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DEVELOPMENT PROGRAM FOR A 200 kW, CW, 28-GHz GYROKLYSTRON

H. Jory, C. Conner, S. Evans, J. Moran, R. Symons, N. Taylor

Quarterly Report No. 14

July through September 1979

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Prepared by
Varian Associates, Inc.
Palo Alto Microwave Tube Division
611 Hansen Way
Palo Alto, California 94303

for
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830

operated by
UNION CARBIDE CORPORATION

for the
DEPARTMENT OF ENERGY

Contract No. W-7405-eng-26

DEVELOPMENT PROGRAM

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ABSTRACT

The objective of this program is to develop a microwave oscillator capable of producing 200 kW CW power output at 28 GHz. The use of the gyrotron or cyclotron resonance interaction is being pursued.

Testing of miter bend tube S/N 2R9 was continued beyond the work described in Quarterly Report No. 13. It failed at 63 kW CW after several hours of operation, due to a cracked collector ceramic. The succeeding miter bend tube, S/N 7, incorporates several changes intended to reduce the heating of that ceramic.

Tube S/N 5, an axisymmetric tube, was pulse tested to 195 kW at 1.2% duty. After consultation with ORNL, tests were interrupted and the test station was assigned to tube #7.

Most of the assemblies of tube S/N 6, another axisymmetric tube, were completed. However, it was decided to delay completion of the tube to allow incorporation of a revised collector ceramic design.

I. INTRODUCTION

The objective of this program is to develop a microwave amplifier or oscillator capable of producing 200 kW of CW power at a frequency of 28 GHz. In addition, it is intended that the program will serve as the first step toward development of a device to produce a similar power level at a frequency of 110 GHz. Feasibility for the 110 GHz device will be demonstrated, whenever practical, in the design of the 28 GHz gyrotron. Tunability or bandwidth is not considered an important parameter in the design, but efficiency is. Mode purity in the output waveguide is not a requirement for the device, but the circular TE mode is considered desirable because of its low loss properties.

With these objectives in mind, the decision was made to pursue an approach based on a cyclotron resonance interaction between an electron beam and microwave fields. The detailed arguments leading to this choice are contained in the final report of the preceding study program[1]. The device configuration of particular interest, called a gyrotron, has been discussed in recent Russian literature[2]. It employs a hollow electron beam interacting with cylindrical resonators of the TE_{0m1} class. The experimental gyrotrons described in the literature have all been of the form of single-cavity oscillators. However, a similar device[3] has demonstrated moderate (16 dB) gain as an amplifier.

The optimum beam for the cyclotron resonance interaction is one in which the electrons have most of their energy in velocities perpendicular to the axial magnetic field. Another requirement is that the small component of axial velocity be essentially the same for all electrons. An electron which has a different axial velocity will not interact efficiently. Generation of a beam with high transverse velocity and small axial velocity spread is another important design problem.

The approach chosen to generate the beam is a magnetron type of gun like the one used in the devices described in the Russian literature. With this type of gun, the shaping of the magnetic field in the gun region becomes quite important.

As a result of the excellent performance of the pulsed oscillator, producing up to 248 kW of peak power at 28 GHz with good efficiency[4], the emphasis of the program has been shifted to stress the construction and delivery of CW oscillators.

During the period covered by this report, two tubes intended for CW operation; serial number 5, an axisymmetric output type, and serial number 2R9, a miter-bend output type; were operated under pulsed conditions and another pair, with the same two types of output arrangements (serial numbers 6 and 7) were in different stages of construction. The following observations on these tubes are reported here in the order in which they were tested or assembled.

II. CW OSCILLATOR NO. 2, NINTH REBUILD (S/N 2R9)

The changes specific to this miter bend output tube were described in Quarterly Report No. 13. At the time of that report, the tube had been pulse tested to slightly over 100 kW peak at 20% duty, also 16 kW of CW power had been obtained.

The specific goal for this tube was operation on EBT-S at the 50 kW level. To achieve this, the testing was to be carried out at the 60 kW level for a total period of 10 hours. It was expected that the tube would run uninterupted for periods of at least 30 minutes during the 10 hours of operation.

The CW power level was increased gradually to a value of 63 kW. Difficulty was experienced in keeping the tube "on" at this level for more than a few minutes because of activation of the crowbar by power supply overcurrent. The overcurrents were caused by either transient gas bursts or microwave power reaching the gun.

During the testing of tube #2R9, the temperature of the heliarc weld in the vicinity of the collector ceramic was monitored using thermocouples. Careful rf shielding was necessary to prevent erroneous readings due to rf power radiating through the collector insulator.

