Date: 9/25/78

Project Title: Assistance for the Georgia Tech Research Reactor

Project No: A-60-604 (Continuation of B-215 which began 6/19/61)

Project Director: Dr. Monte V. Davis

Sponsor: Department of Energy; Oak Ridge Operations

Agreement Period: From 7/1/78 Until 6/30/83

Type Agreement: Contract No. DE-AC05-76ER02852 (Mod. No. M019 dated 8/8/78)

Amount: $11,555.73 ($143,000 total estimated cost, including B-215)

Reports Required: Annual Progress Reports

Sponsor Contact Person(s):

Technical Matters

Contractual Matters

(Thru OCA)

Mr. A. H. Frost, Jr., Chief Research Contracts, Procedures and Reports Branch

Contract Division

Department of Energy

Oak Ridge Operations

P. O. Box E

Oak Ridge, TN 37830

Defense Priority Rating: n/a

Assigned to: Nuclear Research Center (School/Laboratory)
GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 07/30/90

Project No. A-60-604

Center No. Q5235-0A0

Project Director KARAM R A

School/Lab NUCL. RES.

Sponsor EG&G IDAHO/IDAHO FALLS, ID

Contract/Grant No. DE-AC07-76ER02852

Prime Contract No.

Contract Entity GIT

Title ASSISTANCE FOR THE GEORGIA TECH RESEARCH REACTOR

Effective Completion Date 880630 (Performance) 880630 (Reports)

Closeout Actions Required:

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Comments

Subproject Under Main Project No.

Continues Project No.

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NOTE: Final Patent Questionnaire sent to PDPI.
September 16, 1987

Ms. Marlena Clark
U.S. Department of Energy
Oak Ridge Operation
P.O. Box E
Oak Ridge, Tennessee 37831

Dear Ms. Clark:

Enclosed please find a progress report prepared under contract No. DE-AC05-76ER02852 for the Department of Energy. As you know all funds in this contract have been spent. The contract expires June 30, 1988. I would like to extend this contract through 1995. The amount of additional funds requested is $20,000 per year for seven years.

We appreciate DOE's support and look forward to their continued help and encouragement.

Sincerely yours,

R.A. Karam
Director

RAK:jlr
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**TABLE 1** - THERMAL NEUTRON FLUX IN THE GTRR ................................. 8
Administrative responsibility for the Neely Nuclear Research Center (NNRC) resides in the Office of the Vice President for Research of the Georgia Institute of Technology. The NNRC houses two major facilities: the Georgia Tech Research Reactor (GTRR) and the Hot Cell Laboratory. The NNRC is a facility of the University System of the State of Georgia and is available to all universities.

In accordance with a contractual agreement between DOE and Georgia Tech, NNRC facilities have been used in programs of education and training of students in nuclear science and engineering and for faculty and student research.

- The inventory of Co-60 sources at the Hot Cell Laboratory has been increased to 700,000 Ci. Dose rates of up to 1.0 mSv per hour are possible now.
- On a yearly basis, 20-35 commercial companies use the NNRC facilities for their research.
- On a yearly basis, $300,000-$500,000 in sponsored research and services are obtained to support the Center's activities.
- Seven graduate students and fifteen undergraduate students are financially supported by the Center each year.
- Currently, three Ph.D. students are doing their research at the NNRC. It is planned to increase this number to 10.
- Three to six members of the faculty are supported financially part-time on a yearly basis.
- On the average, 100 or more Georgia Tech students use the NNRC in laboratory courses yearly.
- Over one thousand visitors from educational institutions, primarily high schools, have conducted tours at the center yearly.
- Short course training in reactor operation and health physics are offered several times every year for the nuclear industry.
- Atlanta firemen and Georgia Tech policemen are trained in the use of radiation monitoring equipment and in handling radioactive substances.
HIGHLIGHTS

- On the average, the number of universities, other than Georgia Tech, which uses the NNRC on a yearly basis varies between 12 and 20. As an example the following universities have used the facilities at the Neely Nuclear Research Center since last year.

<table>
<thead>
<tr>
<th>University</th>
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<td>1. Emory University</td>
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</tr>
<tr>
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<td>Georgia</td>
</tr>
<tr>
<td>3. University of Georgia</td>
<td>Georgia</td>
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<td>4. Georgia State University</td>
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<td>5. Atlanta University</td>
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<td>Alabama</td>
</tr>
<tr>
<td>14. Tuskegee Institute</td>
<td>Alabama</td>
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</table>

- The inventory of Co-60 sources at the Hot Cell Laboratory has been increased to 700,000 Ci. Dose rates of up to $1.0 \times 10^6$ rads per hour are possible now.

- On a yearly basis, 20-25 commercial companies use the NNRC facilities for their research.

- On a yearly basis, $300,000-$500,000 in sponsored research and services are obtained to support the Center's activities.

- Seven graduate students and fifteen undergraduate students are financially supported by the Center each year.

- Currently, three Ph.D. students are doing their research at the NNRC. It is planned to increase this number to 10.

- Three to six members of the faculty are supported financially part-time on a yearly basis.

- On the average, 100 or more Georgia Tech students use the NNRC in laboratory courses yearly.

- Over one thousand visitors from educational institutions, primarily high schools, have conducted tours at the center yearly.

- Short course training in reactor operation and health physics are offered several times every year for the nuclear industry.

- Atlanta firemen and Georgia Tech policemen are trained in the use of radiation monitoring equipment and in handling radioactive substances.
I. INTRODUCTION

The Neely Nuclear Research Center, Georgia Institute of Technology, is a regional resource for the nation which is used in programs of education and training of students in nuclear science and engineering and for faculty and student research. Additionally, it is a major attraction for high school students in the Atlanta metropolitan area. Over 1000 students come yearly for conducted tours to see and experience first hand some of the applications in nuclear medicine, material research, geological research, food preservation, fiber optics resistance to radiation, color centers research, etc. The Neely Nuclear Research Center has made available its 5 MW research reactor, its Co-60 irradiation facility, and its activation analysis laboratory to large numbers of students and faculty from many universities and colleges.

