

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D. C. 20550

AUG 25 1978

Mr. Anthony Merritt, Director
Office of Research Administration
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Proposal/Grant No.
BNS78-11042

BNS78-11042

Dear Mr. Merritt:

It is a pleasure to inform you that \$9,500 is granted to the University of Pennsylvania to assist in the acquisition of a Germanium Gamma-Ray Detector for Improved Precision in Thermo-luminescent Dating as outlined in the above-numbered proposal listed in the attachment. The acquisition of this equipment is under the direction of Elizabeth K. Ralph, Museum Applied Science Center for Archaeology, University Museum. The grant is effective October 1, 1978 and, unless otherwise amended, will expire on March 31, 1980.

The grant period includes the flexibility period described in Section 241 of NSF 77-47, "NSF Grant Policy Manual."

The provisions of FL 118, "Grant General Conditions," are applicable to this grant.

The reporting requirements outlined in Article 14 of FL 118 are modified to incorporate the procedures set forth in Important Notice No. 73.

Sincerely yours,

/s/ Elmer G. Havens

Grants Officer

Enclosure

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550

AUG 25 1978

Dr. Elizabeth Ralph
Museum for Applied Science Center
For Archaeology (MASCA)
University of Pennsylvania
Philadelphia, Pennsylvania 19104

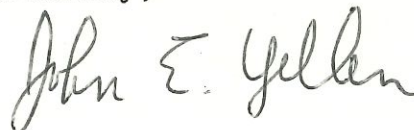
Dear Dr. Ralph:

I am delighted that the National Science Foundation has agreed to support your research project. Since it will be administered through the Anthropology Program, please feel free to contact either me or Mary Greene, the Associate Program Director, if any problems or questions arise. Part of our job is to facilitate your work and help you to see it through to a successful conclusion.

The enclosed materials provide information on the conditions of the grant and our administrative requirements. These are important and should be examined carefully.

We wish you a very successful research program.

Sincerely,



John E. Yellen
Program Director for
Anthropology

Enclosures

AUG 25 1978

**PROJECT
SUMMARY**

NSF AWARD NO.

BNS78-11042

NAME OF INSTITUTION (NSF DIRECTORY NAME) University of Pennsylvania		ADDRESS OF INSTITUTION (INCLUDE BRANCH/CAMPUS & COMPONENT) Museum of Applied Science Center for Archaeology Philadelphia, Pennsylvania 19104	
PRINCIPAL INVESTIGATOR RALPH, Elizabeth 002-14-7858		DIVISION (OFFICE) AND DIRECTORATE BNS/BBS	
		SECTION	
PROPOSAL NUMBER BNS 78 11042	FISCAL YEAR 78	PROGRAM Anthropology	
TITLE OF PROJECT Germanium Gamma-Ray Detector for Improved Precision in Thermoluminescent Dating			
SUMMARY OF PROPOSED WORK (LIMIT TO 22 PICA OR 18 ELITE TYPEWRITTEN LINES) Equipment is provided, a lithium-drifted germanium gamma-ray spectrometer, for use in radiometric analysis of uranium, thorium and potassium in ceramic materials and for estimating the radiation dose-rate present in materials to be dated by thermoluminescence.			

START AND END DATES		AMOUNT GRANTED	PROGRAM APPROVAL	DATE
10/1/78-3/31/80		\$9,500		

PANEL SUMMARY

BNS78-11042, RALPH

A discussion of the reviews led the Panel to conclude that this appeared to be an exciting piece of equipment. The lab is already set up - has great potential for development - the equipment will complement and increase the existing facilities.

The Panel recommended funding.

PROPOSAL NO. 78-11042	INSTITUTION	PLEASE RETURN BY
PRINCIPAL INVESTIGATOR SARMA RALPH	NSF PROGRAM Anthropology	
TITLE Germanium Gamma-ray Detector		

COMMENTS (CONTINUE ON ADDITIONAL SHEET(S) AS NECESSARY)

Any piece of equipment which ~~will~~ promises to improve the accuracy of the TL dating of archaeological materials would be welcome. I must reserve judgement on whether the Germanium Gamma-ray Detector would indeed do this, but it would seem to me that if there is a reasonable possibility, ~~that~~ then this request for an equipment grant should definitely be granted.

The MASCA TL laboratory which has been relatively quiet recently, has just received a new stimulus of life and promises to be well able to take advantage of the opportunity ~~with~~ of improved productivity which would be provided by the addition of this new piece of equipment.

