**GEORGIA INSTITUTE OF TECHNOLOGY**  
Engineering Experiment Station

**PROJECT INITIATION**

Date: 5/4/72

<table>
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<th>Project Title:</th>
<th>Determination of the Inelastic Scattering Cross Section of Polycrystalline Materials as a Function of Temperature</th>
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<td>Project No.:</td>
<td>B-393</td>
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<td>Project Director:</td>
<td>Dr. J. M. Kallfelz</td>
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<td>Sponsor:</td>
<td>Research Corporation</td>
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<tr>
<td>Effective:</td>
<td>June 1, 1972 Estimated to run until: May 30, 1972</td>
</tr>
<tr>
<td>Type Agreement:</td>
<td>Grant (Controller's Account RP-1259) Amount: $10,000</td>
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Reports: Progress Reports — As significant developments occur. Final Report — Summary type, upon completion.

Contact Person: Mr. Jack W. Powers  
Research Corporation  
6075 Roswell Road, N. E.  
Atlanta, Georgia 30328

Assigned to . . . Nuclear & Biological Sciences . . . Division

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PROJECT TERMINATION

PROJECT TITLE: Determination of the Inelastic Scattering Cross Section of Polycrystalline Materials as a Function of Temperature

PROJECT NO: B-393

PROJECT DIRECTOR: J. M. Kallfelz

SPONSOR: Research Corporation

TERMINATION EFFECTIVE: August 31, 1973

CHARGES SHOULD CLEAR ACCOUNTING BY: All acceptable charges have cleared

EES 402 (R10-62)
Dr. Jack Powers, Regional Director
Research Corporation
6075 Roswell Road, N.E.
Atlanta, Georgia 30328

Dear Dr. Powers:

This is a progress report to inform you of the present status of the research we have conducted under the joint grant from the Research Corporation to Georgia Tech and Clark College, to investigate the inelastic scattering cross section of polycrystalline materials. This work has been in progress for approximately one year; as the grant did not include as much student support as we requested, we have pursued this research at a reduced level than that originally planned, so that as we have discussed with you previously we will need a larger time period to complete the proposed research.

We have, however, made good progress on these investigations, as we will discuss below. The general disposition of funds to date has been as follows.

(a) Georgia Tech
(1) Reactor Use Charges--The original grant was for $1,800 for this item. With your permission, $800 was transferred to personal services, to allow for support of an additional student in the spring quarter. The remaining $1,000 was expended in reactor use charges in April and May, so these funds are exhausted. Other reactor use charges for this research were charged to the School of Nuclear Engineering.

(2) Equipment and Supplies--$1,500 was granted for this item. The School of Nuclear Engineering paid $600 for two graphite crystals needed for this research and included in the proposal budget, and with your permission $600 was shifted from this category to student support. The School of Nuclear Engineering has paid for most of the materials and supplies needed to the present, so that we have approximately $850 left in this category, which will be used for final material samples, shielding, and other equipment and supplies needed for the final measurements.

(3) Student Support--The original budget had $2,400 in this category, and with the transfers described above, this was raised to $3,800. Of this, approximately $3,200 has been expended, to support the following graduate students.

B. I. Shamasundar -- 3 quarters
I. J. Unus -- 1 quarter

The remaining $600 will be expended in the summer for student support.

(4) Machinist Charges--$400 was requested for this expense. Of this, approximately $200 has been expended, and the School of Nuclear Engineering has
paid for considerable additional machinist time necessary for this research. The remaining $200 will be used for further personal services which are necessary.

In summary, of the $6,100 granted to Georgia Tech, approximately $4,500 has been expended to date.

(b) Clark College

(1) Student Support--The $2,400 granted for this purpose was used to support the following student during the year: R. Evans.

(2) Equipment and Supplies--The $1,500 budgeted for this item was used to purchase items necessary for the scattering sample temperature control.

Thus there have been three students involved in this research, although one (Mr. Unus) was supported for only one quarter, to assist Mr. Shamasundar, who is including this research in his Ph.D. thesis program. Mr. Evans of Clark worked at Georgia Tech with Mr. Shamasundar in the summer, helping in the construction of equipment for the time-of-flight facility, including the neutron beam-catcher shown in Fig. 1.

The objective during this year was to construct and test several devices, to determine which would be most appropriate for the final measurements. Since our findings thus far are preliminary, for this testing, as yet no papers or talks have resulted from this work.

