ANOMALOUS Q_0 RESULTS IN THE CEBAF SOUTH LINAC

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Abstract

While in practice, the performance of cavities - Q_0 versus E_{acc} - in the assembled CEBAF cryomodule corresponds in nearly every respect to the performance as measured in the vertical test area; there are a few cases where this is not true. On six (6) of the twenty (20) cryomodules installed in the south linac, cavity 4 specifically, and one other cavity in cryomodule 7 have an anomalous low Q_0. Investigation into the source of the low Q_0 on these particular cavities have centered around trapped magnetic fields, slow cooldowns or maldistribution of He flow during cooldown leading to hydride precipitation and Q_0 disease. Other possibilities such as low window Q_0's or harmonic content of the klystron were also considered . A detailed investigation to understand the phenomena leading to the low Q_0's on cryomodule 7 and 8 is discussed. We have found evidence suggesting cooldown dependent Q_0 disease as well as window heating to account for some of the discrepancies but not all. A complete explanation of the problem is still under further investigation.

Introduction

The construction and testing of the cryomodules [1] for the Continuous Electron Beam Accelerator Facility (CEBAF) located in Newport News is nearing completion. The machine will provide a low emittance 200μA beam with energies up to 4 GeV for fundamental experimental studies in nuclear research [2]. The acceleration is achieved from a conventional bunched electron source at 500 keV; a superconducting injector, containing 2 1/4 cryomodules, which provide an energy gain of 45 MeV; and two recirculating linacs containing 20 cryomodules, each capable of achieving an energy gain of 400 MeV. After five recirculating passes, the two linacs produce a beam of 4 GeV to three end stations. Currently 16 of 20 cryomodules have been installed and commissioned in the north linac and 16 of 20 installed cryomodules have been commissioned in the south linac. This paper discusses the anomalous behavior of three cavities in two modules tested in the south linac.

Magnetic Effects

The cryomodules in positions 2L07, 08, 13, 14, 15 and 16 each have one bad cavity, in position 4, with a Q_0 at or below 10^9. The original speculation was that the anomalous behavior was attributable to a high local magnetic field - 2G- due to rebar in the tunnel floor, which peaked under the center of the module near position 4 or to stray magnetic fields - 60G- from the ion pump magnets. Cryomodules 2L07 and 2L08 were warmed up above the transition temperature, 9.5 K to release the trapped magnetic flux. Steel plates were added under 2L07 to shield the rebar and the ion pump magnets were removed from 2L08. The modules were then cooled back down below transition temperature and refilled with liquid helium. On retest we noted no improvement in the Q_0 performance due to these changes.

Cooldown Rates

We next speculated that the degradation in Q_0 may be attributable to cooldowns that occur too slowly. This could be caused by a maldistribution of He flow during a sub-atmospheric cooldown. The entire north linac and the first five modules in the south linac were all cooled down with the gas surrounding the cavities at 1 bar pressure. We have not had any low Q_0's with these cavities. It was only after we commenced testing in the south linac that the modules from 2L07 on, were cooled down with the Kinney vacuum pump on line and pressure within the module near 30 mbar. Cryomodule 0L04, Phoenix, was moved with liquid helium from the injector and installed in slot 2L09 in the south linac. Modules, located in slots 2L10, 2L11,and 2L12 were cooled down along with 2L07 and 2L08, but did not have this anomalous Q_0 effect. During the cooldown the Kinney pump was turned on only after the cooldown had progressed for a few hours. It is possible that these modules had cooled down below 70 K where hydride precipitation becomes less dominant. In line with this thermal rate hypothesis, we have noted that buoyancy (Grashof Number) forces can have a major effect on forced (Reynolds Number) currents in a cryomodule and conceivably could cause the maldistribution of flow leading to Q_0 disease[3]. The other modules 2L13, 14, 15 and 16 were all cooled down with the Kinney pump on the return header and the gas surrounding the niobium cavities rarefied. The one exception to this is 2L17 which was cooled down with 2L16 but has no low Q_0's.

