Project Title: "Fabrication of a Radiofrequency Radiation Facility"

Project No: A-2650

Project Director: J. C. Toler

Sponsor: Southeastern Center for Electrical Engineering Education

Agreement Period: From 4/1/80 Until 9/30/80 (R&D Perf. Period)

Type Agreement: Subcontract No. SCEEE ARB#80-34
(under U.S. Air Force Prime Contract No. FF33615-78-D-0617)

Amount: $137,014 SCEEE
6,254 (Cost Sharing, Acct # E-222-506)
$143,268


Sponsor Contact Person(s):

Technical Matters
Dr. Woodrow W. Everett, Jr.
Management Office
Central Florida Facility
11th & Massachusetts Ave.
St. Cloud, FL 32769
(305) 894-6146

Contractual Matters
(thru OCA)

Defense Priority Rating: N/A

Assigned to: ET/BRG

(Copies TO:)
Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director-EES
Accounting Office
Procurement Office
Security Coordinator (OCA)

Library, Technical Reports Section
EES Information Office
EES Reports & Procedures
Project File (OCA)
Project Code (GTRI)
Other:  

(Copies TO: Library, Technical Reports Section)
SPONSORED PROJECT TERMINATION SHEET

Date 1/29/82

Project Title: "Fabrication of a Radiofrequency Radiation Facility

Project No: A-2650

Project Director: J. C. Toler

Sponsor: Southeastern Center for Electrical Engineering Education (SCEEE)

Effective Termination Date: 8/31/81

Clearance of Accounting Charges: 8/31/81

Grant/Contract Closeout Actions Remaining:

- [x] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [x] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

THIS TERMINATION IS FOR BOTH A-2650-000 and A-2650-001

Assigned to: ECSL/BRD (School/Laboratory)

COPIES TO:

Administrative Coordinator
Research Property Management
Accounting
Procurement/EES Supply Services

Research Security Services
-Reports Coordinator (OCA)
Legal Services (OCA)
Library

EES Public Relations (2)
Computer Input
Project File
Other

FORM OCA 10-781
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: R&D Status Report No. 4
Subcontract SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" for the Quarter April 1980 through June 1980, A-2650

Dear Sirs:

During the first quarter of research and development effort on the subject subcontract, the following tasks were accomplished:

- Cost estimates were obtained for transmitters with a variety of pulse performance capabilities.
- Design of the 12-foot diameter plates for the radiator was finalized, and cost estimates for plate construction were obtained.
- The Plexiglas cage design was reviewed with Dr. V. Popovic of Emory University, and no design changes were identified.

Expenditures during this quarter were $9,975.96, all of which were vouchered to ACO. It is estimated that $218,381 will be required to complete the project.

Respectfully Submitted,

J. C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: R&D Status Report No. 8

Dear Sirs:

During the second quarter of research and development effort on the subject subcontract, the following tasks were undertaken:

- Renovation was begun on the area (Room 19, Baker Building) to house the radiation facility.

- Additional cost estimates were obtained for transmitters with different pulse characteristics and higher output power levels.

- Fabrication of the 85 petals that will make up the ten plates of the radiator was begun.

- Cost estimates for construction of the Plexiglas cages were obtained and a contractor was selected (Custom Plastics, Inc. Atlanta, Ga.).

- A project status meeting was held at AFSAM/RFP and all phases of the project were reviewed in detail.

Cumulative expenditures through this second quarter were $56,637.14, of which $56,313.30 has been vouchered to ACO. It is estimated that $171,720 will be needed to complete the project.

Respectfully Submitted,

J. C. Toler
Project Director
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: R&D Status Report No. 12
Subcontract SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" for the Quarter October 1980 through December 1980.

Dear Sirs:

During the third quarter research and development effort on the subject subcontract, the following tasks were accomplished:

- Purchase orders were placed for many of the materials required for construction of the parallel plate radiator (aluminum sheet, nylon support rods, spring finger contacts, etc.).

- Evaluations of the Plexiglas cage design was begun by monitoring the body weight, colonic temperature, and postural preference of 10 rats in Plexiglas cages relative to 10 rats in conventional metal cages.

- Renovation of the area to house the radiation facility continued with major emphasis on wall construction, painting, and shielding.

- A final round of costs were obtained for transmitters, and these costs were conveyed to AFSA/RFP.

Cumulative expenditures through this quarter were $77,975.50, of which $67,698.28 was vouchered to ACO. It is estimated that $150,381 will be necessary to complete the project.

Respectfully Submitted,

J.C. Toler
Project Director

Approved:

F.L. Cain, Director
Electronics and Computer Systems Laboratory
AN EQUAL EMPLOYMENT/EDUCATION OPPORTUNITY INSTITUTION
Southeastern Center for Electrical Engineering Education, Inc.
1101 Massachusetts Avenue
St. Cloud, Florida 32769

Subject: R&D Status Report No. 13

Dear Sirs:

During the fourth quarter research and development effort on the subject subcontract, the following tasks were accomplished:

- A design review meeting for the 435-MHz transmitter was held with representatives of MICON, Inc. Several alternative designs were reviewed and a final design was selected. The primary basis for the selected design was operational reliability, with cost and maintenance being additional factors.

- Renovation of the area to house the RFR facility continued with the last major modification (rework of the air conditioning/ventilation system) being completed.

- Microwave absorbing material for the room to house control animals was received and installation was begun. After installation, the absorbing materials will be removed and packed back into shipping containers. This will allow the circular, parallel-plate antennas to be erected without damaging the absorbing material.

- A proposal defining a shakedown evaluation of the new RFR facility was prepared and submitted to SAM/RZP for review.

- On 24 February 1981, a program review meeting was held at SAM/RZP. During this review, all aspects of the program were discussed in detail, and no redirection of effort was identified.
Cumulative expenditures through this quarter were $233,795.70, of which $166,384.39 was vouched to ACO. It is estimated that $107,991 will be necessary to complete the program.

Respectfully submitted,

J. C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
March 24, 1981

Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: April Performance and Cost Report No. 1
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 April 1980 through 30 April 1980.

I. Performance Information

No technical efforts were undertaken during this reporting period.

II. Cost Information

Since no technical efforts were undertaken, there were no expenditures on the project during this reporting period.

Respectfully Submitted,

J. C. Toler,
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: May Performance and Cost Report No. 2
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 May 1980 through 31 May 1980.

I. Performance Information

Technical efforts on the project were initiated during this reporting period and involved design considerations for the parallel plate radiator, the Plexiglas cages, and the transmitter. Each of these designs were considered under the previous subcontract; consequently, efforts during this reporting period involved simultaneously reviewing the previous designs and formulating final designs.

Efforts to finalize the design for the 12-foot diameter plates were initiated by meeting with personnel in the EES Mechanical Design Branch. Persons in this Branch routinely work with large mechanical systems and are familiar with metals and metal vendors. As a result of the meeting, it was decided that each plate (a total of ten plates are required) would consist of eight petals, each with a six foot radius and a width corresponding to 45°. Lap joints on each edge of each petal will be milled to provide mating surfaces for adjoining plates. Eighty petals will be required to fabricate the ten plates, and 6061-T6 aluminum sheet metal with a 0.1875-inch thickness will be used. A drawing and design specifications for the petals were prepared, and will be used during the next reporting period to obtain cost estimates.

Another meeting was held with Dr. Popovic of the Emory University Department of physiology to review the Plexiglas cage design. Dr. Popovic expressed concern with the cage ventilation and size; however,
he acknowledged that the size complied with NIH requirements for housing rats. Ventilation concerns stem from the fact that Plexiglas will not conduct heat as well as metal; therefore, it might be possible for rats housed in Plexiglas cages to experience a heat burden not experienced by rats housed in metal cages. Lacking quantitative data, it was decided to proceed with efforts to estimate the costs involved in constructing 250 Plexiglas cages of the present design.

Several telephone contacts were made with Mr. Bob Sepulveda of MICON, Inc. to discuss transmitter design considerations. Questions regarding pulsed operation of the transmitter have not been resolved, and since this mode of operation influences the design significantly, it was not possible to finalize the transmitter design. Mr. Sepulveda discussed design features of a transmitter with the following capabilities:

- Average Power: 1,000 watts
- Peak Power: 30,000 watts
- Pulse Width: 50 microseconds
- Duty Factor: 0.01
- Amplifier Bandwidth: 30 MHz
- Amplifier Gain: 13 dB
- Frequency: 420–450 MHz

Further efforts to finalize the transmitter design will be initiated as soon as the pulse parameters are defined.

II. Cost Information

a. Costs incurred during the reporting period:

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
<td>$2932.52</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>152.66</td>
</tr>
<tr>
<td>Overhead</td>
<td>2228.72</td>
</tr>
<tr>
<td>Materials and Supplies</td>
<td>0.00</td>
</tr>
<tr>
<td>Equipment</td>
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<tr>
<td>Travel</td>
<td>0.00</td>
</tr>
<tr>
<td>Computer Time</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$5313.90</strong></td>
</tr>
</tbody>
</table>
May Performance and Cost Report No. 2  
March 24, 1981  
Page 3  

b. Cumulative costs through this reporting period:

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
<td>$2932.52</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>152.66</td>
</tr>
<tr>
<td>Overhead</td>
<td>2228.72</td>
</tr>
<tr>
<td>Materials and Supplies</td>
<td>0.00</td>
</tr>
<tr>
<td>Equipment</td>
<td>0.00</td>
</tr>
<tr>
<td>Travel</td>
<td>0.00</td>
</tr>
<tr>
<td>Computer Time</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$5313.90</strong></td>
</tr>
</tbody>
</table>

c. Amount vouchered to ACO: $5313.90  

d. Estimated funds necessary to complete project: $223,043  

Respectfully Submitted,  

J. C. Toler  
Project Director  

Approved:  

F. L. Cain, Director  
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: June Performance and Cost Report No. 3
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 June 1980 through 30 June 1980.

I. Performance Information

Technical efforts during this reporting period were a continuation of those begun during the last reporting period, and involved design considerations for the parallel plates, cages, and transmitter.

Cost estimates were received from two organizations for the 80 aluminum petals needed to construct the ten parallel plates. The Ainslee Corp., Braintree, MA bid $49,895 for 85 petals. Estimates from Ainslee Corporation were solicited because they have worked extensively with the Mechanical Design Branch on other metal fabrication projects; however, their estimate on this project was totally unacceptable. The Georgia Tech Main Machine Shop submitted the following bid for the same 85 petals:

- Personal Services - $10,560
- Materials (including special tooling) - $7,500
- Other costs to include hole drilling, swag bolts and nuts, and corner rounding.

Obviously, the project will be undertaken with the Georgia Tech Shop.

Detail drawings and specifications for the Plexiglas cages were completed and submitted to several local companies to obtain cost estimates for cage construction. One company in particular (Custom Plastics, Inc.) has shown considerable interest in the work and has called several times to obtain additional information about the design.
In response to a call from Mr. William Hurt, AFSAM/RZP, MICON, Inc. and three other transmitter manufacturers were requested to provide cost information on a 420–450 MHz transmitter capable of generating a 10 microsecond pulse with a 0.001 duty factor. The output power of this transmitter must provide a 10 mW/cm² exposure field in the parallel-plate RFR facility. No cost estimates for this transmitter have been received, but indications are that the cost will be extremely high.

After a series of internal meetings, it appears that floor space for the facility has been defined. This space consists of 1800 square feet of laboratory/office area currently being used for laser-based research in atmospheric sciences. This research will be relocated in other campus areas. Rennovation of the space to make it suitable for an RFR facility will be rather extensive, and there isn’t enough room for the two stacks of parallel plates plus a transmitter area, assay area, cage wash area, storage area, and computer area. This lack of sufficient space is being investigated and other areas that might be made available are being identified.

II. Cost Information

a. Costs incurred during the reporting period:

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
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<td>Personal Services</td>
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<td>Materials and Supplies</td>
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<tr>
<td>Equipment</td>
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<td>Travel</td>
<td>0.00</td>
</tr>
<tr>
<td>Computer Time</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$4,662.06</td>
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</table>

b. Cummulative costs through this reporting period:

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<th>Item</th>
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<td>Personal Services</td>
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<td>Overhead</td>
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<td>Material and Supplies</td>
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<tr>
<td>Equipment</td>
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<td>0.00</td>
</tr>
<tr>
<td>Computer Time</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$9,975.96</td>
</tr>
</tbody>
</table>

c. Amount vouchered to ACO:  $9,975.96
d. Estimated funds necessary to complete project: $218,381

Respectfully submitted

James C. Toler
Project Director

 Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: July Performance and Cost Report No. 5
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 July 1980 through 31 July 1980.

I. Performance Information

The major efforts during this reporting period were concerned with renovation of the area where the facility will be located and fabrication of the 85 petals for the parallel plates.

Most of the laser equipment in the facility area (Room 19 of the Baker Building) was disconnected from air, coolant, and electrical supplies, and is awaiting relocation in other laboratory areas. Relocation to these other areas is being detained until renovation is completed in these areas. In the meantime, the laser equipment was moved to the center of the floor space, and initial efforts with wall, electrical, ventilation, etc. layout were begun. The wall structure will involve standard 2' x 4' studs covered with sheetrock. Sheetrock on the interior walls of the radiation area will have aluminum backing that will help reduce stray radiation. Aluminum seams at each joint will have to be connected in an electrically-conductive manner. Consideration is also being given to cost-effective techniques for accomplishing shielding in the area ceiling.

Efforts to fabricate the 85 petals for the ten plates are proceeding well, and a source for 12' x 6' sheets of 6061-T6 aluminum with a 0.1875-inch thickness has been located. Also, an out-of-town firm with a laser cutting machine has been located and will be used to cut the six-foot radius on each of the petals. This should result in a considerably smoother cut, and therefore less expense in the petal fabrication effort.

An additional 8' x 8' area adjoining the radiation facility was identified as possible floor space for the computer area. This area is
now part of a lounge and a structural modification to the building will have to be made if it is to become part of the RFR facility. The possibility of using this area is being investigated with on-campus personnel responsible for space allocations.

Transmitter cost estimates were obtained from two of the four transmitter manufacturers and, as expected, they were very high (approximately $1,000,000). No delivery dates were provided and the estimates were far from complete; therefore, efforts to secure firm transmitter bids are still underway. It appears that part of the difficulty in obtaining firm bids is a feeling on the part of the manufacturers that there is no serious intent to purchase a transmitter with the specified characteristics.

II. Cost Information

a. Costs incurred during the reporting period:

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
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<tbody>
<tr>
<td>Personal Services</td>
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<td>Fringe Benefits</td>
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<td>Overhead</td>
<td>7,754.20</td>
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<td>Materials and Supplies</td>
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<tr>
<td>Equipment</td>
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<td>Computer Time</td>
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<td><strong>TOTAL</strong></td>
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b. Cumulative costs through this reporting period:

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<thead>
<tr>
<th>Category</th>
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<tbody>
<tr>
<td>Personal Services</td>
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<td>Materials and Supplies</td>
<td>27.53</td>
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<tr>
<td>Equipment</td>
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<td>Travel</td>
<td>0.00</td>
</tr>
<tr>
<td>Computer Time</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$29,483.29</strong></td>
</tr>
</tbody>
</table>

c. Amount vouchered to ACO: $29,483.29
d. Estimated funds necessary to complete project: $198,873

Respectfully Submitted,

J. C. Toler,
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical  
Engineering Education, Inc.  
FTU South Orlando Resident Office  
7300 Lake Ellenor Drive  
Orlando, Florida 32809  

Subject: August Performance and Cost Report No. 6  
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650  

Dear Sirs:  

Performance and cost information for the subject subcontract are presented below for the period 1 August 1980 through 31 August 1980.  

I. Performance Information  

Cost estimates obtained from various local firms for the Plexiglas cages were reviewed, and the bid from Custom Plastics, Inc. was accepted. In this bill, Custom Plastics will provide all Plexiglas pre-cut to the required dimensions. This Plexiglas will be received in-house where the cages will be assembled using student assistants. The cost-per-cage for the Custom Plastics efforts will be $19.25, and there will be the opportunity to have a small number of cages assembled for evaluation before all materials are cut.