RATING: EXCELLENT VERY GOOD GOOD FAIR POOR

PRINCIPAL
INVESTIGATOR COPY

Verbatim but anonymous copies of reviews, ratings and associated correspondence will be sent only to the principal investigator/project director on request. Subject to this NSF policy and applicable laws, including the Freedom of Information Act, 5 USC 552, reviewers' comments will be given maximum protection from disclosure.

PROPOSAL NO. 7911042	INSTITUTION U Penna	PLEASE RETURN BY
PRINCIPAL INVESTIGATOR William W. Stephens	NSF PROGRAM Anthropology	
TITLE Germanium Gamma-ray Detector for improved precision in Thermoluminescent Dating		

COMMENTS (CONTINUE ON ADDITIONAL SHEET(S) AS NECESSARY)

I strongly support this application. I think the case for equipping a TL dating laboratory with a Ge(Li) detector is a sound one and that if anything the applicant has played down its importance; its introduction may well be a watershed for the technique. As is said in the application the preliminary experiments made by Professor Stephens showed the way and we at Oxford have followed (as also has the TL lab. at Brookhaven). It would therefore be highly appropriate to equip MASCA in this way. There is no question of part-time utilization of the existing Ge(Li) crystal in the Tandem Lab.; 24-hours 7-days a week will be routine. I think it is good that the type of crystal proposed differs somewhat from the type we have ordered at Oxford. Each type will have pro's and con's and interchange of samples will be fruitful (and educative).

RATING: EXCELLENT VERY GOOD GOOD FAIR POOR

**PRINCIPAL
INVESTIGATOR COPY**

Verbatim but anonymous copies of reviews, ratings and associated correspondence will be sent only to the principal investigator/project director on request. Subject to this NSF policy and applicable laws, including the Freedom of Information Act, 5 USC 552, reviewers' comments will be given maximum protection from disclosure.

PROPOSAL NO. 7811042	INSTITUTION U Penna	PLEASE RETURN BY
PRINCIPAL INVESTIGATOR William W. STEPHENS		NSF PROGRAM Anthropology
TITLE Germanium Gamma-ray Detector for improved precision in Thermoluminescent Dating		

COMMENTS (CONTINUE ON ADDITIONAL SHEET(S) AS NECESSARY)

The concept and development of gamma spectroscopy for the study of radio-activity in ceramics is an excellent one and has the potential for making a significant contribution to TL dating. The proposed equipment expenditures appear reasonable and I highly recommend support.

There are, however, a number of deficiencies in the proposal:

1. The dependence of alpha counting efficiency on radioactive particle size described on page 4 is a strength of that technique for TL dating of fine grains, not a limitation. The alpha dose rate to the fine grains also depends, in the same way, on particle size. Thus the alpha counting of coarsely ground material will not give the exact U and Th but will give the correct alpha dose rate. The U and Th can be obtained by α counting by simply pulverizing the material to less than the alpha range. Gamma spectroscopy will give the correct U and Th but calculating the correct alpha dose-rate is then very difficult if not impossible, as the particle size effects must be folded in.
2. The MASCA approach (equation page 4.) has always suffered greatly because no allowance is made for potassium and the wide variation in potassium to U and Th that is well documented to occur in ceramics. (This is a much larger error than the 5% from Th/U ratio variations.) Measuring potassium by the gamma spectroscopy is mentioned several times but it is not clear how this will be used as it is implied that the same very limited approach of equation 4 will be continued.
3. The errors due to variations in Th/U ratio and radon emanation referred to are handled to some extent in alpha counting by the "pairs technique" which gives the Th/U ratio and by counting sealed and unsealed samples to get the radon emanation. The potential value of gamma counting is that it might do these more accurately.

Despite the above comments, gamma spectroscopy does have a significant potential to help determine beta and gamma dose-rates more accurately and in studying disequilibrium in the decay chains.

RATING: EXCELLENT VERY GOOD GOOD FAIR POOR

PRINCIPAL
INVESTIGATOR COPY

Verbatim but anonymous copies of reviews, ratings and associated correspondence will be sent only to the principal investigator/project director on request. Subject to this NSF policy and applicable laws, including the Freedom of Information Act, 5 USC 552, reviewers' comments will be given maximum protection from disclosure.

MASCA

PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

Cover Page Format

ENG - 78-11042

FOR CONSIDERATION BY THE ORGANIZATION (Please specify):

Research Proposal to
NSF Division of Engineering
Engineering Equipment Grant Request

EC + E Program
Dr. Rosterboch

PROGRAM ANNOUNCEMENT/SOLICITATION NO.
NSF 77-45

CLOSING DATE (IF ANY): February 1, 1978

NAME OF SUBMITTING ORGANIZATION TO WHICH 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./16
Philadelphia, PA. 19104

TITLE OF PROPOSED PROJECT

Germanium Gamma-ray Detector for improved precision in Thermoluminescent Dating

REQUESTED AMOUNT

19,000.00

PROPOSED DURATION

Purchase time for equipment

DESIRED STARTING DATE

August 1978

PI/PD NAME AND SOCIAL SECURITY NO. (SSN)*

Elizabeth Ralph 002-14-7858

PI/PD PHONE NO.