This report of MNRC utilization is prepared in compliance with the requirement of Contract No. AC05-76ER02852 between the U.S. Department of Energy and the Georgia Institute of Technology. The report contains information with regard to facilities descriptions (brief), personnel, organization, programs, a partial publication list, and a budget request for extension of contract.

II. FACILITY DESCRIPTION

The Neely Nuclear Research Center of the Georgia Institute of Technology houses two major facilities: the Georgia Tech Research Reactor (GTRR) and the Hot Cell Laboratory.

The GTRR is a heterogeneous, heavy-water moderated and cooled reactor, fueled with plates of aluminum-uranium alloy. It is designed to produce a thermal flux of more than $10^7$ n/cm$^2$/sec at a power of 5 MW and an exit moderator temperature of 137°F. A cutaway perspective view of the reactor is shown in Figure 1. A horizontal cross section of the GTRR is shown in Figure 2.

The reactor core is approximately two feet in diameter, two feet high and, when fully loaded, contains provisions for up to nineteen fuel assemblies spaced six inches apart in a triangular array. Each assembly contains sixteen fuel plates. The total uranium-235 content of a full loading is 3.2 kg. The fuel is centrally located in a six foot diameter aluminum reactor vessel which provides a two foot thick D$_2$O reflector completely surrounding the core.

EXPERIMENTAL FACILITIES

Experimental Facilities

The reactor is equipped with numerous horizontal and vertical experimental facilities to be used for the extraction of beams of fast and slow neutrons and for the performance of irradiations within the facilities. Measured neutron fluxes in some of these facilities are given in Table 1 and Figure 3. The expected usage of the different experimental openings is described in the following sections and their location is shown in Figure 2.

Vertical Experimental Facilities

The top of the reactor contains a total of 46 vertical penetrations of which 41 are for experimental use, including fuel element portions. Twenty-seven of these are located in the D$_2$O region within the reactor vessel. The remaining fourteen are dispersed throughout the graphite reflector region. All penetrations other than fuel element positions are provided with double...
aluminum thimbles. The outer thimble supports and protects the inner sample thimble. Experimental thimbles located in the graphite reflector region are equipped with an "O" ring to effect a gas seal between the I.D. of the outer thimble and the I.D. of the penetration liner. Experimental penetrations in the D2O region are sealed by an "O" ring located in the lower top shield port plug.

Nineteen of the D2O region openings are fuel assembly positions, any of which could be used for irradiations. A second group of thimbles, designated V20 and V23, are extensions of the core lattice, but are intended primarily for sample irradiations. These thimbles, 3 1/4 inch diameter, are located peripherally about the lattice and extend down to the plenum chamber of the core support assembly. Stations V24 and V25 are similar to this group except that each position is approximately 28 inches from the center of the core and eight inches inside the vessel wall. The thimbles extend to just below the core midplane.

Openings V27 and V28 are four inch I.D. fast flux facilities located just inside the D2O region. These thimbles can be used for irradiation of specimens in a neutron flux which is predominantly fast. The conversion of thermal neutrons to fast will be accomplished by building into the inner (sample) thimble a sheet of enriched uranium. When used in this manner the outer thimble is connected to the plenum chamber. This allows the D2O coolant to flow upward between the outer and inner thimbles to provide cooling for the converter plate.

Stations V33 and V42 are four inch I.D. vertical thimbles. All ten are in the graphite region and approximately eight inches outside the reactor vessel wall. They extend to a point just below the midplane of the core. V45 and V46 are six inch I.D. vertical thimbles which stop near the top of the thermal column approximately 30 inches above the core midplane. They are located in the graphite region approximately 12 inches outside the reactor vessel wall. Stations V43 and V44 are similar, except in depth, to V45 and V46. These thimbles extend downward to the midplane of the core.

Horizontal Experimental Facilities

The reactor contains 22 horizontal openings, a thermal column, and a bio-medical irradiation facility. Stations H1 through H10 are horizontal beam ports, all of which lie in the horizontal plane passing through the center of the reactor. Stations H1, H3, H4, H7, H8, and H10 are so located that they look directly at fuel elements and thus give good fast or epithermal neutron beams. The locations of the horizontal openings and their sizes are as follows:

a. H1 is a six inch I.D. beam port which extends into the D2O region to a point 16 inches from the core center.

b. H3, H4, H7, and H8 are 4 inch I.D. beam ports similar to H1.

c. H2, H5, H6, and H9 are 4 inch I.D. beam ports which extend to a point approximately 20 inches from the core center.

d. H10 is a rectangular beam port measuring 2 inches by 6 inches which extends to a point 15 inches from the core center.
All 10 ports are provided with rotating shutters so that the beam intensity may be reduced to avoid the danger of overexposure to radiation while adjustments are made to equipment. The shutter assembly extends to the top of the reactor shielding and is entirely removable; however, only the lower portion revolves during opening and closing of the port. Each shutter is sealed at the top to prevent the leakage of argon-41 from the beam port thimbles into the ventilation system during reactor operation. These shutters are manually operated from the top of the reactor shield structure. Indicating lights showing open or closed positions are located on the face of the shield above the beam port opening and in the reactor control room. Provisions are included to supply utilities to these locations.

H11 and H12 are 6 inch tangent through-tubes which extend across the reactor. They pass through the D_2O region tangent to the core. H11 is located near the top of the active core and H12 on the opposite side near the bottom of the core. These holes are particularly useful for performing engineering-type experiments requiring the circulation of a coolant.

H13 and H14 are 11 inch square through-tubes. They pass through the graphite region below the reactor vessel and are intended primarily for sample irradiations.