Stud walls in the facility were erected and installation of the sheet rock was begun. Also, modification of the lighting and electrical service to the facility was initiated. During the next reporting period, construction of all walls should be completed, wall painting should be underway, and modification of the lighting and electrical services should be completed. No efforts have begun yet on modification of the ventilation system in the facility area.

II. Cost Information  

a. Cost incurred during the reporting period:  

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
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<tr>
<td>Fringe Benefits</td>
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<td>Overhead</td>
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<tr>
<td>Materials and Supplies</td>
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<td>Equipment</td>
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<td>Travel</td>
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<td>Computer Time</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$13,115.30</strong></td>
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</table>
b. Cumulative costs through this reporting period:

<table>
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<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
<td>$23,087.15</td>
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<tr>
<td>Fringe Benefits</td>
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<td>Overhead</td>
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<td>Materials and Supplies</td>
<td>69.18</td>
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<td>Equipment</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$42,598.59</strong></td>
</tr>
</tbody>
</table>

c. Amount vouchered to ACO: $42,598.59

d. Estimated funds necessary to complete project: $185,758

Respectfully Submitted,

J. C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: September Performance and Cost Report No. 7
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-
frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 September 1980 through 30 September 1980.

I. Performance Information

The design for the circular, parallel-plate radiation facility will involve five plates (four sets of plates), each of which is constructed of eight petal-shaped sheets of 6061-T6 aluminum with a thickness of 0.1875 inches. The eight sheets for each plate will be joined together with flush-mounted swag bolts. A 18-inch separation between plates will be maintained by PVC rods with 1.5-inch diameters. These rods will be black in color and will be male on one end, female on the other end. An aluminum support stand to serve as a base for the plates has also been designed.

A limited study to assure that rats will adapt well to the Plexiglas cages is necessary before constructing 250 cages. During this reporting period, this study was defined as follows: (1) 20 rats will be housed, 10 in Plexiglas cages and 10 in standard metal cages, (2) all cages will be maintained in the same room (temperature, humidity, audible noise, light-dark sequence, etc.), (3) daily measurements will be made to determine body temperature and weight, and (4) daily observations will be made to determine relative postural preferences, eating/drinking habits, etc. All rats will be obtained from the Emory breeding colony and will weight approximately 100 grams when the study is initiated. The body temperature and weight will be compared with typical temperature and weight profiles compiled on thousands of rats by Emory. Hopefully, rats used in this limited study will have body temperatures and weights comparable to the control rats, and will exhibit no unusual behavioral habits.
Preparations of the room to house the circular, parallel-plate facility continued during this reporting period. Photographs showing the construction status are attached and room locations are referenced as follows to the attached floor plan:

Photograph A  Room Location 19C
Photograph B  Room Location 19A
Photograph C  Room Location 19D
Photograph D  Room Location 19H

Authority to modify the building was received, and the computer room (Room Location 19E) construction can now begin. This will involve removing the wall common to Rooms 19E and 19H plus adding the back wall in Room 19E.

A project review meeting was held on September 18, 1980 in San Antonio, Texas with Mr. William Hurt and Mr. John Mitchell. The following areas were discussed during this meeting:

1. Status of the room clearing/construction,
2. Status of plate construction,
3. Status of cage design/construction, and
4. Status of transmitter design.

In the discussion of transmitter design status, it was requested that technical and cost information be obtained for three additional configurations as follows:

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Average Power Density</th>
<th>Duty Factor</th>
<th>Pulse Width</th>
<th>Average Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>10 mW/cm²</td>
<td>CW</td>
<td>-</td>
<td>700W</td>
</tr>
<tr>
<td>II</td>
<td>10 mW/cm²</td>
<td>0.1%</td>
<td>1 msec</td>
<td>700W</td>
</tr>
<tr>
<td>III</td>
<td>10 mW/cm²</td>
<td>5%</td>
<td>1 msec</td>
<td>700W</td>
</tr>
</tbody>
</table>

Manufacturers have been contacted and quotes have been requested for these three transmitter configurations.

II. Cost Information

a. Cost incurred during the reporting period were as follows:

<table>
<thead>
<tr>
<th>Personal Services</th>
<th>$7,224.49</th>
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</thead>
<tbody>
<tr>
<td>Fringe Benefits</td>
<td>758.06</td>
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<tr>
<td>Overhead</td>
<td>5,273.88</td>
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<tr>
<td>Materials &amp; Supplies</td>
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<td>Equipment</td>
<td>0.00</td>
</tr>
<tr>
<td>Travel</td>
<td>580.00</td>
</tr>
<tr>
<td>Computer Time</td>
<td>0.00</td>
</tr>
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</table>

TOTAL  $14,038.55
b. Cumulative costs through this reporting period:

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
</tr>
</thead>
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<tr>
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<td>Fringe Benefits</td>
<td>3,186.24</td>
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<td>Overhead</td>
<td>22,287.96</td>
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<td>Material &amp; Supplies</td>
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<tr>
<td>Travel</td>
<td>580.00</td>
</tr>
<tr>
<td>Computer Time</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$56,637.14</strong></td>
</tr>
</tbody>
</table>

c. Amount vouchered to ACO: $56,313.30

d. Estimated funds necessary to complete project: $171,719.86

Respectfully submitted,

James C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
is at 3 Sept. We are now rewiring lights, chisels, etc. but air conditioning people still have not shown. Also still waiting final OK on making hole in the wall for door into Dm. 19E.

To William on 22 Sept.

Room 19
BAKER BLDG

1/8" = 1'
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: October Performance and Cost Report No. 9
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 October 1980 through 31 October 1980.

I. Performance Information

The major technical efforts during this reporting period involved ordering materials for the facility, conducting evaluations to determine adaptability of the rats to the Plexiglas cages, completing more construction on the rooms to house the radiation facility, and obtaining additional cost estimates from transmitter manufacturers.

Purchase orders were placed for the following materials after contacting prospective vendors by telephone:

- 1 microwave absorber kit
- 22 pieces of 0.19" x 60" x 144" 6061-T6 aluminum sheet
- 10 prototype Plexiglas rat cages
- 1 triple-beam balance with animal cage
- 25 feet of 0.375" diameter threaded nylon rod
- 300 feet of 1.5" diameter PVC rod

Cost bids from three vendors will be received for each of the material items above, and decisions will then be made regarding the bids to be
accepted. Based on telephone conversations with prospective vendors, cost bids are expected to be within the original budget estimates.

Evaluations to determine adaptability of rats to the Plexiglas cages were begun. Ten Plexiglas cages were constructed using materials provided by Custom Plastics, Inc. (It is currently planned that this company will be contracted to cut the Plexiglas for all cages.) Prototype jigs were assembled and used to maintain individual pieces of Plexiglas in position while glue was applied. The design of these jigs will be upgraded and final jigs will then be built for use in constructing the remaining cages. Twenty rats weighing approximately 100 grams each and 10 standard metal cages were obtained from Dr. Vojin Popovic in the Emory University Department of Physiology. The 20 rats were housed one-to-a-cage in the 10 Plexiglas and 10 metal cages, and daily evaluations consisting of the following were begun:

- Measure body temperature,
- Measure body weight, and
- Observe postural preferences.

All 20 rats were housed in the same room so temperature, humidity, audible noise, light/dark sequences, etc. were the same for all animals. During the next reporting period, the 20-day evaluation will be completed and the data will be prepared for analysis. If the Plexiglas cage design is adequate, body temperature and weight will be the same for rats housed in the two different cage types.

More construction on the rooms to house the radiation facility was completed during this reporting period. The cinder-block wall common to Rooms 19E and 19H was removed and a conventional stud wall with a door opening was erected. Also, a conventional stud wall was erected at the back of Room 19H, thereby enclosing an area that will be used as the computer room. Sheet rock was mounted to the outside walls of Rooms 19A and 19B, and the conventional 2' x 2' acoustic ceiling panels in these rooms were replaced with aluminum-backed panels. The replacement panels will provide additional shielding in the rooms, and prevent excessive levels of stray radiation in offices located on floors above the facility.
After considerable delay, cost estimates were obtained from manufacturers for the three transmitter configurations identified in the last monthly report. Realistic estimates were received from Cober, Microwave Cavity Labs, and Micon. Of these, the Micon estimate appears most acceptable, but this decision will be made during a program review meeting to be scheduled for next month. All cost estimates were conveyed via telephone to the program monitor.

II. Cost Information

a. Costs incurred during the reporting period were as follows:

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
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<td>Fringe Benefits</td>
<td>631.19</td>
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<td>Overhead</td>
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<tr>
<td>Materials &amp; Supplies</td>
<td>10,415.93</td>
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<td>Equipment</td>
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<td>Travel</td>
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<td>Computer Time</td>
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<td><strong>TOTAL</strong></td>
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b. Cumulative costs through this reporting period:

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<td>Materials &amp; Supplies</td>
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<td>Equipment</td>
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<td>Travel</td>
<td>549.56</td>
</tr>
<tr>
<td>Computer Time</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$77,975.90</strong></td>
</tr>
</tbody>
</table>

c. Amount vouchered to ACO: $67,698.28

d. Estimated funds necessary to complete project: $150,381

Respectfully Submitted,

J. C. Toler
Project Director

Approval:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: November Performance and Cost Report No. 10
Subcontract No. SCREE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 November 1980 through 30 November 1980.

I. Performance Information

The major technical efforts during this reporting period involved completion of evaluations to determine adaptability of the rats to the Plexiglas cages, continued modification of the rooms to house the exposure facility, continued ordering of materials for facility construction, hosting a project status review meeting, and initial identification of biological endpoints to be monitored during subsequent radiation exposure.

Evaluation of the Plexiglas cages involved housing ten rats in individual cages while monitoring body weight, rectal temperature, and postural preferences as a function of time. Ten control rats were housed in ten conventional metal cages in the same room with the Plexiglas cages. The twenty rats were obtained from the Emory breeding colony (Dr. Popovic) at a weight of approximately 110 grams. Body weight, rectal temperature, and postural preference data for the 20 rats were obtained daily, excluding Saturday and Sunday. Postural preference data involved visual observations to determine the position of the rats relative to cage length and width.

Results of the body weight and temperature evaluations are shown in Figures 1 and 2. It is noted that the weight data indicates that rats housed in the Plexiglas cages weighed less than the controls during most of the first 20 days of the evaluation. This was attributed to difficulties with the water bottle, which differed between the Plexiglas and metal cages. The initial water bottles in the Plexiglas cages had a design flaw in that, under some conditions, they would drain their contents into the waste tray of the cage. This occurred in several of the cages.
during the first weekend of the evaluation (8-9 November), with the result that rats in the Plexiglas cages lost weight. These bottles were immediately replaced with other bottles on hand, and the weight data for the two groups of rats began to converge. However, the replacement bottles were quite large relative to the holder provided for water bottles on the Plexiglas cages. Smaller bottles with an improved sipper tube design were exchanged for the larger bottles of 21 November, and proved to be too small to contain enough water for the entire weekend. Again, rats in the Plexiglas cage lost weight relative to the controls. On 24 November, the large water bottles were again placed in service, and weight curves for the two groups became parallel.

Temperature data for the two groups of rats (Figure 2) showed identicalness within approximately 0.5°C throughout the evaluation period. Prior to compilation of these data, there was concern that the Plexiglas cages might be ventilated to the extent that body temperature would be lower relative to rats in conventional metal cages.

Postural preferences were much more difficult to judge than body weight and temperature, and the results are cause for some concern. In early November, the rats were small and tended to lay across the cage narrow dimension as often as along the cage long dimension. As they grew, there was a greater tendency to lay along the cage long dimension, but it was not uncommon for several of the rats to be curled up at one end of the cage during any given observation period. It is important for the rats to position themselves along the cage long dimension in order to be aligned with the horizontally polarized exposure field.

Modification of the area to house the radiation facility continued, but the major modification -- rework of the air conditioning/ventilation system -- is not progressing well. The air conditioning/ventilation system modification involves extensive work with approvals for changes in building design. It is noted that the necessity for this modification is not certain since the facility is on a separate air conditioning/ventilation system and has its own exhaust to outside air. However, relocation of vents and ducts will help to assure an even distribution of air in the facility, and this will contribute to uniformity in temperature and humidity. All acoustic ceiling panels have now been replaced with aluminum-backed panels to assure that rooms for control and experimental animals are identical. Previously, aluminum-backed panels were installed only in the room for experimental animals.

Additional materials needed for the facility were ordered, with the result that all major materials are either on hand or on order. A rather major difficulty has arisen with the order for sheet aluminum to be used in construction of the circular, parallel plates. The Machine Shop
should have ordered 12' x 6' aluminum sheets from which four of the plate petals could be cut. Instead, 12' x 5' sheets were ordered, and these sheets were cut in half upon receipt to ease the storage problem. When it was learned that sheets of the wrong size had been ordered, the supplier was contacted regarding a material return; however, return of the material was not possible because the sheets had been cut in half. Only one plate petal can be cut from each of the 6' x 5' sheets, so twice as much aluminum sheet will now be necessary to fabricate the required 88 petals. At this time, the additional cost is estimated at $6000, but efforts will be made to sell the scrape metal to reduce this cost.

On 20 November 1980, a project status review meeting was held at Georgia Tech. Attending this meeting were J. Toler, J. Schaefer, D. Freedman, and B. Jenkins of Georgia Tech and W. Hurt of AFSAM. All financial and technical aspects of the project were reviewed, and no redirection was defined. This meeting included discussions with Dr. V. Popovic regarding biological endpoints that might be monitored during subsequent bioeffects studies. These endpoints included body weight, arterial blood pressure, heart rate, blood volume, hematocrit ratio, differential count, and total blood count. The endpoints can be monitored as a function of resting versus exercise states, and with/without norepinephrine administration. Mr. Hurt suggested that thought be given to a facility "shakedown" to begin at the conclusion of the present program. Such a "shakedown" could be limited to 50 rats (25 radiates and 25 controls) and could be conducted during the last three months of the government's fiscal year (July-September 1981). Since funding for the "shakedown" must begin at least three months prior to the radiation (to allow for obtaining cannulation of the rats, training of medical personnel, etc.), technical and funding aspects of the proposed effort need to be submitted to AFSAM as soon as possible. Work on preparation of this proposal effort is underway.

II. Cost Information

a. Costs incurred during the reporting period:

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
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<td>Materials &amp; Supplies</td>
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<td>Equipment</td>
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<td>Travel</td>
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<tr>
<td>Computer Time</td>
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<td><strong>TOTAL</strong></td>
<td><strong>$8,400.83</strong></td>
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b. Cumulative costs through this reporting period:

<table>
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<th>Category</th>
<th>Cost</th>
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</thead>
<tbody>
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<td>Personal Services</td>
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<td>Fringe Benefits</td>
<td>4,107.14</td>
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<td>Overhead</td>
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<td>Materials &amp; Supplies</td>
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<td>Equipment</td>
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<td>Computer Time</td>
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<td><strong>Total</strong></td>
<td><strong>$86,376.73</strong></td>
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</table>

c. Amount vouchered to ACO: $78,458.51

d. Estimated funds necessary to complete project: $141,980

Respectfully submitted,

James C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Temperature (°C)

Rats in plastic cages
Rats in metal cages

Date of Measurement (November, 1980)
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: December Performance and Cost Report No. 11
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 December 1980 through 31 December 1981.

I. Performance Information

The major technical efforts during this reporting period involved conducting additional evaluations of the Plexiglas rat cages, modifying the design of the Plexiglas cages, continuing efforts to modify the air conditioning/ventilation system in the exposure facility, planning for the facility "shakedown", and finalizing the transmitter design.