215-243-8163

PI/PD DEPARTMENT
Museum Applied Science Center
for Archaeology (MASCA)

PI/PD ORGANIZATION
University Museum
University of Pennsylvania

ADDITIONAL PI/PD AND SSN*

William E. Stephens

ADDITIONAL PI/PD AND SSN*

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.

NSF Engineering
202-632-5790

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-1101.

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 α -counting and the failure of several of the key assumptions in converting α -counts to uranium and thorium concentrations. Potassium concentration is currently 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.

2 Fine-grain approach new?

4 Evidence for particle size α f-variation?

7 ? How would n-actV det. ion-exchange effect?

8. (i) Non-uniformity of u , Th as det. system (quartz distrib: is!) (see Heimlich).

(ii) '50 keV - 10 keV'?

2 is 2.0 keV?

TABLE OF CONTENTS

ABSTRACT	Page i
PROJECT DESCRIPTION	
Introduction and Background	1
Problems and Objectives	3
Preliminary Experiments	7
Other Applications	8
Bibliography	9
PERSONNEL (Curricula Vitae)	10
BUDGET AND EQUIPMENT SUMMARY	
Equipment	19
Budget	21
CURRENT SUPPORT	
Facilities	23
Organization Chart	25
Current Grants	26
APPENDIX	
Figures	27
Tables	30

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 (α , β , 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 ^{235}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 sensitivity^t 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^M KeV. At 1.332 MeV (⁶⁰Co) 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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- Zimmerman, D.W., 1971, Thermoluminescent Dating using Fine Grains from Pottery, Archaeometry 13(1) : 29-52.

CURRICULUM VITAE

NAME: ELIZABETH K. RALPH

BORN: February 5, 1921. Trenton, New Jersey.

RESIDENCE: Box 357, Woosamonsa Road, Pennington, New Jersey.

SOCIAL SECURITY NO. 002-14-7858

EDUCATION: Wellesley College, B.A., 1942. Chemistry.
University of Pennsylvania, M.S. 1951. Physics
University of Pennsylvania, Ph.D. 1973. Geology

EXPERIENCE: Junior Electronics Engineer, then Chemist, then
Assistant to Chief Radio Engineer, then Pro-
ject Engineer at Foote, Pierson and Company
and Kearfott Manufacturing Company, Newark,
New Jersey, 1942-49.

University of Pennsylvania
Research Assistant, Department of Physics,
1951-55.
Associate, Department of Physics, 1955-

University of Pennsylvania, the University Museum
Associate Director, Applied Science Center
for Archaeology, 1962-

MEMBERSHIP IN SCIENTIFIC ORGANIZATIONS:

American Association for the Advancement of
Science
Sigma Xi, Chapter member, 1956-
Archaeological Institute of America,
Phila. Chapter 1962-
American Geophysical Union, Member, 1964-
Philadelphia Anthropological Society

FIELD WORK: In charge of field tests of instruments for
archaeological exploration and the search
for the buried city of Sybaris, Italy. 1962-67.

Additional archaeological field surveys with
instruments for underground exploration:

1963 - Navan Fort, N. Ireland; Fort Louisbourg
Nova Scotia, Canada; Fort Loudon, Pa.;
Caleb Pusey House, Chester, Pa.;
Horseshoe Bend, Wilmington, Del.

FIELD WORK, CONTINUED:

- 1964 - Fort Lennox, Ile-aux-Noix, Quebec Province, Canada; Hagley Mills, Wilmington, Del.
- 1965 - Gordion, Turkey; Artena and Sele, Italy; Hope Lodge, Whitemarsh, Pa.; Camden, South Carolina; Snaketown, Tucson, and San Xavier, Arizona.
- 1966 - Gravina, Veii, Sele, Artena, and Metapontum, Italy; Helice and Porto Cheli, Greece; Harvard Forest, Petersham, Mass.
- 1967 - Siris, Italy; Thera and Llis, Greece.
- 1968 - Elis, Greece; Dun Ailinne, Ireland; St. Croix Island, Calais, Maine; Morton Mortonsen House, Norwood, Pa.
- 1969 - Ciro and Cosa, Italy; Divostin and other Neolithic sites, Yugoslavia.
- 1971 - Lake Magdalena, Jalisco, Mexico; Aleria, Corsica; Gravina di Puglia, Italy; Kingscote, England; Wissant, France.
- 1972 - Tepe Malyan, Iran
- June 1972 - San Francisco Mts., Arizona.
Search for lava flows which cooled during "recent" periods of reversed polarity.
- 1973 - Malkata, Thebes, Egypt