H15 and H16 are twin 1 1/2 inch I.D. tubes, housed in a common re-entrant nozzle, which pass through the D_2O reflector tangent to the core. They are intended as pneumatic sample handling devices for experiments requiring irradiations of short duration.

H17 and H22B are instrument ports. They contain the ion chambers and counters required for the operation and control of the reactor.

A thermal column, 5 feet square, is provided as an extension of the graphite reflector. It is fitted with a shutter and with heavy shielding located at the outer face. The shutter opens horizontally giving a port 4 inches by 4 inches or 16 inches by 16 inches. A number of removable graphite stringers which extend up to the reactor tank wall are provided in the thermal column water tanks.

A shielded room for bio-medical research is located in the side of the reactor opposite the thermal column. This facility is designed to allow accurate exposures of biological specimens to a wide-angle beam of thermal neutrons with a relatively low background of fast neutrons and gamma rays. It is fitted with a bismuth gamma shield, water tanks for neutron attenuation, a collimator, shutter, and provisions for a converter plate system. The opening in the reactor is surrounded by the shielded room. The use of a converter plate will permit the fast flux to be increased to about $10^7$ n/cm$^2$/sec with a corresponding decrease in thermal flux and increase in gamma rays.

The bio-medical facility shutter is operated by means of a hydraulic cylinder which is capable of opening or closing it in 20 seconds or less. The system is fail-safe in that power or equipment failure closes the shutter, but keeps the hydraulically operated entrance door in place. The required operating equipment is located in the basement area. This same area houses the D_2O system which cools the bismuth shield and fills the water tanks.

The shielded room is approximately 10 feet by 12 feet inside and is shielded with 2 feet of barytes concrete along the sides. The back wall, which is subject to beam impingement, consists of 4 feet of ordinary concrete covered by 1/4 inch of boral and 1/2 inch of lead. The roof is ordinary concrete 3 feet thick. Access to this area is through a vertically moving, hydraulically operated, shield door. Emergency access, in the event of door failure, is possible through a manhole in the ceiling of the room. This manhole may be removed by means of the building crane. A ladder is permanently installed on the wall below the manhole.
The design of the Hot Cell Laboratory is unique and very appropriate for qualification testing. Major features include the following:

- A quality assurance program that meets the highest standards; ionization chambers calibration traceable to the National Bureau of Standards.
- 700,000 Ci Co\textsuperscript{60} sources
- Master-slave manipulators for remote handling
- Wall penetrations to allow electrical and/or mechanical monitoring for irradiated objects
- 15-ton crane for heavy objects handling
- Large Hot Cell to accommodate large objects: 7 feet wide x 13 feet high and 23 feet long
- Water, air and gas supplies are available to accommodate experimental needs
- Electrical power with the following line voltages:
  - 120 V, 60 Hz, 10 15 amps
  - 220 V, 60 Hz, 10 20 amps
  - 440 V, 60 Hz, 30 60 amps
- A 3-ton crane inside the Hot Cell with remote operation capability
- Dose rates up to $1 \times 10^7$ rads/hour air
- A vertical pipe irradiation facility is located in the cobalt storage pool for irradiation of small components (6" diameter x 12" high)
- Technical support is available in electrical and/or mechanical experimental apparatus setup or design
FIGURE 1
CUTAWAY PERSPECTIVE VIEW OF THE GTRR

FIGURE 2
HORIZONTAL SECTION OF GTRR AT THE CORE MIDPLANE
FIGURE 2
HORIZONTAL SECTION OF GTRR AT THE CORE MIDPLANE

GTRR THERMAL NEUTRON FLUX MEASURED AT 1 MW POWER
FIGURE 4
GTTR THERMAL NEUTRON FLUX MEASURED AT 1 MW POWER

FIGURE 3
GTTR THERMAL NEUTRON FLUX MEASURED AT 1 MW POWER
<table>
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<th>SYMBOL</th>
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<th>SIZE</th>
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<th>THERMAL NEUTRON FLUX ((\text{5 Mw}))</th>
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<td>H-1</td>
<td>Horizontal Beam Tube</td>
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<td>1.2 x (10^{14})</td>
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<td>H-2 to H-9</td>
<td>Horizontal Beam Tube</td>
<td>4&quot; ID</td>
<td>1.2-2.4 x (10^{13})</td>
<td>0.75-1.2 x (10^{14})</td>
</tr>
<tr>
<td>H-10</td>
<td>Horizontal Beam Tube</td>
<td>2&quot; x 6&quot;</td>
<td>2.2 x (10^{13})</td>
<td>1.1 x (10^{14})</td>
</tr>
<tr>
<td>H-11, H-12</td>
<td>Horizontal thru-tube</td>
<td>6&quot; ID</td>
<td>2.0 x (10^{13})</td>
<td>1.0 x (10^{14})</td>
</tr>
<tr>
<td>H-13, H-14</td>
<td>Horizontal thru-tunnel</td>
<td>12&quot; x 12&quot;</td>
<td>5 x (10^{12})^*</td>
<td>2.5 x (10^{13})</td>
</tr>
<tr>
<td>H-15, H-16</td>
<td>Pneumatic Tube</td>
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<td>1.3 x (10^{13})</td>
<td>6.5 x (10^{13})</td>
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<tr>
<td>V-1 to V-19</td>
<td>Fuel Element Positions</td>
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<td>3 x (10^{13})^*</td>
<td>1.5 x (10^{14})</td>
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<tr>
<td>V-20 to V-23</td>
<td>Vertical Thimble (core)</td>
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<td>2.3 x (10^{13})</td>
<td>1.1 x (10^{14})</td>
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<tr>
<td>V-24, V-25</td>
<td>Vertical Thimble (reflector)</td>
<td>3-1/2&quot; ID</td>
<td>4 x (10^{12})^*</td>
<td>2 x (10^{13})</td>
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<tr>
<td>V-27, V-28</td>
<td>Fast Flux Facility</td>
<td>4&quot; ID **</td>
<td>3 x (10^{12})^*</td>
<td>1.5 x (10^{13})</td>
</tr>
<tr>
<td>V-33 to V-42</td>
<td>Vertical Thimble (reflector)</td>
<td>4&quot; ID</td>
<td>8.4 x (10^{11})</td>
<td>4.2 x (10^{12})</td>
</tr>
<tr>
<td>V-43 to V-46</td>
<td>Vertical Thimble (reflector)</td>
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<td>8.1 x (10^{11})</td>
<td>4.5 x (10^{12})</td>
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<td></td>
<td>Bio-Medical Facility</td>
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<tr>
<td></td>
<td>Room</td>
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<td>5.0 x (10^{10})</td>
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<td></td>
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<td>1.7 x (10^{12})</td>
<td>8.5 x (10^{12})</td>
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</tbody>
</table>

