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Research Department - Mound Laboratory

July 20, 1965

POLONIUM RADIOISOTOPE THERMOELECTRIC SPACE GENERATOR PROGRAM

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We have received a copy of the request for proposal for this program. Extracted from this proposal are comments pertinent to our input into this study. The request for proposal is for the performance of a study, including the preparation of a preliminary design and a development program of a 400 watt(e) polonium-210 fueled thermoelectric generator intended for use in an earth orbital space mission. This study is to be performed within a 90-day period and is the first phase of a multiphase development program. It shall be conducted as a competition among two or three contractors selected to perform the effort. Based on the results of this and Government studies, a decision will be made whether to continue with the follow-on development program. It is expected, in the event of continuation, that the development program will be initiated a few months after completion of the study.

In the scope of work, it is stated that the contractor shall conduct a preliminary engineering design and integration study of a 400 watt(e) polonium-210 fueled thermoelectric generator (RTG) and its support equipment, for a 90-day earth orbital mission. Specifically, the Contractor shall:

A. Liaison and Interfaces

1. As and to the extent directed by the Contracting Officer:

a. Perform coordination and liaison activities with the User Organization(s) and/or its (their) contractors to establish interfaces, including design constraints, between Contractor-furnished services and items and the services, equipment, and facilities furnished by the User Organization(s) under its (their) satellite program(s)

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b. Conduct liaison with the Commission and/or its Contractors to obtain the fuel form and the fuel encapsulation information.

2. Utilizing the above established interfaces and the system specifications in the Appendix, prepare a technical interface specification which shall be used as a reference document during the study program. This document shall be revised, as necessary, throughout the study program. This specification shall include performance, design, fabrication, test and other pertinent requirements of Contractor-furnished items.

3. Prepare a detailed operating plan which shall describe all pertinent aspects of the use of the RTG in a routine space mission including normal operation and credible malfunction conditions. This plan shall be in accordance with the requirements established between the Commission and the User Organization. The plan shall not include any aspects of fuel production and encapsulation.

B. Design and Analyses

1. Prepare a preliminary design(s), which shall include definition of materials, fabrication techniques, component weights, operating temperatures, and other pertinent characteristics of a RTG which meet the requirements contained in the technical interface specifications prepared under A.2. above.

2. Prepare a preliminary design(s) of the ground support equipment required for the transportation, handling, and use of the generator and/or its fuel capsules at the launch complex. This equipment shall include, but not be limited to, a field test kit for the RTG, handling equipment capable of both loading and unloading the fuel, and shipping and storage cask(s), if required, which shall meet the technical interface specifications prepared under A.2. above, and which shall conform to applicable ICC Shipping Regulations. Other ground support equipment, such as is necessary to handle accident conditions, shall be identified.

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3. Conduct analyses in support of the work set forth under B.1. and B.2. above. These analyses shall include, but not be limited to:

   a. Evaluation of alternate approaches including tradeoffs of weight, volume, fuel quantity, efficiency, reliability, other pertinent considerations, and the reasons for the approach(es) selected.

   b. A detailed determination of the preferred fuel form.

   c. Preliminary review of the safety aspects of the RTG and/or fuel capsules designed under B.1. above, with respect to normal operations and credible accidents related to the handling, testing, transportation, storage, launch, and post-launch operations.

   d. Assessment of overall RTG reliability based on reliability analyses of each subsystem.

   e. Evaluation of RTG design flexibility over a range of power levels and mission lifetimes.

   f. Analysis of the fueling and defueling operations at the launch complex, including dose rate profile as a function of distance from the RTG.

   g. Analysis of fuel loadings and fuel delivery schedules required to meet planned launch schedules.

   h. Analysis of cooling requirements to provide for indefinite holds on the launch pad.

   i. Analysis of RTG performance under pre-launch and ascent to orbit conditions.

   j. Design considerations for thermal and/or electrical means of dissipating excess energy related to the decay of the radioisotope.

k. Detailed definition of areas where basic data and engineering design data and experience are not available, thereby, requiring research and technological development.

C. Development Program Plan

Prepare a development program plan for Phases II, III, and IV as outlined below. This plan shall be sufficiently detailed to enable the Commission to thoroughly evaluate the remaining program phases. The plan shall include:

1. Detailed breakdown of the program into tasks and subtasks.

2. Detailed descriptions of the effort in each task and subtask, including objectives and approaches.

3. Detailed cost estimates for each task and/or subtask.

4. Schedules which show the duration and interrelationship of the task and subtasks and major milestones of the program.

5. A critical-path scheduling technique for the purpose of program management.

6. A reliability program which will demonstrate RTG reliability based on component life test mean-time-between-failure data.