After several runs of approximately one hour duration, the collector ceramic cracked and the tube went "down to air". Figures 1 and 2 show the crack highlighted by dye. It would appear that circumferential stress created by the nonuniform power flow through the ceramic and the heating due to rf losses in the ceramic and adjoining metal parts caused the failure.

Discussion of Collector-Resonance Induced Instabilities

Under a given set of operating conditions, the gyrotron will oscillate at a frequency which is determined by parameter values and by the nature of the microwave load. Included in the microwave load is some coupling to a highly reactive collector. Cold testing indicates a high density of

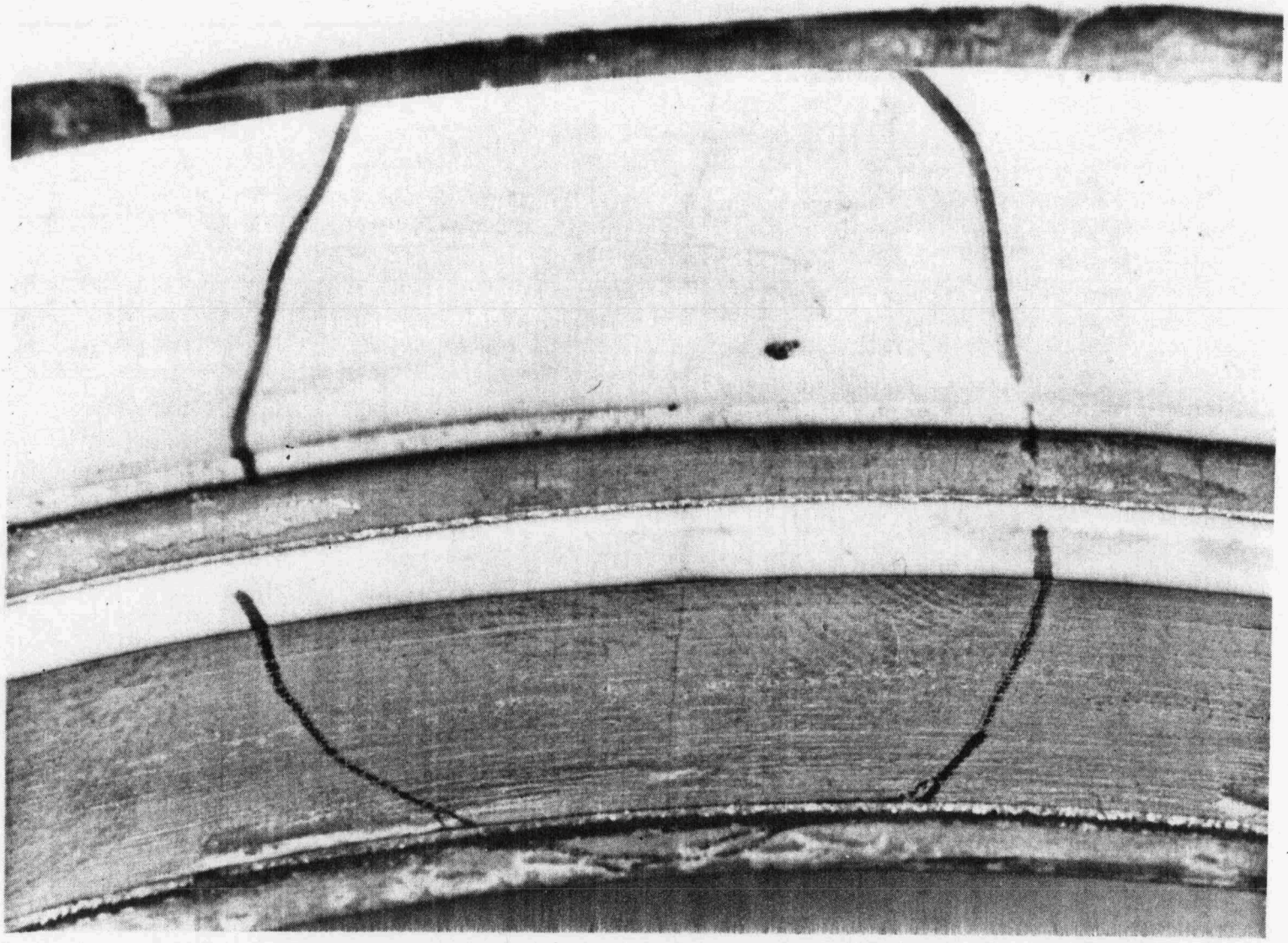

FIGURE 1. VGA-8000 S/N 2R9 COLLECTOR CERAMIC (INNER AND END SURFACES)