*calculated value
** without U-235

Converter
III. PERSONNEL

Administrative responsibility for the Neely Nuclear Research Center resides in the Office of the Vice President for Research, Dr. Thomas E. Stelson. The organization chart for the NNRC is shown in Figure 4.

The Nuclear Safeguards Committee is appointed by the President of the Institute for the purpose of maintaining the health and safety standards associated with the operation of the reactor and its associated facilities. The committee is composed of senior technical people with rich experience in reactor engineering, reactor operation, chemistry and radiochemistry, instrumentation and control, radiological safety, and mechanical and electrical systems. Current membership of the committee is as follows:

1. Dr. Prateen Desai (Thermal Hydraulics)
2. Dr. Howard Edwards (Instrumentation)
3. Dr. Richard Fink (Chemistry)
4. Dr. Waverly Graham (Nuclear Engineering)
5. Dr. Bernd Kahn, Chairman, (Nuclear Engineering)
6. Dr. Robert MacDonald (Nuclear Engineering)
7. Dr. James A. Mahaffey (Nuclear Engineering)
8. Dr. Henry Neumann (Chemistry)
9. Mr. Les Petherick (Toxic Waste)
10. Dr. James R. Stevenson (Physics)
11. Mr. Jack Vickery (Security)
12. Dr. David Walker (Environment)

The reactor operation's group consists of L. Dean McDowell, William Downs and David Cox. The Hot Cell Laboratory manager is Jerry Taylor. The electronic and mechanical support is provided by Mitchell Mercer and David Cox respectively. The experimental research group includes Ronaldo Davila, In Sup Choi and Curt Lindner. Student trainees are Laura Lucio, Tonya Hall, and Bruce Works. Administrative secretaries for the NNRC are Daphne Aycock and Judy Rodgers.

The Health Physics group includes Robert Boyd, Steve Millspaugh and Paul Sharpe.

The power generation from the GTRR on a yearly basis is about 200 megawatt hours.
Figure 4

Neely Nuclear Research Center Organization Chart
IV. PROGRAM

The programs at the NNRC comprise: (1) neutron activation analysis; (2) neutron radiography; (3) radiation effects on material; (4) food preservation; (5) medical applications; (6) training; (7) high school students tours and projects.

1. Neutron Activation Analysis

The GTRR is a facility where a neutron field is generated by the fission process in uranium. The magnitude of the neutron field can be varied over a wide range. When a sample of composite material is placed in the neutron field, the nuclei of most elements in the sample capture neutrons and become radioactive. This induced radioactivity in trace elements is then used to uniquely identify the parent element. For example, the element arsenic \( \text{As}^{76} \) when it absorbs one neutron it becomes \( \text{As}^{75} \) which decays with a half-life of 26.4 hours and emits gamma rays with the following energies 0.559 Mev (43%), 0.657 Mev (6%), 1.22 Mev (5%), 1.44 Mev (0.7%), 1.789 Mev (3%) and 2.10 Mev (9%). The numbers in parenthesis indicate the probability per decay of having that energy photon emitted when one atom of \( \text{As}^{75} \) decays to \( \text{As}^{76} \). (Note that not all decays of \( \text{As}^{75} \) result in emission of gamma rays. More than half of the \( \text{As}^{75} \) decays result in the emission of electrons only.)

Quantification of the energy of the gamma photon and the half-life of the decaying isotope are sufficient conditions to uniquely identify the parent isotope. When this identification is combined with instrument efficiency and irradiation and counting times, one is able to quantitatively determine the amount of the isotope present in the sample. This technique is known as neutron activation analysis.

Neutron Activation Analysis (NAA) is an analytical technique based on the determination of the number and energy of gamma and/or x-rays emitted by radioisotopes produced in the same matrix by neutron irradiation. Quantitative analysis is obtained by comparing the number of characteristic x- or gamma-rays of the unknown with the number determined for a standard that has been subjected to the identical irradiation.

Activation analysis measures the total amount of an element in a material without regard to chemical form and has the following advantages:

1. It is one of the most sensitive analytical techniques available (Table 1);

2. It is often non-destructive and usually requires no sample preparation;

3. It is multi-element in its application. Special techniques are used when interfering elements are present.

The sensitivity obtained by Activation Analysis is a function of the neutron cross section of the element in question, available neutron flux, length of irradiation, resolution of the detector, matrix composition, and the "total" sample size. Interference free detection limits shown in Table 1 are obtainable for 1 gm (or 1 ml) samples. Depending on the matrix, higher sensitivities may be possible by longer irradiation time by concentrating the sample by evaporation or ion exchange.
Applications of NAA in research include the following diverse fields: medical, environmental pollution control, agricultural-forestry, crime detection, archaeology, geology, life sciences, material science, condensed matter physics, etc. In the following paragraphs, brief descriptions of research important to Georgia Tech, other Georgia universities, and the State, which has been, and is being conducted at the Neely Nuclear Research Center, are given.