7. A quality control program to assure RTG reproducibility consistent with MIL-Q-9858A.

8. A design qualification and flight acceptance testing program, consistent with MIL-STD-810A and including thermal vacuum testing.

9. A safety program to meet the RTG system safety criteria of routine intact reentry.

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Note: The schedule and cost information (exclusive of fuel) shall be prepared for:

1. A minimum-time-to-develop program.

2. A minimum-cost-to-develop program.

3. The Contractor-recommended program to deliver the first flight RTG for launch in mid 1968.

Phase II - Generator Subsystem Development. This phase shall consist of the final design of the RTG and component development, including:

1. Preparation of drawings, specifications, and processes required to fabricate a prototype RTG and necessary ground support equipment.

2. Fabrication and testing of RTG components to demonstrate achievement of system specifications.

3. Performance of safety testing and analyses of the RTG and/or its components necessary to prepare a preliminary safety analyses report.

Phase III - Prototype System Development and Qualification. This phase shall include:

1. Fabrication and qualification testing of electrically heated prototype RTGs and one fueled prototype RTG (for launch pad demonstrations) in accordance with the drawings, specifications, and processes prepared under Phase II above. Also, two additional electrically heated prototype generators shall be fabricated for User requirements.

2. Fabrication and test of ground support equipment.

3. Using the information and test results obtained under this and previous program phases, prepare a Final Safety Analyses Report based on the mission application.

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Phase IV-Flight Demonstration Systems. This phase shall include:

1. Fabrication, assembly, test, and delivery to the launch site of three (3) RTGs for flight testing.

2. Continuing the safety efforts in support of obtaining approval for operational mission use.

3. Providing engineering planning, surveillance, and technical direction for launch support.

4. Preparing final technical data, drawings, and specifications for follow-on procurement of operational RTGs.

D. Cost Estimates of Production Units

The Contractor shall prepare a cost estimate for operational RTG units, excluding fuel costs, assuming delivery of 4-6 RTGs per year. The cost estimates should consider a production Quality-Assurance Program including sampling, inspection, and flight acceptance testing requirements.

In the proposal, the system specifications are defined as follows:

1. Power

The generator shall be capable of providing 400 electrical watts to the satellite bus continuously throughout mission lifetime.

2. Voltage

21 minimum - 31 maximum over mission lifetime from a DC to DC converter if required, which will be provided by the User.

3. Generator Design Life

The generator shall be capable of meeting mission requirements after being subjected to electrical heating and/or fueled cyclic operations by the User for a period of six (6) months before launch.

4. Mission Life

90 days in space.

5. Launch Pad Hold Time

14 days.

6. Fuel Delivery Time

Thirty (30) days should be assumed between fuel encapsulation and delivery to the launch site.

7. Fuel

The fuel form shall be either polonium metal or gadolinium polonide in a tantalum matrix (1:5 GdPo:Ta). The maximum surface temperature of the fuel shall not exceed 1,000°C under any conditions. The following is the design data:

Isotope	
Half-life (days)	138.4
Helium evolution rate (cc at STP/curie)	0.0226
Power (thermal watts/curie)	0.0320

Po Metal (as loaded into capsule)

Density (g/cc)	9.4
Melting point (°C)	252.0
Boiling point (°C)	962.0
Heat of vaporization (K^{cal}/mole)	24.6
Linear coefficient of expansion (cm/cm°C) -196 to +30°C)	2.35×10^{-5}
Vapor pressure (438-745°C)	$\log P_{(mm\ of\ Hg)} = \frac{-5377.8 \pm 6.7}{T\ (°K)} + 7.2345 \pm 0.0068$
Power density (thermal watts/cc)	1355.0

GdPo-Ta Matrix (as loaded into capsule)

Density (g/cc)	10.0
Power density (thermal watts/cc)	120.0
Melting point (°C)	1675.0 of GdPo ±50°C

The chemical and physical characteristics of Ta should be used for other calculations concerning this fuel form.

8. Heat Source Assembly

The polonium-210 fuel shall be contained within a tantalum liner whose thickness can vary between 20 and 60 mils. TIG welding shall be used on the liner closure.

The outer fuel capsule container shall be a refractory metal and shall be designed to both retain its integrity for a period of five years when exposed to a salt water environment and survive impact at terminal

velocity and operating temperature upon granite. This outer container shall be welded by either TIG or EB. Capsule void volume and wall thickness, within the limits specified, are design variables.

A major design consideration of the heat source assembly shall be ease of fueling and defueling.

9. Thermoelectric Conversion Assembly

The thermoelectric power conversion assembly design shall be based only on the lead-telluride and lead-telluride/bismuth-telluride thermoelectric technology represented by the SNAP-9A, 11, 17B, and 19 Programs.