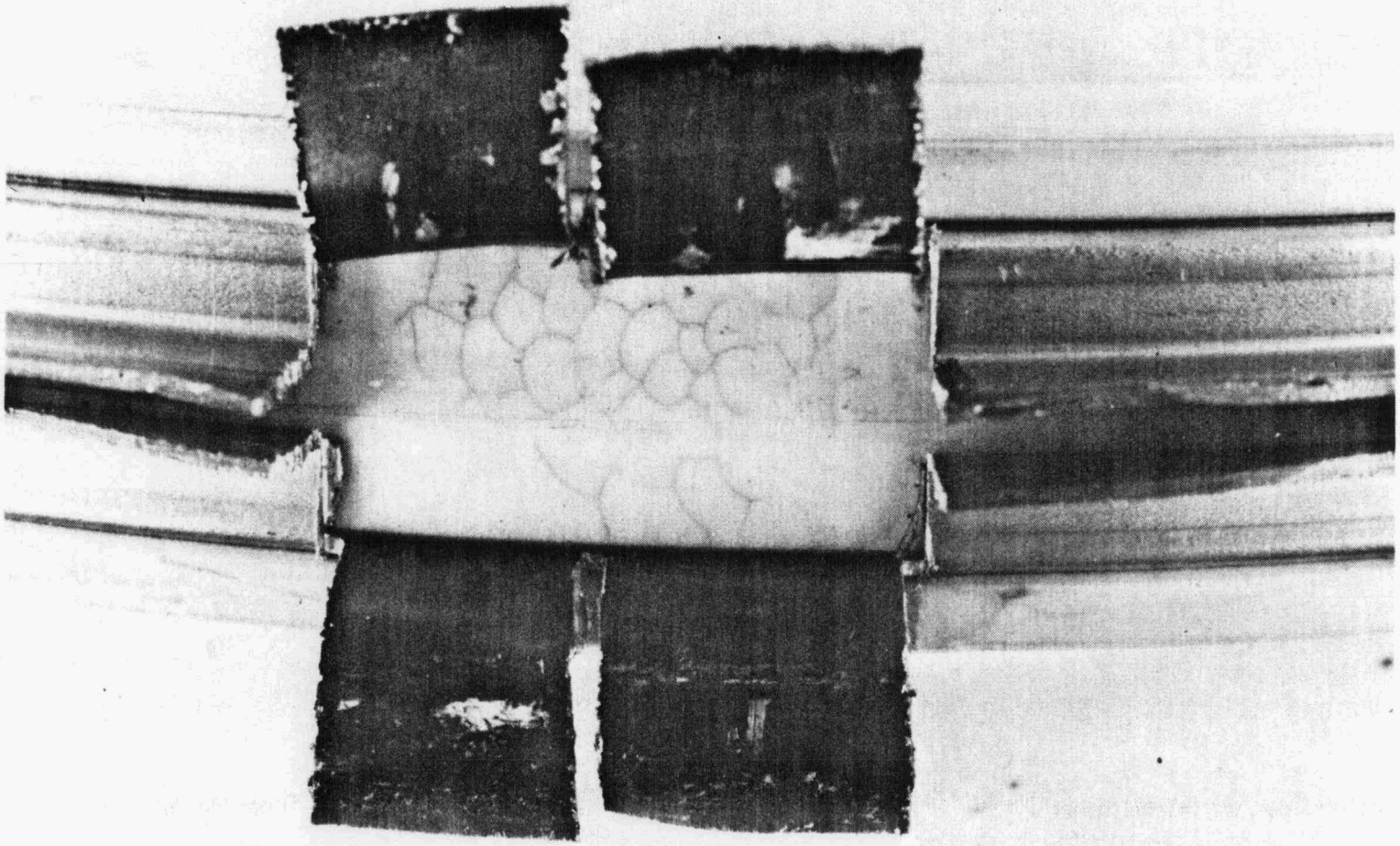

FIGURE 2. VGA-8000 S/N 2R9 COLLECTOR CERAMIC (OUTER SURFACE)

collector resonances which perturb the resonance curve of the gyrotron cavity. While these perturbations do not grossly affect the interaction with the electron beam, the high Q resonances causing them have different distributions of microwave stored energy and energy loss in the collector, as well as in the collector insulator region. A jump from one resonance to another in the collector can result in transient gas bursts, which, upon reaching the gun, may cause a gun fault. To minimize this problem, tubes must be processed over a fair range of parameters with gradually increasing power levels. However, even after following such procedures and successfully operating for extended periods of time under a particular set of conditions, a change in frequency could cause sufficient out-gassing due to rf power redistribution in the collector to cause a crowbar firing.