A. Human Health and Trace Elements

Recently the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, has authorized a project through its Committee on Diet, Nutrition, and Cancer to evaluate the role trace elements play in human health. The project was necessarily limited to few trace elements: selenium, molybdenum, zinc, iron, iodine, and arsenic. The following are excerpts from the committee's report on selenium only as one illustrative example of many.

Selenium

"Selenium has two known biochemical modes of action: as a constituent of glutathione peroxidase, it prevents free-radical damage to cell constituents, and it acts as a potent antagonist of chronic and acute toxicity resulting from exposure to cadmium and mercury. Although both these modes of action may be related to reduction in the risk of cancer, it is not known whether these are the mechanisms of which selenium affects carcinogenesis, nor is it known at which state of carcinogenesis selenium might be effective."

"There is only limited knowledge about the effect of different doses of selenium on the reduction of cancer incidence in animals. Much of the information on the element's inhibitory effects has been obtained with doses that are close to toxic levels. One study suggests that selenium-deficient diets increase the risk of cancer, compared to diets containing nutritionally adequate but not excessive levels. Because of the relatively narrow range between toxic and optimum levels of selenium (National Research Council, 1980), it is essential to define a range of selenium intake that does not result in chronic toxicity but is effective in reducing cancer risk. Experiments to establish nutrient requirements have demonstrated that the amount of selenium required for optimum nutrition is dependent on dietary levels of fat, vitamin E, and certain heavy metals. There is also evidence that at least the interaction between selenium and fat is an important determinant of the element's effect on cancer. However, these interactions have not been quantified."

"The results of a few epidemiological studies suggest a correlation between exposure to high levels of selenium and a reduction in the risk of certain cancers (National Research Council, 1982, Chapter 10). But these data are not conclusive, partly because the database on the selenium content of foods is poor. Because selenium concentrations in food are dependent on the geochemical environment, dietary selenium levels vary widely from one region to another and cannot be calculated accurately on the basis of universal food composition data. Other reservations apply to blood concentrations of selenium as indicators of nutritional status, since there are no standard reference materials to
safe guardian of the analytical accuracy and comparability of results obtained by different laboratories. Populations in certain geographical areas of the world have substantially different levels of selenium intake, although other nutrient intakes are virtually identical. Epidemiological and/or intervention studies in such areas appear to be more promising than those in populations either with adequate selenium intakes or with relatively small differences in intake."

"The metabolism of selenium depends on the chemical form of the element. These metabolic differences may affect the impact of selenium on carcinogenesis. Very little is known about the long-term consequences of elevated intakes of different forms of selenium, and there are no adequate means for diagnosing subclinical pathogenesis resulting from the accumulation of selenium in tissues".

It is obvious that neutron activation analysis in combination with mass spectrometry (also available at Georgia Tech) can be used together to study not only the effects of the selenium element on health but also selenium compounds.

The database on the effects of selenium on health is not complete. Yet, this database is significantly larger and more complete than those of Mo, Zn, Fe, As, Mn, Hg, Cu, Cd, I, F, Ga, Ge, Y, Nb, Rh, In, Pd, etc. Obviously a golden opportunity exists for joint research activities between the Neely Nuclear Research Center and the medical communities in and around Atlanta (Emory University and/or Medical College of Georgia) to systematically study effects of trace elements on health. A joint research effort of this nature is underway between the group headed by Dr. Daniel Nixon, Professor of Medical Oncology, Emory University and the Neely Nuclear Research Center. Already more than 200 samples of cancerous tissues of lung, colon, liver and numerous samples of blood and urine have been analyzed for trace elements.

Recently a joint proposal between NNRC, Georgia Tech and the medical school at Emory University on determining the role trace elements play in healthy and cancerous tissues has been submitted to the National Cancer Institute. It is expected that the information gained from this study would lead to dietary recommendations for cancer prevention.

B. Trace Elements and Plant Health (Agriculture)

In addition to trace element research on human health, the Neely Nuclear Research Center is cooperating with two different groups at the University of Georgia: Dr. Robert Wilkinson, Experiment Station, Griffin, Georgia and Dr. Robert Isaac of the Athens campus, to determine trace elements in plant tissues. Here again more than 100 samples have been analyzed. A project to establish a database for the role of trace elements in plant life is no less in magnitude than that of human health. Such a project is not only feasible, it is being performed right now on an informal basis, with the University of Georgia faculty using the operational neutron activation analysis system at NNRC.

C. Environmental-Pollution Control

NAA is also used to quantitatively determine pollutants in the atmosphere, water and soil. In some cases pollutant composition has a unique relationship to the source of emission. For example, pollutants from coal burning can be traced to the type of coal being burned and to the place where it is being burned. It is yet another example of how the GTRR and its NAA facility is being used in research in Georgia.
D. Crime Detection

Investigation by Dr. Vincent Guinn at General Atomic, San Diego, California, shows that activation analysis of wipings taken from a suspect's hands will reveal not only whether he has fired a gun recently but also the type of ammunition used, the number of bullets fired, and the hand in which the gun was held. This is possible because when a gun is discharged, gunpowder residues spread over a wide area, including the holder of the gun. These residues contain small amounts of various metals that can be measured easily by activation analysis.

The uncanny ability of activation analysis to detect and identify very tiny amounts of certain elements has come to the aid of law-enforcement officers in a variety of ways. Human hair, for example, contains small traces of metallic elements like sodium, gold, and copper. Activation analysis has shown that the quantities of these elements present in each hair are relatively constant for an individual but vary from person to person. A recent murder conviction in Canada was based partly on the fact that a hair found in the hand of the murder victim matched the suspect's hair when the nuclear fingerprints were compared. The French courts also have admitted activation analysis data as evidence in criminal cases.