10. Heat Rejection Assembly

Only convective fluid cooling, including forced convection and heat pipes shall be considered. This does not exclude conductive or radiative coupling between the thermopile and heat rejection system. Current technology in materials and components shall be used to the maximum extent possible.

11. Insulation

Only MIN-K 1301 shall be used as the insulation material within the thermoelectric conversion assembly. Other generator insulation shall be based on current technology to the maximum extent possible.

12. Thermal Interface

The generator shall be thermally engineered so that minimum heat input is allowed into the bays adjacent to the possible locations for the RTG indicated in Figures 1 and 2 of the vehicle drawings.

13. Electrical Interface

RTG electrical output shall be delivered to a converter provided by the Using Agency. This converter will be designed to provide the necessary electrical protection to the RTG as specified by the RTG Contractor.

If it is desirable to dump the excess power of the RTG during mission lifetime as electrical energy, the Using Agency will provide such a capability.

14. Envelope Size

The generator shall be dimensionally compatible with the envelope constraints as set forth in Figures 1 and 2 of the vehicle drawings.

15. Shielding

The maximum allowable total integrated radiation dosage to the payload at end of mission life is 20 rads at a distance of 208 inches ahead of the forward bulk head of the vehicles in Figures 1 and 2.

The following measured radiation from a bare source of Po metal shall be used:

	Energy (mev)	Abundance (particles/thermal watt-sec)
Gamma	0.8	1.4×10^{7}
X-Ray	0.077	1.7×10^{6}
	0.01 to 0.015	3.4×10^{8}
Alphas	5.3 (~ 100%)	1.1×10^{12}
	4.5 (1.22×10^{-3}%)	1.4×10^{7}
Neutrons	1.0 to 4.0	3100 metal 6200 GdPo-Ta

Self-shielding factor for the matrix fuel form shall be calculated by the Contractor.

16. Telemetry Sensors

The generator shall be designed with sufficient number of sensors to adequately indicate the operational condition. The electrical conditioning of the sensors' output will be provided by the Using Agency.

17. Safety

The generator shall be designed to assure complete containment of the fuel material except under certain limited conditions where loss of containment does not subject the populace to an undue hazard. No re-entry safety allowance can be taken for the re-entry vehicle and/or satellite. The normal mode of generator disposal will be by means of orbit termination by a controlled re-entry mechanism located on the satellite.

18. Orbit

The satellite vehicle will be launched from the Western Test Range with an orbital inclination of 97° (sun synchronous) at an altitude varying between 120 to 250 nautical miles.

19. Reliability

The generator shall be designed and tested to demonstrate a reliability of 0.998 at a 50% confidence level. This reliability shall be based on component life test mean-time-between-failure (MTBF) data.

20. Environment

a. Vibration

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During boost and ascent, the generator will be exposed to vibrations as follows:

Sinusoidal

Freq. Range (cps)	Amplitude
5-14	0.5 inches peak to peak
14-400	5g
400-3000	15g

Random

Freq. Range	Spectral Density (g^2/cps)
20-400	0.20
400-2000	0.40

During the non-powered orbital flight, the vibration level will be near zero. For test purposes, the equipment should be able to withstand the specified sinusoidal vibration levels for 25 minutes in each of three orthogonal axes and the random levels for a period of five minutes, similarly oriented.

b. Pressure

The absolute pressure during ascent is reduced from sea level to 25 mm of Hg in approximately 90 seconds. A maximum pressure reduction rate of 15 mm of Hg per second takes place in the transonic region for a maximum duration of 30 seconds.

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c. Shock

During ascent, the generator may be exposed to a shock of 40g for a duration of 8 milliseconds. The equipment shall be designed to withstand such a shock applied in each of three orthogonal axes.

d. Acceleration

The power supply shall be designed to withstand an acceleration of 15g peak axially and 2g in both lateral axes. The time of duration shall be supplied by the User.

e. Acoustic

The generator shall be designed to withstand an acoustic-sound pressure level of 144db.

f. Electromagnetic Interference (emi)

The power supply shall be designed to meet the standards in MIL-E-6051C and MIL-STD-826.

g. Radiofrequency Interference (rfi)