Measurements

Initially cryomodules 2L07 and 2L08 were cooled down on 28 May as shown on fig 1 and fig 2 of the attached graphs. Measurements are for silicon diode thermometers connected to the HOM load at the mid plane of the cavities. The minimum rate for one cavity in a cryounit during the cooldown appears to be on the order of 75 K/hr through the critical range between 70 and 200 K. During the 13 September cooldown of these same two cryomodules, the rate was also 75 K/hr; however, the gas was at 1 bar pressure as opposed to some reduced value approaching 31 mbar. These cooldown curves are shown in fig 3 and fig 4. The total time to cool down from ambient to liquid helium temperatures during the May sub- atmospheric cooldown was longer than the September atmospheric cooldown. This is attributable to smaller heat transfer coefficient that one obtains in a rarefied atmosphere. Despite this total time difference, the rate through 200 - 70 K disease zone was the same.

The Q_0's of the cavities for these two cryomodules were measured [4] as indicated; once initially after the first cooldown; then after the small warm up to test for the magnetic effects and then finally after the September complete warmup and cooldown. For comparison, the Vertical Test Area (VTA) data is also added. The results of these Q_0 versus gradient curves are presented for cryomodule 2L07-04 on fig 5 for all four tests. Within the measurement error there is no difference in Q_0 after the three tests as measured in the accelerator. Similarly the data for cryomodule 2L07-06 are also presented on fig 6 for the same time periods. Again within measurement error there is no change in performance as measured in the accelerator.

Window Measurements

To test another theory, these two cavities in cryomodule 7 were measured both off and on resonance. While 2L07-06 shows no power dissipation off resonance, 2L07-04 does, as indicated on fig 7. For all practical purposes the power dissipated is nearly the same on and off resonance below the field emission region. This suggests that the losses are attributable primarily to the windows and not to the cavity. This high loss was forewarned by an anomalous low top hat Q_0 during the VTA tests; however, the problem has become more acute after the module was transported to the tunnel. This suggests that the window Q_0 has become worse.

Q_0 Disease

Finally the Q_0 versus gradient curve was measured on cryomodule 2L08-04 after the three cooldowns. While there was no improvement after the second cooldown to test for magnetic effects, there is some small improvement after the third which suggests a cooldown rate problem. For comparison purposes the VTA measurements are added as shown on fig 8. To further test this Q_0 disease hypothesis cryomodules 2L18 and 2L19 have been cooled down at 1 bar and will be tested to see if any cavity, and particularly cavity 4, has been effected. To some degree the Q_0 disease hypothesis is not clear. As indicated cryomodules 2L07, 08, 10, 11, 12, 13, 14, 15, 16 and 17 have all been cooled down at reduced pressure at rates typically around 75 K/hr. There is no Q_0 degradation in 2L10, 11, 12 and 17; nearly 40 %, yet all of the modules were treated essentially the same.

RESULTS

The data suggests however; that we have several competing problems. Namely cavity 2L08-04 suffers from temperature or cooldown effects and is most likely Q_0 disease. In the case of 2L08-04, magnetic effects have not been ruled out since we only removed the offending ion pump magnets and did not shield the rebar in the tunnel floor. Cavity 2L07-04 has shown no improvement after any attempt at correction. We have even looked at the harmonic content of one klystron to see if the HOM loads in the bath were dissipating power to no effect. Cavity 2L07-06 has a window problem which may have been signaled by a low hat mode Q_0 in the VTA. It is apparent that all three of these cavities show evidence of a loading mechanism unrelated to field emission. Armed with this additional information we intend to reexamine the other modules with low Q_0's in 2L13, 14 15, and 16.

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References

[1] H.F. Dylla, "Operating Experience with SRF Cavities", In Proceedings of the 1993 Particle Accelerator Conference, Wash DC.

[2] H.A. Grunder, et al., "Continuous Electron Beam Accelerator Facility", in Proceedings of the 1987 IEEE Particle Accelerator Conference, Washington DC Vol 1 pp 13-18.

[3] K. Saito, P. Kneisel, "Q Degradation in Superconducting Cavities" CEBAF Tech Note 91-033.

[4] M. Drury, et al., "Commissioning of the CEBAF Cryomodules" in Proceedings of the 1993 Particle Accelerator Conference, Wash DC.