ELIZABETH K. RALPH

PUBLICATIONS:

- 1955a University of Pennsylvania Radiocarbon Dates I. Science, Vol. 121, No. 3136, pp. 149-151, Washington, D.C.
- 1955b Radiocarbon Dates for Kara Kamar, Afghanistan, University of Pennsylvania II. Science, Vol. 122, No. 3176, pp. 921-922 (with C.S. Coon). Washington, D.C.
- 1956 C¹⁴ Dating. Pennsylvania Archaeologist, Vol. XXVI. No. 1, pp. 27-31.
- 1957 Age is No Longer a Secret. Wellesley Alumnae Magazine, Vol. XLI, No. 3, pp. 142-143. Massachusetts.
- 1959a Radiocarbon Dating in the Arctic. American Antiquity, Vol. 24, No. 4, pp. 365-74 (with F. G. Rainey). Salt Lake City.
- 1959b Double Trouble. Expedition, Vol. 1, No. 3, pp. 24-25. The University Museum, Philadelphia.
- 1959c University of Pennsylvania, Radiocarbon Dates III. American Journal of Science, Radiocarbon Supplement, Vol. 1, pp. 45-58. New Haven.
- 1960a Carbon-14 Measurements of Known Age Samples. Nature, Vol. 188, No. 4746, pp. 185-7 (with R. Stuckenrath, Jr.). London.
- 1960b New Radiocarbon Dates and the Maya Correlation Problem. American Antiquity, Vol. 26, No. 2, pp. 165-184 (with L. Satterthwaite). Salt Lake City.
- 1961a University of Pennsylvania, Radiocarbon Dates IV. American Journal of Science, Radiocarbon Supplement, Vol. 3, pp. 4-14 (with R. Ackerman). New Haven.
- 1961b C¹⁴ Dates for Sites in the Mediterranean Area. American Journal of Archaeology, Vol. 65, pp. 357-367 (with E. Kohler). Princeton.
- 1961c Radiocarbon "Effective" Half-Life for Maya Calendar Correlations. American Antiquity, Vol. 27, No. 2, pp. 229-230. Salt Lake City.

ELIZABETH K. RALPH

PUBLICATIONS, CONTINUED:

- 1962a University of Pennsylvania Radiocarbon Dates V. Radiocarbon (supplement to the American Journal of Science), Vol. 4, pp. 144-159 (with R. Stuckenrath, Jr.). New Haven.
- 1962b New Instrument Techniques in Archaeology. Proceedings of the Symposium on Detection of Underground Objects, Materials and Properties; 19-20 March, 1962. U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., pp. 151-155 (with F.G. Rainey).
- 1962c Prospezioni Geofisiche. Relazione Sulla Campagna di Prospezioni, Aprile, Maggio, Giugno 1962, nella Piana del Fiume Crati. Relazione sulla Esplorazione Geofisica (Sibari), pp. 2-32. Fondazione Ing. C.M. Lerici del Politecnico, Milano.
- 1963 Search for a City Buried 2700 Years. Wellesley Alumnae Magazine, Vol. 47, No. 5, pp. 283-285, 310. Brattleboro, Vt.
- 1964a Comparison of a Proton and a Rubidium Magnetometer for Archaeological Prospecting. Archaeometry, Vol. 7, pp. 20-27. Oxford.
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- 1971b Dating Techniques for the Archaeologist, Coedited by H. N. Michael and E. K. Ralph, The M.I.T. Press, Cambridge, Mass. and London, England.
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- 1974a University of Pennsylvania Radiocarbon Dates XVI. Radiocarbon, Vol. 16, No. 2, pp. 198-218 (with H. N. Michael).
- 1974b Twenty-five Years of Radiocarbon Dating: Retrospect and Prospect. American Scientist, Vol. 62, No. 5 (Sept.-Oct., 1974), pp. 553-560 (with H. N. Michael).
- 1974c Radiocarbon Dates and Reality. Reprinted from MASCA Newsletter, vol. 9, no. 1, August 1973. Archaeology of Eastern North America, vol. 2, no. 1, pp. 1-20 (with H. N. Michael and M. C. Han).
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WILLIAM E. STEPHENS