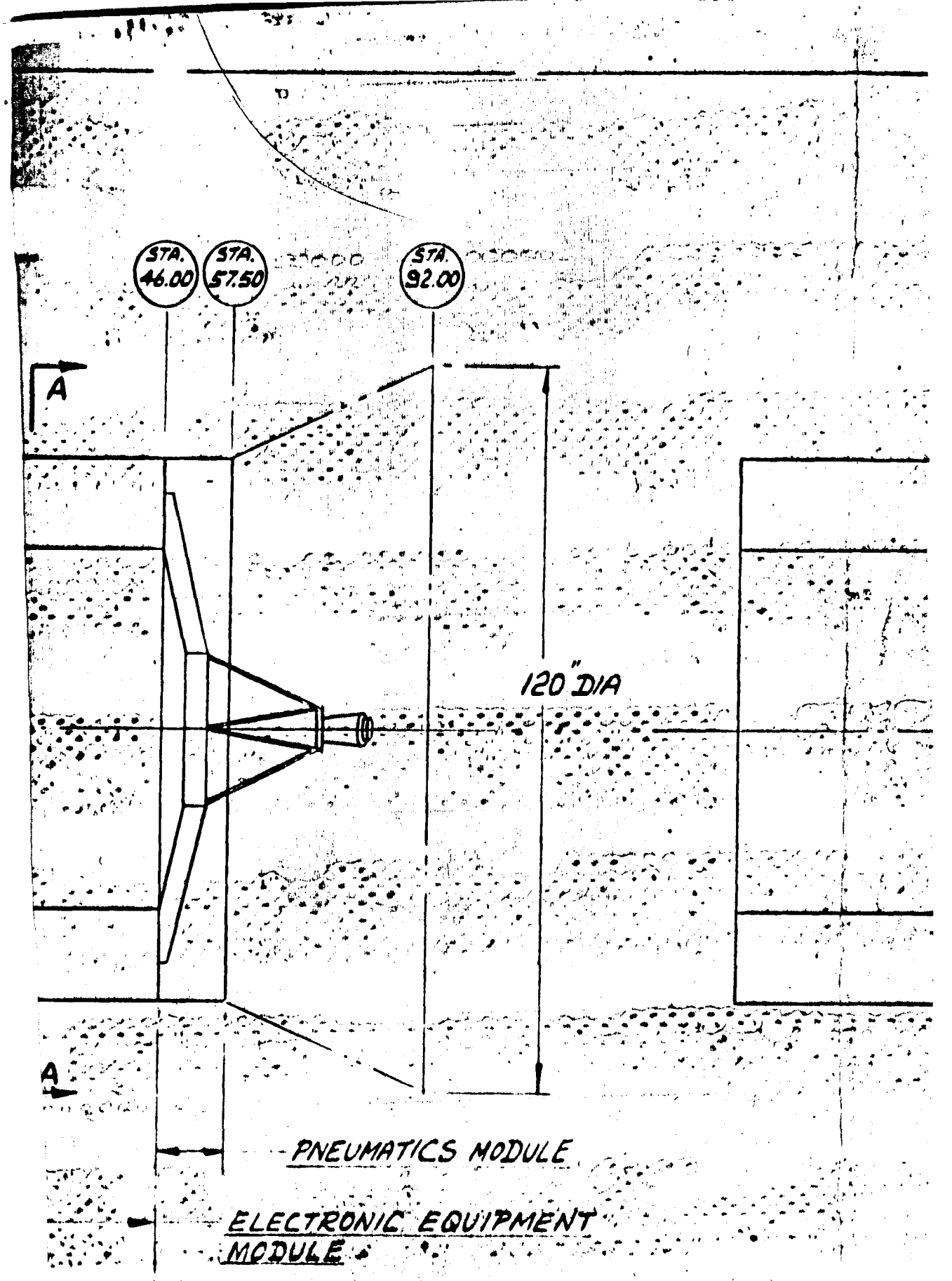
The power supply shall be designed to meet the standards in MIL-E-6051C.

NOTE: The polonium properties have been reviewed and corrected. The corrections are incorporated into this memo.

