I. POWER SYSTEMS IN PERSPECTIVE

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A short introduction to place this overall review of progress in space power systems advanced technology in context is appropriate. Although many points are made which are obvious to anyone working in the space power field, they are necessary to place the whole conference in perspective. The discussion is in two parts: power systems that are currently in use and advanced power systems.

The chemical power system most used has been the battery. A brief survey revealed that from the time NASA was organized until May 1966 there have been 138 space flights and over 700 sounding rockets flown. Every booster and sounding rocket used a battery for power, and every payload had a battery aboard it somewhere. Even the two large Echo balloons had small supplies aboard to power radio beacons, and these included batteries. The first flight which did not have a battery in the payload was Pageos, the passive geodetic satellite, which was another large balloon flown in June 1966.

Another chemical power system in use recently is the hydrogen-oxygen fuel cell. The Gemini fuel cell (fig. I-1) is one of the two modules that together provide an average power of a little under 1 kilowatt. The Apollo fuel cell (fig. I-2) is one of three modules that provide an average power level of a little less than $1\frac{1}{2}$ kilowatts. Fuel cells are the lightest power supply for durations of a few days to a few weeks. About 5 years ago fuel cell technology was just being firmly established. Today the fuel cell power system is in use.

These are the chemical power systems in use. The only solar power system in use is the solar photocell. It has been the workhorse long-time power supply since NASA's inception and has been a very reliable power system. The solar cell arrays are lightweight, but energy storage weights for dark periods are heavy for some missions. An important trend in recent years has been a growth in the size of photocell arrays. In the early days of NASA, the power levels of photocell arrays were at the most a few tens of watts. Recently larger arrays have been flown. The largest array flown by NASA was on the Orbiting Astronomical Observatory (OAO) (figs. I-3 and I-4). The solar panels are 114 square feet in area and produce a power of somewhat under 1 kilowatt. A still larger array producing $1\frac{1}{2}$ kilowatts has been flown by the Air Force. An artist's sketch of that array on the Agena vehicle is shown in figure I-5. Figure I-6 shows one wing of the 19-foot-long, 5-foot-wide $1\frac{1}{2}$-kilowatt array. The array, folded around the rocket engine of the Agena, is shown in figure I-7.

The only nuclear power system in use is the radioisotope thermoelectric generator (RTG). Isotope thermoelectric systems appear to be very reliable. Although heavier than the photocell arrays, they require no energy storage for dark periods and no orientation. However, nuclear safety must be assured for each application. SNAP-9A, a 25-watt RTG, has been flown on a

Navy navigation satellite. The first NASA use of isotope thermoelectric systems will be on Nimbus B. Nimbus B (fig. I-8) uses two SNAP-19 radioisotope thermoelectric generators (fig. I-9) for supplementary power to the main photocell supply. Each unit produces 30 watts of unconditioned power. The SNAP-19 is 22 inches across the radiator fins and 11 inches long and weighs about 30 pounds.

As in the case of fuel cells, 5 years ago the technology of radioisotope thermoelectric generators was just being firmly established. Today they are reaching mission use.

These are all the power systems actually in use. Rather conspicuous by their absence are any power systems using reactors and providing the large powers associated with reactor power systems. They are absent primarily because the development of large reactor power systems has been more difficult and time consuming than anticipated about 5 years ago. One reactor power system has flown; that is the SNAP-10A, a 500-watt reactor thermoelectric system, which has been flown on a test flight although it has not been used on missions. The 500-watt power level is low for reactor thermoelectric systems and therefore the probability is reduced that SNAP-10A will have mission use. However, the technology acquired is being used to develop larger systems.

The technology program work on these systems, batteries, fuel cells, solar cells, and radioisotope generators, is described in papers II to IV. Later presentations discuss power systems which are not in use, or advanced power systems.

The three principal power systems not in use on which the Lewis Research Center is working are the Brayton-cycle, gas-turbine power system; the Rankine-cycle, vapor-turbine power system; and the thermionic emitter. Some of the characteristics of these three power systems are as follows:

System	Characteristics
Brayton	High efficiency Large radiator area Considerable existing technology
Rankine	Lowest weight for given temperature level Smaller radiator area than Brayton cycle Two-phase, liquid metal system
Thermionics	Very high temperature High power density Smallest radiator area of the three systems

The thermionics system requires temperature levels considerably higher than the other two systems for its operation. However, if these temperature levels can be achieved, it offers high power density, the smallest radiator area, and a weight as good as the weight of the Rankine system at the lower temperature levels. In addition, it is a static system built of small modules with the redundancy of parallel connections.