Born: May 29, 1912 - St. Louis, Missouri

Marital Status: Married, 2 children

Education: A.B., Washington University, 1932
 M.S., Washington University, 1934
 Ph.D., California Institute of Technology, 1938

Professional Record:

Graduate Assistant in Physics, Washington University1932-34
 Graduate Assistant in Radiology, Calif. Inst. of Tech.1935-38
 Westinghouse Research Fellow, East Pittsburgh1938-40
 Lecturer, University of Pittsburgh1938-39
 Instr. in Physics, Stanford University1940-41
 Instr. in Physics, Univ. of Penna.1946-48
 Assistant Professor of Physics, Univ. of Penna.1942-46
 Associate Professor of Physics, Univ. of Penna.1946-48
 Professor of Physics, Univ. of Penna.1948-
 Visiting Professor, University of Zurich1957, 1969
 Chairman, Physics Department, Univ. of Penna.1963-68
 On leave to Calif. Inst. of Tech.Fall 1966-67
 Acting Dean of College of Arts & Sciences, Univ. of Penna.1968
 Dean of the College of Arts and Sciences and
 Vice Provost of the University of Pennsylvania.....1969-74
 Visiting Fellow, Australian National Univ., CanberraFall 1974
 Visiting Senior Fellow, Princeton UniversitySpring 1975

Memberships:

Phi Beta Kappa
 Sigma Xi
 American Physical Society, Fellow
 AAUP
 AAAS, Fellow
 Research Club
 American Astronomical Society

W. E. Stephens - Bibliography

69 publications, 1934-1966

Radiative Capture of ^3He by ^3He (with W.D. Harrison, T.A. Tombrello and H. Winkler), Phys. Rev., 160, 4, 752-755 (1967).

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Experimental Investigation of the Nuclear Reaction $^{16}\text{O} + ^{12}\text{C}$ at Low Energies (with M. G. Mazarakis and G. O. De Bolt, Jr.) Bull. Am. Phys. Soc. 16, 600 (1971).

$^{12}\text{C} + ^{12}\text{C}$ Cross sections from 5 to 2.4 MeV in the C.M. (with M. G. Mazarakis and G. O. De Bolt, Jr.) Bull. Am. Phys. Soc. 16, 600 (1971).

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Experimental Measurements of the $^{12}\text{C} + ^{12}\text{C}$ Nuclear Reactions at Low Energies (with M. G. Mazarakis) Phys. Rev. C 7, 1280-7(1973).

Electron Spin, pp. 288-290, The Encyclopedia of Physics, Van Nostrand Reinhold Co., N.Y. 1974.

"Is the Solar Neutrino Flux Deficient," (in press) Earth and Extraterrestrial Sciences (1976).

"Rate of Stellar Collapses in the Galaxy" Astrophysics and Space Science 49, 169-177(1977) (With K. Lande)

"Upper Limit on Superheavy Element in Monazite from Madagascar" Phys. Rev. C. 16, 477 (1977) (with R. Middleton, et al.)

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 (\$18,500 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 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 FWHM/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	
HV power supply for detector bias	
NIM Assembly	
NIM Power Supply	
Total Cost	\$24,000.00

Support

University Museum	5,000.00
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<u>TOTAL REQUESTED</u>	<u>\$19,000.00</u>
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SPECIALIZED RESEARCH EQUIPMENT CERTIFICATION FORMAT

UNIVERSITY

University of Pennsylvania

BRANCH/CAMPUS

COLLEGE OR DIVISION

Faculty of Arts and Sciences

DEPARTMENT

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 purchased June 1972
 dia: 43.3mm \$11,500
 length: 46.0mm NSF funds
 drift depth: 17.0mm
 nominal active volume 65cm³
 resolution: 2.4 KeV at 1.332 MeV

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

FACILITIESMASCA 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.