The proposed solutions to such instabilities involve means to (1) minimize the rf coupling of the gyrotron cavity to the collector and (2) to reduce the Q of the collector resonances. Tube number 7 incorporates both such improvements, where the Q-damping is accomplished by closely coupling an external microwave load to the collector through a 2.5-inch diameter guide at the top of the collector.

III. TUBE NO. 5R1

Tube number 5R1 was returned to test after reassembling and reprocessing. The two discs of the window were carefully positioned within the desired limits. Under 1.2% duty pulsed conditions a peak power output of 195 kW was measured. This is the highest peak power attained in the program to date on a tube designed for CW operation. The frequency versus magnetic field characteristic with the readjusted window, was improved (as shown in Figure 3) but was still not as broad as had been obtained in earlier pulsed tube designs with single disc output windows. A small readjustment gave further improvement in the frequency characteristic but the maximum power output was essentially unchanged.

The reduction in loaded Q of the cavity, from about 1400 to eventually 450, affected the operation of the tube in other ways beside the increase in efficiency. It was more difficult to bring the tube into oscillation in the TE_{021} mode. There was a marked tendency for oscillation to start in the TE_{221} (26.7 GHz) mode, for example. This was prevented by increasing the current in magnet number 2; however, the tube still required patience to bring into oscillation. This is, of course, the effect one would expect; the lower the loaded Q of the desired mode, the harder the starting.

Operating CW, the tube was run 1/2 hour at 48 kW, (4A, 70 kV) and (1/2 hr + 1/2 hr + 3/4 hr) at 66 kW, (6A, 80 kV). When the cooling water was turned on the collector and body the morning after 66 kW operation, a small leak developed in the collector ceramic seal (ion pump pressure 10^{-7} torr). The leak appeared to be in the braze and was readily stopped by applying sealant. The previous pulsed measurements were then reproduced, i.e., 190 to 200 kW of peak power at 1.2% duty. Before returning to CW operation, however, it was decided through consultation with Oak Ridge, to postpone further testing of number 5 and instead to proceed with testing miter bend tube number 7 for EBT-S.