The three heat sources, solar, isotopic, and reactor, and the power conversion system or systems which currently appear to be the most interesting for these heat sources are as follows:

Heat source	Power conversion system
Solar	Brayton
Isotope	Brayton
Reactor:	
SNAP-8	Mercury Rankine, thermoelectric
Advanced	Brayton, potassium Rankine, thermionic

This listing is not meant to imply that these are the only power systems of interest in an absolute sense, but that, at this time, they appear to be the most attractive. Further technology work might very well change this viewpoint. For solar and isotopic heat sources, efficiency is important. In solar power systems, large collectors are required. The higher the efficiency, the smaller the area of the collector. Isotopes are of limited availability and high cost. High efficiency which will reduce the requirements for these isotopes is desirable. The desire for high efficiency leads to the interest in the Brayton cycle for these heat sources. In addition, power levels of interest for solar and isotope systems are from a few kilowatts to a few tens of kilowatts as compared with tens to hundreds of kilowatts for reactor systems. At these lower power levels, the large radiator area of the Brayton cycle is a lesser handicap.

In considering reactor heat sources, an important feature arises immediately. Only one reactor, the SNAP-8, is sufficiently developed to be usable for missions of the 1970's. The technology of advanced reactors is not far advanced, and apparently it will be the late 1970's or 1980's before any of these reactors might appear in mission use. The SNAP-8 reactor is a liquid-metal-cooled reactor with a peak coolant temperature of 1300° F. In the late 1950's, the mercury Rankine power conversion system was chosen as the power conversion system for the SNAP-8. The choice was made because the Rankine system had both low weight and small radiator area. The SNAP-8 is the only reactor power system fully committed to development at this time. Some technology work is being done on thermoelectric converters which could be used with the SNAP-8 reactor. For an advanced reactor, all three power conversion systems are possible choices. Not enough technology work has been completed to determine which system is best. Technology work is being conducted on all three power conversion systems in order to make this determination.

These various advanced systems, the Brayton cycle, SNAP-8, the potassium Rankine cycle, and thermionics, and how they might fit into the future missions of NASA are discussed in papers V to X.

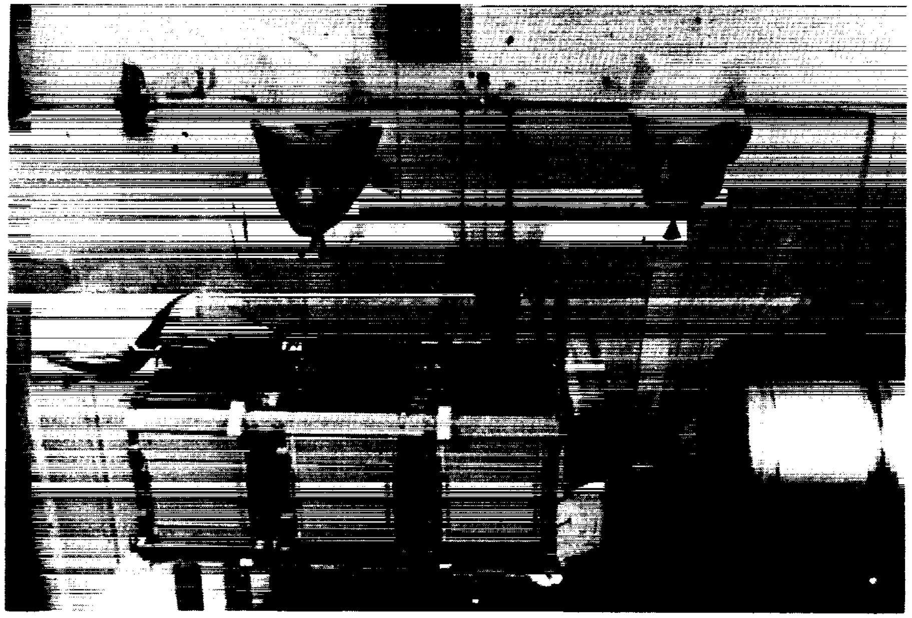

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Figure I-1. - Gemini fuel cell.

