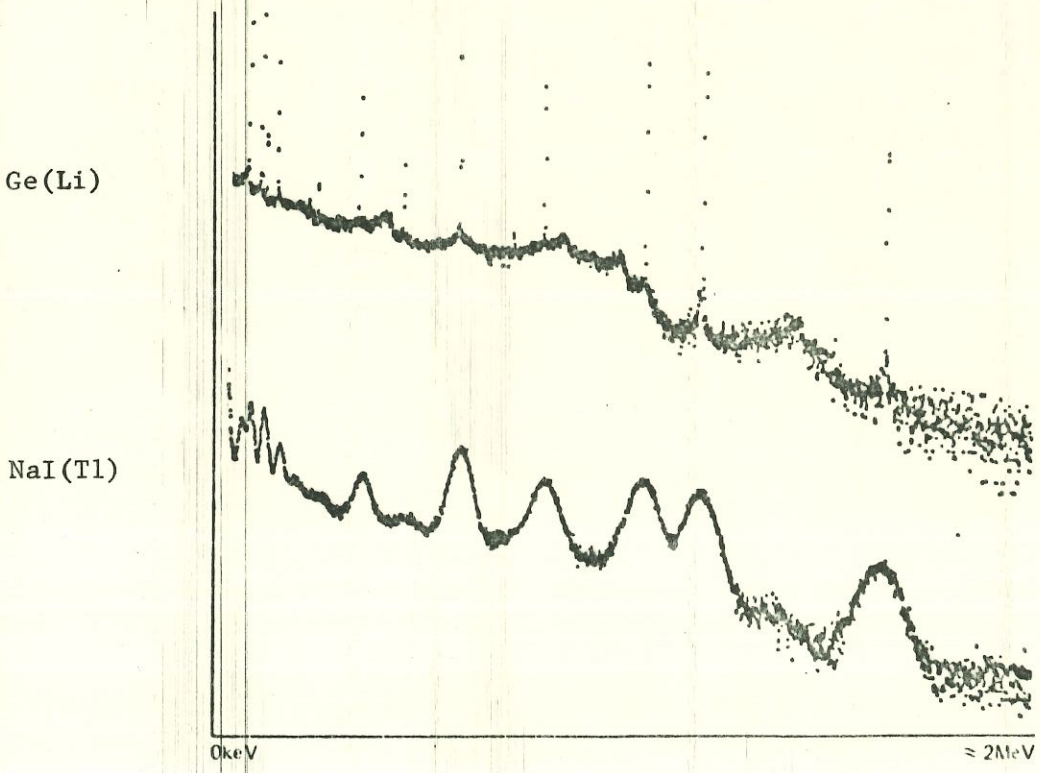


Figure 3 10%, 2.0keV Ge(Li) vs. 3" x 3" NaI(Tl) NBS Mixed Point Source, (SRM 4215C) 25cm, 100sec. Count Time.

TABLE 1 *

DOSE-RATE (mrad/yr)

	α	β	γ
uranium series:	2273	119.6	103.5
thorium series:	2053	80.3	138.7

*from Bell (1970)

TABLE 2

TOTAL DOSE-RATE (mrad/yr) for $R(\alpha) = 1/cm^2 \cdot ksec$

*k =	0.02	0.25
Th/U = 4.0	284.08	806.60
Th/U = 0.5	268.65	784.26
% difference	5%	3%

$$* k = \frac{(TL/rad)_\alpha}{(TL/rad)_\beta}$$

quartz may be as low as 0.02

TABLE 3

PERCENT OF TOTAL DOSE-RATE DUE TO α-RADIATION

Thorium Family	90%
Thorium w/ 100% ^{220}Rn loss	91%
Uranium Family	91%
Uranium w/ 100% ^{222}Rn and ^{219}Rn loss	95%

TABLE 4

TOTAL DOSE-RATE* (mrad/yr) FOR R(α) = 1/cm^2·ksec

k =	0.02	0.25
Th + U Families	268.65	784.26
Th + U w/o ^{222}Rn and daughters	186.21	664.80
Difference	31%	18%