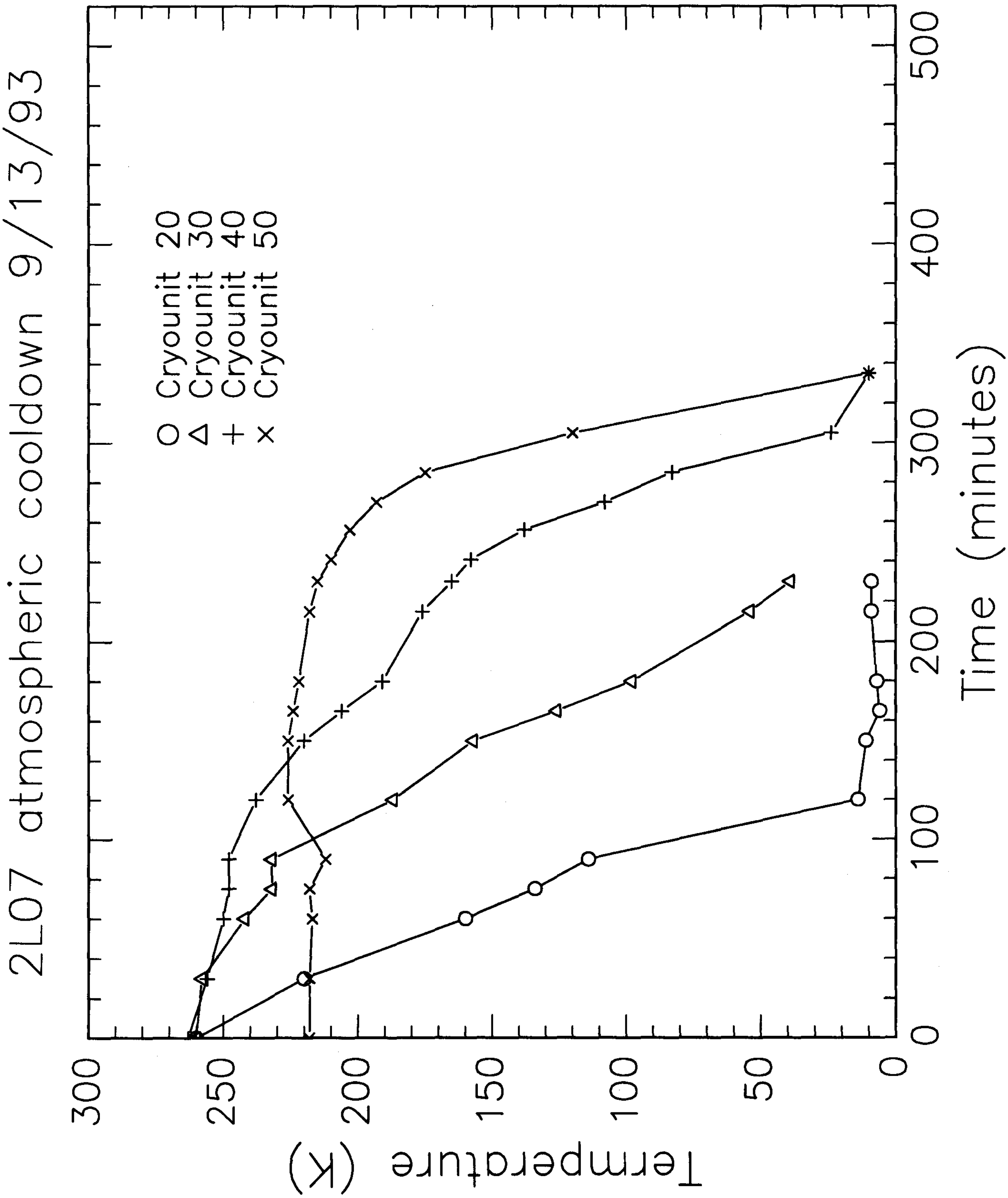

2L07 atmospheric cooldown 9/13/93
○ Cryounit 20
△ Cryounit 30
+ Cryounit 40
× Cryounit 50
Temperature (K)
Time (minutes)
0
50
100
150
200
250
300
400
500