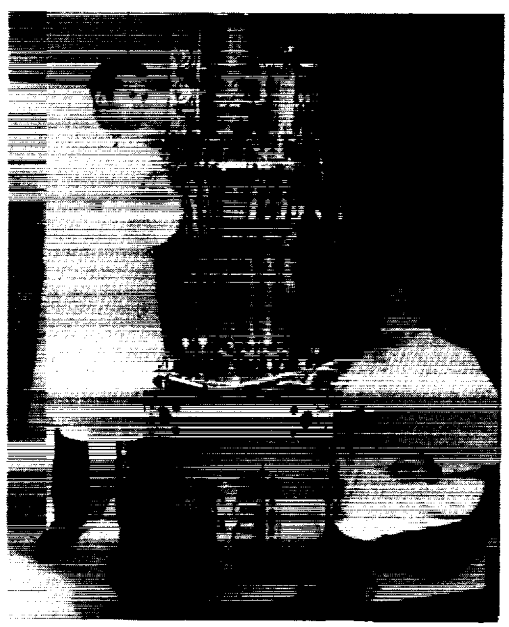

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Figure I-2. - Apollo fuel cell.

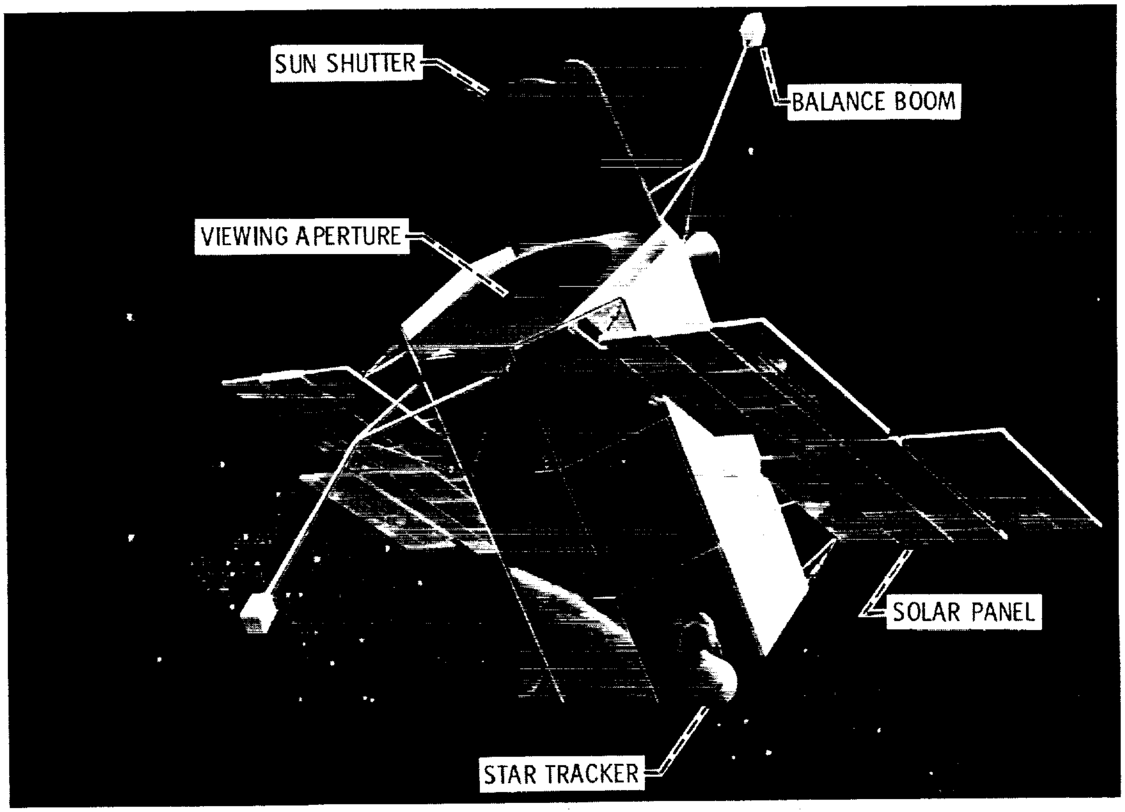

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Figure I-3. - Orbiting astronomical observatory (OAO).