Original Signed by
JAMES A. POWERS

James A. Powers

JAP: kh



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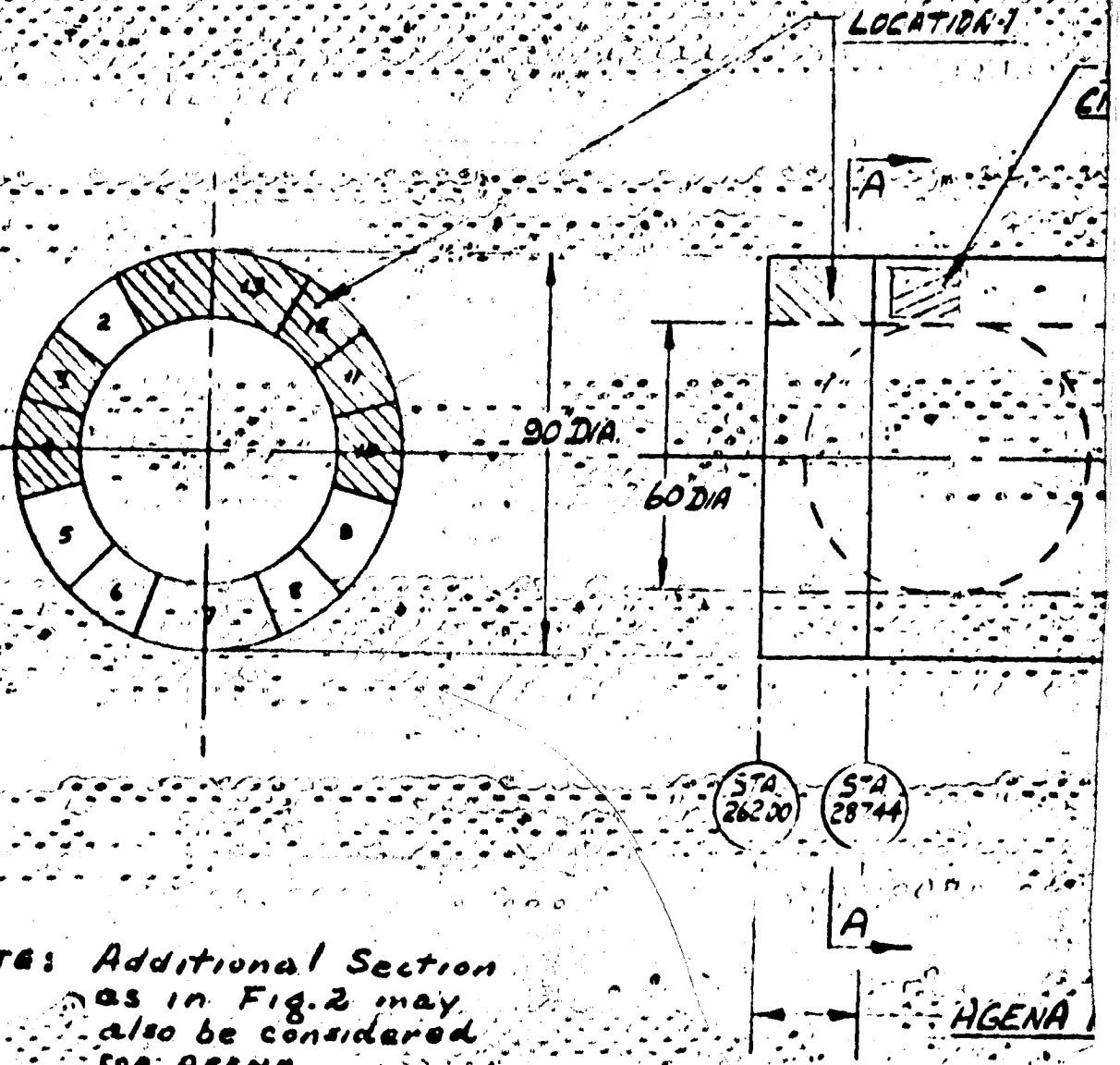
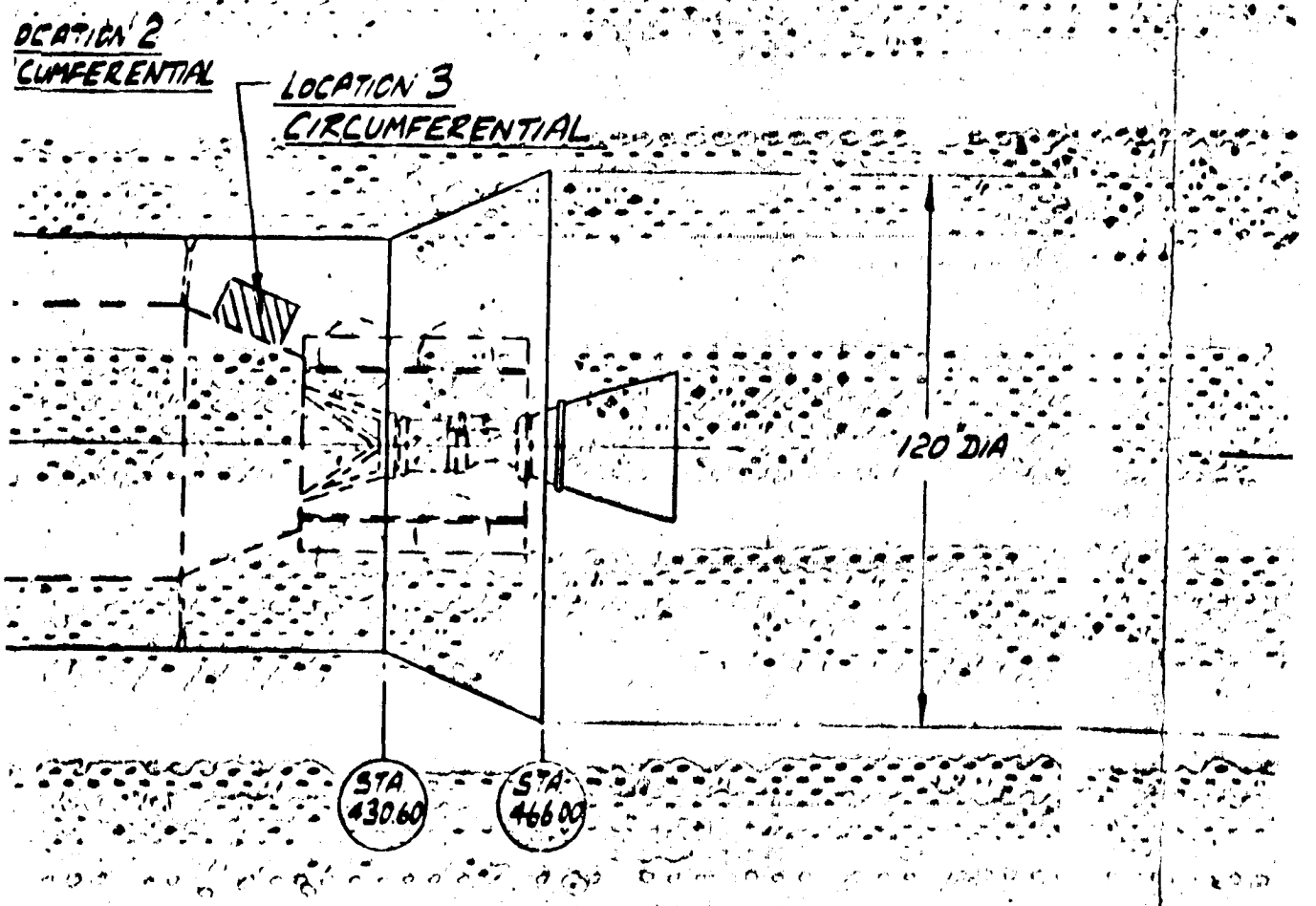