FIGURE 1

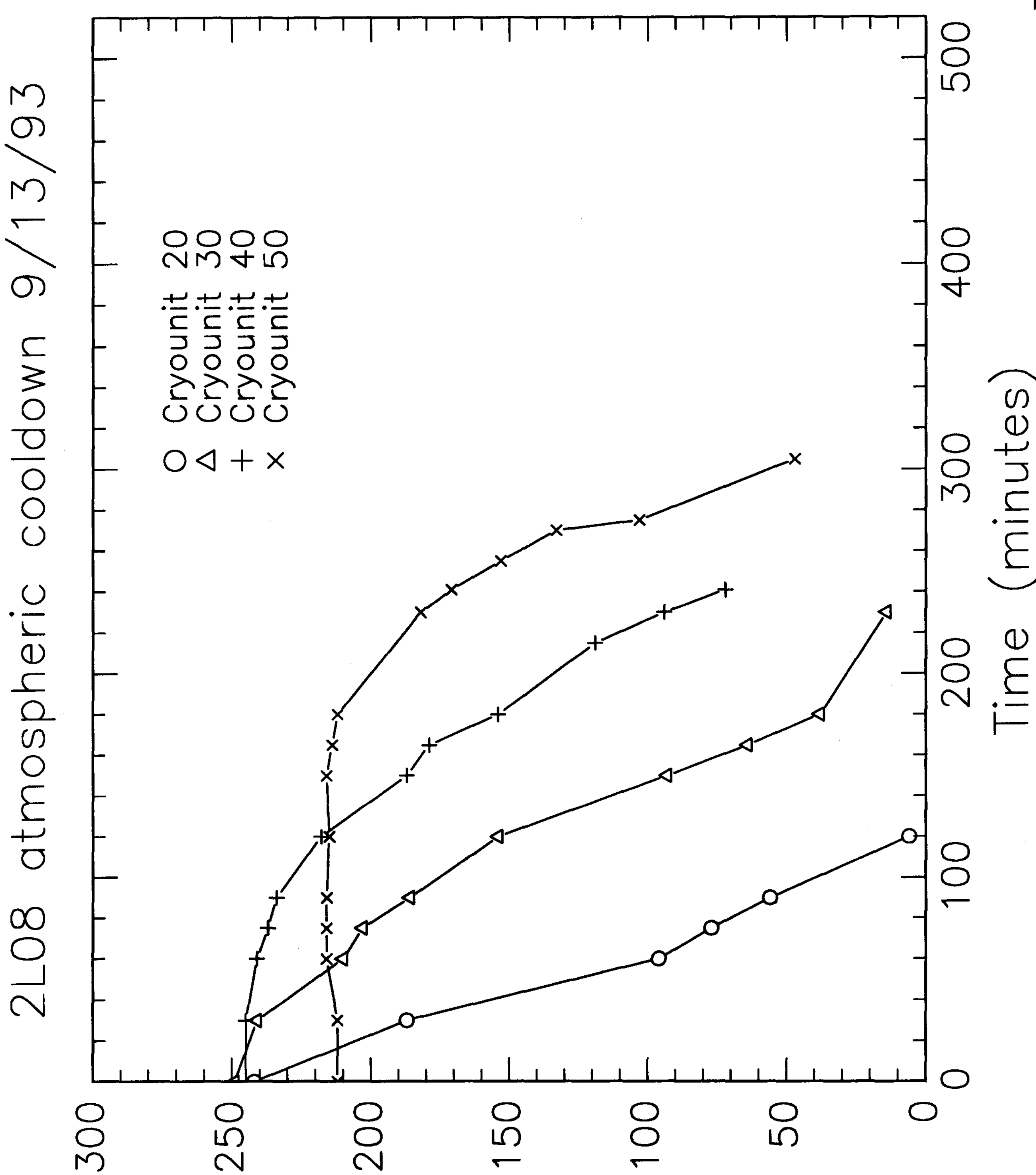

2L08 atmospheric cooldown 9/13/93
Cryounit 20
Cryounit 30
Cryounit 40
Cryounit 50
Temperature (K)
Time (minutes)
0
50
100
150
200
250
300
0
100
200
300
400
500