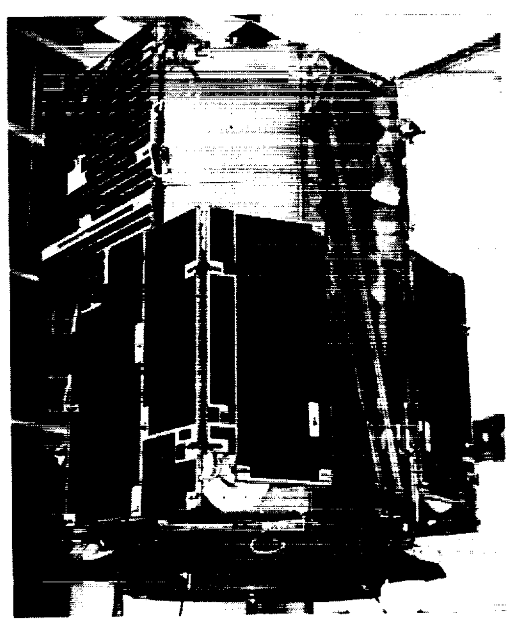

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Figure I-4. - OAO with solar panels folded.

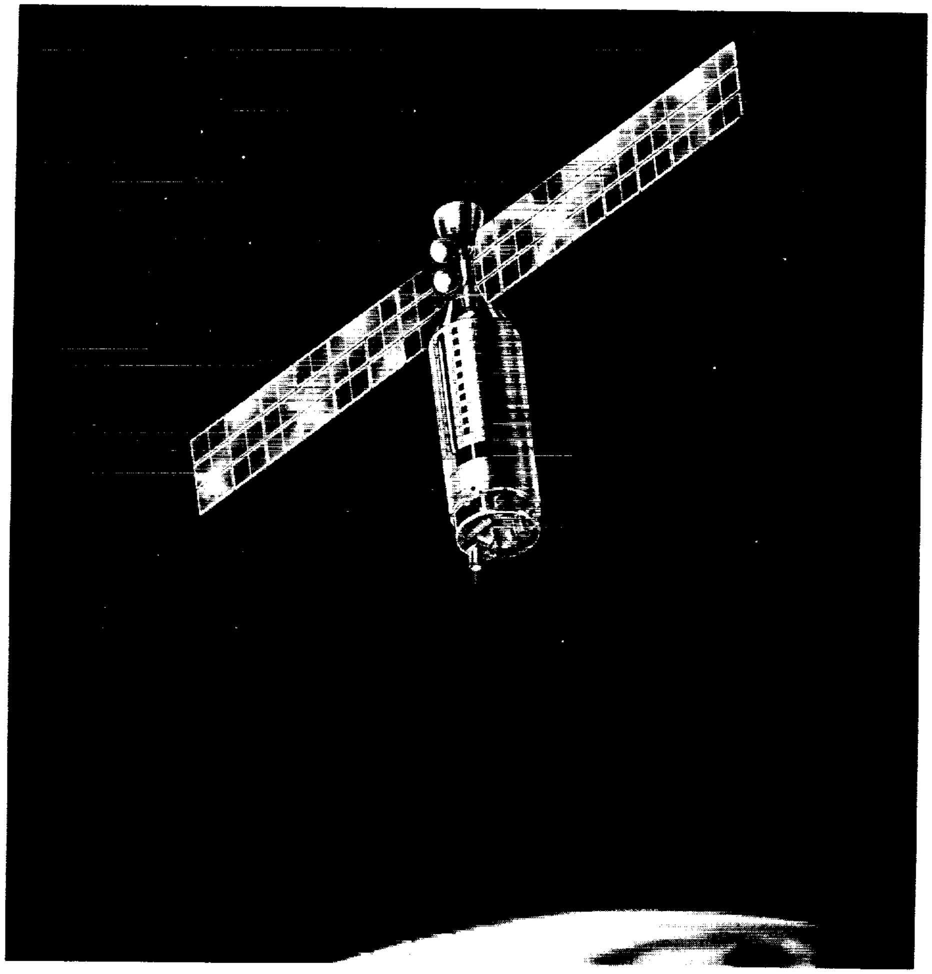

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Figure I-5. - 1.5 Kilowatt solar cell array on the Agena.