During the last reporting period, evaluations were conducted to determine whether the body temperature, body weight, and postural preferences of rats housed in Plexiglas cages would differ from rats housed in conventional cages. Ten Plexiglas cages of the design planned for this program were fabricated and ten metal cages plus 20 young rats were obtained from Emory University. All cages and animals were located in the Baker Building Animal Housing Facility. Data were obtained daily (except Saturday and Sunday) during November. These data indicated that body temperature of animals in the two different cage types were essentially the same; however, problems with water bottles biased the body weight data and there were questions regarding postural preferences of rats in the Plexiglas cages. During this reporting period, additional body weight data were obtained and a design change was defined for the Plexiglas cage floor. The body weight data are shown in Figure 1, and indicate that weights of animals in the two cage types were essentially identical. The evaluations were terminated in mid-December because animals were not maintained in the housing facility over the holidays.
As noted in the last report, postural preference of rats in the Plexiglas cages were such that they tended to curl up at one of the two cage ends. This meant that their long dimension was not parallel to the cage long dimension, and will therefore not be parallel to the electric field vector during radiation exposure. In an effort to encourage the rats to align themselves along the cage long dimension, rods that make up the cage floor are being rearranged in a few trial cages. The rearrangement involves making the middle of the cage floor lower than either of the edges, with the hope that laying across the uneven floor will be uncomfortable enough that the rats will align themselves in the desired direction.

Changes in the air conditioning/ventilation system for the exposure facility have still not been made; however, a meeting was held with facility design personnel and the exact changes that have to be made were defined. Fortunately, modifications to the system are not as extensive as initially thought. No firm date has been provided by which these modifications will be completed, but facility personnel are aware that erection of the parallel plate structure will begin the last of February.

Meetings were held with Dr. Popovic to define a realistic biological effort for the facility "shakedown" scheduled to begin in July 1981. Decisions regarding biological endpoints to be monitored were made after discussing with Dr. J. Krupp, AFSAM, the endpoints being monitored by the University of Washington. This discussion was held with the thought that it would be desirable to monitor comparable endpoints, and then compare results obtained at the two different frequencies (435 and 2450 MHz). Following this discussion, it was decided to monitor body weight, arterial blood pressure, blood volume, heart rate, total white blood cell count, differential count, and hematocrit ratio in 50 cannulated rats (25 irradiates and 25 controls). Arterial blood pressure and heart rate will be monitored both before and after norepinephrine administration. Procedures for accomplishing this monitoring, a schedule for endpoint monitoring, and a budget were transmitted to AFSAM (W. Hurt) just prior to Christmas.

Several additional design features for the 435 MHz transmitter were identified during this reporting period. For example, connectors at the four output ports will be Type HN, and can therefore handle 1 kW CW and 100 kW peak. These four outputs will be available in a recessed opening
in the cabinet top. One cabinet 19" wide x 26" deep x 60" high should house all components of the transmitter. A tentative layout of the front panels for the transmitter was sketched to show the relative location of the power supply, oscillator, modulator, preamplifier, final amplifiers, and control/monitoring panels. System safety features will be such that the transmitter is shut down if VSWR exceeds a preset level, the output power drops below a preset level, the back door on the cabinet is opened, a front panel chassis is pulled out, etc. Meters indicating forward and reflected power levels will be mounted on front panels and will be most helpful when tuning the amplifiers, repairing the transmitter, assuring that each set of plates is radiating properly, etc. These design features, plus others that are now defined, will have to be reviewed with the transmitter manufacturer to assure that they can be accommodated within the available budget.

II. Cost Information

a. Costs incurred during the reporting period:

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
<td>$4,602.62</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>500.45</td>
</tr>
<tr>
<td>Overhead</td>
<td>3,359.91</td>
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<tr>
<td>Materials &amp; Supplies</td>
<td>20,300.21</td>
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<tr>
<td>Equipment</td>
<td>0.00</td>
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<tr>
<td>Travel</td>
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</tr>
<tr>
<td>Computer Time</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
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</tbody>
</table>

b. Cumulative costs through this reporting period:

<table>
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<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
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<td>4,607.59</td>
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<td>32,087.50</td>
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<td>Materials &amp; Supplies</td>
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<td>Equipment</td>
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<tr>
<td>Computer Time</td>
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</tr>
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<td><strong>$115,139.92</strong></td>
</tr>
</tbody>
</table>

c. Amount vouchered to ACO: $ 88,390.52
d. Estimated funds necessary to complete project: $113,217

Respectfully submitted,

J. C. Toler,
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
FTU South Orlando Resident Office
7300 Lake Ellenor Drive
Orlando, Florida 32809

Subject: January Performance and Cost Report No. 13
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility" A-2650

Dear Sirs:

Performance and cost information for the subject subcontract are presented below for the period 1 January 1981 through 31 January 1981.

I. Performance Information

The major technical efforts during this reporting period involved the primary transmitter design review and additional efforts toward finishing the rooms to house the radiation facility.

On 26 January, 1981, a meeting was held at Georgia Tech with Mr. Bob Sepulveda and Mr. George Greentahl of MICON, Inc. to review all design aspects of the 435-MHz transmitter. Several alternate transmitter designs were presented by Mr. Sepulveda, and each was analyzed in terms of cost, reliability, maintenance, etc. After considerable review, the design shown in Figure 1 was selected in preference to the initial design shown in Figure 2. The primary basis for this selection was the significantly increased reliability that resulted from splitting the power amplifier into two units. Each of these units will use an Eimac Type 8938 tube that will be operated at 12 kW peak and 500 W average; however, the tube is capable of dissipating 1500 W average and is identified as a 1 kW average tube with a lifetime of 1000 hours. Use of two tubes, each operating at half power, should substantially improve reliability and reduce the possibility of tube failure during chronic RFR exposures. No firm data are available on average tube lifetime under these conditions, but it is expected that the lifetime will be approximately doubled.

The transmitter system will include (1) all cooling (a closed-loop, liquid coolant system), (2) VSWR monitor, (3) external sync capability for pulse operation, (4) front panel meters for power monitoring, (6)
power level monitor, (7) safety interlocks on the cabinet door, and (8) documentation in the form of a manual presenting information on operation, maintenance, troubleshooting, etc. plus block diagrams and schematics. The system will be housed in a single cabinet 60 inches high and 19 inches wide. Power requirements are 208 volts, 3 phase, 30 amps/phase. The back of the cabinet will have protected terminal strips with the following contacts:

- Normally open contacts that monitor VSWR and
- Normally open contacts that monitor power level.

Four Type HN connectors (rated at 1 kWa and 100 kWp) located in a recessed area on the cabinet top will provide the power outputs for the antennas in the radiation facility. The total transmitter system will dissipate approximately 6 kW of heat and must be operated in area with an ambient temperature below 80°F. In its pulsed mode of operation, the transmitter will provide a continuously variable pulse width of 0.25- to-10 microseconds and a duty factor of 0.05. This range of pulse widths will allow extended life of the amplifier tubes. It is noted that pulse widths up to approximately 20 microseconds can be accommodated, but with substantially reduced tube life.

The last major renovation effort needed for the RFR facility has been modification of the air conditioning system to provide adequate ventilation and aid in odor control. The efforts have lagged for the past few months because they involve modification of a rather complex air conditioning system; however, initiation efforts in this area were begun during this reporting period. These efforts involve (1) separating certain large air ducts and (2) installing two blowers as necessary to convert the existing air intake to an air exhaust. This work is being done above false ceilings in the rooms that will house the control and radiation animals. Additional renovation of the air conditioning system will continue during the next reporting period.

II. Cost Information

a. Costs incurred during the reporting period:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
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<tr>
<td>Personal Services</td>
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<td>Computer Time</td>
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<tr>
<td><strong>TOTAL</strong></td>
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b. Cummulative costs through this reporting period:

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</tr>
</tbody>
</table>

c. Amount vouchered to ACO: $100,704.87

d. Estimated funds necessary to complete project: $101,586

Respectfully Submitted,

J. C. Toler,
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Figure 1. Initial Transmitter System Configuration.

- Oscillator, Modulator and Pre-amp
- Amplifier and Isolator
- Power Amplifier
- Four-Way Power Splitter

- Isolator
- Isolator
- Isolator
- Isolator
Figure 2. Final Transmitter System Configuration.
Southeastern Center for Electrical  
  Engineering Education, Inc.  
  FTU South Orlando Resident Office  
  7300 Lake Ellenor Drive  
  Orlando, Florida  32809  

Subject: February Performance and Cost Report No.14  
  Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-  
  frequency Radiation Facility" A-2650  

Dear Sirs:  

Performance and cost information for the subject subcontract are  
presented below for the period 1 February 1981 through 28 February 1981.  

I. Performance Information  

The major technical efforts during this reporting period were con-  
cerned with completing rework of the facility air conditioning system,  
installing microwave absorber, preparing information describing technical  
and biological tasks for the facility "shakedown" evaluation, and  
participating in a project status review.  

All major rework of the facility air conditioning has been completed  
and the facility has been cleared for installation of the microwave  
absorber material. The rework during this reporting period involved re-  
ducing two large air ducts to six smaller ducts and routing them to areas  
in the facility where heat and/or odor control are potential problems.  
Now there are ducts in the control animal room, radiated animal room,  
transmitter room, and cage wash/dry room. Further work yet to be done  
involves installation of thermostats and verification checks to assure  
that the existing thermostats function properly.  

Microwave absorber for one of the two animal rooms was received, and  
installation in the control room was begun. This installation involved  
attaching strips of Velcro hook material to the four walls of the room and  
Velcro eye material to the absorber. Installation using this procedure  
will permit the absorber to be removed, as necessary, from the walls with-  
out being torn up. Each 2' x 2' piece of absorber was individually fitted  
to the Velcro material at a specific wall location, and both absorber and
wall were marked. This procedure was used because earlier experience has shown that irregularities in absorber size will otherwise make installation using Velcro unreliable. An unreliable installation of absorber can not be tolerated because, if a piece of absorber falls from the wall, it may hit animal cages and thereby interfere with experimental results. After being fitted to the wall, each piece of absorber will be returned to its shipping container while the parallel plates are erected. This will prevent the absorber from being damaged during construction of the plate waveguides.

An experimental design for a "shakedown" evaluation of the new RFR facility was prepared and submitted in proposal format to AFSAM/RFP. In this proposal, 25 rats will be exposed to a 10 mW/cm² pulsed-wave field obtained by coupling the total transmitter output power into one set of parallel plates. Twenty-five rats will also be maintained as controls. All 50 rats will be cannulated by Dr. Popovic of Emory University, and the cannula will provide access to five key blood parameters. These parameters plus body weight and colonic temperature will be monitored for (1) one month pre-radiation to establish baseline data, (2) four months during radiation to determine whether biological effects exist, and (3) one month post-radiation to assure that all values return to baseline levels. The five blood parameters are arterial blood pressure, circulating blood volume, heart rate, hematocrit ratio, and total white blood cell count.

On 24 February 1981, a project review meeting was held at AFSAM/RZP. Attending the meeting were Messers. John Mitchell and William Hurt from AFSAM/RZP and Messers. Jim Toler, Fred Cain, and Joe Schaefer from Georgia Tech. All areas of the project were reviewed and no redirection was provided.

II. Cost Information

a. Costs incurred during the reporting period:

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<th>Item</th>
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<td>Travel</td>
<td>1640.00</td>
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<tr>
<td>Computer Time</td>
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</tr>
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February Performance and Cost Report No. 14
March 24, 1981
Page 3

b. Cumulative costs through this reporting period:

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<th>Description</th>
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<td>0.00</td>
</tr>
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<td><strong>TOTAL</strong></td>
<td><strong>$138,753.06</strong></td>
</tr>
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c. Amount vouchered to ACO: $112,254.39

d. Estimated funds necessary to complete project: $89,604

Respectfully Submitted

J. C. Toler  
Project Director

Approved:

F. L. Cain, Director  
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
1101 Massachusetts Avenue
St. Cloud, Florida 32769

Subject: March Performance and Cost Report No. 15
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-
frequency Radiation Facility," Georgia Tech Project No. A-2650

Gentlemen:

Performance and cost information for the subject subcontract are presented below for the period 1 March 1981 through 31 March 1981.

I. Performance Information

The major technical efforts during this reporting period were concerned with continued installation of microwave absorbing material on interior walls of the rooms that will house control and irradiate animals, meetings with manufacturers of cage washers, finalizing the delivery schedule for items still not received, and initiating the contract for cages to be used for housing rats during bioeffects experiments.

The second and final kit of microwave absorbing material was received from Advanced Absorber, Inc. and installation of this material was begun in the room that will house the radiated rats. Installation of absorbing material in the control room was begun during the last reporting period and is now essentially complete. The installation procedures in the radiation room will parallel those used in the control room, and involve attaching Velcro hook material to the four walls of the radiation room. Concurrently, Velcro eye material is attached to the back of each 2' x 2' piece of absorbing material. When the attachment of hook and eye material is complete, individual pieces of absorbing material will be fitted onto the walls, and each location will be marked prior to removing the absorbing material and storing it in shipping boxes. Removal and storage is necessary to permit erection of the parallel plates without damage to the absorbing material.
To date, meetings with representatives of seven different manufacturers of cage washers have been held. In each meeting, our cage washing/drying requirements were presented, and the representatives were asked to discuss specifications of the unit(s) they consider to be best suited for our needs. The seven representatives were from CRS Systems, CESCO, Metalwash Machinery, Heinicke, Better-Built Machinery, Girton Manufacturing, and Fisher/Jet Clean. (Two other companies suggested by Dr. J. Krupp, SAM/RZP, were contacted, but both companies responded by saying that they did not offer a product line that included cage washers/dryers.) Quality and size varied widely from one manufacturer to the other as is evident in the fact that costs range from $8,875 to $16,150. These costs do not include necessary options such as auxiliary water heater, bottle and sipper tube racks, feed table, discharge table, etc. Typical cost for these options is approximately $2,500. In discussions with cage washer/dryer representatives, it has become apparent that another facility modification will likely be necessary. This modification involves an exhaust fan in the cage washer room to vent high humidity to areas away from the control room. This fan has been priced at $950 plus installation, and will probably involve modification to the building.

The 85 petals for the parallel plates are now scheduled for delivery the last of April. This represents a 24 day slippage caused by deplorable work done by the company that cut the petals out of the 12' x 6' aluminum sheets. This work was to be accomplished using a laser cutting device that would leave a smooth edge and cost approximately 70 percent of conventional cutting techniques. When the plates were returned, the edges appeared to have been cut using a large can opener. Gouges approximately 0.25 inches deep existed every inch along the edge. The result was that all petals had to be recut in our machine shop, which not only delayed delivery of the petals but also doubled their cost.

A contract has been initiated with Custom Plastics, Inc. to provide Plexiglas cut to dimensions necessary for the rat cages. At this time, the cost and delivery of these cage parts are within original estimates.

During the next reporting period, mounting of absorbing material on the radiation room walls should be completed and erection of the parallel plates should begin.
Performance and Cost Report No. 15
April 15, 1981
Page Three

II. Cost Information

a. Cost incurred during the reporting period:

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b. Cumulative costs through this reporting period:

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<td>Computer Time</td>
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c. Amount vouchered to ACO: $166,384.39

d. Estimated funds necessary to complete project: $107,991

Respectfully submitted

J. C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
1101 Massachusetts Avenue
St. Cloud, Florida 32769

Subject: April 1981 Performance and Cost Report No. 16
Subcontract No. SCEEE ARB/80-34, "Fabrication of a Radio-frequency Radiation Facility," Georgia Tech Project No. A-2650

Gentlemen:

Performance and cost information for the subject subcontract are presented below for the period 1 April 1981 through 30 April 1981.

I. Performance Information

The major technical efforts during this reporting period were concerned with continued installation of microwave absorbing material on interior walls of the radiation room and working out changes in the delivery schedule of major facility subsystems.

The major efforts associated with installation of absorbing material in the radiation room are essentially complete, with the only remaining efforts involving custom trimming of individual pieces to fit in corners and around the door. Paint has been ordered from the material manufacturer so cut surfaces of the absorbing material can be "touched up" to be aesthetically acceptable.

Delays in delivery of most major subsystems continue, and scheduling changes are being made to accommodate the delays. Petals for the circular plates are now expected at the end of May. These petals (88 total) have been essentially recut since they were received from the metal shop that was to cut them using a laser tool. As reported earlier, the six-foot outside radius was so jagged that it appeared to have been cut with a large can opener. In smoothing out this cut, the radius had to be reduced to 71 inches. The four-inch inside radius was nearly as bad, and efforts to smooth it out have resulted in a one-inch enlargement of this radius. Since this radius must fit against the four-inch diameter antenna cylinder, brass bushings have been made and are being attached to each petal. All petals were cut larger than 45 degrees, so efforts to fit eight petals into a complete circle have been impossible. This has necessitated recutting each petal, then custom fitting each group of eight petals into a plate. The petals are then individually marked so they can be reassembled in the radiation facility. This process of custom assembly of each plate is currently underway for both the radiation and control assemblies.
In earlier conversations with Custom Plastics, Inc., it was indicated that Plexiglas parts for small numbers of cages could be obtained while cutting of other parts continued. This was desired because it would allow the 230 cages to be assembled a few at a time. This situation has now changed and no parts will be available until all parts have been cut and checked. This may cause more than one set of cage assembly jigs to have to be fabricated. Delivery of Plexiglas parts for the 230 cages is scheduled for 20 May 1981.