FIGURE 2

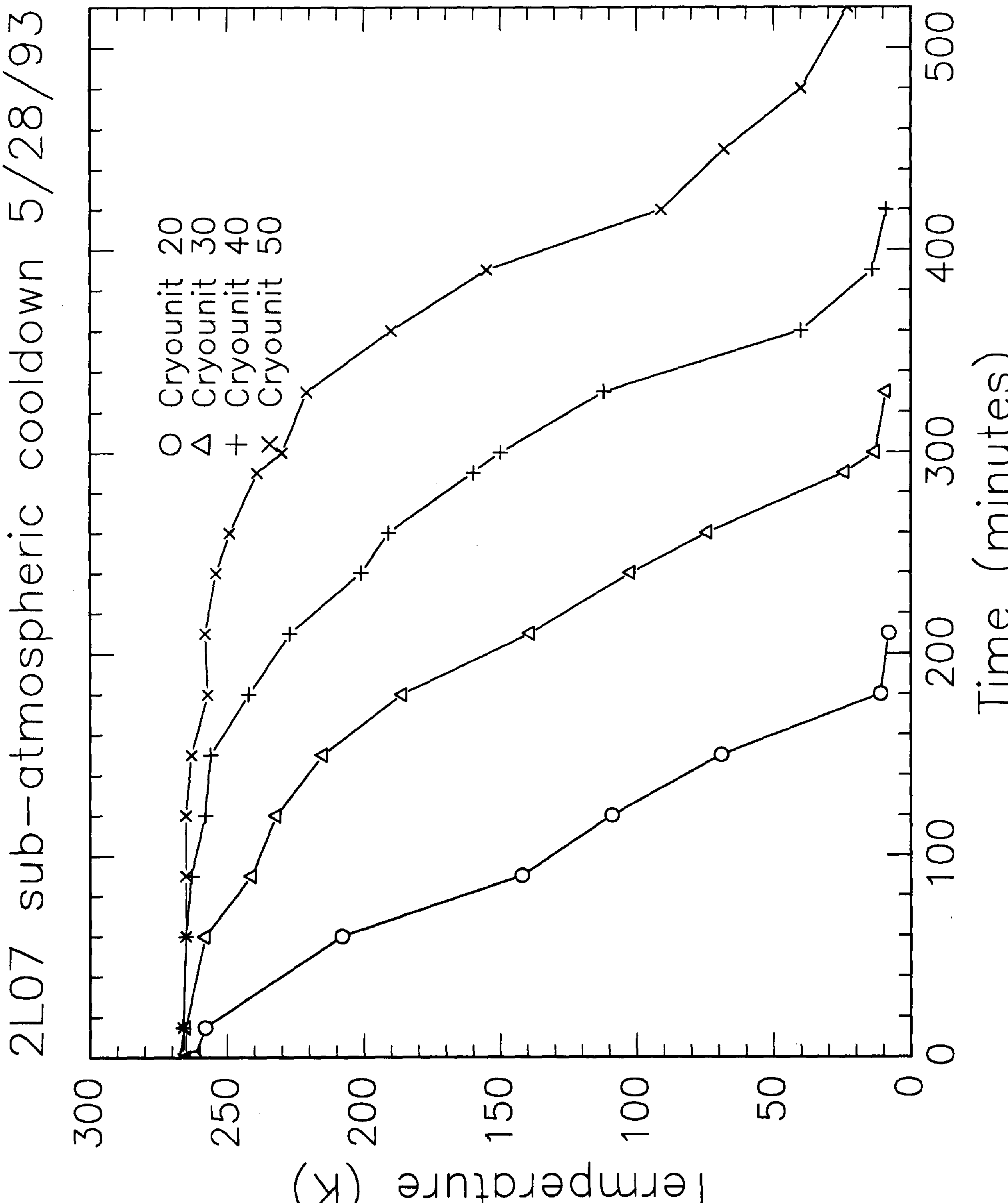

2L07 sub-atmospheric cooldown 5/28/93
O Cryounit 20
Δ Cryounit 30
+ Cryounit 40
X Cryounit 50
Time (minutes)
Temperature (K)
0
100
200
300
400
500
0
50
100
150
200
250
300