*Assumes Th/U = 0.5

BUDGET Revised 7/31/78

Ge(Li)-gamma-ray detector (Princeton Gamma Tech)	$10,800.00

1. Configuration: cylindrical closed ended coaxial.
2. Core Diameter: 12 mm.
3. Performance:
   a. Efficiency: 12% relative to a 3x3" NaI for the 1.332 MeV peak of ^{60}Co at a source-detector distance of 25 cm.
   b. Resolution: 2.0 KeV FWHM @ 1.332 MeV
      1.0 keV FWHM @ 122 keV
      FWTM/FWHM 2.
   c. Peak to Compton Ratio: 35.0 @ 1.332 MeV
   d. Count rate: 2000 cps

Teletype (DECwriter)	1,700.00
Cassette Recorder and Interface	1,000.00
Other -Amplifier, NIM Assembly, NIM Power Supply	1,000.00
Total Cost	$14,500.00

SUPPORT

University Museum	5,000.00

TOTAL REQUESTED from NSF $ 9,500.00

BUDGET REVISED 7/31/78

Ge(Li)-gamma-ray detector (Princeton Gamma Tech) $10,800.00

1. Configuration: cylindrical closed ended coaxial.

2. Core Diameter: 12 mm.

3. Performance:

   a. Efficiency: 12% relative to a 3x3" NaI for the 1.332 MeV peak of ^{60}Co at a source-detector distance of 25 cm.

   b. Resolution: 2.0 KeV FWHM @ 1.332 MeV
      1.0 keV FWHM @ 122 keV
      FWTM/FWHM 2.

   c. Peak to Compton Ratio : 35.0 @ 1.332 MeV

   d. Count rate: 2000 cps

Pulse Height Analyzer (Tracor Northern 1710)	8,500.00
Teletype (DECwriter)	1,700.00
Cassette Recorder and Interface	1,000.00
Other	2,000.00
~~Amplifier~~	1,000.00
~~HV power supply for detector bias~~	
NIM Assembly	
NIM Power Supply	
NSF Total Cost	$24,000.00
	9500.00

Support

University Museum	5,000.00
Total Cost	14,500.00
14,500	9,500.00
TOTAL REQUESTED from NSF	$19,000.00

UNIVERSITY OF PENNSYLVANIA
Office of Research Administration
PROPOSAL TRANSMITTAL AND APPROVAL FORM

PRINCIPAL INVESTIGATOR(S)	DATE
E.K. Ralph/ W.E. Stephens	31 Jan 1978

POSITION/TITLE	TEL. NO.	SOC. SEC. NO.
Associate Directors of Research MASCA	243-8168	002-14-7858

DEPARTMENT: Museum Applied Science Center for Archaeology (MASCA) University Museum
SCHOOL:

TYPE OF PROJECT
☒ RESEARCH ☐ TRAINING ☐ OTHER (Specify) _____

TITLE OF PROJECT
Germanium Gamma-ray Detector for improved precision in TL-Dating

☒ NEW PROJECT ☐ SUPPLEMENTAL ☐ RENEWAL
☐ NON-COMPETING CONTINUATION ☐ REVISION

SPONSOR: NSF
IDENT. NO. (If Any):

FUNDS REQUESTED	INDIRECT COST RATE	PROPOSED START DATE	DURATION
~~$19,000.00~~ $9500.00		~~Aug.~~ Sept. 1978	

IDENTIFY SPACE AND FACILITIES TO BE USED FOR PROJECT: (Bldg., Room, Type, etc.)
~~DRL BW 4,6,8 Laboratory~~
University Museum, room 182

SPECIAL INSTRUCTIONS: (Mailing, Deadline Date, etc.)
Postmark on or before 1 February 1978

OTHER APPROVAL INFORMATION (Check Each of the Following)

1. ☐ Yes ■ No — Does the project involve human subjects? If YES, fill out Part I on reverse side.
2. ☐ Yes ■ No — Will additional space, facilities or renovations be required now or in the future? If YES, fill out Part II on reverse side.
3. ☐ Yes ■ No — Is additional equipment required for project? If YES, identify source of funds _____ If major equipment installation is required, fill out Part II on reverse side.
4. ■ Yes ☐ No — Does the project involve participation by personnel from other Departments or Responsibility Centers? If YES, fill out Part III on reverse side.
5. ☐ Yes ■ No — Does the project involve the use of animals? If YES, project must be reviewed in accordance with Animal Care Policy dated 1/31/75. (Contact DLAM on extension 6468 for further information.)
6. ☐ Yes ■ No — Does the project involve the use of radioactive materials or radiation-producing machines? If YES, consult the Radiation Safety Office on extension 7187.
7. ☐ Yes ■ No — Will any portion of the research or training be conducted Off-Campus?
8. ■ Yes ☐ No — For proposals to other than HEW, is Cost Sharing required? If YES, specify the source and amount of funds: Matching Funds, University Museum: $5,000.00
9. ☐ Yes ■ No — Are Subcontracts included in this project proposal? If YES, identify proposed subcontractors and amount of support proposed.
10. ☐ Yes ■ No — Does project involve in vitro formation of a recombinant DNA capable of replicating in a host cell? If "Yes", project must be reviewed by the Biohazards Committee.