Delivery of the MICON transmitter is still scheduled for June 3, 1981.

II. Cost Information

a. Cost incurred during the reporting period:

- Personal Services $2,824.01
- Fringe Benefits 284.73
- Overhead 2,061.53
- Materials and Supplies 510.56
- Equipment 0.00
- Travel 0.00
- Computer Time 0.00

TOTAL $5,680.83

b. Cumulative costs through this reporting period:

- Personal Services $57,084.63
- Fringe Benefits 5,993.03
- Overhead 41,832.23
- Materials and Supplies 132,469.08
- Equipment 0.00
- Travel 2,097.56
- Computer Time 0.00

TOTAL $239,476.53
Performance and Cost Report No. 16
May 14, 1981
Page Three

c. Amount vouchered to ACO: $145,696

d. Estimated funds necessary to complete project: $34,130

Respectfully submitted

J. C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
1101 Massachusetts Avenue
St. Cloud, Florida 32769

Reference: Subcontract No. SCEEE ARB/80-34
"Fabrication of a Radiofrequency Radiation Facility"
Georgia Tech Project No. A-2650

Subject: Performance and Cost Report No. 17
May 1, 1981 through May 31, 1981

Gentlemen:

Performance and cost information for the subject subcontract are presented below for the period 1 May 1981 through 31 May 1981.

I. Performance Information

The major technical efforts during this reporting period were concerned with erection of the circular, parallel-plate structures, assembly of the rat cages, and following changes in the transmitter delivery schedule.

As noted in the previous monthly report, extensive delays were encountered in delivery of the 88 petals that make up the circular plates because the inside and outside radii of each petal had to be recut. During this reporting period, the recutting/custom fitting was completed and petals for both the radiation and control structures were assembled in the main machine shop. This effort revealed that the support pedestals were not sufficiently steady and that swag bolts for joining the petals together were inadequate. The height of the support pedestals was then reduced and adjustable cables were added between each of the eight radials that make up the pedestals. With these remedial measures incorporated, it is expected that the originally-planned structural supports between the top plate and the ceiling will not be necessary in the final installation. The swag bolt inadequacy resulted because the metal plates were not perfectly smooth; therefore, when the machine shop milled lap joints on each petal, the resulting edges were thin in some places and thick in others. When the swag bolts were installed, either the bolt head or the nut (depending on whether the upper or lower edge was thin) pulled through the metal, resulting in no support at these points. To alleviate this problem, pop rivets were used to joint the petals together. A rivet
type was selected such that the head will not protrude enough to perturb the exposure field.

Following these design improvements, the plates and petals were disassembled in the shop and primer/paint (an off-white color) was then applied to the pedestal and petals for the Control Room. After the paint had sufficiently dried, the pedestal and plates were delivered and erection in the Control Room was begun. The Radiation Room pedestal and petals will follow early in the next reporting period.

Plexiglas parts for the 250 rat cages were received on 20 May 1981, but cage assembly was not begun because of efforts on the plate erection. Assembly of these cages will be initiated during the next report period.

There are strong indications that the transmitter will not be delivered on the scheduled 3 June 1981 date. The manufacturer provides typical reasons for this (late delivery of components, delivery of the wrong components, etc.), and efforts are now underway to establish a firm date on which delivery can be expected. Conversations to date indicate that this date will be near the end of June. If this is the case, a no-cost, one-month extension to the contract termination will be requested to allow time for transmitter hook-up, checkout, and dosimetry measurements.

II. Cost Information

a. Costs incurred during the reporting period:

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<td><strong>Total</strong></td>
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b. Cumulative costs through this reporting period:

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<td><strong>Total</strong></td>
<td><strong>$248,221.49</strong></td>
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</table>
Performance and Cost Report No. 17
June 19, 1981
Page Three

c. Amount vouchered to ACO: $154,360.44

d. Estimated funds necessary to complete project: $25,386

Respectfully submitted,

James C. Toler
Project Director

Approved:

F. L. Cain, Director
Electronics and Computer Systems Laboratory
Southeastern Center for Electrical Engineering Education, Inc.
1101 Massachusetts Avenue
St. Cloud, Florida 32769

Attention: Mr. Warren Peele

Reference: SCEEE Subcontract No. ARB/80-34
Fabrication of a Radiofrequency Radiation Facility
Georgia Tech Project No. A-2650

Subject: June 1981 Performance and Cost Report No. 18
Reporting Period 1 June 1981 through 30 June 1981

Gentlemen:

Performance and cost information for the subject subcontract are presented below for the period 1 June 1981 through 30 June 1981.

I. Performance Information

The major technical efforts during this reporting period were concerned with continued installation of the circular, parallel plate structures, assembly of the rat cages, participation in an Air Force-sponsored Program Review meeting, and acceptance testing of the transmitter. Also, a request to extend the subcontract by one month at no additional cost was submitted to the Southeastern Center for Electrical Engineering Education, Inc.

Eighty eight petals for the circular, parallel plate structure in the Control Room were delivered and erection of the structure was begun during the last reporting period. During this reporting period, this effort was continued until the support pedestal and first set of plates were completed. At that point, it was noted that the single coat of paint applied to the petals was not sufficient to prevent significant color variations from one petal to the next (the paint was applied over a coat of dark green primer). After discussions with the Paint Shop personnel, it was decided that all petals not already assembled into the structure should be returned for a second coat of paint. Also, all petals for the Radiation Room structure should receive two coats of paint prior to delivery. Petals already assembled into the Control Room structure were spray-painted in place, as was the support pedestal. Following this, all petals were delivered and erection of the parallel plate structures in both the Control Room and Radiation Room was completed.
Touch-up painting is still needed in numerous places where tools were dropped, pop rivets were inserted, etc. Coaxial cables and associated baluns were installed in the slotted cylinder antenna that is a part of the parallel plate structure in the Radiation Room (no cables were installed in the Control Room antenna). The cable for one set of plates is capable of handling RF power levels necessary to generate a 10 mW/cm² exposure field. Cables for the other three sets of plates will handle power levels capable of generating 1 mW/cm² exposure fields.

After completing erection of the circular, parallel plates, absorbing material was mounted on the walls of each room. The Velcro hook and eye material used to support individual pieces of absorbing material worked well. Cutting and custom fitting of materials around the entry doors were necessary. Where pieces of material were cut, paint obtained from the manufacturer was applied to assure uniformity in appearance.

Cage construction efforts continued during this reporting period, but were minimal because project personnel were heavily involved in erection of the plate structures and mounting of the absorbing material. Tops and food hopper/water bottle support assemblies for approximately 160 cages have been finished. To date, 103 cages have been fully assembled, with assembly of the remaining cages scheduled for the next reporting period.

During the period 22-24 June 1981, Mr. J. Toler participated in the Air Force-sponsored RFR Effects Program Review held at SAM/RZP, Brooks AFB, TX. A paper titled "A Circular, Parallel-Plate Radiation Facility for Chronically Exposing Large Rodent Populations to 435 MHz Environments" was presented. The Program Review provided an excellent opportunity to learn about other bioeffects research efforts, and especially about other efforts concerned with long-term, low-level exposure of large rat populations.

During this reporting period, a request was submitted to extend by one month the 30 June 1981 termination of the program. The basis for the request was the fact that the 3 June 1981 delivery date for the transmitter slipped to 25 June 1981, so additional time was needed for acceptance testing and interconnection with the slotted cylinder antenna. Verbal concurrence with this request was obtained from Mr. William Hurt, Program Monitor, prior to its submittal.

The MICON transmitter was delivered on 25 June 1981 with integration and cable interconnection efforts undertaken throughout the day. On the following day, efforts to energize the transmitter and obtain the full 5 kW peak power at the four output ports were not successful (the required 200 W average power was available at the output ports). Troubleshooting efforts revealed that high-wattage resistors in logic circuits controlling
the safety interlocks had been burned out. At the end of this reporting period, replacement components were on order and efforts were directed toward the cause of the failure. The nature of the failure is not considered overly serious since it is restricted to the safety interlock circuitry and these circuits operated satisfactory at MICON prior to shipment.

II. Cost Information

a. Cost incurred during the reporting period:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
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<tr>
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<td>Computer Time</td>
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b. Cumulative costs through this reporting period:

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C. Amount vouchered to ACO: $171,156

D. Estimated funds necessary to complete project: $5,615

Respectfully Submitted,

[Redacted]

James C. Toole,
Project Director

F. L. Cain, Director
Electronics and Computer Systems Laboratory
CONSTRUCTION OF A 435–MHZ RADIOFREQUENCY RADIATION FACILITY FOR LONG-TERM BIOEFFECTS STUDIES INVOLVING LARGE RODENT POPULATIONS

By

J. C. Toler, D. J. Schaefer, and D. J. Freedman

Submitted to
AIR FORCE SCHOOL OF AEROSPACE MEDICINE
CODE SAM/RZP
BROOKS AIR FORCE BASE, TEXAS 78235

Under
Subcontract Nos. SCEEE ARB/80-34 and SCEEE ARB/81-34

September 1981

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332
CONSTRUCTION OF A 435-MHz RADIOFREQUENCY RADIATION FACILITY
FOR LONG TERM BIOEFFECTS STUDIES INVOLVING LARGE RODENT POPULATIONS

July 1981

By
J. C. Toler, D. J. Schaefer, and D. J. Freedman

Submitted Under
Subcontract No. SCEEE AR8/LO-34
Subcontract No. SCEEE AR8/81-34

Submitted to
AIR FORCE SCHOOL OF AEROSPACE MEDICINE
Code SAM/RZP
Brooks Air Force Base, TX 78235

Submitted by
BIOMEDICAL RESEARCH DIVISION
Electronics and Computer Systems Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, GA 30332
There is an increasing public and scientific concern with the fact that biological systems are exposed to low-level radiofrequency radiation for extended time periods without full knowledge of the consequences of this exposure. These consequences are difficult to define for several reasons, one of which is the lack of technically adequate radiation facilities that can be dedicated to bioeffects research programs for long time periods. To partially alleviate this difficulty resulting from the lack of adequate radiation facilities, the Air Force School of Aerospace Medicine (Code SAM/RZP) has sponsored a series of three research programs at Georgia Tech to design and construct a radiofrequency radiation facility for the 420-to-450 MHz frequency range.

During the initial program (Subcontract No. SCEEE ARB/78-3 under Air Force Contract No. F33615-78-D-0617), four different radiation facility concepts were analyzed to determine their adequacy for long-term, low-level exposure of large rodent populations. The analysis indicated that a four-tier circular, parallel-plate facility should provide a technically adequate and cost effective means for chronically radiating large rodent populations. Overall design parameters were then derived assuming that 100 rats were to be exposed for their lifetime to a 435-MHz environment with a power density of approximately 1 mW/cm².

The second program (Subcontract No. SCEEE ARB/79-20 under Air Force Contract No. F33615-78-D-0617) involved construction and evaluation of a prototype, single-tier version of the circular, parallel-plate radiation facility. The facility construction used aluminum-backed Styrofoam panels to assemble two circular plates with eight-foot diameters. These plates were positioned one above the other and separated by Styrofoam blocks whose heights could be easily varied. Provisions were also made for a slotted-cylinder feed antenna. The facility evaluation involved the measurement of field patterns, voltage standing wave ratio, and coupling as a function of frequency, azimuth position of the circular plates, radial distance from the plate center, horizontal distance from
the plate center, and various configurations of the slotted-cylinder feed antenna. Additional evaluations involved measuring the incident and scattered field at given animal locations as a function of cage contents and number. Also, the design of a transmitter capable of generating pulsed- and continuous-wave fields and Plexiglas cages for housing the rats during exposure were developed.

The third program is described in this report. It involved the construction of two full-scale, 435-MHz, four-tier, circular, parallel-plate structures (one for 100 control rats and one for 100 exposure rats) in adjoining rooms, the walls of which were lined with microwave absorbing material. Floor space for a computer room, cage washer room, assay room, storage room, transmitter room, and buffer room was also provided. All rooms are contiguous and located on the ground-level floor of the Baker Building on the Georgia Tech main campus. A transmitter capable of generating a 1.0 mW/cm² (10 mW/cm² under limited conditions) pulsed- or continuous-wave exposure environment was purchased and interfaced with the parallel plates in the radiation room. Also, 250 cages for housing rats during radiation exposure were constructed of Plexiglas sheet and glass rod materials. All work was conducted in the Biomedical Research Division of the Electronics and Computer Systems Laboratory in Georgia Tech's Engineering Experiment Station. The period of performance was 1 April 1980 to 1 August 1981, and the internal designation for the program was Project A-2650. Mr. William Hurt of the Air Force School of Aerospace Medicine served as Program Monitor.

At the conclusion of this program, the design and construction of major components for a radiofrequency radiation facility were completed, and with other components such as cage washer, data acquisition system, and electronic balance, the facility will be ready for 435-MHz, long-term, low-level bioeffects studies involving statistically significant rat populations.

Respectfully submitted,

[Signature]

J. C. Toler
Project Director

F. L. Cain, Director
Electronics and Computer Systems Laboratory
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. INTRODUCTION</td>
<td>I-1</td>
</tr>
<tr>
<td>II. ANALYSES AND EVALUATIONS OF FACILITY CONCEPTS</td>
<td>II-1</td>
</tr>
<tr>
<td>A. Feasibility Analyses</td>
<td>II-1</td>
</tr>
<tr>
<td>1. Circular Waveguide Concept</td>
<td>II-1</td>
</tr>
<tr>
<td>2. Free-Space Radiation Concept</td>
<td>II-3</td>
</tr>
<tr>
<td>3. Compact Range Radiation Concept</td>
<td>II-4</td>
</tr>
<tr>
<td>4. Circular, Parallel-Plate Radiation Concept</td>
<td>II-7</td>
</tr>
<tr>
<td>B. Prototype Evaluation</td>
<td>II-9</td>
</tr>
<tr>
<td>1. Antenna Development</td>
<td>II-9</td>
</tr>
<tr>
<td>2. Circular Parallel-Plate Waveguide</td>
<td>II-12</td>
</tr>
<tr>
<td>3. Cage Design and Construction</td>
<td>II-14</td>
</tr>
<tr>
<td>4. Transmitter Design</td>
<td>II-15</td>
</tr>
<tr>
<td>III. CONSTRUCTION OF CIRCULAR PARALLEL-PLATE WAVEGUIDE</td>
<td>III-1</td>
</tr>
<tr>
<td>A. Circular, Parallel Plates</td>
<td>III-1</td>
</tr>
<tr>
<td>B. Slotted-Cylinder Antenna</td>
<td>III-3</td>
</tr>
<tr>
<td>IV. ANIMAL CAGE ANALYSIS</td>
<td>IV-1</td>
</tr>
<tr>
<td>V. TRANSMITTER SYSTEM</td>
<td>V-1</td>
</tr>
<tr>
<td>A. High Voltage Power Supply Subassembly for #1 and #2 Power Amplifiers</td>
<td>V-4</td>
</tr>
<tr>
<td>B. High Voltage Power Supply Subassembly for #1 and #2 Driver Amplifiers</td>
<td>V-4</td>
</tr>
<tr>
<td>C. Oscillator, Preamplifier, and Modulator Subassembly</td>
<td>V-4</td>
</tr>
<tr>
<td>D. System Control Subassembly</td>
<td>V-5</td>
</tr>
<tr>
<td>E. #1 and #2 Driver Amplifier Subassembly</td>
<td>V-6</td>
</tr>
<tr>
<td>F. #1 and #2 Power Amplifier Subassembly</td>
<td>V-6</td>
</tr>
<tr>
<td>G. Circulator Load Subassembly</td>
<td>V-6</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