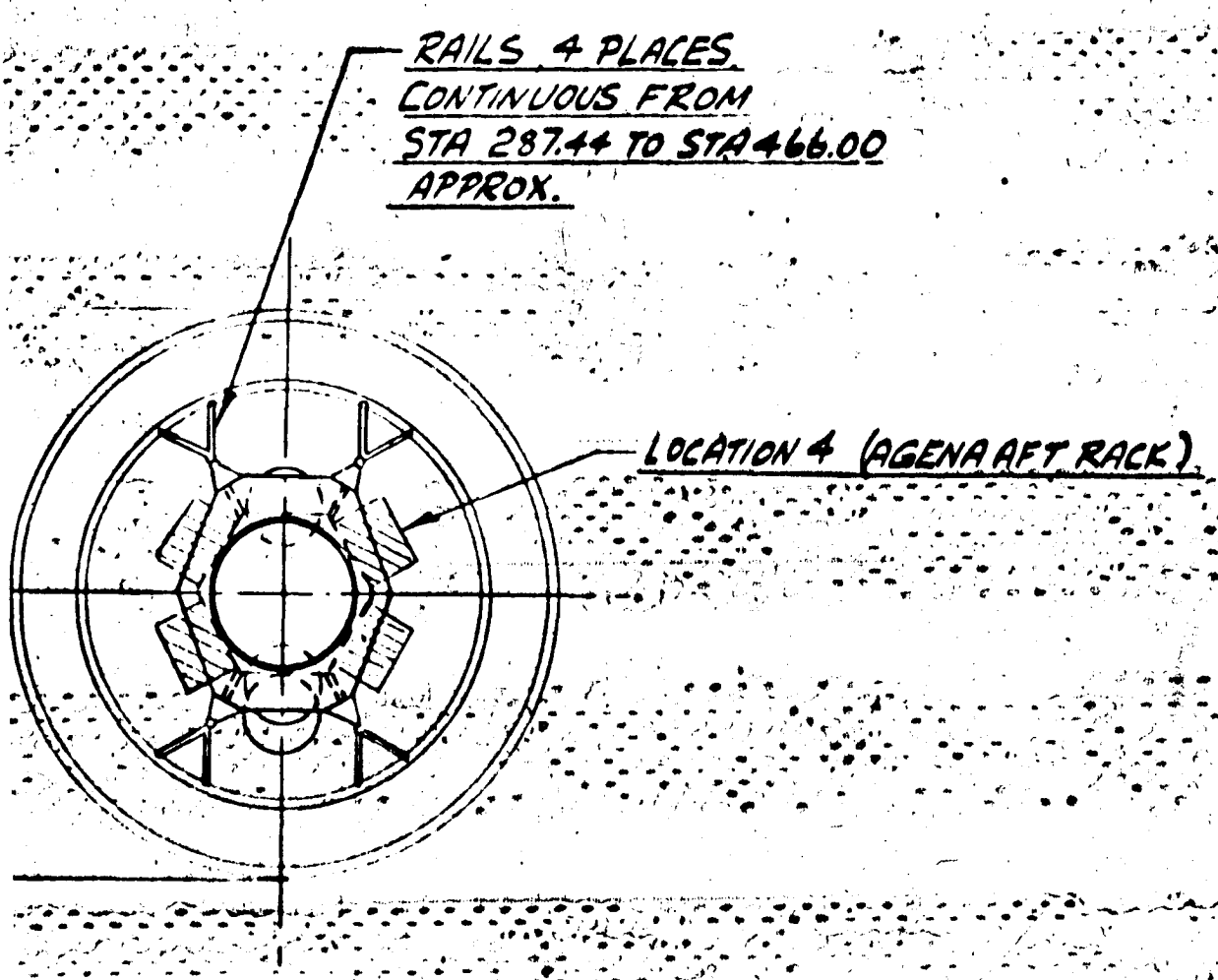
NOTE: Additional Section as in Fig. 2 may also be considered for AGENA