APPROVAL CERTIFICATIONS

1. PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: I certify that the above information is accurate and complete as of this date. I agree to accept responsibility for scientific and technical conduct of the project and for provision of required technical reports if a grant or contract is awarded as a result of this application.

EKR
William E. Stephens
(Signature Principal Investigator/Project Director) (Date)

2. DEPARTMENT CHAIRMAN: The attached application (proposal) is approved. It is within the total program and academic objectives of the Department. Adequate space is available or planned for the conduct of the project. The professional time allocations described therein are realistic. The use of human subjects is approved as applicable.

Biddle
(Signature of the Department Chairman) (Date)

3. DEAN OF SCHOOL: The proposed project is approved. It is consistent with the total program objectives of this school and the commitments to this project are acceptable.

Biddle
(Signature of Dean) (Date)

COMMENTS:

NOTE: This form is not sent to sponsors with proposal. The title or cover page of the proposal itself should allow for signatures of the Principal Investigator(s) and the authorizing offical of the University.

RA-001 3-76 (Rev. 1/77)

UNIVERSITY OF PENNSYLVANIA
Office of Research Administration
PROPOSAL TRANSMITTAL AND APPROVAL FORM

PRINCIPAL INVESTIGATOR(S)	DATE
E. K. Ralph / W. E. Stephens	31 July 1978

POSITION/TITLE	TEL. NO.	SOC. SEC. NO.
Associate Directors of Research MASCA	243-8168	002-14-7858

DEPARTMENT	SCHOOL
Museum Applied Science Center for Archaeology (MASCA) University Museum	

TYPE OF PROJECT
☒ RESEARCH ☐ TRAINING ☐ OTHER (Specify) _____

TITLE OF PROJECT
Germanium Gamma-ray Detector for improved precision in TL-Dating

☒ NEW PROJECT ☐ SUPPLEMENTAL ☐ RENEWAL
☐ NON-COMPETING CONTINUATION ☐ REVISION

SPONSOR	IDENT. NO. (If Any)
NSF	

FUNDS REQUESTED	INDIRECT COST RATE	PROPOSED START DATE	DURATION
$9,500.00		Sept. 1978	

IDENTIFY SPACE AND FACILITIES TO BE USED FOR PROJECT: (Bldg., Room, Type, etc.)

University Museum, Room 182

SPECIAL INSTRUCTIONS: (Mailing, Deadline Date, etc.)

OTHER APPROVAL INFORMATION (Check Each of the Following)

1. ☐ Yes ☒ No — Does the project involve human subjects? If YES, fill out Part I on reverse side.
2. ☐ Yes ☒ No — Will additional space, facilities or renovations be required now or in the future? If YES, fill out Part II on reverse side.
3. ☐ Yes ☒ No — Is additional equipment required for project? If YES, identify source of funds _____ If major equipment installation is required, fill out Part II on reverse side.
4. ☐ Yes ☐ No — Does the project involve participation by personnel from other Departments or Responsibility Centers? If YES, fill out Part III on reverse side.
5. ☐ Yes ☒ No — Does the project involve the use of animals? If YES, project must be reviewed in accordance with Animal Care Policy dated 1/31/75. (Contact DLAM on extension 6468 for further information.)
6. ☐ Yes ☒ No — Does the project involve the use of radioactive materials or radiation-producing machines? If YES, consult the Radiation Safety Office on extension 7187.
7. ☐ Yes ☒ No — Will any portion of the research or training be conducted Off-Campus?
8. ☒ Yes ☐ No — For proposals to other than HEW, is Cost Sharing required? If YES, specify the source and amount of funds

   Matching Funds, University Museum: $5,000.00
9. ☐ Yes ☒ No — Are Subcontracts included in this project proposal? If YES, identify proposed subcontractors and amount of support proposed.