Continued

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI. OVERALL FACILITY DESCRIPTION.</td>
<td>VI-1</td>
</tr>
<tr>
<td>VII. ANALYSIS OF THE ANTENNA, DISTRIBUTION, AND PARALLEL-PLATE SYSTEM.</td>
<td>VII-1</td>
</tr>
<tr>
<td>VIII. REFERENCES.</td>
<td>VIII-1</td>
</tr>
</tbody>
</table>

LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Typical radiation pattern at 440 MHz obtained with prototype circular, parallel-plate waveguide and slotted-cylinder antenna</td>
<td>II-13</td>
</tr>
<tr>
<td>2.</td>
<td>Details of plate construction showing the eight petals.</td>
<td>III-2</td>
</tr>
<tr>
<td>3.</td>
<td>Pedestal used to support circular, parallel-plate waveguides.</td>
<td>III-4</td>
</tr>
<tr>
<td>4.</td>
<td>Technique used to assemble slotted-cylinder antenna</td>
<td>III-6</td>
</tr>
<tr>
<td>5.</td>
<td>Technique used to mount cables to slotted antenna</td>
<td>III-7</td>
</tr>
<tr>
<td>6.</td>
<td>Initial design of Plexiglas cage for housing rats during RFR exposure.</td>
<td>IV-2</td>
</tr>
<tr>
<td>7.</td>
<td>Comparison of body weight of rats housed in Plexiglas cages to rats housed in standard metal cages.</td>
<td>IV-3</td>
</tr>
<tr>
<td>8.</td>
<td>Comparison of body temperature of rats housed in Plexiglas cages to rats housed in standard metal cages.</td>
<td>IV-4</td>
</tr>
<tr>
<td>9.</td>
<td>Final cage design showing changed water bottle and food hopper positions.</td>
<td>IV-6</td>
</tr>
<tr>
<td>10.</td>
<td>Photograph of MICON Model R9DAT Transmitter</td>
<td>V-2</td>
</tr>
<tr>
<td>11.</td>
<td>Block diagram of MICON Model R9DAT Transmitter</td>
<td>V-3</td>
</tr>
<tr>
<td>12.</td>
<td>Overall layout of RFR facility.</td>
<td>VI-2</td>
</tr>
<tr>
<td>13.</td>
<td>Diagram of impedance transforming balum</td>
<td>VII-6</td>
</tr>
</tbody>
</table>

ii
LIST OF TABLES

Table | Page
-----|-----
I. OVERALL PERFORMANCE SPECIFICATIONS FOR MODEL R9DAT TRANSMITTER | V-8
SECTION I
INTRODUCTION

Over the past several years, an extensive public and scientific interest has evolved concerning the possibility that long-term exposure of biological systems to low-level radiofrequency radiation may adversely affect the vital processes of organisms. With the public, much of this interest has resulted from exaggerated reporting, and continuing interest stems largely from inaccurate insinuation rather than factual knowledge. In the scientific community, there has been at least some exaggerated interest, but there has also been a valid technical basis for investigating interactions between radiofrequency radiation and biological phenomena. This technical basis is a direct consequence of the postulated [1]
- interaction between natural electromagnetic environments and the regulation of vital processes and
- role of endogenous electromagnetic fields in the coordination of normal physiological processes.

In view of the public and scientific interest in bioeffects and the postulated involvement of electromagnetic waves in regulation and coordination, it is important that research be conducted to determine whether vital biological processes are influenced by long-term exposure to low-level radiofrequency radiation. This research is necessarily difficult because it is highly interdisciplinary and requires the capability for exposing statistically significant animal populations to controlled electromagnetic environments for extended time periods while assaying sensitive biological endpoints for indications of subtle alterations. It is also highly demanding in terms of exposure facility availability, measurement precision, personnel qualifications, dosimetry, animal care, funding requirements, etc. Therefore, it is essential that all aspects of the research be carefully planned prior to initiation of animal exposures and examination of biological endpoints.
The research described in this report was undertaken for the purpose of developing a cost-effective facility technically suitable for long-term exposure of 100 rats to low-level radiation in the frequency range of 420-to-450 MHz. The resulting facility, consisting of two circular, parallel-plate waveguide assemblies, approximately 2000 square feet of floor space divided into eight rooms, 250 rat cages, and a transmitter, is housed in the Baker Building on the Georgia Tech main campus. With the addition of support equipment, such as a data management system, cage washer, etc., the facility will be ready for the initiation of research to determine whether long-term exposure to 435 MHz low-level radiofrequency radiation influences vital biological processes.

This report describes the engineering efforts undertaken in developing the radiofrequency radiation facility. In Section II, analyses leading to the establishment of a satisfactory facility concept, and experimental evaluations of the concept, are summarized for reference purposes. Detailed reports describing these analyses and evaluations have been published [2,3] and they document the selection of a circular, parallel-plate concept for the radiofrequency radiator. Section III describes the approach used in constructing the circular, parallel-plate radiator and its feed antenna. Analyses conducted to assure that the cage design was adequate are described in Section IV and the transmitter system is described in Section V. An overall description of the entire facility, including the circular, parallel-plate radiator, lighting, temperature control, and various support areas is given in Section VI. Finally, in Section VII, the efforts undertaken to characterize the performance of the antenna, distribution, and parallel plate systems are described.
SECTION II
ANALYSES AND EVALUATIONS OF FACILITY CONCEPTS

Two research programs preceded this program concerned with the actual construction of a facility for long-term, low-level radiofrequency radiation (RFR) exposure of large rodent populations. In the first of these two programs, four commonly used and/or new RFR facility concepts were theoretically analyzed to determine their adequacy for long-term bioeffects studies in the 420-to-450 MHz frequency range. One of these concepts -- the circular, parallel-plate concept -- was identified as providing a technically adequate and cost effective approach for the RFR facility. A prototype of this concept was constructed and extensively evaluated during the second research program. In this section, results from these two programs are summarized as reference information for the following discussion of the final RFR facility construction and evaluation.

A. Feasibility Analyses

During the initial program [2], several commonly used and/or new RFR facility concepts were analyzed to determine their adequacy for long-term bioeffects studies involving large rodent populations exposed to 420-to-450 MHz fields. These concepts included

- the circular waveguide radiation concept,
- the free-space radiation concept,
- the compact range radiation concept, and
- the circular, parallel-plate radiation concept.

Primary technical considerations during the concept analyses were exposure field configurations, ease of animal access, dosimetry, and nonperturbing provisions for water/food delivery. Additionally, nontechnical considerations such as construction and maintenance costs, floor space requirements, etc., were also analyzed. Major results of these analyses for each RFR concept are summarized below.

1. Circular Waveguide Concept

For this concept, individual waveguides are used to house the experimental animals during radiation exposure. Attractive features of the concept include the fact that
the field incident on a given animal is not influenced by scattering from other animals and their cages,

- the waveguides can be located in close proximity to one another, thereby minimizing floor space requirements without compromising easy observation of the animals, and

- continuous monitoring of input and output power provides a theoretically straight-forward procedure for dosimetry determinations.

In a typical application [4], the TE$_{11}$ mode is propagated in waveguides excited by two radial probes positioned 90 degrees apart and driven with a 90 degree phase difference. The Specific Absorption Rate (SAR) of individual animals is determined by measuring the difference between input and output powers, and dividing this difference by the mass of the animal.

In the analysis of this concept, electromagnetic fields in the circular waveguide were derived and the results were used to develop a design for a 450-MHz system capable of providing a 1.0 mW/cm$^2$ incident power density. The analysis began by deriving TE$_{11}$ mode field configurations in the waveguide for the case of single-probe excitation, and then progressed to the case of two-probe excitation. The dominant TE$_{11}$ mode propagates under the conditions

$$0.293 \frac{v}{f} < a \leq 0.383 \frac{v}{f},$$

where $v$ is the speed of light in the dielectric filling the waveguide, $f$ is the frequency, and $a$ is the inside radius of the waveguide. Analysis results for single-probe excitation indicated that the relative power distribution across the circular waveguide had both a $\phi$ and $r$-dependence ($\phi$ is the angular position and $r$ is the waveguide radius). For the $\phi$-dependence, the greatest change in power distribution across the waveguide occurred at $\phi = 0$ and $\phi = \pi$. For the $r$-dependence, the power distribution was greatest at the waveguide center, and decreased to a minimum at the waveguide wall. For a radius of less than $0.49a$ in the cylinder, the...
power density was everywhere greater than 50 percent of the maximum. For the case of two-probe excitation, the \( \phi \)-dependence of the power distribution across the waveguide cross-section disappeared, but the same \( r \)-dependence was maintained. Also, for this excitation, energy near the waveguide center propagated with circular polarization. The region where propagation was approximately circular comprised approximately six percent of the total cross-sectional area of the waveguide.

Based on the single-probe and dual-probe analyses, it was concluded that the waveguide diameter for 450 MHz would have to be between 17 and 20 inches. Impedance matching between the probes and the chamber dictated a waveguide length of approximately six feet. Input power to provide a 1 mW/cm\(^2\) power density would be approximately 2.0 watts per waveguide. A materials cost of $224,000 was estimated for construction of 200 waveguides, assuming aluminum and expanded aluminum mesh to be the primary construction materials.

2. Free-Space Radiation Concept

For this concept, a suitable antenna is used to illuminate an array of animal cages positioned on a contour shaped in a manner to assure that all cages receive the same incident power density. The equal-power-density contour is achieved by positioning off-axis cages closer to the source antenna. In previous applications [5], this concept has been used to expose relatively small numbers of experimental animals in a configuration where the radiation axis was horizontal. For an application involving 100 radiate and 100 control rats, a vertical radiation axis was preferred in order to minimize cage support difficulties and ease cage cleaning and observation tasks.

An open-ended circular waveguide with a 180-degree corrugated flange was selected from several candidate antennas for the illuminator. This antenna has equal E- and H-plane beamwidths of approximately 65 degrees, and both measured and theoretical patterns are readily available for analysis. Using a typical radiation pattern, dimensions for an equal-power-density contour were calculated as a function of the off-axis radiation angle. Cages positioned on this contour formed circular rings and the horizontal distance from the radiation axis to each ring was the
circle radius. Both this radius and the vertical dimension between one ring of cages and the next were functions of the cage-to-cage separation that had to be provided to maintain intercage scattering within tolerable limits. For a radiation system with the on-axis cage 15 feet from the source antenna and an intercage spacing of 18 inches, it was shown that 125 cages could be accommodated in seven rings of cages.

Calculations of transmitter output power necessary to provide a 1.0 mW/cm² exposure environment for this radiation concept were made assuming a 9 dB gain for the open-ended waveguide antenna with circular polarization. This polarization was necessary because the rat cages were positioned tangent to the equal-power-density contour; therefore, if the source antenna were linearly polarized, the incident electric field would be parallel to the long dimension of only a part of the animals. For the circularly-polarized antenna, a transmitter output power of 600 watts would provide the 1 mW/cm² exposure environment. The materials cost for two identical contours (one for radiates and one for controls) and antennas was estimated to be $174,000.

3. Compact Range Radiation Concept

For this radiation concept, the exposure environment is generated over a predictable volume near the aperture of a full or cut paraboloidal reflector. The concept offers the ability to produce an exposure environment with a planar phase front very near the aperture and to collimate this environment such that reflections are minimized. In this way, a plane-wave exposure environment can be generated in a reasonably-sized indoor facility. Since the exposure environment is collimated throughout the plane-wave volume, it is range-independent and therefore, essentially constant as a function of distance from the aperture. This means that the exact location of the animals within the exposure volume is of minimal concern. Although the plane wave is not completely uniform in amplitude because of illumination taper and space attenuation, proper selection of the feed antenna and reflector will generate an environment that is approximately uniform over an appreciable area. Polarization of the exposure environment is determined by the feed antenna design; therefore, either linear or circular polarization can readily be provided.
In view of the above features of the compact range radiation concept, it was analyzed to determine its feasibility as a facility suitable for chronically exposing 100 rats to relatively low-level environments. The analysis noted that a paraboloid of revolution can be defined as the locus of points equidistant between a point (the focal point) and an imaginary plane erected perpendicular to the axis of the paraboloid [6]; thus, rays reflected by the paraboloid will have points of constant phase on the imaginary plane. In this manner, a point source of electromagnetic energy placed at the focal point of a paraboloidal reflector will provide a plane wave exposure environment over an area close to the reflector. This environment will propagate parallel to the reflector axis as a good approximation of a plane wave for a distance corresponding to several reflector radii.

In addition to a planar phase front, the exposure environment must also provide a uniform amplitude over the area occupied by the experimental animals. However, as the electromagnetic energy propagates from the focal point to the reflector surface, it diverges as a spherical wave; therefore, some energy will travel a greater distance between the focal point and reflector than will other energy, and the result will be a non-uniform amplitude distribution. To correct this, the amplitude pattern of the feed antenna at the focal point must be shaped to compensate for the different distances traveled by the energy in reaching the reflector surface.

In most applications, the feed antenna is not shaped to provide amplitude uniformity over the exposure area; instead, experimentation has shown that an amplitude non-uniformity of approximately 1.0 dB is generally acceptable and will exist over an exposure area equal to approximately one-half of the reflector aperture. Therefore, a reflector with an aperture of 12 feet-by-12 feet will provide an exposure area with an approximate diameter of six feet and an amplitude uniformity of 1.0 dB or better.

II-5
Obviously, it would be difficult to satisfactorily illuminate the entire surface of a circular paraboloidal reflector. If this illumination were attempted, the energy propagating for some portions of the reflector would be incident on the feed antenna support structure. Diffraction of this energy by the structure introduces interference patterns that destroy the uniform and planar character of the exposure environment. For these reasons, only the upper portion of the circular reflector is normally used in compact range designs. From an electromagnetic point-of-view, the lower portion of the paraboloidal reflector can, in fact, be completely discarded.

During the feasibility analysis, the primary concerns were (1) the quality of the exposure environment that could be generated over an area capable of accommodating 100 rats with an intercage spacing adequate for eliminating unacceptable scattering and (2) the physical dimensions of the resulting compact range. The concern with exposure environment quality involved factors such as feed antenna design, smoothness tolerances on the reflector surface, dosimetry, etc. Similarly, concern with physical dimensions involved factors such as floor space requirements, ceiling height requirements, animal accessibility, construction costs, etc. The point-of-departure in analyzing the compact range radiation concept was the fact that the usable exposure area will be approximately one-half of the reflector aperture. Graphical techniques were used to indicate the reflector size necessary to accommodate 100 individually housed rats with an intercage spacing of 18 inches. These techniques revealed that a reflector aperture approximately 33 feet-by-33 feet would be necessary. These dimensions obviously presented significant difficulties in housing and constructing the reflector as well as problems in accessing the animals during the radiation study. Numerous technical approaches for reducing the reflector dimensions were considered, but all introduced unacceptable compromises in either amplitude or phase characteristics of the exposure environment.

Because of its excessive size, the compact range was not considered feasible as a radiation concept; however, material costs for constructing the reflector and transmitter output power requirements were estimated. These estimates were $523,000 and 2250 watts, respectively.
4. Circular, Parallel-Plate Radiation Concept

There was no indication in the open literature that circular, parallel-plate waveguides had been considered as a radiation concept for bioeffects studies involving large rodent populations. However, these waveguides can be fed at their center in such a way that energy travels radially outward to a circular array of animal cages. With the feed antenna and parallel plates designed for circular symmetry, the exposure field will also exhibit circular symmetry, and all caged animals will be exposed to the same field.

The field configuration in circular, parallel-plate waveguides is a function of the spacing between the plates. For example, if the plate spacing is less than one-half wavelength, only the dominant TEM mode propagates. In this mode, the electric field in normal to the plates and the resulting polarization is vertical. If spacing between the plates is greater than one-half wavelength, both the TE and TM modes propagate. For the TE mode, the electric field is parallel to the plates and the resulting polarization is horizontal. If plate spacing is maintained greater than one-half wavelength but less than one wavelength, only the lowest-order TE mode propagates. In general, the TM modes that propagate in parallel-plate waveguides with spacing greater than one-half wavelength are of no interest in bioeffects studies because of the non-magnetic nature of biological materials. Also, these modes are vertically polarized and would couple minimally to experimental animals.