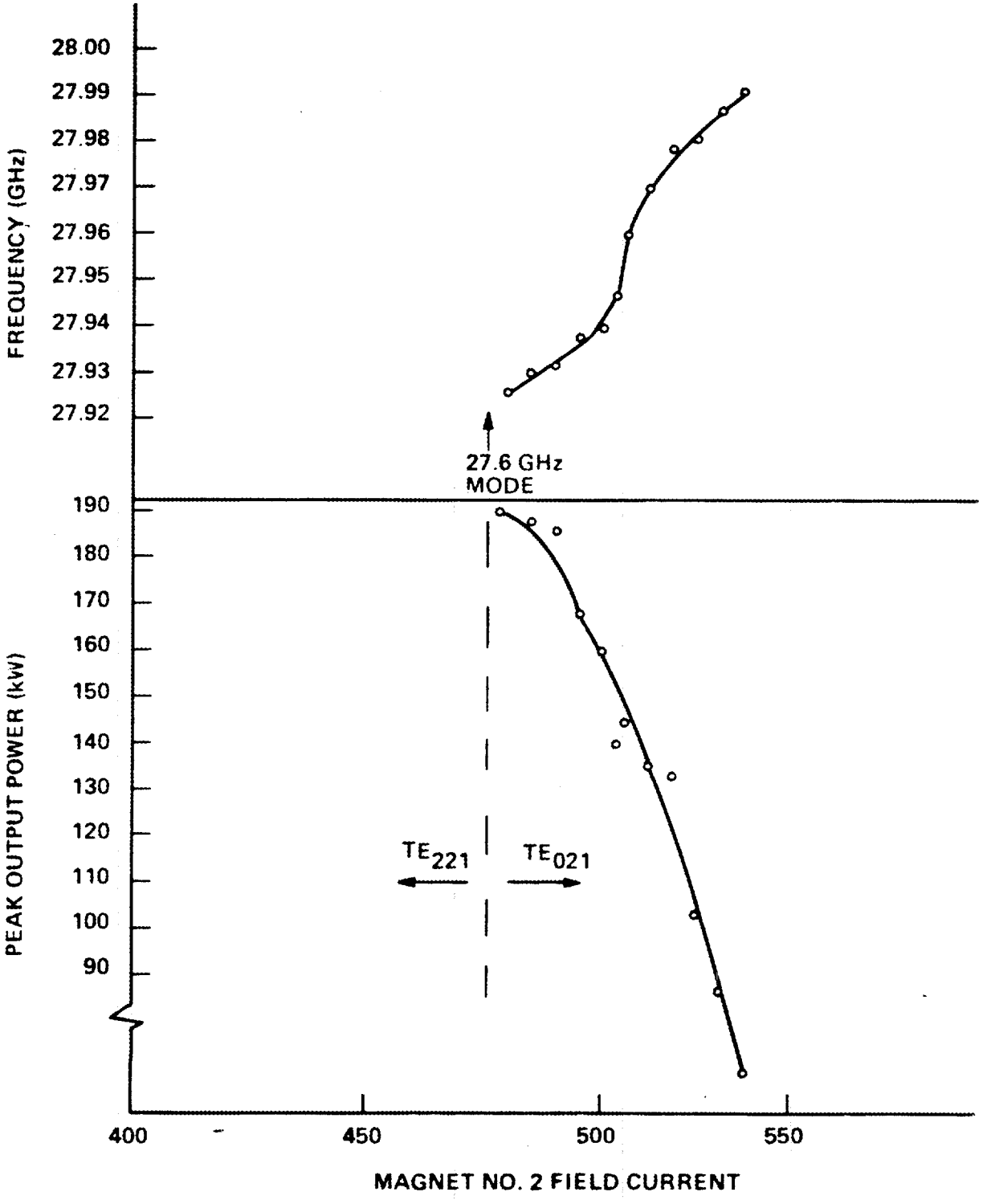

FIGURE 3. FREQUENCY AND POWER CHARACTERISTICS FOR CW TUBE NUMBER 5R IN PULSED TESTING

IV. TUBE NO. 7

This miter bend tube with reduced collector coupling and increased collector loading provided a pulsed rf output of 120 kW at 80 kilovolts, 8 amperes and 1.2% duty. Only part of the low output could be attributed to the high loaded Q (750) that was chosen for this tube. The choice of Q was very advantageous as far as ease of starting oscillation in the proper mode. This, combined with the reduced coupling to the collector (smaller diameter drift tube, to cut off the TE_{21} mode at the operating frequency), the increased collector loading (waveguide output, plus Kanthal on the lower collector cone), and the selective mode suppression in the cavity resulted in an exceptionally well behaved tube.

An attempt to change the loading by adjusting the window spacing resulted in a fractured outer window due to the pressure of the contained FC-75 between the Hansen fittings. This outer window was replaced, the pulsed results checked, and CW measurements then started. In less than 2 days the CW rf power output was brought up to the 50 kW level.

Failure of some polyethylene tubing used in the collector waveguide water load then occurred due to local overheating. This necessitated removing the tube and magnet, disassembling and drying the individual magnet coils and removing the water from the HV oil tank.

In repeating the operation with a new conical-ceramic collector water load in place, the 50 kW to 60 kW level was quickly reattained. Following one day of exploratory operation, the tube was run for 10 hours in the range of 65 to 70 kW; a summation of operating periods, each of which was greater than 1/2 hour and two of which individually exceeded 1 1/2 hours.

During various stages of testing the tube, cycling of the emission current level was observed for a period of 1 to 4 minutes. Typical current variation for the cycling is from 7.4 amperes to 9 amperes, although under one set of conditions, it varied from 5.5 amperes to 8.4 amperes.

There are currently two separate possible explanations for the cycling behavior, both involving mechanical problems in the gun. One is the cracking observed in the heater's ceramic potting material and the other is the cracking of a weld in a cathode support member. Investigation of both suspected problems determined the weld cracking could be prevented by minor modifications to the existing parts. These modifications will be incorporated immediately in all new guns. The cracking of the ceramic potting could best be dealt with by redesigning the assembly with radiant cathode heating. Work on this approach has begun, however, the tubes will not have the new design before March of next year.

Fortunately, rf performance of tube number 7 is so stable that no real problem results even during the cycling emission. In addition, if the filament is heated rapidly, by initially holding its heating current at 9 amperes rather than at 6 amperes, the assembly appears to mechanically "lock" itself in a stable equilibrium configuration and emission cycling is eliminated or greatly reduced.

After running the 10-hour test, an additional hour of sensitivity measurements were made during which all of the test parameters were varied slightly and the output power and frequency changes recorded (Figure 4).

It was noted that for a 10% change in modulating anode voltage there was a corresponding 45% change in output power. In looking at the beam voltage variation it was seen that for a 1.8% change in beam voltage there was a 19% change in output power (Figure 5). A 10% change in beam current resulted in a 20% change in output power.