APPROVAL CERTIFICATIONS

1. PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: I certify that the above information is accurate and complete as of this date. I agree to accept responsibility for scientific and technical conduct of the project and for provision of required technical reports if a grant or contract is awarded as a result of this application.

   Elizabeth K. Ralph 7/31/78
   (Signature Principal Investigator/Project Director) (Date)
2. DEPARTMENT CHAIRMAN: The attached application (proposal) is approved. It is within the total program and academic objectives of the Department. Adequate space is available or planned for the conduct of the project. The professional time allocations described therein are realistic. The use of human subjects is approved as applicable.

   (Signature of the Department Chairman) (Date)
3. DEAN OF SCHOOL: The proposed project is approved. It is consistent with the total program objectives of this school and the commitments to this project are acceptable.

   (Signature of Dean) (Date)

COMMENTS:

NOTE: This form is not sent to sponsors with proposal. The title or cover page of the proposal itself should allow for signatures of the Principal Investigator(s) and the authorizing offical of the University.

RA 001 3 76

EXHIBIT II-3

PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION
Cover Page

FOR CONSIDERATION BY NSF ORGANIZATIONAL UNIT (please specify):
NSF Division of Engineering
Engineering Equipment Grant Request

PROGRAM ANNOUNCEMENT/SOLICITATION NO.:

CLOSING DATE (IF ANY): September 1, 1978

NAME OF SUBMITTING ORGANIZATION TO WHOM AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS):
Trustees of the University of Pennsylvania

ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE):
Office of Research Administration, 409 Franklin Building/I6
Philadelphia, PA 19104

TITLE OF PROPOSED PROJECT:
Germanium Gamma-ray Detector for improved precision in Thermoluminescent Dating

REQUESTED AMOUNT	PROPOSED DURATION	DESIRED STARTING DATE
$9500.00	Purchase time for equipment	September 1978

PI/PD NAME AND SOCIAL SECURITY NO. (SSN)*	PI/PD PHONE NO.
Elizabeth Ralph 002-14-7858	215-243-8168

PI/PD DEPARTMENT	PI/PD ORGANIZATION
Museum Applied Science Center for Archaeology (MASCA)	University Museum, University of Pennsylvania

ADDITIONAL PI/PD AND SSN*	ADDITIONAL PI/PD AND SSN*
William E. Stephens	
ADDITIONAL PI/PD AND SSN*	ADDITIONAL PI/PD AND SSN*

FOR RENEWAL OR CONTINUING AWARD REQUEST, LIST PREVIOUS AWARD NO.:

REMARKS. *Submission of social security numbers is voluntary and will not affect the organization's eligibility for an award. However, they are an integral part of the NSF information system and assist in processing the proposal.

PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR	AUTHORIZED ORGANIZATIONAL REP.	OTHER ENDORSEMENT (optional)
NAME: Elizabeth K. Ralph	NAME: Anthony Merritt	NAME: Arthur E. Humphrey
SIGNATURE: Elizabeth K. Ralph	SIGNATURE:	SIGNATURE:
TITLE: Associate Director of MASCA	TITLE: Director of Office of Research Administration	TITLE: Dean of Engineering
DATE: 31 July 1978	DATE: 31 July 1978	DATE: 31 July 1978

Revised 7/31/78

SUMMARY PROPOSAL BUDGET

EXHIBIT II-4

ORGANIZATION AND ADDRESS

MASCA, University Museum

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR

Elizabeth K. Ralph

FOR NSF USE ONLY

PROPOSAL NO.

DURATION (MONTHS)

PROPOSED	REVISED

NSF USE	A. SENIOR PERSONNEL (LIST BY NAME; SHOW NUMBERS OF PEOPLE IN BRACKETS; SALARY AMOUNTS MAY BE LISTED ON SEPARATE SCHEDULE) GPM 205.1b	NSF FUNDED MAN MONTHS CAL.	ACAD.	SUMR.	FUNDS REQUESTED BY PROPOSER	FUNDS GRANTED BY NSF (IF DIFFERENT)
	1. P.I./P.D.				$	$
	2. CO P.I./P.D.				$	$
	3. CO P.I./P.D.				$	$
	4. CO P.I./P.D.				$	$
	5. CO P.I./P.D.				$	$
11115	6. ( ) ← SUBTOTALS A1 - A5 →				$	$
	FACULTY AND OTHER SENIOR ASSOCIATES (ATTACH EXTRA SHEET IF NECESSARY)					
	7.				$	$
	8.				$	$
	9.				$	$
	10.				$	$
	11.				$	$
11117	12. ( ) ← SUBTOTALS A7 - A11 →				$	$
	B. OTHER PERSONNEL (LIST NUMBERS IN BRACKETS)					
11141	1. ( ) POSTDOCTORAL ASSOCIATES				$	$
11149	2. ( ) OTHER PROFESSIONALS				$	$
11150	3. ( ) GRADUATE STUDENTS				$	$
11152	4. ( ) UNDERGRADUATE STUDENTS				$	$
11182	5. ( ) SECRETARIAL - CLERICAL				$	$
11183	6. ( ) TECHNICAL, SHOP, OTHER				$	$
	TOTAL SALARIES AND WAGES (A+B)				$	$
11200	C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$	$
	TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$	$