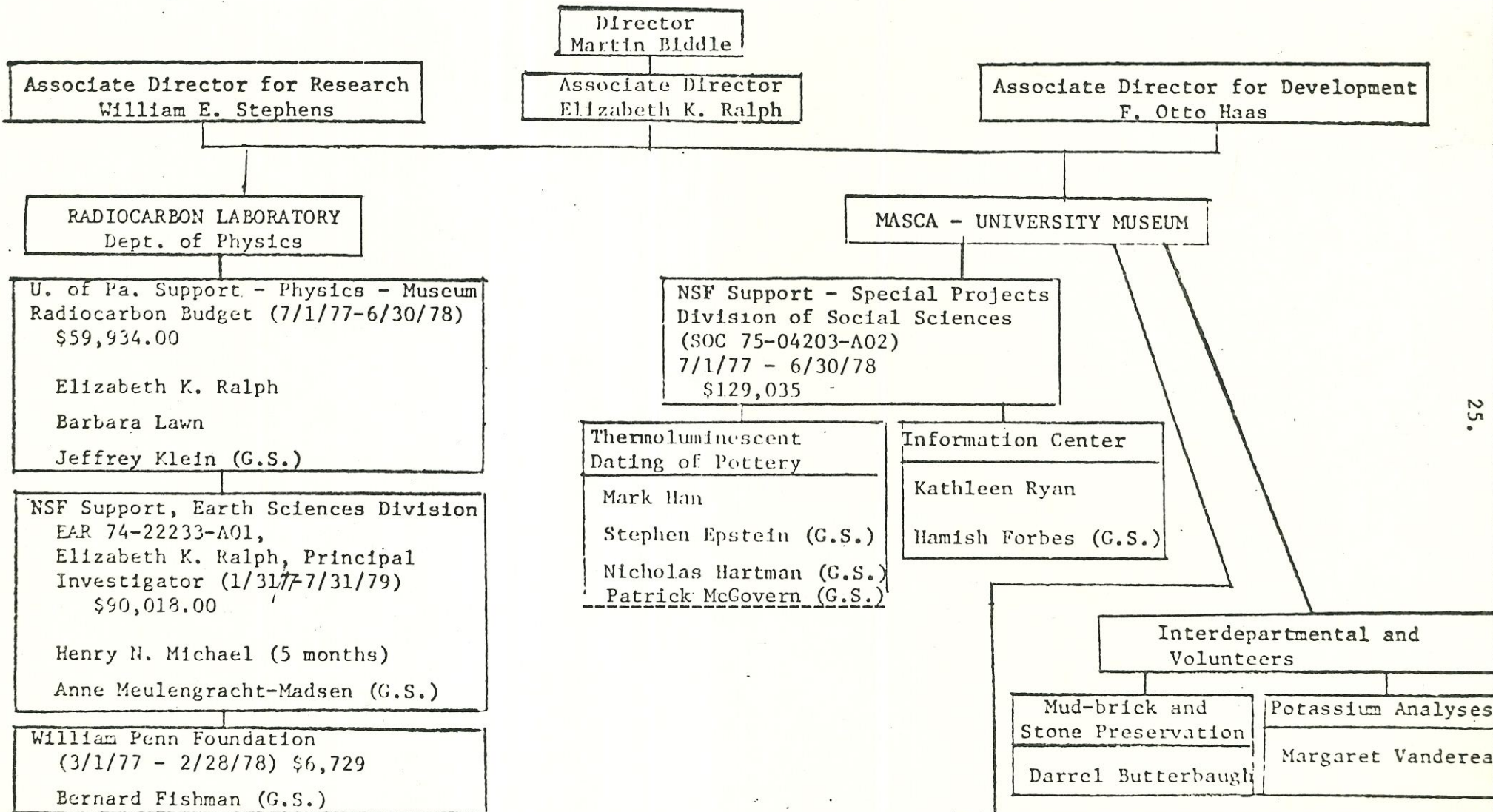
One CO_2 combustion and purification train, as shown diagrammatically in Figs. 3 and 4.

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



- 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 APPLICATIONSCurrent Support