The feasibility analysis for the circular, parallel-plate radiation concept began with the assumption that \( n \) cages were to be arrayed around the plate periphery. With a plate diameter of \( D \) and intercage separation of \( h \), the equation

\[
D = \frac{nh}{\pi} \quad (2)
\]

was used to calculate a family of plate diameters as functions of cage spacing and number. These calculations showed that, for 100 cages with an intercage separation of 18 inches, a plate diameter of 48 feet would be required. Obviously, this plate diameter is not feasible; however,
the radiation concept is maintained if several sets of waveguides are stacked on top of one another in a tier arrangement. By stacking plates, smaller plate diameters can be used to expose 100 animals while maintaining the 18-inch cage separation. If fact, four sets of stacked plates with 12-foot diameters would be adequate for exposing 100 animals whose intercage separation was 18 inches.

As noted earlier, spacing between the plates had to be maintained greater than one-half wavelength but less than one wavelength for propagation of the lowest-order TE mode. Using a frequency of 435 MHz (midway between the 420-to-435 MHz frequency range of interest), this criteria translated to

\[ 13.57 < S < 27.14, \]  \hspace{1cm} (3)

where \( S \) is the spacing between plates in inches. A plate spacing of 18 inches was conveniently chosen. Using this plate spacing dimension, and assuming that four stacks of 12-foot diameter plates would be satisfactory, it was determined that an area with a 20 foot-by-20 foot floor space and 10-foot ceiling height would adequately house the facility. This floor space permitted appropriate microwave absorbing material (18-inch thick material offers \(-30\) dB reflectively at 500 MHz) to line the facility walls, and sufficient space around the stacks of plates to access the animals.

The remaining considerations were directed to calculations of power density variation across the height and width of cages used to house the rats, antenna types suitable for feeding the waveguide structures, transmitter output power requirements, and overall facility cost. Calculations of power density variation noted that the TE mode exposure environment provided a cosine-squared distribution between the plates. These calculations showed that variations in both vertical and horizontal power density across an animal cage were less than 0.5 dB, and were therefore acceptable. A small loop antenna positioned at the center of each set of plates was recommended as the feed antenna. Transmitter output power calculations revealed that approximately 105 watts would provide a 1.0 mW/cm\(^2\) exposure environment between the plates. The estimated cost of
At the conclusion of this initial program, it was recommended that a prototype circular, parallel-plate waveguide be constructed and evaluated. The evaluation would require that a small loop antenna also be designed and constructed, and that 25 rat cages be constructed so the waveguide could be fully loaded during its evaluation. The power source for the facility could be provided by available signal generators and amplifiers; however, the development of a transmitter design was recommended. The evaluation should be primarily concerned with determining the adequacy of the loop feed antenna and probing the uniformity of the exposure field in the azimuth plane. Also, the 18-inch intercage separation distance should be investigated by scattering measurements to determine its adequacy.

B. Prototype Evaluation

During this follow-on program [3], recommendations made at the conclusion of the initial program were implemented essentially verbatim. Therefore, design considerations for a feed antenna were developed, a prototype, single-set of circular, parallel plates was constructed and evaluated, 25 rat cages were constructed, and a transmitter design was developed. These efforts are summarized in the following paragraphs.

1. Antenna Development

During the initial program [2], it was recommended that small loop antennas be used to feed the parallel-plate waveguide; therefore, initial efforts during this program were directed to design considerations for small loops. These efforts resulted in semi-rigid coaxial cable with a 0.085-inch diameter being used to construct a loop with a diameter of 1.25 inches. Concurrently, a pair of circular plates with a 3-foot diameter was constructed using aluminum-backed hardboard. Construction of these plates was such that the separation distance could be easily changed. Using frequency scaling and a network analyzer, this parallel-plate waveguide and loop antenna configuration were evaluated to determine antenna efficiency and resonant frequency as a function of plate spacing. The resonance was observed to be extremely sharp with a center frequency.
of 1.256 GHz and the antenna efficiency was determined to be approximately 5 percent.

With these indications that the circular plate/loop antenna configuration was yielding sharp resonances and that efficiency of the loop was extremely low, efforts to identify a more suitable antenna were begun. These efforts resulted in slotted cylinders being considered as the feed antenna for the parallel plates. As the name implies, these antennas consist of hollow metal cylinders with rectangular slots cut along their axial dimensions [7,8]. They have been most widely used in applications where horizontal polarization with an essentially constant-amplitude horizontal pattern is required; consequently, slotted-cylinder antennas have been used as radiators for FM radio and UHF television broadcasting. Performance of slotted-cylinder antennas can be understood by considering the slot to be fed by a coaxial cable routed along the inside of the cylinder. If the impedance around the cylinder circumference is sufficiently low, current will flow in horizontal loops around the cylinder. Under these conditions, a vertical slotted cylinder will radiate a horizontally polarized field. The amplitude of this field in the horizontal plane is dependent on the cylinder diameter. In general, the radiated field tends to be greater on the cylinder side where the slot is located; however, if the cylinder diameter is a sufficiently small part of a wavelength, i.e., approximately 0.15\(\lambda\), the radiated field in the horizontal plane becomes essentially uniform. If the cylinder diameter is increased to the point of becoming a significant part of a wavelength, the field in the region of the shadow cast by the cylinder becomes small. Generally, as the cylinder diameter becomes large, the horizontal field approximates a cardioid [9].

Slot width influences the capacitive loading of the antenna in much the same way as cylinder circumference influences inductive loading. When slot width is small relative to wavelength, the horizontal pattern is independent of the axial distribution of the field along the slot. In general, for slotted cylinders, the effect of greater slot width is to increase the length of the slot required for resonance for a given cylinder diameter. Resonant length tends to become quite long as
cylinder diameter becomes small, but decreases as the cylinder diameter increases. Thus, the interactive relationship between slot width, slot length, and cylinder diameter is evident.

A major concern in considering the slotted cylinder as a feed antenna for the circular, parallel-plate waveguide was input impedance. This impedance can be varied over a rather large range by changing the effective capacitance. For center-fed cylinders with diameters small relative to wavelength, the impedance at the first resonant point is rather high, i.e., in the range of 300 to 1000 ohms. This indicates that the feed should be a parallel-wire transmission line, perhaps with a inline balun. If cylinder diameter is appreciably increased, a second resonant point occurs, and it has an impedance of approximately 40 ohms. This indicates that the feed should be a coaxial cable. These impedance values can be varied somewhat by feeding the antenna off-center.

Other concerns in considering the slotted cylinder as the feed antenna for the circular, parallel-plate waveguide were bandwidth and radiation pattern. Published information on bandwidth was almost nonexistent; however, reference was made in one instance [8] to measurements that indicated bandwidths at the first resonance of between four and eight percent. These measurements were made at frequencies where the standing wave ratio on the feed line was two-to-one. Published information on radiation patterns was somewhat more available, but it involved theoretically-derived, rather than experimentally-measured, data. Theoretically-derived patterns [9,10] showed essentially uniform amplitudes in the horizontal plane.

After extensively analyzing the design and performance features of slotted-cylinder antennas, a design effort was undertaken to tailor such an antenna for use with a circular, parallel-plate waveguide. The primary parameters to be defined, and their final design values, were

- **D** -- diameter of the cylinder -- 4 inches,
- **T** -- thickness of the cylinder wall -- 0.125 inches,
- **L** -- length of the slot -- 14 inches, and
- **W** -- width of the slot -- 0.125 inches.
A commercially-available aluminum cylinder with a 4-inch diameter and a 0.125-inch wall thickness was obtained and the desired slot was cut along its axial dimension. After construction of the circular, parallel-plate waveguide, this antenna was installed and performance evaluations were conducted.

2. Circular Parallel-Plate Waveguide

As recommended at the conclusion of the initial program, a prototype set of circular, parallel plates with a 12-foot diameter and 18-inch separation spacing was constructed and evaluated; however, the size of the anechoic chamber within which evaluations were to be conducted would accommodate plates with a maximum diameter of eight feet. Eight-foot diameter plates were therefore constructed using aluminum-backed Styrofoam sheets and wooden supports. The Styrofoam sheets were 4 feet-by-8 feet by 1-inch thick, and two sheets were joined together using conductive tape, then trimmed to an 8-foot diameter circle. Wooden supports were glued to the Styrofoam side of the sheet to provide rigidity. These supports were hinged in a way that allowed each plate to be folded in half in order to enter the anechoic chamber door. Styrofoam blocks with a 1-foot square base and an 18-inch height were used as spacers between the two plates. A 4-inch diameter hole was provided in the center of each plate to permit installation and removal of feed antennas. In the anechoic chamber, these plates were mounted on an antenna positioner that was attached to the chamber floor below the absorbing material.

The resulting circular, parallel plates provided a lightweight and inexpensive waveguide adequate for evaluating the facility concept. With the slotted cylinder antenna in position, coupling, VSWR, radiation pattern, and scattering evaluations were conducted. Approximately 150 pattern recordings were made to characterize the prototype waveguide's performance under a variety of parallel plate and slotted antenna conditions. Typically, a slot 14.5 inches long and 0.0625 inches wide provided resonance at 440 MHz and a peak-to-peak horizontal field amplitude uniformity of 2 dB or less in the azimuth plane. The cross-polarized component of the field was 15 dB or more below the horizontal component. A typical radiation pattern is shown in Figure 1.
Figure 1. Typical radiation pattern at 440 MHz obtained with prototype, circular, parallel-plate waveguide and slotted-cylinder antenna.
3. Cage Design and Construction

A cage design using Plexiglas sheet and glass rod materials was developed for housing the rats during performance evaluations of the prototype circular-plate waveguide. This design used 0.25-inch thick Plexiglas for three sides, the food hopper, and the soil tray. The top and fourth side were constructed of 0.375-inch thick Plexiglas. The thicker Plexiglas on the fourth side was necessary to provide a grating through which the rats could access food. The food hopper was capable of holding a supply of pellets sufficient for several days. The hopper grating was constructed using three-millimeter diameter glass rods mounted vertically on 0.4375-inch centers through an opening or window in the thicker cage side. This arrangement allowed the rats to feed ad libitum. Six-millimeter glass rods were mounted parallel to the transverse axis of the cage on 0.75-inch centers to form the cage bottom and top. In the bottom, these rods permitted animal waste to drop through the cage onto a soil collection tray for subsequent disposal or analysis, as appropriate.

Water for the rats was provided by individual water bottles that utilized glass rather than metal sipper tubes to minimize field perturbations that may affect power exposure and absorption [4]. To determine the relative effect of water-filled glass and metal sipper tubes on the exposure field, a small dipole antenna was imbedded in the nose of a body of phantom modelling material shaped to simulate a rat. This antenna was connected to the input of a power meter which served as a relative power indicator. The simulated rat was then irradiated with a 450-MHz field and relative power indications were noted as a function of various sipper tube conditions. The test results indicated that, if a sipper tube (either metal or glass) was positioned parallel to the direction of propagation of the incident exposure field, power coupled to the drinking rat was likely to increase. The increase for a metal sipper tube was profound, while only a slight increase occurred if a water-filled glass sipper tube was used. No power increase (and even a slight reduction) occurred when a glass water-filled sipper tube was oriented perpendicular to the direction of propagation of the incident exposure field.
4. Transmitter Design

Overall designs were developed for pulsed- and continuous-wave transmitters suitable for long-term bioeffects studies requiring a 1.0 mW/cm$^2$ exposure field. These designs assumed that a four-tier arrangement of 12-foot diameter circular, parallel-plate waveguides fed with a slotted cylinder antenna would be used to expose 100 rats individually housed in Plexiglas cages. Therefore, the transmitter had to provide four signal sources, each with an output of approximately 200 watts average and 5.0 kilowatts peak.

Two basic transmitter designs were analyzed relative to the radiation needs for long-term, low-level bioeffects studies. The major difference in the designs was whether power splitting was accomplished at low or high power levels. Ultimately, a design in which power splitting was accomplished at high power levels was marginally recommended. Representative sources for this transmitter were provided.
SECTION III
CONSTRUCTION OF CIRCULAR PARALLEL-PLATE WAVEGUIDE

As noted in the previous section, a single-tier prototype model of the circular, parallel-plate waveguide and its slotted-cylinder feed antenna were constructed and evaluated. The evaluation results clearly indicated the feasibility of the radiation concept, so the decision was made to design and construct a full-scale facility consisting of two identical four-tier assemblies of circular, parallel plates with slotted-cylinder feed antennas. This design and construction effort is described in this section.

A. Circular, Parallel Plates

The two four-tier assemblies of circular, parallel plates (one for exposure and one for control animals) were constructed using ten circular aluminum plates with 12-foot diameters. Five circular plates made up the exposure waveguide while the remaining five circular plates made up the control waveguide. The design of these plates kept in mind the possibility of moving the entire facility to another location at some future date; therefore, each plate was constructed of eight petals, each with a six-foot outer radius and a width dictated by a 45 degree angle. Lap joints one-inch wide were milled on the two radial edges of each petal to provide mating surfaces necessary for joining eight adjacent petals to form one complete plate. Type 6061-T6 aluminum sheet metal with a 0.1875-inch thickness was selected for the petals since it was relatively light weight, easily machined, and sufficiently thick to provide necessary structural strength and mating surfaces for lap joints. A total of 85 (five spares) of these petals were cut from 12 foot-by-6 foot sheets of Type 6061-T6 aluminum. The fabrication involved sizing each petal to a 45 degree width, cutting a six-foot diameter outer radius, and cutting a two-inch diameter inner radius. The inner radius for each petal provided a four-inch hole in the center when eight petals were joined together to form a plate. This hole was used for installation of the slotted-cylinder antenna. After petals were cut to the proper size, lap joints were milled along the radial edges of each petal. A drawing of the eight petals assembled into a plate is shown in Figure 2.
Figure 2. Details of plate construction showing the eight petals.
Because of the petal size, fabrication in the Georgia Tech Main Machine Shop was difficult. In fact, special jigs had to be built, and even with these jigs, petals were not fabricated to exact dimensions. Therefore, after all petals were cut and milled, the two four-tier assemblies of parallel plates were erected in the Main Machine Shop using custom fitting where necessary. When an assembly was completely erected, an identification code was stamped into each petal. Pop rivets spaced six inches apart along the lap joints were used to hold the assembly together. The 18-inch plate separation distance was maintained by plastic rods with 1.5-inch diameters. Threaded nylon rods were used to join the plastic rods together through the metal plates.

After assembly to each radiator, the plates were disassembled, and individual petals were primed, then painted with two coats of paint with an off-white color. All 85 petals were then delivered to their final location, and the identification code stamped in each petal was used to guide their reassembly into two identical waveguides. The base for each assembly consisted of a 24-inch high pedestal made of a center post with eight radial panels. These panels were positioned under the lap joints in the bottom plate and attachment to the plastic spacer rods was provided by threaded nylon bolts. Electrical isolation was provided between the bottom plate and the pedestal, and large-head bolts in the bottom of each pedestal panel were provided for leveling the assembled waveguides. Steel cables with turn-buckle adjusters were attached between pedestal panels at lower, outside corner positions to add rigidity to the assemblies. A drawing of the support pedestal is shown in Figure 3.

B. Slotted-Cylinder Antenna

As noted in Section II, the slotted-cylinder antenna was constructed using an eight-foot long, four-inch diameter aluminum cylinder with a wall thickness of 0.125-inches. This cylinder was cut into four individual sections, two 30 inches long and two 18 inches long. Slots for the antenna were cut the desired length along the axial dimension of these sections. The two longer sections provided the feed antennas for the upper and lower pairs of plates within the waveguide assembly. For the upper antenna, 18 inches of the cylinder section was positioned between
Figure 3. Pedestal used to support circular, parallel-plate waveguides.
the two plates making up the top-most waveguide, and 12 inches extended above the upper plate to facilitate installation of the feed cables, baluns, connectors, etc. For the lower antenna, 18 inches of the cylinder section was positioned between the two plates making up the bottom waveguide, and 12 inches extended into a nylon insert in the center of the support pedestal. The two 18-inch long sections provided the feed antennas for the two internally located waveguides in the four-tier assembly.