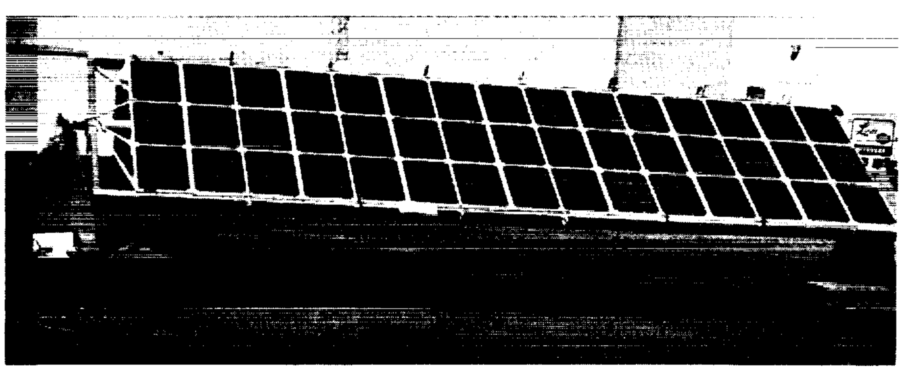

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Figure I-6. - One-half of 1.5 kilowatt solar cell array.

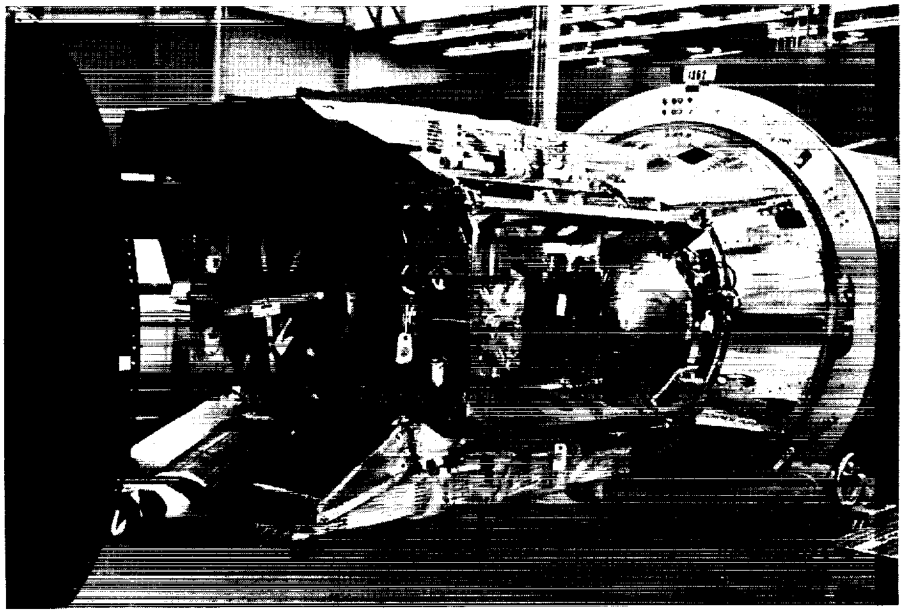

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Figure I-7. - Folded solar cell array.