The fact that a person died from poisoning can sometimes be determined through activation analysis. Even nonlethal doses of arsenic, for example, produce arsenic-rich regions in the subject's hair that gradually move from root to tip as the hair grows. Hair even hundreds of years old can be analyzed successfully for arsenic and other residues.

English scientists recently found an unusual amount of arsenic in a relic of hair from Napoleon's head. The suspicion is now that he was slowly poisoned to death.

The case of King Eric XIV of Sweden is similar. A murder legend has persisted in Sweden for four centuries. When the king's body was exhumed recently, activation analysis showed that his body contained traces of poisonous arsenic.

Activation analysis goes beyond these ghoulish activities in helping to solve crimes. Besides being able to match human hair, it can also compare infinitesimal grease spots, specks of dirt too small to be seen with the naked eye, and tiny flakes of paint from automobiles in accidents. It can do this in either of two ways. It can either match bits of material left behind at the scene of a crime to a suspect, or it can identify minute traces of substances that he has carried away from the scene. What's more, identification can be made without damaging the specimens. Thus, they can later be admitted as evidence in court.

E. Geology

At the University of Georgia, Athens campus, Dr. Michael Roden is engaged in research regarding radiation damage in mineral apatite $\text{Ca}_5(\text{PO}_4(\text{F,Cl,OH}))$, zircon ($\text{ArSiO}_4$) and sphene ($\text{CaTiO(SiO}_4$)) caused by spontaneous fission of uranium. The spontaneous fission of uranium in a mineral produces two energetic fission fragments; these fragments travel through the crystal lattice at high velocities producing a linear zone of defects or a "fission track." Fission tracks are 10 to 20 microns in length, and they can be observed with an optical microscope after etching the mineral with strong acids or bases. Fission tracks are stable in a mineral only at lower temperatures; at elevated temperatures diffusion or
recombination of defects cause fission tracks to anneal or disappear. The research is focussed on the kinetics of track annealing in the minerals apatite, zircon and sphene, and the application of these kinetics to thermal problems in geology and geophysics.

The density of fission tracks in a mineral is proportional to: (1) the concentration of uranium in the mineral; (2) the "thermal age" of the mineral, that is, the length of time that fission tracks have been accumulating at lower temperatures. The reactor is used to determine uranium concentrations of minerals. This is accomplished by irradiating the minerals with thermal neutrons which causes the fission of uranium, thereby inducing a new set of fission tracks. The uranium concentration is proportional to the density of induced tracks and neutron fluence. The density of induced tracks and fluence are determined by standard techniques and a thermal age, or more generally the "fission-track age," is calculated.

The fission-track age of mineral is the time since it cooled below the "closure temperature," the temperature above which track annealing occurs. For the minerals apatite, zircon and sphene, closure temperatures are approximately 100°C, 220°C and 300°C, respectively. Hence, when the fission-track age of any or all of these minerals in a rock is determined it amounts to determining the thermal history. For a rock that has cooled rapidly, the fission-track ages of these three minerals are identical and they indicate the time of crystallization. However, for a rock that has experienced a slower or more complex cooling history, the fission-track ages are different and they post-date crystallization. Furthermore, the fission-track ages define a cooling curve for the rock body, that is, a set of times and temperatures which indicates the timing and rate of cooling. The fission-track method has application to many problems of interest to the Department of Energy. For example, the determination of the thermal histories of sedimentary basins, which contain the world's oil and gas resources is important information. The closure temperatures of apatite and zircon are near the upper and lower limits of the oil and gas windows, therefore, fission-track dating can be utilized to determine the thermal maturity of basin rocks and hence the probability of finding oil and gas. Another project involving annealing studies on three varieties of apatite-fluorapatite, hydroxyapatite and chlorapatite, has recently been initiated. This research will provide data on the relationship between chemical composition (particularly the presence or absence of hydroxyl groups) and susceptibility to radiation damage. Presently, understanding of radiation damage in minerals is limited, although a large body of literature exists on radiation damage in other solids. Data from minerals will be useful to materials scientists examining the effects of water on first-barrier radwaste isolation systems.

F. Other Uses of Neutron Activation Analysis

Briefly stated NAA has also been used in the following:

- Petroleum industry uses NAA to determine vanadium content in refinery feed
- Agriculture—detecting pesticide residue on crops
- Computers—measuring impurities in silicon semiconductors
2. Neutron Radiography

Neutron radiography is a nondestructive testing technique which utilizes a beam of neutrons to examine the internal details of an object and record them on industrial x-ray film. The value of thermal neutrons in radiography is that their absorption characteristics are quite different from those of x-rays. For elements at either end of the periodic table, the absorption characteristics are essentially reversed.

Heavy elements such as lead, bismuth, and uranium are practically transparent to thermal neutrons, whereas they readily absorb x-rays. Conversely, hydrogen, lithium, boron, and other light elements attenuate thermal neutrons, but allow x-rays to pass freely without interference. For example, with neutron radiography it would be an easy matter to record the height of a column of water behind several inches of lead. There are also a number of other advantages to neutron radiography. For instance, it is possible to determine differences not only between elements, but also between isotopes of the same element. This is not the case with x-rays. X-rays interact with atomic orbiting electrons, and x-ray attenuation is therefore proportional to material density and atomic number. Neutrons, on the other hand, interact with the atomic nucleus, and their attenuation is proportional to material density and neutron absorption or scattering cross section, but is independent of atomic number. Accordingly, neutron radiography permits radiographic examination of many material combinations that cannot be differentiated effectively using x-rays.

Neutron radiography has found application in a wide variety of industries. The National Aeronautics and Space Administration, for example, specifies neutron radiography on all man-rated Apollo ordinance devices. The technique is also used to:

1. Inspect certain types of explosive and pyrotechnical devices for cracks, voids, gaps, and density variations.
2. Accurately determine hydriding in titanium and zirconium.
3. Locate flaws and check system integrity of electronic devices.
4. Inspect honeycomb bonding.
5. Indicate inclusions and impurities in investment cast products such as turbine blades.
6. Check proper location of O-rings in critical components.
7. Inspect metal composites.