Radiocarbon Laboratory

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

Elizabeth K. Ralph, Principal Investigator
6 man-months

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

Elizabeth K. Ralph, Principal Investigator
2 man-months

MASCA Laboratories

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

Martin Biddle, Principal Investigator
1.2 man-months

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

Elizabeth K. Ralph, Principal Investigator
2 man-months

Pending Support

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

APPENDIX

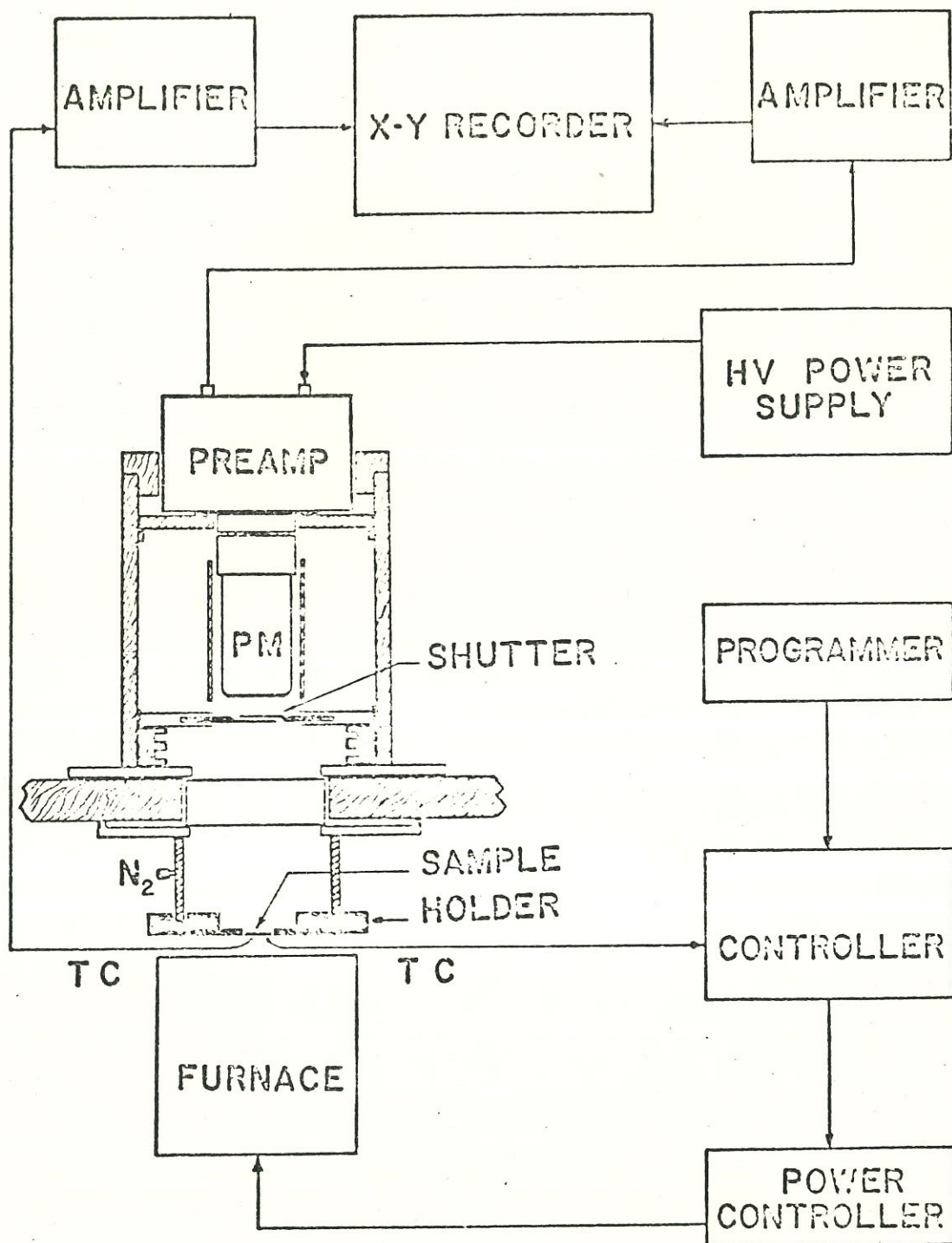


Figure 1. Block diagram of TL glow curve apparatus and programmer,

which provides a linear rate of temperature increase for heating the sample.