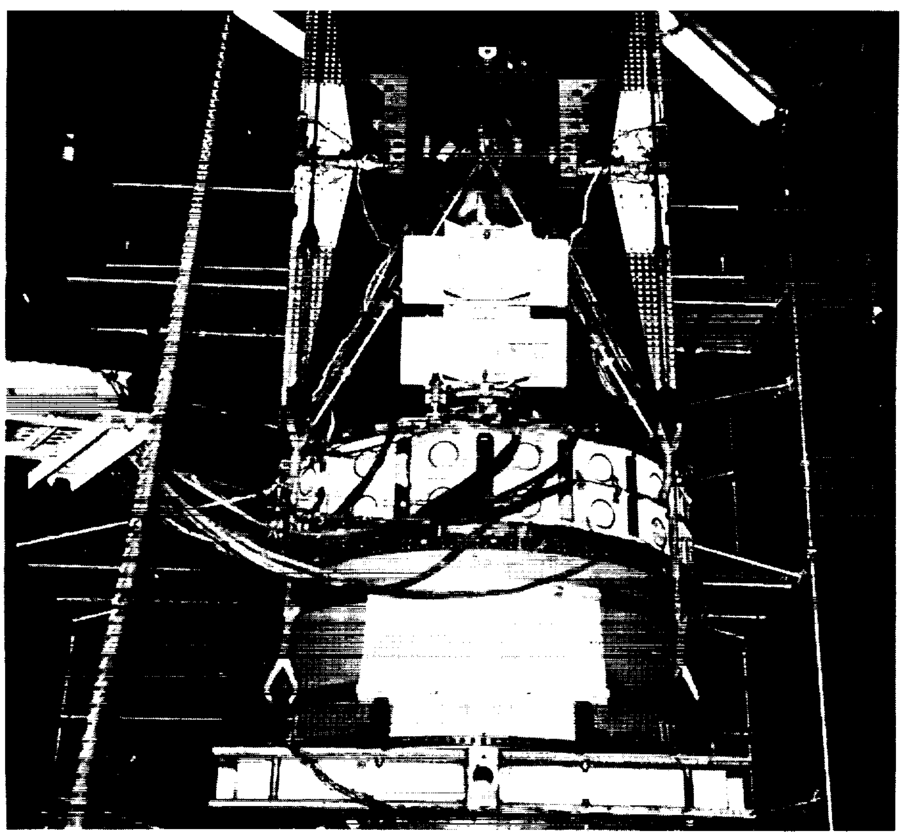

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Figure I-8. - Nimbus with SNAP-19 generator.

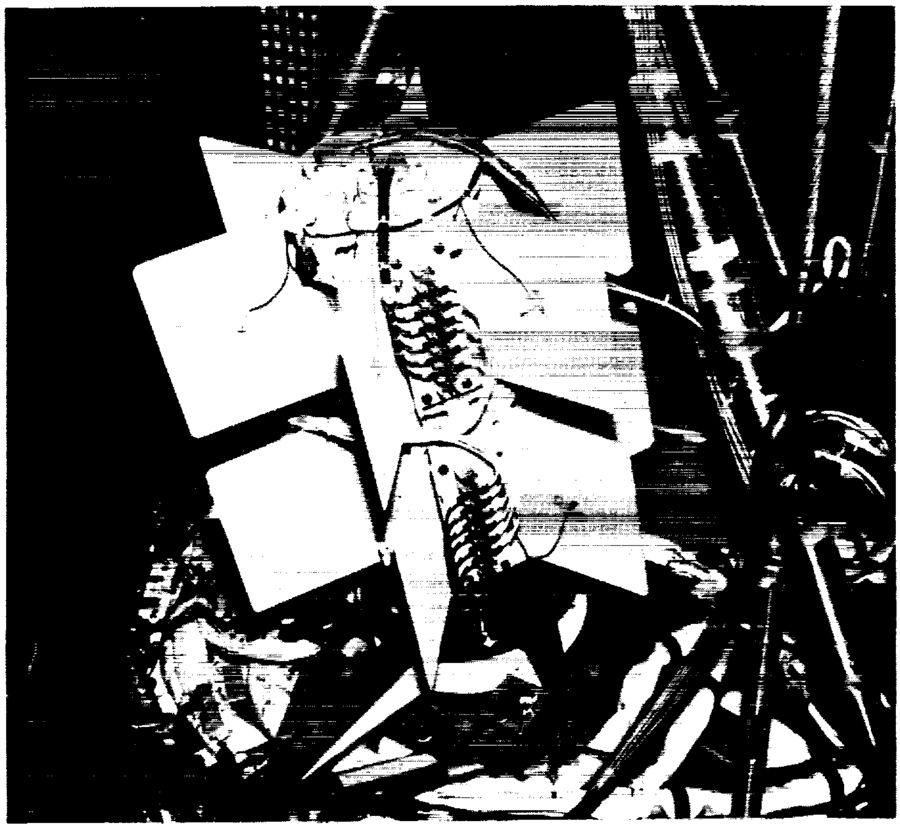

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Figure I-9. - Closeup of SNAP-19 generator on Nimbus.