It is interesting that the same neutron beam used to inspect several inches of uranium or lead can be used to inspect specimens such as leaves, insects, and thinner biological specimens.

The H-1 neutron beam at the GTRR has been qualified and certified for turbine blade radiography. Figure 5 shows a neutron radiograph of jet engine blades.
3. Radiation Effects on Material

NNRC with its major 60 Co irradiation facility (700,000 Ci) has been engaged in several aspects of research involving radiation effects on matter. Several types of molecular sieves are being tested for physical and or chemical changes that might be induced by intense radiation fields. Interest in molecular sieves stems from the fact that these substances can be used in the nuclear power industry to isolate radioactive gases from the environment. For example, silver and hydrogen zeolites are molecular sieves which adsorb noble gases. One possible application for these zeolites is isolating and containing radioactive krypton and xenon from the environment. In a nuclear power plant radioactive xenon and krypton gases are produced continuously by the fission process. Under normal operating conditions these gases are kept within the sealed tubes holding the fuel and would not get into the environment. Under accident conditions however, the radioactive gases would escape. If the flow of air within the structure which houses the reactor were to be channeled through columns containing silver or hydrogen zeolite, even in case of an accident, the radioactive xenon and krypton gas would be held back and prevented from entering the environment. Factors which could prevent using these molecular sieves in this application pertain to physical and/or chemical changes which might be brought about by the intense radiation field and which would adversely affect the adsorption characteristics. Research at NNRC for SRL establishing the physical and chemical changes induced by high radiation dose rates and total doses was recently completed.

Other activities of research similar to the zeolite project involved activated carbon, computer chips, printed circuits, optical fibers, and a host of electrical and mechanical objects used in the nuclear power industry. In fact NNRC has been testing and validating the reliability of nuclear power plant components for some time.

4. Food Preservation

Increased research involving food preservation with gamma radiation is inevitable. Increasingly it is found that chemical preservatives are carcinogenic and alternatives must be found. Radiation treatment might be the answer.

Recently the NNRC has been helping a group of scientists at the Tuskegee Institute. The Carver Research Foundation of Tuskegee Institute is engaged in research with NNRC to determine the effects of low doses of gamma radiation on sweet potato roots. The research is multi-faceted with a team of eight scientists investigating the effects of radiation on not only the food quality of the root but also on the sweet potato weevil and storage rot development in the roots following irradiation. The study involves the irradiation of roots of two cultivars (Jewel and Georgia Jet) at three separate times following harvest in early October. The times chosen (immediately following harvest, right after curing the sweet potato roots, and some time period into storage) correspond to times when the farmer would normally be moving the sweet potatoes.

Preliminary indications show that a dose of twenty kilorads (0.2kGy) of gamma radiation will sterilize the sweet potato weevil. Thus irradiation will provide an alternative to the use of methyl bromide as a fumigant in areas where sweet potato shipments are controlled by quarantine to prevent the spread of the weevil. At those low dose levels it appears that the food quality of the sweet potato roots will not be adversely affected and sprouting will be
prevented. However, the effects of gamma radiation on sweet potato food qualities at doses of 10, 20, 30 and 40 kilorads (0.1, 0.2, 0.3, and 0.4 kGy) continues. The food qualities being studied are appearance, color, texture, vitamins, carbohydrates (sugars and starch), proteins and enzymes. All results are compared to control sweet potatoes subject to the same conditions with the exception of radiation. The NNRC facility was chosen because it could handle large quantities of sweet potatoes at high dose rates so that conditions would be similar to those at commercial irradiators. Additionally the dose and dose rate measuring instruments are calibrated with traceability to the National Bureau of Standards.

The Tuskegee scientists involved in the study are: Dr. Margaret Tolbert, Biochemist and Director, Carver Research Foundation of Tuskegee Institute; Dr. Phil Loretan, Nuclear Engineer; Dr. Raj Saini, entomologist; Dr. O.O. Dopeolu, Parasitologist; Dr. John Lu, Food Scientist; Dr. Ron Chung, Food Scientist; Dr. Ralphenia Pace, Nutritionist and Dr. Conrad Bonsi, Plant Pathologist.

Cooperative research efforts along these lines with food scientists at the University of Georgia and/or Emory are being developed. Radiation research on Georgia agricultural products which need chemical preservatives would be valuable. This type of research is most suitable for Georgia Tech scientists in cooperation with food scientists. At Georgia Tech gas chromatography and mass spectrometry are well known tools used to determine molecular compounds. It is imperative that radiation effects on the food nutrients such as vitamins, carbohydrates, sugars, starches, protein and enzymes be quantified from the point of view of chemical chains breaking up and new chains linking together to form new compounds. It is the chemical difference between the control samples (unirradiated) and irradiated samples which must be studied and assessed for health effects.

The facilities for conducting such research are available. What is needed is interest and cooperation among scientists from different disciplines. It can be done under the leadership of NNRC personnel.

Other food preservation efforts involved Clemson University (tomatoes and peaches), University of Georgia (liquid eggs), Atlanta University (bean sprouts), Tuskegee (Vidalia onions).

5. Medical Applications

In addition to the study of the role of trace elements in healthy and cancerous tissues, cited above under Neutron Activation Analysis, NNRC has been engaged in boron neutron capture therapy since 1983. Boron neutron capture therapy (BNCT) is an alternate form of radiation therapy in which a \(^{10}\)B-enriched compound is injected into a patient with a brain tumor. The boron concentrates in the tumor but is excluded from the healthy brain by the blood brain barrier. The patient's head is then irradiated in a beam of epithermal neutrons, which when captured in the boron in the tumor, emitting a highly-energetic, yet short-ranged alpha particle and Li nucleus. A very large, localized dose is therefore delivered to the tumor, while the adjacent tissues receive only that dose from the transit of the neutrons.