One of the devices which has been constructed is a curved plate chopper rotor, shown in Figs. 2a and 2b. For very low energy neutrons, the transmission of this rotor is superior to that for a flat plate rotor. This device is completed, except for balancing. It will be tested shortly, and it is planned to use it for measurements in the very low energy range.

Another proposed method of measurement involved a double crystal diffractometer, which has been constructed and is shown in Fig. 3. Our test measurements with this device indicate that this method is inferior, because of intensity considerations, to the time-of-flight technique; therefore, it is planned now not to pursue this method further, except possibly for some checking measurements.

Our preliminary test measurements utilizing the time-of-flight technique indicate that it is superior, and it is planned to use this method for the final measurements. Fig. 4 shows some preliminary results using the flat-plate chopper, which is adequate down to about .001 eV. The scattering sample used here is just for testing, and has an unknown purity; thus the obvious discrepancy with previous reported results is not conclusive.

Also shown in Fig. 4 is the result of a theoretical calculation of the inelastic scattering cross section, which we have performed using a fairly crude scattering model, the single-phonon Placzek expansion (1).
Dr. Jack Powers, Regional Director  
Research Corporation  
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June 7, 1972  
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The temperature control device is still being constructed, under the primary supervision of Mr. Ed Patterson at Clark, and should be completed this summer. It is anticipated that Mr. Patterson will complete his Ph.D. program soon and will also be involved in this research next year.

Presently we are investigating sources for the very pure moderator samples needed for the final measurements. Also we are planning the final shielding arrangements and sample set-up. When the samples have been obtained we plan to measure the room-temperature cross sections first, using the time-of-flight technique. The temperature dependent measurements will be made later, when the temperature control device is completed.

As mentioned earlier, the student support granted was for one student from each school rather than the two which we had requested. This has delayed the completion of the originally proposed research; we anticipate that about one more year will be required to complete the execution and evaluation of the experiments in the original program, i.e. measurements of the inelastic scattering cross section for several crystalline moderators, in the temperature range of about 300°K - 700°K, if at least two students are involved for this year. If we do not obtain more student support, we will have to reduce the goals of the program, possibly by restricting ourselves primarily to one crystalline material, or to only room temperature measurements. Therefore, we would like to submit a request to you for a renewed grant of $5,500 to be split between Georgia Tech and Clark College for the support of one student for a year at each school.

We would once again like to thank the Research Corporation for the grant to support our joint research, which is scientifically interesting and helps to provide further mutually beneficial cooperation between Georgia Tech and Clark College. Please let us know if you desire further information about the present status of our research.

Sincerely,

John M. Kalifelz  
Assoc. Prof. of Nucl. Engrg.  
Ga. Institute of Technology

G. S. Kiang  
Assoc. Prof. of Physics  
Clark College

G. H. Walker  
Assoc. Prof. of Physics  
Clark College

cc: Dr. O. P. Puri, Chairman  
Dept. of Physics, Clark College
Dr. G. W. Leddicotte, Acting Chief  
NBSD-EES, Georgia Tech
Dr. Lynn Weaver, Director  
School of Nuclear Engrg., Georgia Tech
Mr. A. H. Ecker  
ORA Reports Office, Georgia Tech (2)
Reference

Fig. 1. Time-of-Flight Facility at Georgia Tech Research Reactor
1: neutron chopper; 2: neutron detector;
3: neutron beam-catcher; 4: shielding; 5: time-of-flight analyzer
Fig. 2a. Cross Section of Georgia Tech Curved Plate Slow Neutron Chopper
Fig. 2b. Curved Plate Chopper Rotor
(See Fig. 2a for Cross Section)
Rotor Length: 6 inches
Diameter: 4.5 inches

Fig. 3. Double Crystal Diffractometer
1: reactor face 2: primary neutron beam
3: primary crystal 4: secondary crystal
5: monoenergetic neutron beam 6: shielding
Fig. 4. The total neutron cross section for beryllium (below $E = .005$ eV, this is mainly the thermal inelastic scattering cross section) $T = 300^\circ K$

Preliminary test measurements at the Georgia Tech Research Reactor, using slow chopper and time-of-flight method - April 1972.

Previous reported results, from BNL-325.