It is of note that the tube remained "on" during all of these variations of operating conditions.

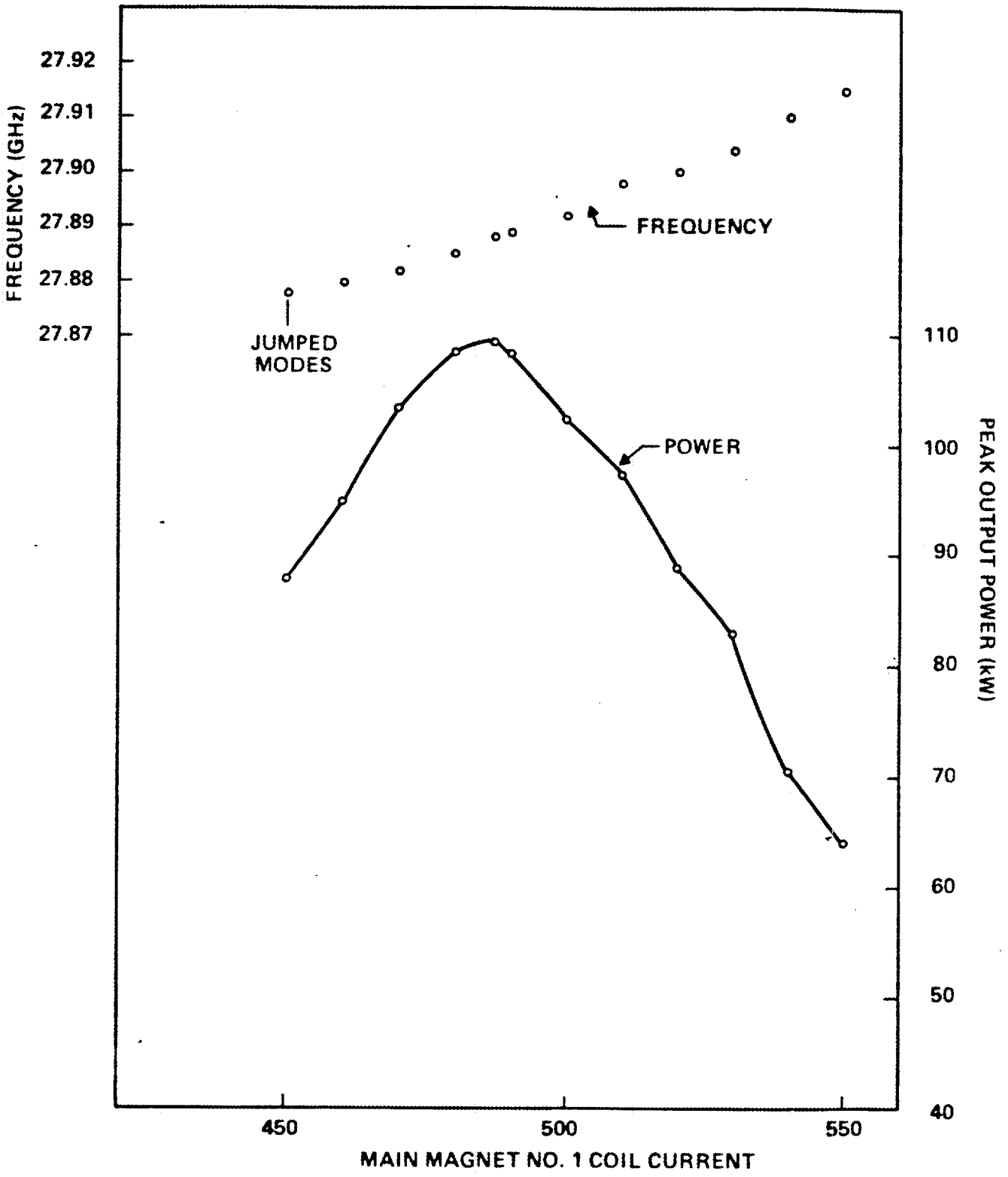

FIGURE 4. FREQUENCY & POWER VS MAGNETIC FIELD CURRENTS FOR CW TUBE NUMBER 7

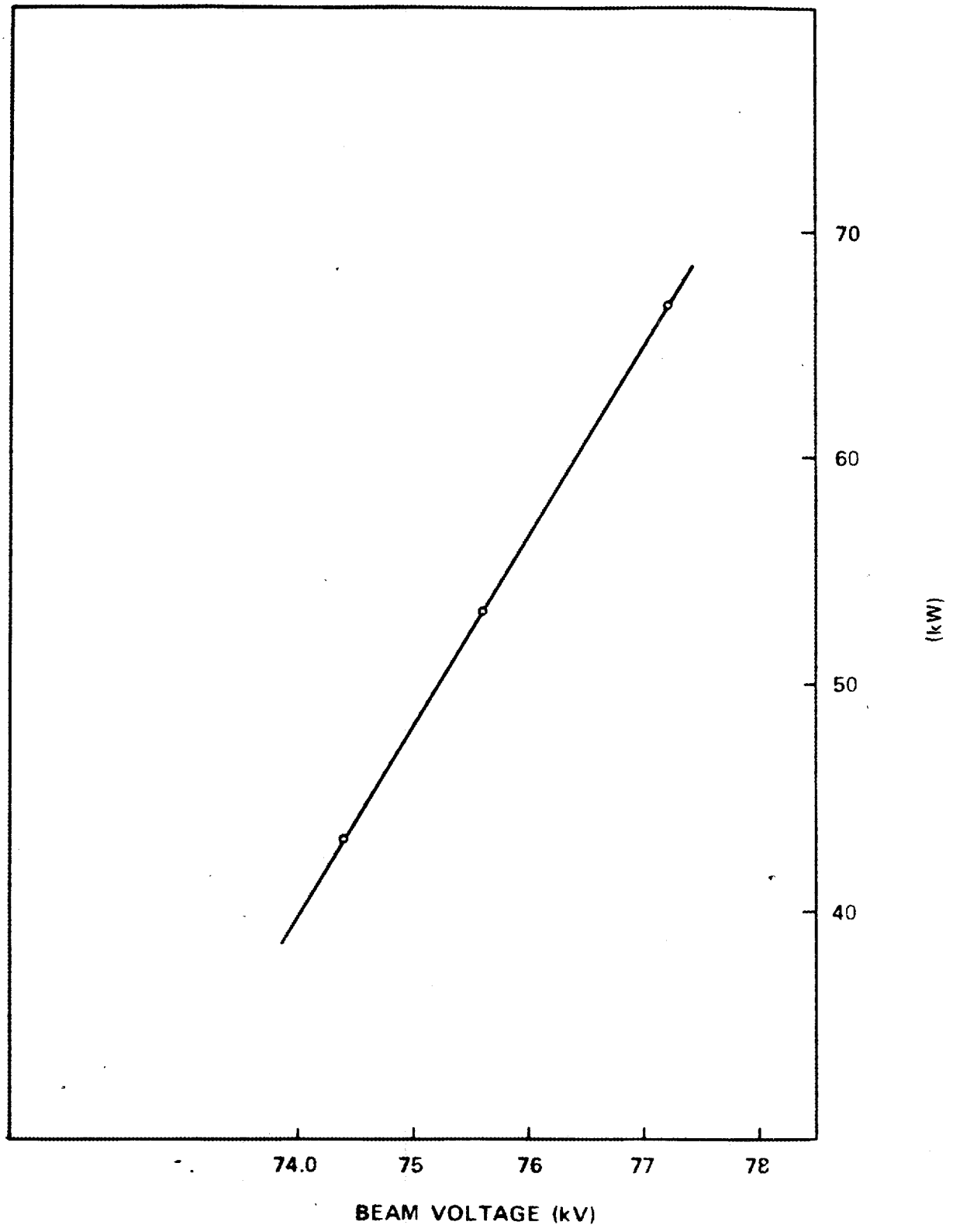

FIGURE 5. OUTPUT POWER VS BEAM VOLTAGE
FOR CW TUBE NUMBER 7

V. TUBE NO. 6

Most of the assembly brazes were completed on this tube. Some difficulty was experienced in brazing the water cooling channel section of the transverse magnet region. Also, the collector seal weld flanges distorted appreciably when they were brazed to the collector ceramic. Design modifications may be required in order to successfully construct the collector seal assembly.

VI. PROGRAM SCHEDULE AND PLANS

A revised milestone chart is shown in Figure 6. No further effort is planned for tube S/N 2 and 4.

Tube S/N 7 will be shipped to Oak Ridge during the first week of the next report period.

Tube S/N 5R1 will be returned to test to insure reliable CW operation at 60 kW.

Building of tube S/N 6 will be completed in October, followed by November testing.

A proposal to complete the 200 kW CW, 28 GHz gyrotron project was submitted to Union Carbide Corporation on September 24, 1979. That and subsequent discussions are expected to result in further schedule changes.