The four individual sections of the slotted-cylinder antenna were joined by press-fitting nipples as illustrated in Figure 4. Assembly of the antenna sections involved gently pressing one cylinder section onto the nipple of the lower antenna to achieve a tight fit. Each pair of cylinder sections were joined at the plane of the circular plates. To assure that there was no wave propagation inside the cylinder (and therefore no electrical interference between adjacent waveguides), the top of each nipple was sealed by a metal plate isolator. Holes were provided in this isolator to allow passage of transmission lines. The presence of nipple inserts inside the slotted-cylinder antenna altered the impedance somewhat; however, the baluns/transformers and tuning stubs were adjusted to compensate for this alteration.

Excitation of the slotted-cylinder antenna was accomplished by attaching twin-lead cables across the slots in each of the four antenna sections. These cables were routed from the ceiling of the radiation room down through the center of the aluminum cylinder. Attachment across the four slots required a mechanically strong connector capable of providing good electrical contact between the twin-lead cables and the slots. Also, it was important that the connectors not introduce excessive stray capacitance or inductance. The connectors provided for this purpose are shown in Figure 5. Construction of these connectors involved cutting sectoral sections out of nylon block and mounting them across the slots with flat-head screws. Advantages of the nylon material included its transparency to 435-MHz fields and its mechanical strength. Holes were drilled into the nylon block to accept the twin-lead transmission lines from the baluns/transformers. Set screws were then used to make the electrical connection between the cylinder walls and transmission lines.
Figure 4. Technique used to assemble slotted-cylinder antenna.
Figure 5. Technique used to mount cables to slotted antenna.
SECTION IV
ANIMAL CAGE ANALYSIS

During the earlier research programs, cage designs were developed using Plexiglas material for the four sides, glass rods mounted to the sides for the cage bottom, glass rods mounted in a removable Plexiglas frame for the cage top, an end-mounted food hopper, and a plastic water bottle with glass sipper tube (see Figure 6). The evaluations conducted during the programs were concerned with determining the glass rod diameters and spacings that should be used, defining a water bottle configuration that did not compromise dosimetry, and assuring that rats could comfortably adjust to the glass rod bottom. Also during this program, additional analyses involving growth rates, core temperatures, and postural preferences were conducted. This section describes these additional analyses.

Body weight and core temperature analyses were conducted concurrently for the purpose of comparing, as a function of time, rats housed in the new Plexiglas cages with rats housed in conventional metal cages. Growth rate and body temperature were considered important indicators of overall health status, and, if rats housed in the two different type cages experienced different growth rates and/or core temperatures, features of the Plexiglas cage design would need to be reconsidered. A metal cage rack complete with ten conventional metal cages was obtained and ten Plexiglas cages were constructed with the glass rods in the cage bottom positioned parallel to the cage long dimension. Twenty male Sprague-Dawley rats were obtained from Emory University and arbitrarily divided between the two types of cages. Both groups of caged rats were housed adjacent to each other in the same room, with food and water provided ad libitum. Body weight and core temperature were measured daily (except Saturday and Sunday) as the rats grew from approximately 110 grams to approximately 170 grams. The resulting data are shown in Figures 7 and 8. An analysis of these data concluded that, as far as body weight and core temperature were concerned, housing rats in Plexiglas cages introduced no biological differences that would not have occurred if the rats were housed in conventional metal cages. Therefore, the Plexiglas cages should prove satisfactory for RFR studies.
Figure 6. Initial design of Plexiglas cage for housing rats during RFR exposure.
Figure 7. Comparison of body weight of rats housed in Plexiglas cages to rats housed in standard metal cages.

Note: For presentation purposes, data points are plotted on either side of measurement day.
Figure 8. Comparison of body temperature of rats housed in Plexiglas cages to rats housed in standard metal cages.
Concurrent with the analysis of body weight and core temperature, rats housed in the Plexiglas cages were observed daily (except Saturday and Sunday) for postural preferences. These observations were made to determine if the direction of the glass rods in the cage bottom influenced whether the rats positioned themselves parallel or perpendicular to the cage long dimension. During RFR exposure, it is desired that the rats position themselves parallel to the cage long dimension so coupling with the exposure field will be maximized. A five-level code was devised for scoring rat postural positions in the cages, and these positions were scored at random times during the day. The scoring defined whether the rats were parallel to the cage long dimension (Score 1), perpendicular to the cage long dimension (Score 5), or in some intermediate position (Scores 2, 3, or 4). Results of these 15-day observations were of concern because they clearly indicated that there was no preference for a position parallel to the cage long dimension. In fact, while the rats were young and small, there was a slight indication that a position perpendicular to the cage long dimension was preferred.

In an effort to encourage the rats to position themselves parallel to the cage long dimension (and therefore parallel to electric field vector of the exposure field), modifications to the glass rod floors were made in two series of cages. Modifications to the first series of cages involved leaving the glass rods parallel to the cage long dimension, but positioning them such that rods in the cage center were slightly lower than those on either side. It was thought that this uneven floor might encourage the rats to position themselves along the level direction, i.e., parallel to the cage long dimension. For the other series of cages, all glass rods were level, but their orientation was changed such that they were perpendicular to the cage long dimension.

Using the previously described scoring system, postural preferences of the rats were observed over an 11-day period. Mean rat positions were calculated and compared with the results obtained during the initial observations. This comparison clearly indicated (mean rat positions were 3.41, 3.43, and 1.91, respectively, for the three floor arrangements) a desired postural position when the glass rods in the cage floors are perpendicular to the cage long dimension.
Subsequent to the evaluations of body weight, body temperature, and postural preference, minor design changes were made in the cage to facilitate provisions for watering and feeding. These changes involved moving the food hopper to the cage side next to the water bottle, and providing a Plexiglas frame to support a plastic water bottle in its desired position. The changes finalized the cage design with the final cage as shown below in Figure 9.

Figure 9. Final cage design showing changed water bottle and food hopper positions.
The transmitter provided for the RFR facility is a Model R9DAT unit purchased from Microwave Control Company (MICON), Bricktown, NJ. The unit is designed as a research transmitter capable of operating in either of two modes to provide pulsed- or continuous-wave RF outputs at a fixed frequency of 435 MHz. Four separate outputs (one for each circular, parallel-plate waveguide) are provided on the unit top. The power level at all four outputs is adjustable by means of one front panel control. In Mode 1, the transmitter provides a continuous-wave output of up to 200 watts average at each of the four outputs. In Mode 2, a pulsed-wave output of up to 5000 watts peak is provided at each of the four outputs. Other front panel controls allow the pulse width to be varied from 0.25 to 10 microseconds and pulse repetition frequency to varied from 1.0 to 5.0 kilohertz. Primary power is also applied by the operation of circuit breakers on the front panels.

A photograph of the MICON Model R9DAT Transmitter is shown in Figure 10. The transmitter is made up of eight major subassemblies mounted in a single equipment cabinet. These eight subassemblies are evident in Figure 10, and from the top down, they are identified as:

- the Circulator Load Subassembly,
- the #1 and #2 Power Amplifier Subassembly,
- the #1 and #2 Driver Amplifier Subassembly,
- the System Control Subassembly,
- the Oscillator, Preamplifier, and Modulator Subassembly,
- the High Voltage Power Supply Subassembly for #1 and #2 Driver Amplifiers,
- the High Voltage Power Supply Subassembly for #1 Power Amplifier, and
- the High Voltage Power Supply Subassembly for #2 Power Amplifier.

These subassemblies are shown in block diagram form in Figure 11, and a brief description of each is provided in the following paragraphs.
Figure 10. Photograph of MICON Model R9DAT Transmitter.
Figure 11. Block diagram of MICON Model R9DAT Transmitter.
A. High Voltage Power Supply Subassembly for # 1 and # 2 Power Amplifiers

These two subassemblies are identical and they provide the high voltages necessary for the two output Power Amplifiers. Front panel controls on each subassembly include a main circuit breaker, status indicator lamps, and a current overload/reset switch. The power supplies contain an overcurrent monitoring circuit that prevents excessive current drain during operation. After any overcurrent situation has been corrected, the reset switch may be momentarily actuated manually to resume operation. Each supply is cooled by a fan whose input is a screened opening on the front panel.

B. High Voltage Power Supply Subassembly for # 1 and # 2 Driver Amplifiers

The high voltage power supply for both of the Driver Amplifiers is contained in this subassembly. Front panel controls include circuit breakers, status indicator lamps, an overcurrent/reset switch, and test points. The indicator lamps show operate, standby, and overcurrent conditions for each power supply. A manual momentary actuation of the reset switch is necessary for operation of the power supplies after the cause of an overcurrent condition has been cleared. The test points monitor current supplied by each supply, with 1.0 volt equal to 100 milliamps of output current. Cooling for the subassembly is provided by a fan whose screened input is located in the front panel center.

C. Oscillator, Preamplifier, and Modulator Subassembly

This subassembly provides the solid-state devices and functions necessary to excite the Driver Amplifier Subassembly. Three main controls are provided on the panel, two that enable the operator to control pulse width and pulse repetition frequency, and a third that permits either internal or external modulation to be selected. Two coaxial connections are available, one to provide output synchronization pulses and one to provide an input for external modulation. Under normal operations, the output of this subassembly is approximately 10 watts average in either the pulsed- or continuous-wave mode. Cooling is provided by a single fan whose screened input is located on the front panel.
D. System Control Subassembly

This subassembly, as its name implies, contains all of the controls necessary to operate the Model R9DAT Transmitter in any of its modes. Eight meters (two for each of the four RF outputs) provide a continuous indication of each RF output by displaying approximate forward and reflected power levels. For meters indicating forward power, the full-scale reading is approximately 200 watts and 5000 watts, respectively, in the continuous- and pulsed-wave modes. Meters indicating reflected power display a voltage standing wave ratio (VSWR) of 2:1 at full scale for both continuous- and pulsed-wave operation. If any one of the four output loads presents a VSWR in excess of 2:1, a VSWR monitor automatically functions to disable all high voltage power supplies. In addition, at the end of a 10-second time period during which the excessive VSWR condition continues to exist, normally-open relay contacts operate to signal an external auto-dialer mechanism (not provided) to call assigned telephone numbers. Other controls on the front panel permit the transmitter to be placed in either the standby or operate mode, and to be manually reset after any overcurrent condition. A switch to permit selection of either continuous- or pulsed-wave operation and a RF output control are also provided on the front panel. Indicator lamps on the front panel reflect the overall status of transmitter operation. A fault analyzer is also part of this subassembly, and this analyzer de-energizes the transmitter if pre-set conditions at selected monitor points are exceeded. Another set of contacts is provided in the subassembly to permit de-energizing of the transmitter if the RFR room is entered when radiation is underway. Operation of these contacts energizes a Sonalert in the subassembly, and a loud tone is emitted for approximately two minutes. At the end of two minutes, the auto-dialer mechanism is operated and a sequence of telephone numbers is called. To re-establish normal operation, the monitor in the RFR room must be reset and the reset switch on the System Control Subassembly must be momentarily actuated manually. An additional overcurrent protection monitor is provided in this subassembly to protect the transmitter from excessive current drain. Like the RFR room monitor, this overcurrent protection monitor operates the Sonalert and de-energizes the transmitter.
E. #1 and #2 Driver Amplifier Subassembly

This subassembly accepts the 10 watt output of the Oscillator, Preamplifier, and Modulator Subassembly, routes it through two cascaded amplifiers and a two-way power splitter, and provides outputs for the Power Amplifier Subassembly. At the output of the first driver amplifier, the power levels are approximately 48 watts average and 150 watts peak, respectively, for continuous- and pulsed-wave operation. These power levels are amplified to approximately 275 watts average for continuous-wave operation and 2750 watts peak for pulsed-wave operation of the second driver amplifier. The output of the second driver amplifier is split such that continuous- and pulsed-wave outputs of approximately 120 watts average and 1200 watts peak are provided. Cooling for the subassembly is provided by two fans with screened openings for air input on the front panel.

F. #1 and #2 Power Amplifier Subassembly

This subassembly contain two identical high power cavity amplifiers that provide either continuous- or pulsed-wave outputs for the Circulator Load Subassembly. In the pulsed-wave mode, the maximum output of the subassembly is 12 kW, which is split in a two-way power splitter to provide in excess of 5 kW peak to each RF output. In the continuous-wave mode, the maximum output of the subassembly is 600 watts average, which after routing through the two-way power splitter, provides in excess of 250 watts average to each RF output. The cavity amplifiers are protected against overtemperature by sensors that de-energize all high voltage if the internal temperature exceeds 100°C. Overtemperature lamps that indicate an overtemperature condition are provided on the front panel. Each cavity amplifier has a cooling fan, and screened openings for air input to these fans are on the front panel.

G. Circulator Load Subassembly

Output power from the Power Amplifier Subassembly is split, monitored, and interfaced with the RF outputs of the transmitter by this subassembly. The power splitting is accomplished in high power, two-way splitters that take the two outputs from the Power Amplifiers and provide four outputs. Each of these outputs is routed through a circulator that
provides protection against unacceptable changes in load conditions. The circulators provide sampling ports that permit the monitoring of forward and reflected power for each output (eight monitors). Signals from these eight monitors are accessible on the front panels via eight coaxial connectors. The output level of these signals range from 0 to +10 dBm for forward power. Reflected power monitoring is based on a 2:1 VSWR which, if exceeded, de-energizes all high voltage power supplies. The subassembly is air-cooled through a screened opening in the front panel.

In addition to the eight major subassemblies, the transmitter requires interconnecting cables. These cables are provided in the equipment cabinet and interconnect the various subassemblies via connectors on the back of individual chasses. Each cable and connector are color-coded to expedite the interconnection of chasses and, where appropriate, like connectors are keyed so they can not be connected to the wrong point.

Overall performance specifications for the Model R9DAT Transmitter are summarized in Table I.

The subassemblies and cabling described above define the major operational and performance capabilities of the MICON Model R9DAT Transmitter; however, there is an additional important capability provided by a device external to the cabinet-mounted subassemblies shown in Figure 10. This capability involves a MICON Model 01A-28-0005 Power Combiner that accepts as inputs the four Circulator/Load Unit outputs on the cabinet top, and provides a single output with pulsed- and continuous-wave power levels of 16 kW and 800 W, respectively. This single output can be connected to one of the slotted cylinder antennas to provide an exposure power density in excess of 10 mW/cm² for 25 rodents. In constructing the circular, parallel-plate facility, the third-level slotted cylinder antenna was provided with high power cables capable of handling the 16 kW and 800 W power levels.
<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>435 MHz</td>
</tr>
<tr>
<td><strong>Power Output:</strong></td>
<td></td>
</tr>
<tr>
<td>Mode 1, continuous wave, each of</td>
<td>200 Watts</td>
</tr>
<tr>
<td>four outputs</td>
<td></td>
</tr>
<tr>
<td>Mode 2, pulsed-wave, each of</td>
<td>5000 Watts</td>
</tr>
<tr>
<td>four outputs</td>
<td></td>
</tr>
<tr>
<td><strong>RF Power Balance</strong></td>
<td>± 0.5 dB</td>
</tr>
<tr>
<td><strong>Pulse Rise Time</strong></td>
<td>0.12 microseconds Max.</td>
</tr>
<tr>
<td><strong>Pulse Fall Time</strong></td>
<td>0.2 microseconds Max.</td>
</tr>
<tr>
<td><strong>Pulse Width</strong></td>
<td>0.25-10 microseconds</td>
</tr>
<tr>
<td><strong>Pulse Repetition Frequency</strong></td>
<td>1-5 kHz</td>
</tr>
<tr>
<td><strong>RF Power Adjustment</strong></td>
<td>Max. to -6 dB</td>
</tr>
<tr>
<td><strong>Sync Output</strong></td>
<td>+5 V at 50 ohms</td>
</tr>
</tbody>
</table>
The overall facility for long-term exposure of large rodent populations to 435-MHz pulsed- and continuous-wave environments consists of (1) the four-tier assembly of circular, parallel-plate waveguides located in a radiation room, the walls of which are lined with microwave absorbing material, (2) an identical four-tier assembly of circular, parallel-plate waveguides located in a control room, the walls of which are also lined with microwave absorbing material, (3) a 435-MHz transmitter capable of either pulsed- or continuous-wave operation and providing four outputs, each with 200 watts average and 5.0 kilowatts peak power, (4) 250 Plexiglas cages for individually housing rats during radiation exposure, (5) a room to house the transmitter and its auxiliary equipment, (6) a room to house devices needed for assay of biological endpoints, (7) a room to house a cage washer/dryer, (8) a room to house a computer-based data management system, (9) a room for storage of food, cages, detergents, disinfectants, etc., and (10) a buffer area to isolate the control and radiation rooms from other activity in the building. The cages, transmitter, and circular, parallel-plate waveguides have been described in previous sections of this report. In this section, the rooms for housing the facility are described.