Theoretical calculation with single-phonon Placzek model (1), $\sigma$-inelastic.
Some polycrystalline materials, such as beryllium and graphite, are of importance for nuclear reactors. Previous direct measurements of their inelastic scattering probability "cross section," $\sigma_i$, for neutrons had limited accuracy, as indicated by large differences in the reported results for $\sigma_i$ of graphite at a particular energy. Furthermore, $\sigma_i$ values from theoretical calculations were often in poor agreement with experimental results, and in some cases there was only one or no direct measurement of $\sigma_i$ (e.g., Be and BeO). In recent years, investigations of decay constants and energy distributions for neutron fields in these crystalline materials have become important since they yield information valuable for nuclear reactor physics. However, the interpretation of these investigations requires the correct value for $\sigma_i$, and it was obvious that an accurate determination of this parameter was required.

The goal of our research was such a determination of $\sigma_i$, as a function of incident neutron energy, for several material temperatures. Our high accuracy experiments achieved his goal for beryllium, graphite, and beryllium oxide at room temperature. The beryllium oxide values were the first published experimental results, and it was concluded that a previous value for graphite was too high. The temperature control apparatus was not constructed, so measurements at elevated temperatures were not performed.

Our original goal was expanded to include several related topics. We measured the total neutron cross section for beryllium, and showed that effects of the grain size of the sample, often ignored in the analysis of previous experiments, make the results thereof questionable. We furthermore investigated the "diffusion approximation" to the equation which describes the behavior of neutron fields (the Boltzmann equation). We concluded that this approximation was being applied for some cases for which it was not applicable, in investigations of neutron behavior in polycrystalline materials.
REPORT OF RESEARCH CORPORATION GRANT

STUDENT PARTICIPATION (Give names of students working on the project, their role in the research, their achievements and their career plans.)

Georgia Tech Students:

- I. Shamasundar - Under the project, Dr. Shamasundar completed his Ph.D. degree in Nuclear Engineering at Georgia Tech in January 1974. (Thesis title: "Investigation of Neutron Thermalization in Polycrystalline Moderators.") He has since been working in the field of nuclear reactor development as a staff member of the General Atomic Co., San Diego, California.

- J. Unus - Dr. Unus has an M.S. in Nuclear Engineering from Georgia Tech and worked in the project one quarter, performing and analyzing an experiment necessary for the project. He received his Ph.D. in Physics from Emory University in the fall of 1977.

PAPERS AND SCIENTIFIC TALKS (Give titles and references to papers or talks resulting from the work. Attach two copies of any reprints available, if not previously forwarded.)

(a) B. I. Shamasundar, Ph.D. Thesis (see above).


(b) and (c) are published abstracts of papers presented at the 1974 annual American Nuclear Society (ANS) meeting.

OTHER SUPPORT (List amounts and sources—including institutional—of other contributions received or expected for this work.)

Georgia Tech Support (Institutional Funds): TOTAL $18,817

- Dr. John M. Kallfelz salary (20% time 6/71-12/73) $8,960
- Mr. B. I. Shamasundar (6/71-1/74; Quarters not fully covered by grant) $6,297
- Georgia Tech Research Reactor Use Charges $2,960
- Material (Graphite Crystals) $600

EXPENDITURE OF RESEARCH CORPORATION GRANT FUNDS (The terminal report should be approved by an authorized officer of the institution.)

Expenditures by Georgia Tech:

a. Equipment, supplies (Itemize major expenditures)

Material and Supplies: $457.55

Major Items:
- Beryllium from Brush-Wellman Co. $285.60
- Graphite from Union Carbide Corp. $84.75

b. Stipends (Academic status, rates, periods of appointment) Personal Services: TOTAL $4,628.15

- I. J. Unus - " " 4/72-6/72. $560.00
- J. M. Burke - Machinist 10/71 $167.48
- R. E. Meek - Electronic Technician 3/72. $11.84
- P. D. Field - Electronic Technician 3/72. $7.58

C. Other expenditures (Itemize and give purpose) TOTAL $4,914.30

- Transfer to Clark College, July 15, 1971 of their portion of grant for temperature control equipment and student support $3,900.00
- Georgia Tech Research Reactor Use Charges $1,000.00
- Retirement (for machinist and electronic tech. under b.) $14.30

Date December 20, 1977

Signature of principal investigator / ___________________________

Date December 22, 1977

Signature of authorized officer of institution (required for terminal report only)

Wright L. Allen, Deputy Director

Office of Contract Administration

Name and position of authorized officer of institution

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