D. EQUIPMENT (LIST ITEMS AND DOLLAR AMOUNTS FOR EACH ITEM)

Ge(Li)-gamma-ray detector (Princeton Gamma Tech) $10,800
Teletype (DEC writer) $1,700
Cassette Recorder and Interface $1,000
NIM Assembly, NIM Power Supply and Amplifier $1,000

($5000 of this to be contributed by University Museum)

23181	TOTAL EQUIPMENT	$ 14,500	$
	E. MATERIALS AND SUPPLIES		
32630		$	$
	F. DOMESTIC TRAVEL		
42111		$	$
	G. FOREIGN TRAVEL (LIST DESTINATION AND AMOUNT FOR EACH TRIP; GPM 731)		
42112		$	$

REVISED 7/31/78

SUMMARY PROPOSAL BUDGET

EXHIBIT II-4

ORGANIZATION AND ADDRESS: MASCA, University Museum

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Elizabeth K. Ralph

FOR NSF USE ONLY
PROPOSAL NO.
DURATION (MONTHS) — PROPOSED | REVISED

NSF USE	A. SENIOR PERSONNEL (LIST BY NAME; SHOW NUMBERS OF PEOPLE IN BRACKETS; SALARY AMOUNTS MAY BE LISTED ON SEPARATE SCHEDULE) GPM 205.1b	NSF FUNDED MAN MONTHS CAL.	ACAD.	SUMR.	FUNDS REQUESTED BY PROPOSER	FUNDS GRANTED BY NSF (IF DIFFERENT)
	1. P.I./P.D.				$	$
	2. CO P.I./P.D.				$	$
	3. CO P.I./P.D.				$	$
	4. CO P.I./P.D.				$	$
	5. CO P.I./P.D.				$	$
11115	6. ( ) ← SUBTOTALS A1 - A5 →				$	$
	FACULTY AND OTHER SENIOR ASSOCIATES (ATTACH EXTRA SHEET IF NECESSARY)					
	7.				$	$
	8.				$	$
	9.				$	$
	10.				$	$
	11.				$	$
11117	12. ( ) ← SUBTOTALS A7 - A11 →				$	$
	B. OTHER PERSONNEL (LIST NUMBERS IN BRACKETS)					
11141	1. ( ) POSTDOCTORAL ASSOCIATES				$	$
11149	2. ( ) OTHER PROFESSIONALS				$	$
11150	3. ( ) GRADUATE STUDENTS				$	$
11152	4. ( ) UNDERGRADUATE STUDENTS				$	$
11182	5. ( ) SECRETARIAL - CLERICAL				$	$
11183	6. ( ) TECHNICAL, SHOP, OTHER				$	$
	TOTAL SALARIES AND WAGES (A+B)				$	$
11200	C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$	$
	TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$	$
	D. EQUIPMENT (LIST ITEMS AND DOLLAR AMOUNTS FOR EACH ITEM)					
23181	TOTAL EQUIPMENT				$ 14,500	$
	E. MATERIALS AND SUPPLIES					
32630					$	$
	F. DOMESTIC TRAVEL					
42111					$	$
	G. FOREIGN TRAVEL (LIST DESTINATION AND AMOUNT FOR EACH TRIP; GPM 731)					
42112					$	$

D. EQUIPMENT (LIST ITEMS AND DOLLAR AMOUNTS FOR EACH ITEM)

Ge(Li) - gamma-ray detector (Princeton Gamma Tech) $10,800
Teletype (DEC writer) $1,700
Cassette Recorder and Interface $1,000
NIM Assembly, NIM Power Supply and Amplifier $1080

($5000 of this to be contributed by University Museum)