WD EQUIPMENT SECTION

NOTE:- LOCATIONS 1, 2 & 3 TO LOCATION 4.

FIGURE 1



ARE PREFERABLE

POSSIBLE RTG LOCATIONS

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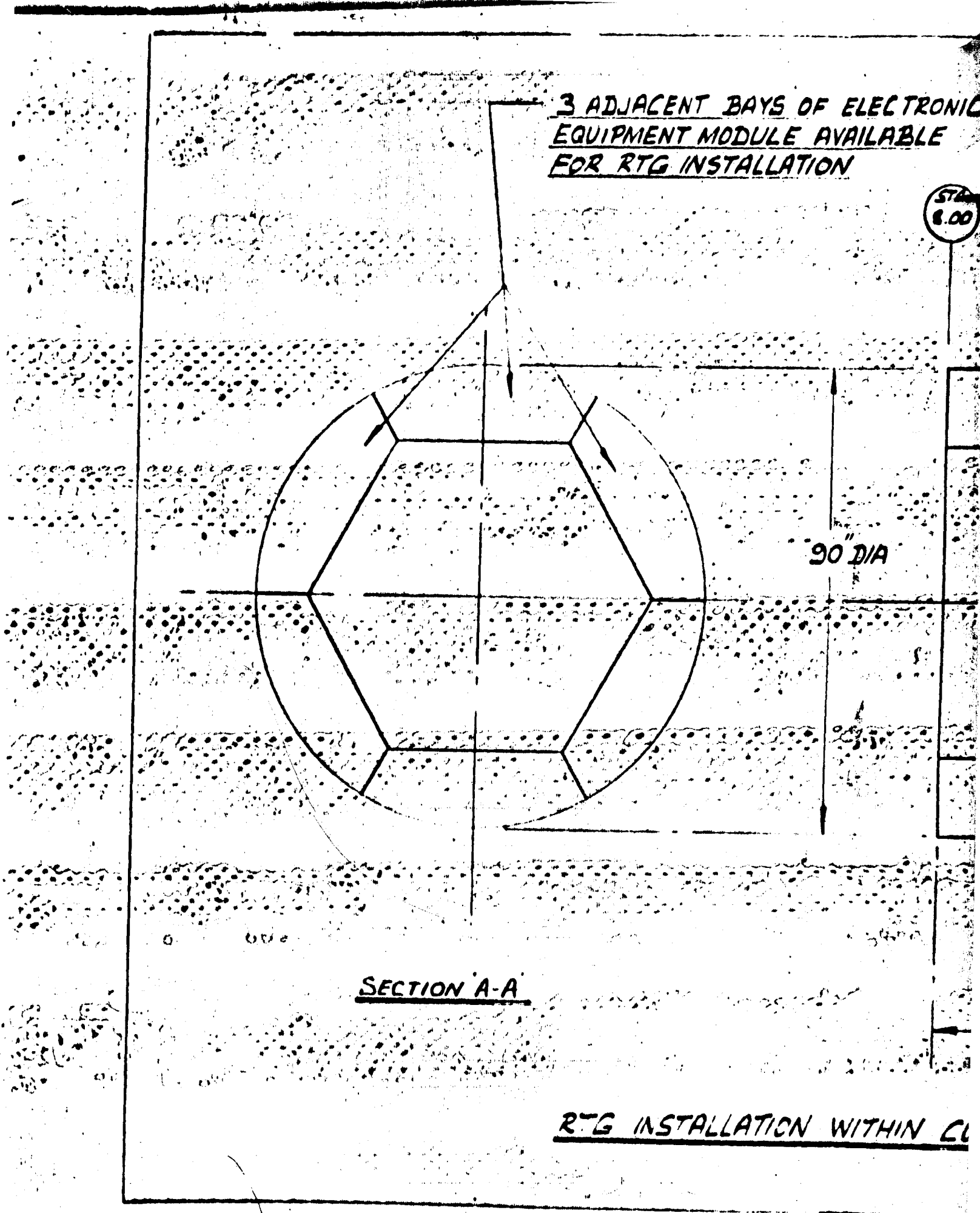
3 ADJACENT BAYS OF ELECTRONIC
EQUIPMENT MODULE AVAILABLE