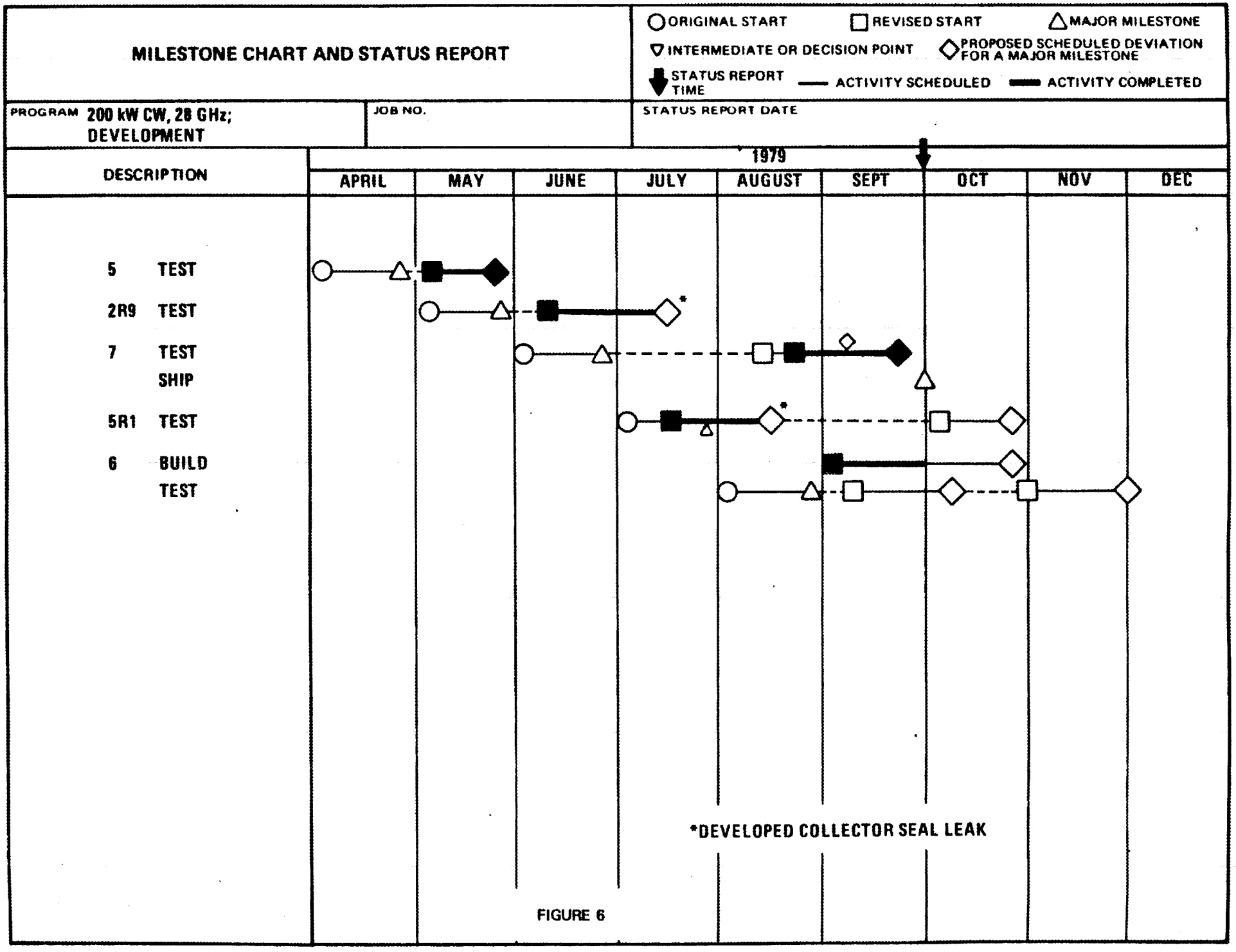
MILESTONE CHART AND STATUS REPORT
ORIGINAL START
REVISED START
MAJOR MILESTONE
INTERMEDIATE OR DECISION POINT
PROPOSED SCHEDULED DEVIATION FOR A MAJOR MILESTONE
STATUS REPORT TIME
ACTIVITY SCHEDULED
ACTIVITY COMPLETED
PROGRAM 200 kW CW, 28 GHz; DEVELOPMENT
JOB NO.
STATUS REPORT DATE
DESCRIPTION
1979
APRIL
MAY
JUNE
JULY
AUGUST
SEPT
OCT
NOV
DEC
5 TEST
2R9 TEST
7 TEST
SHIP
5R1 TEST
6 BUILD
TEST
*DEVELOPED COLLECTOR SEAL LEAK

FIGURE 6

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