Clinical trials of BNCT have recently been conducted in Japan with good results. However, the treatment is limited to superficial tumors due to the poor penetration of the thermal neutron beam. Now, a more deeply penetrating epithermal neutron beam has been developed at the Georgia Tech Research Reactor (GTRR).
The GTRR beam is constructed from aluminum and sulfur filters. The cross sections of these two elements are greater at fast, than at epithermal or thermal energies. The combination of the two in a reactor beam port transmits a neutron beam in which less than 4% of the flux is fast neutrons. The thermal neutrons are then absorbed by cadmium, leaving a highly epithermal neutron beam.

The dose from the photons and neutrons have been mapped in the beam along with their penetration in a polyethylene head phantom. The thermal flux generated from the incident epithermal neutrons peaks three centimeters into the phantom and remains above the incident flux to a depth of seven centimeters.

The Relative Biological Effectiveness (RBE) of the beam as a whole was also determined. Chromosome aberration production in the plant, Tradescantia paludosa served as the endpoint. An RBE of 1.2-1.5 was measured.

Animal trials were also conducted on tumor-bearing rats. Boron-10, as Na₂B₁₂H₁₁SH, was injected into the rats. A plasma exchange was then performed to lower the boron in the blood relative to the tumor at the time of irradiation. The rat's tumor-bearing foot was then inserted into a head phantom in the epithermal beam to simulate a deep-seated brain tumor and the rat irradiated.

Six rats were irradiated in the filtered beam—four without the boron, to test the effect of the 'background' radiation, and two with the entire BNCT treatment. No evidence of radiation effects other than a slight weight loss was found. Despite falling several hundred rads short of the minimum dose required for permanent regression, the tumor dose to the final rat was sufficient to stunt the growth two weeks and reduce the tumor volume by 27%.

In cooperation with Theragenics, a radiopharmaceutical company, NNRC is expanding the prototype beam into a clinical facility. Design and optimization studies are being conducted under the auspices of the National Science Foundation using the Cray Supercomputer at San Diego State University. Based on recommendations from the design study, an epithermal facility will be constructed at the GTRR for clinical testing of BNCT. In addition, several nuclear analytical techniques are being developed at the GTRR for quality assurance and assessment of the Boron-10 component in the therapy.

6. Training

NNRC is very active in training students at Georgia Tech in reactor laboratory and radiation detection. The reactor experiments involve the following: approach to criticality, checkouts and operating the GTRR, control rod calibration by various methods, flux mapping, material reactivity coefficients, temperature coefficient, power calibration, activation analysis, and cross section measurement using a single energy neutron from a neutron diffractometer. Radiation detection experiments involve scintillation detection, semiconductors, and gas-filled counters.

In addition to student training in nuclear science and engineering, NNRC sponsors short courses for training reactor operators for nuclear power plants. More than 200 trainees from Georgia Power and TVA have taken the short courses.

NNRC also sponsors a short course in health physics. The topics covered include the following: basic radiation technology; radiation safety officer duties; federal, state and local regulations; licenses; biological effects of ionizing radiation; portable instruments frequently used to detect and measure radiation; fixed laboratory instruments used to detect and measure radiation;
laboratory techniques to control radiation; radioactive material shipment; practical radiation safety practices; and hands-on control and actual startup of the 5 MW Georgia Tech Research Reactor.

7. High School Tours and Projects

More than 100 tours for high school students ranging in size from 10-30 students per tour are conducted by the Neely Nuclear Research Center staff per year. One institution, the Fernbank Science Center, an arm of the DeKalb County School Board, brings on a regular basis groups of bright ninth grade students to visit the center as part of its scientific tools and techniques program.

The Neely Nuclear Research Center also helps many high school students with science projects. One example is that of young Jenni Rausch. She studied the effects of Co radiation on Escherichia Coli, Micrococcus Luteus, and Rhodospirillum Rubrum bacteria. Miss Rausch received the first place award in the microbiology classification in Fulton County and third on a statewide competition involving more than 500 entries.

Tours at NNRC easily occupy one staff person at half time.

V. REQUIREMENT FOR NEW FUNDS

The Neely Nuclear Research Center is widely used to strengthen nuclear science instruction as well as research opportunities and application of nuclear analytical techniques. On a yearly basis, 15-25 universities use NNRC in their research. Some 35-50 faculty are involved. The number of college students who use NNRC is approximately 120. The number of high school students who tour NNRC is over 1000 yearly. High school students projects average about 5 yearly.

Involvement with high schools requires more than one-half man year per year. It would be most helpful if DOE would help defray this cost which is estimated to be $20,000 per year.

It is requested that this contract be extended through 1995. Total cost to DOE is 7 years x $20,000 per year or $140,000.

VI. PUBLICATION LIST

It is most unfortunate that no effort was made until recently to keep accurate records of publications generated at or by using the NNRC. What follows is a very partial list . . . very incomplete but it is all I can put together in short order.
Publications List


22. Dawes, M.A., R.S. Saini, M.A. Mullen, J.H. Brower, and P.A. Loretan (1986), "Sensitivity of Sweet Potato Weevil (Coleoptera: Curculionidae) to Gamma Radiation." Accepted for publication in Journal to Economic Entomology.


32. "Preparation of Reactor-Produced No-Carrier-Added $^{18}$F-Fluoride and Its Use in the Synthesis of Labeled Organic Compounds of Interest in Radiopharmaceuticals (tentative title), R.W. Fink, to be presented as a review paper at the Int. Conf. on Nuclear and Radiochemistry, Lindau, West Germany, October, 1984 (tentative, pending travel grant from Georgia Tech Foundation)