FOR RTG INSTALLATION
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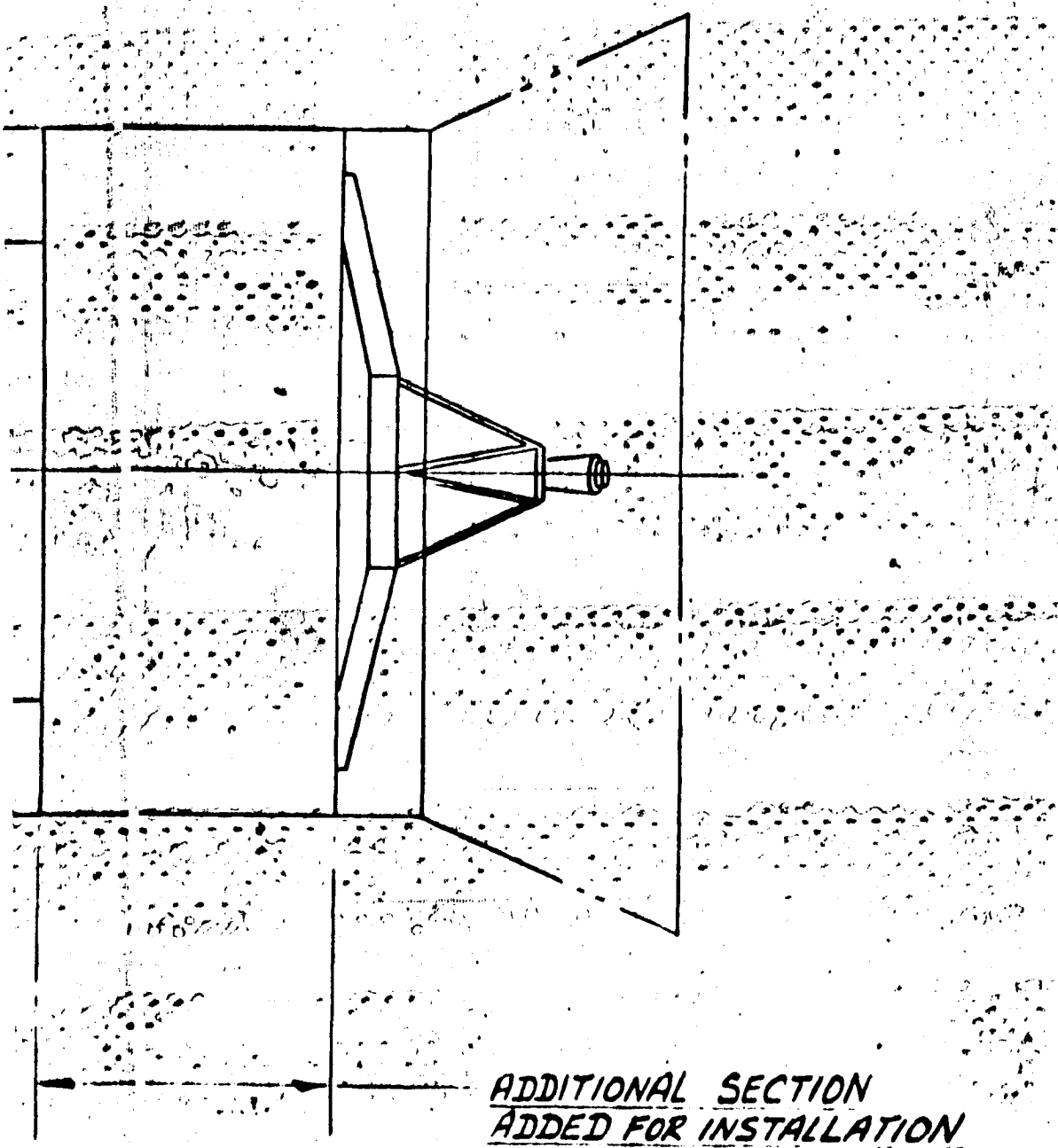
SECTION A-A
RTG INSTALLATION WITHIN CU

FIGURE 2



ATE RTG INSTALLATION IN
ADDITIONAL SECTION

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