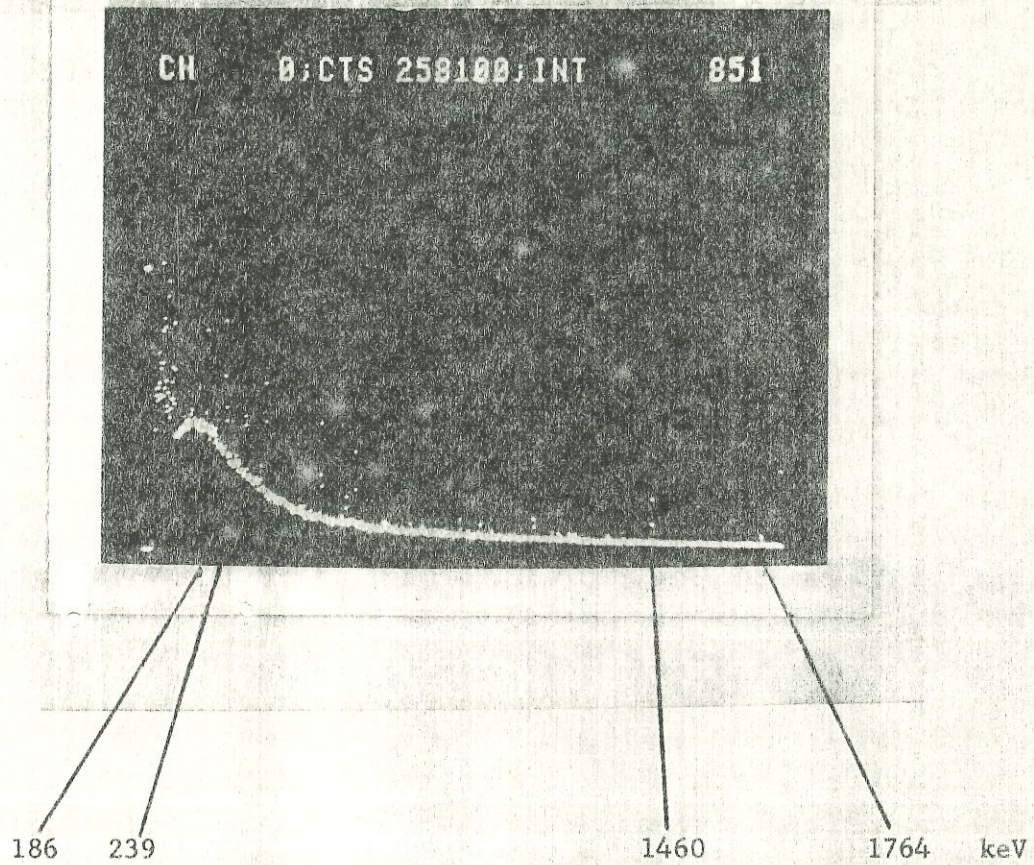


Figure 2. Photograph from CRT of Pulse Height Analyzer connected to Ge(Li) Detector. (TL sample # PT 175)

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

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

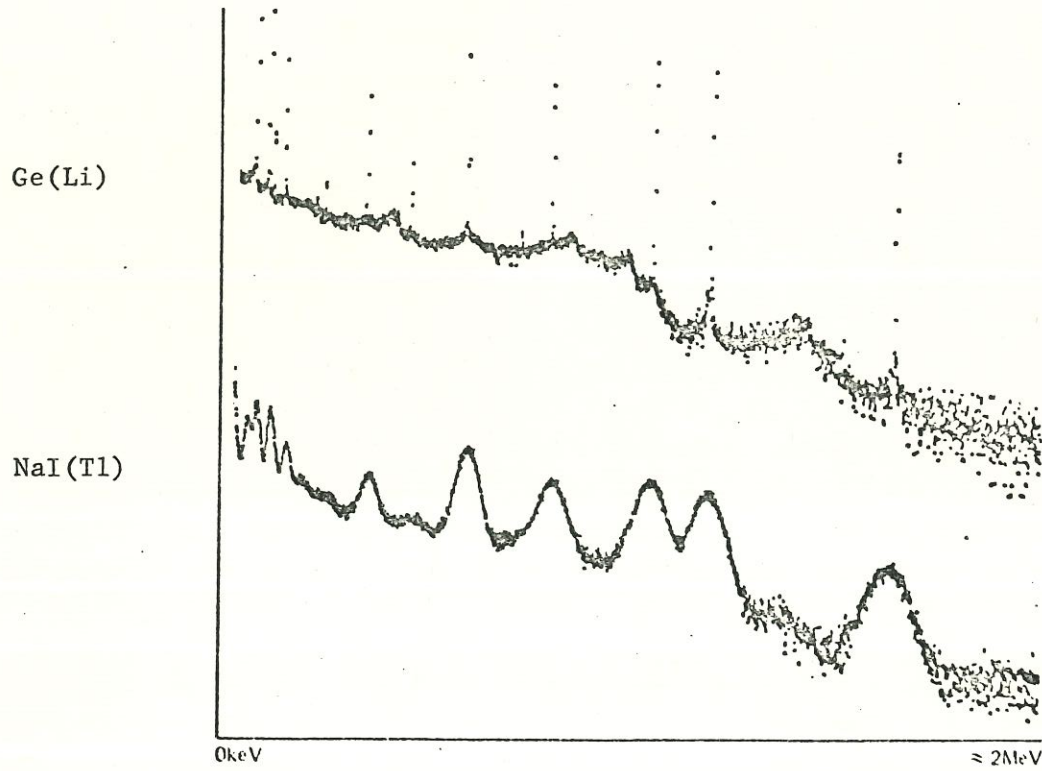


Figure 3 10%, 2.0keV Ge(Li) vs. 3'' x 3'' NaI(Tl) NBS Mixed Point Source, (SRM 4215C) 25cm, 100sec. Count Time.

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 $R(\alpha) = 1/\text{cm}^2 \cdot \text{ksec}$

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

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

quartz may be as low as 0.02

TABLE 3PERCENT 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 4TOTAL DOSE-RATE* (mrad/yr) FOR $R(\alpha) = 1/\text{cm}^2 \cdot \text{ksec}$

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