The overall layout of the RFR facility is shown in Figure 12. The total facility occupies approximately 2000 square feet in Rooms 19 and 19A (basement level, northeast corner) of the Baker Building on the Georgia Tech main campus. The identification of each room in Figure 12 and its size are as follows:

<table>
<thead>
<tr>
<th>Room Purpose</th>
<th>Room Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Room</td>
<td>23 x 23 feet</td>
</tr>
<tr>
<td>Control Room</td>
<td>23 x 23 feet</td>
</tr>
<tr>
<td>Transmitter Room</td>
<td>6 x 23 feet</td>
</tr>
<tr>
<td>Buffer Room</td>
<td>7 x 50 feet</td>
</tr>
<tr>
<td>Computer Room</td>
<td>10 x 10 feet</td>
</tr>
</tbody>
</table>

VI-1
Figure 12. Overall layout of RFR facility.
The microwave absorbing material lining the walls of the RFR and Control Rooms was purchased from Advanced Absorber, Inc. and has a height of 18 inches. At 500 MHz, the specified reflectivity of this material is -30 dB. It was mounted to the walls using Velcro hook and eye material. Strips of hook material were glued in appropriate locations to the sheetrock walls of the RFR and Control Rooms using contact cement. Similarly, strips of eye material were glued in appropriate locations to the absorbing material using contact cement. This approach makes it possible to remove the absorbing material without tearing apart the individual blocks. All rooms making up the RFR facility are heated and/or cooled by an air conditioning system isolated from the system used by the remainder of the Baker Building. Since the facility is located in a corner area of the Baker Building, two of its perimeter walls are outside walls; therefore, vents for the heating and cooling system are easily exhausted to outside air. This is important for odor control and will help assure a disease-free rat colony. Lighting for the RFR and Control Rooms is powered by an automatic timer with a manual over-ride capability. The control for this timer is at the entry to the rooms. Sheetrock used to form the perimeter walls for the RFR and Control Rooms is aluminum-backed, thereby providing a layer of foil shielding to reduce radiation leakage from the RFR Room. No extensive amount of shielding will be necessary to control leakage radiation since these perimeter walls are lined with the microwave absorbing material. The common wall between the RFR and Control Rooms provides a double layer of foil shielding because aluminum-backed sheetrock was mounted to both sides of the studs for this wall. Shielding continuity between adjoining pieces of sheetrock is maintained by overlaying the aluminum foil from one piece of sheetrock to the next, then taping the seam with electrically-conductive aluminum tape. The ceiling for the RFR and Control Rooms consists of two foot-by-two foot panels of acoustic tile suspended in a grid of T-supports.
Each of these panels is covered with a layer of aluminum foil to reduce any radiation that might leak into office areas on the first floor level of the Baker Building. Again, no extensive amount of shielding was considered necessary since the circular, parallel-plate waveguides will direct their radiation outward, not upward.

In the Cage Washer Room, a four-inch soil stack is provided as a drain for the cage washer. Also, 208V, 3 phase power is available in this area for the cage washer. In the Transmitter Room, 208V, 3 phase power is available for the transmitter. Dual receptacle outlets for 60 Hz, 115V power are available in all rooms, including the RFR and Control Rooms, where the outlets are located behind the microwave absorbing materials.
SECTION VII
ANALYSIS OF THE ANTENNA, DISTRIBUTION, AND PARALLEL PLATE SYSTEMS

A major effort during this program involved analysis of the antenna, distribution, and waveguide systems. During the second research program, a prototype version of these systems was analyzed in sufficient detail to clearly indicate their feasibility as a radiation facility concept. However, additional analyses were necessary to characterize the performance of these systems in their final installation. These analyses were conducted during this program, and the three systems were considered as consisting of the following components:

- a four-tier assembly of circular, parallel-plate waveguides,
- the antennas to excite a particular mode of electromagnetic wave propagation,
- the transmission lines required to feed the antennas,
- the impedance matching and current balancing networks in the transmission lines, and
- the connectors/isolating devices for cabling.

The point-of-departure for analyzing the antenna, distribution, and parallel plate systems noted that, to achieve maximal coupling to the experimental animals, the electric field vector must be parallel to the animal's long dimension. Since the experimental animals will be positioned around the circular plate circumference, equipotential lines of the propagating field must form circles concentric about the axis of the plates; thus, the parallel-plate radiators must propagate in the TE$_{10}$ mode. For this propagation mode, the horizontal electric field will exhibit a half-cosine distribution, with the peak midway between each pair of plates. This distribution can be analyzed by comparing a linear electric field distribution with the electric field $E_1$ expressed as $E_1 = E_{01}$, where $E_{01}$ is a constant, to a TE$_{10}$ electric field $E_2$ expressed as $E_2 = E_{02} \cos \left(\frac{\pi}{2d}z\right)$, where $E_{02}$ is a constant, $2d$ is the plate separation and $z$ is the vertical displacement ($z=0$ midway between plates). The squares of these quantities times a scaling factor (the inverse of the waveguide impedance $z$) yields the power density. For equal linear and cosine distribution power levels, the result is
\[
\left( \frac{1}{Z_g} \right) \int_{-d}^{d} \frac{E_{01}^2}{dz} = \left( \frac{1}{Z_g} \right) \int_{-d}^{d} \frac{E_{02}^2}{dz} \left( \cos \frac{\pi z}{2d} \right)^2 dz, \tag{4}
\]

which yields

\[
\frac{E_{02}^2}{Z_g} = 2 \frac{E_{01}^2}{Z_g}. \tag{5}
\]

Thus, it is clear that, midway between each set of plates \(z=0\) and for equal input power levels, the cosine distribution causes the power density to be twice the value for a linear distribution.

The impedance \(Z\) for the \(TE_{10}\) mode wave propagation is given by

\[
Z = \frac{\eta}{\sqrt{1 - \left( \frac{f_c}{f} \right)^2}}, \tag{6}
\]

where \(\eta\) = the intrinsic impedance of the medium between the parallel plates,

\(f\) = the operating frequency of the parallel-plate radiator, and

\(f_c\) = the cutoff frequency of the radiator (328 MHz for an 18-inch plate separation distance).

The impedance of a set of parallel plates operating at 435 MHz in the \(TE_{10}\) mode and with an 18-inch separation distance is 574 ohms. The radiator can be analyzed as radiating into free space; therefore, the normalized reflected power \(|\rho|^2\) can be determined as

\[
|\rho|^2 = \left( \frac{574 - 377}{574 + 377} \right)^2 = 0.04. \tag{7}
\]

This indicates that 4 percent of the incident power will be reflected, and this level was considered quite acceptable for a long-term, low-level radiation facility.
The effect of experimental animals (rats) on waveguide impedance was analyzed by modeling the rats along an equipotential line as parallel dielectric slabs within a parallel-plate capacitor. The combination of rats and parallel plates yielded a composite dielectric constant (parallel capacitors model). This modeling approach yielded results that were approximate but the effort involved was much more consistent with the scope of this program than would have been the case if an exact solution had been sought. Assuming an array of 25 rats, each 7 inches long, with a dielectric constant of 49, and separated center-to-center by 18 inches, the effective relative dielectric constant of the array was determined to be 1.61. The waveguide impedance becomes 452 ohms, thereby causing 1.4 percent of the incident power to be reflected. This low level of reflected power is very attractive.

Analyses also indicated that the waveguide with its 18-inch plate separation distance could support TM and TEM propagation modes if they were excited. Consequently, care had to be exercised to assure that they were not excited. The impedance for the $\text{TE}_{10}$ and TEM modes of propagation were determined to be 248 ohms and 327 ohms, respectively. To excite only the $\text{TE}_{10}$ mode, the slotted-cylinder antenna described in Section II was selected as the feed for the circular, parallel-plate waveguide. This antenna develops an electric field across the narrow dimension of the slot, thereby generating a radiation field polarized such that equipotential lines are concentric circles about the cylinder. The impedance of the 14.5-inch slotted-cylinder antenna, when center fed with a balanced transmission line, varied from 700 to 1400 ohms depending on the transmission lines and nipples within the line. As a result, the antenna was well matched to the waveguide impedance.

Analysis efforts also indicated that each pair of plates in the tier assembly should be electrically isolated from the other pairs of plates. Without this isolation, electrical interference phenomena could distort propagated fields and result in the different waveguides generating different exposure fields. The circular, parallel plates located internal to the tier assembly were part of two different waveguides—the upper plate surface for one waveguide and the lower surface of the same plate
for another waveguide. To determine the extent to which the waveguides were electrically isolated, skin depth calculations were made using the expression [11]

$$\delta = \frac{1}{\sigma R_s}$$

(8)

where $\delta$ = skin depth

$\sigma$ = conductivity ($3.72 \times 10^7$ mho/meter for aluminum), and

$R_s$ = skin resistance ($3.26 \times 10^{-7}$ $\sqrt{\text{frequency}}$ in Hertz for aluminum).

At 435 MHz, the skin depth was found to be $1.56 \times 10^{-4}$ inches. This value was orders of magnitude less that the thickness of any aluminum sheet that would be used to construct the four-tier assembly of circular, parallel plates; therefore, each pair of plates is well isolated from the others.

A possible source of power dissipation in the exposure facility that needed to be analyzed before finalizing the design was attenuation in the parallel plates. The waveguide attenuation per unit length $a$ for the TE$_{10}$ mode is given by [11]

$$a = \frac{2 R_s f^2}{\eta f_c \sqrt{1 - \left(\frac{f_c}{f_c}\right)^2}}$$

(9)

where $a$ = plate separation distance and the other terms are as previously defined. The attenuation was calculated to be $1.735 \times 10^{-6}$ nepers per inch or $1.5066 \times 10^{-5}$ dB per inch. Thus, over a plate radius of 72 inches, the signal will be attenuated only $1.08 \times 10^{-3}$ dB. Essentially no signal will therefore be lost due to attenuation in the waveguide.

Proper functioning of the slotted-cylinder antenna required that it be fed with balanced currents at a high impedance. Devices used for impedance transformation and current balancing had to be compact since they were to be located inside the four-inch cylinder that formed the antenna. Additionally, these devices had to be capable of handling high peak and average power levels. The impedance transforming balun shown
in Figure 13 was developed to meet this criteria. The balun ideally consists of a piece of coaxial transmission line with two quarter-wavelength slots milled into it at locations 180 degrees displaced from each other. At the end of the slotted coaxial cable, the center conductor -- which has been extended to become one lead in a twin-lead transmission line -- is shorted to one half of the outer conductor by means of a shorting post. The other half of the outer conductor is electrically connected to a lead having the same diameter as the center conductor. This lead, and the center conductor, then form the twin-lead transmission line with a characteristic impedance of 250 ohms. The twin-lead transmission line was deliberately maintained less than one-tenth wavelength to limit its impedance transforming characteristics and minimize the possibility of undesired stray radiation. Since the twin-lead conductors were electrically separated through the balun by a half wavelength, they were 180 degrees out of phase, and therefore balanced.

In the analysis of impedance transforming baluns, it was noted that the ideal balun may be modelled as two 100-ohm transmission lines in parallel and connected to a coaxial line as shown in Figure 13. One of the two 100-ohm lines is terminated in a short circuit while the other is terminated in a load (ultimately the antenna). If the length $L$ of each 100-ohm transmission line is one-quarter wavelength, the impedance at their junction with the coaxial cable can be determined. In this case, the short circuit transforms to an open at the junction and the load $Z_L$ transforms back to become

$$Z_T = \frac{(100)^2}{Z_L}.$$  \hspace{1cm} (10)

For a matched system, $Z_T = 50$ ohms, so $Z_L$ must be 200 ohms. This value is somewhat low and does not provide a good match to the slotted-cylinder antenna. However, if the slot lengths in the balun coaxial cable are shortened slightly by means of metal adjusting devices (see Figure 13), the currents can be kept nearly balanced while the impedance necessary for the best match can be changed markedly. This procedure was used to coarse tune the slotted-cylinder antenna.

VII-5
Figure 13. Diagram of Impedance Transforming Balun.

VII-6
The impedance transforming baluns were located inside the slotted-cylinder antennas, and, since they did not provide a perfect match, tuning stubs were used in the signal distribution system exterior to the slotted-cylinder antennas. These open stubs provided an ability to (1) accomplish fine tuning, (2) adjust the match to compensate for aging, and (3) equalize the power transmitted to each pair of parallel plates. These stubs function by canceling the reactive portion of the transformed impedance at a certain point on the transmission line, thus reducing the magnitude of the impedance discontinuity. Single and multiple stubs were used as necessary to achieve an impedance match such that the reflected power was approximately 14 dB below the incident power at each waveguide. The stubs were fabricated from open-circuited sections of RG-8 coaxial transmission line. They were connected in parallel with the main transmission line by means of "T" connectors and located above the edge of the parallel plates in the ceiling for convenient access. The open ends of the stubs were protected by tape to a thickness greater than a conductor spacing to prevent the introduction of unwanted capacitances due to the presence of metal objects within their fringing fields.

It was necessary for the exposure facility to function properly with reasonably high levels of average and peak powers. Specifically, three of the parallel plate waveguides had to accommodate 200 watts of average power and 5 kilowatts of peak power. The fourth parallel plate waveguide had to accommodate 800 watts of average power and 20 kilowatts of peak power. In general, average power limitations were determined by power levels capable of causing thermal destruction of conductors or, more commonly, thermal destruction of dielectrics. Peak power limitations were determined by power levels capable of causing dielectric breakdown (arching). The analysis effort noted that a dry air dielectric is excellent for high average powers since it is essentially lossless, but relatively poor dielectric breakdown properties limit its peak power capabilities. Coaxial cables filled with a polyethylene foam dielectric were chosen for the transmission lines since they exhibited superior peak and average power characteristics. These cables can tolerate the highest average powers anticipated with a voltage standing wave ratio of
4.0 without exceeding their power ratings. The impedance transforming baluns have the same power ratings as these cables.

The slotted-cylinder antenna was analyzed to determine its peak power rating. Dry air experiences electrical breakdown under an electric field strength of 30,000 volts per centimeter. The antenna slot was 0.125 inches (0.3175 centimeters) wide. Thus, voltages in excess of 9,525 volts would be necessary to cause air in the slot to break down. In a conservative analysis, it was assumed that the impedance looking into the slot was 1,400 ohms. It was further assumed that the potential at the center of the slot was 1.414 times the potential that would have been present if the electric field was uniformly distributed, rather than cosine distributed, along the slot. Under these circumstances, the peak power rating of the slot was determined to be 32.4 kilowatts. Since the cylinder impedance is usually closer to 700 ohms, a more likely peak power rating is 64.8 kilowatts. Both ratings far exceed the power levels the slots will have to withstand.

An eighth-wavelength dipole antenna was used to map horizontal and vertical components of the electric field along the edge of each pair of parallel plates. The purpose of this mapping was to assure that (1) all experimental animals would be exposed to the same environment and (2) the waveguides were operating in the TE\textsubscript{10} mode. Measurements of the horizontal field component were also made to establish the existence of a cosine field distribution between the plates of each waveguide.

The horizontal component of the field was found to vary by 2dB peak-to-peak around the circumference of the plates. The vertical field electric component was 17dB down from the horizontal component, thereby confirming TE propagation. The horizontal field component was found to exhibit a half-cosine variation between the plates, and this established the propagation mode as TE\textsubscript{10}. The exposure fields of each waveguide were probed to determine whether any interference was distorting the propagated fields. The electric field structure was found to be essentially identical for each set of plates and interference distortion was not observed.
SECTION VIII

REFERENCES