FIGURE 3

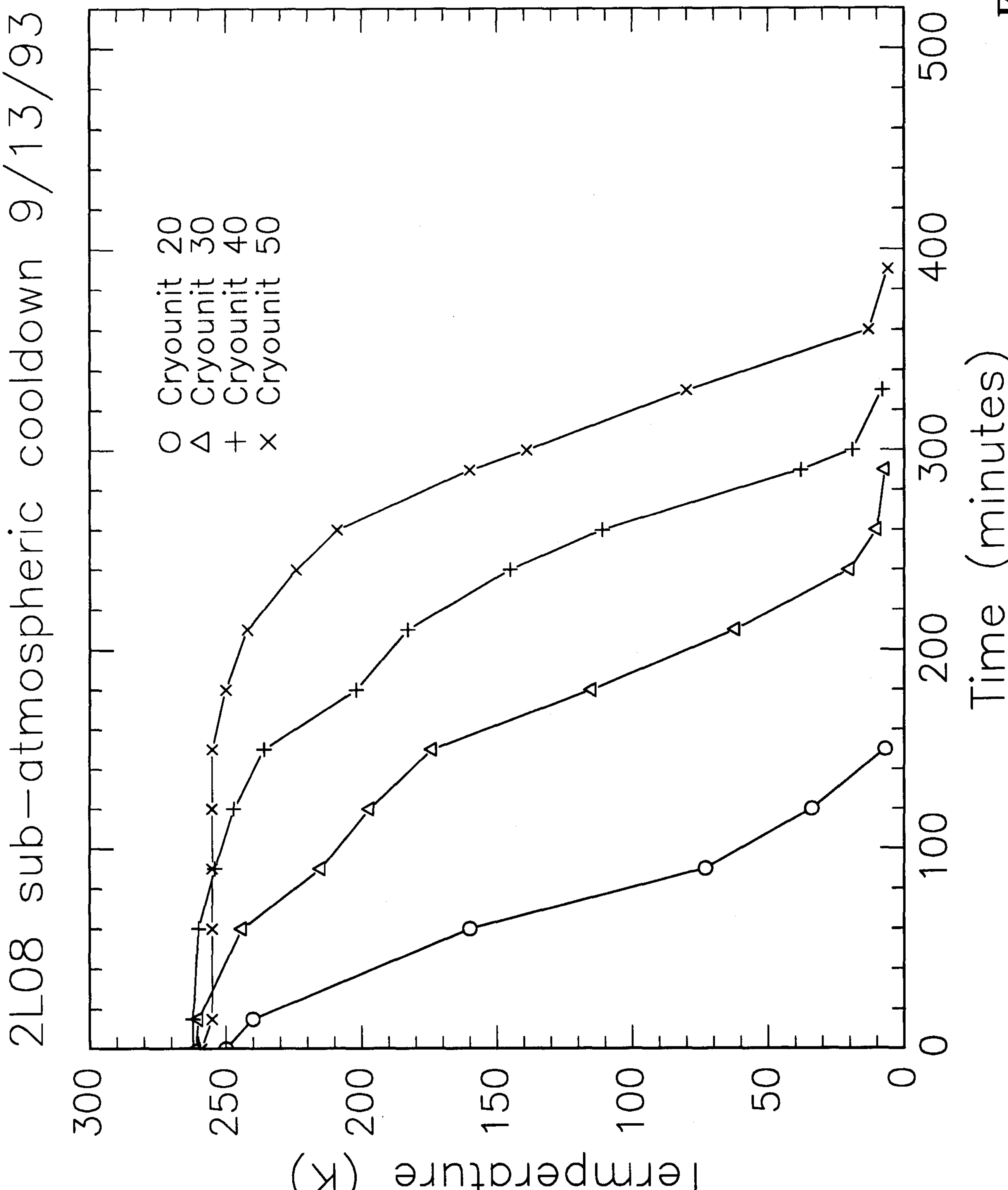

2L08 sub-atmospheric cooldown 9/13/93
○ Cryounit 20
△ Cryounit 30
+ Cryounit 40
× Cryounit 50
Temperature (K)
Time (minutes)
0
50
100
150
200
250
300
0
100
200
300
400
500

FIGURE 4

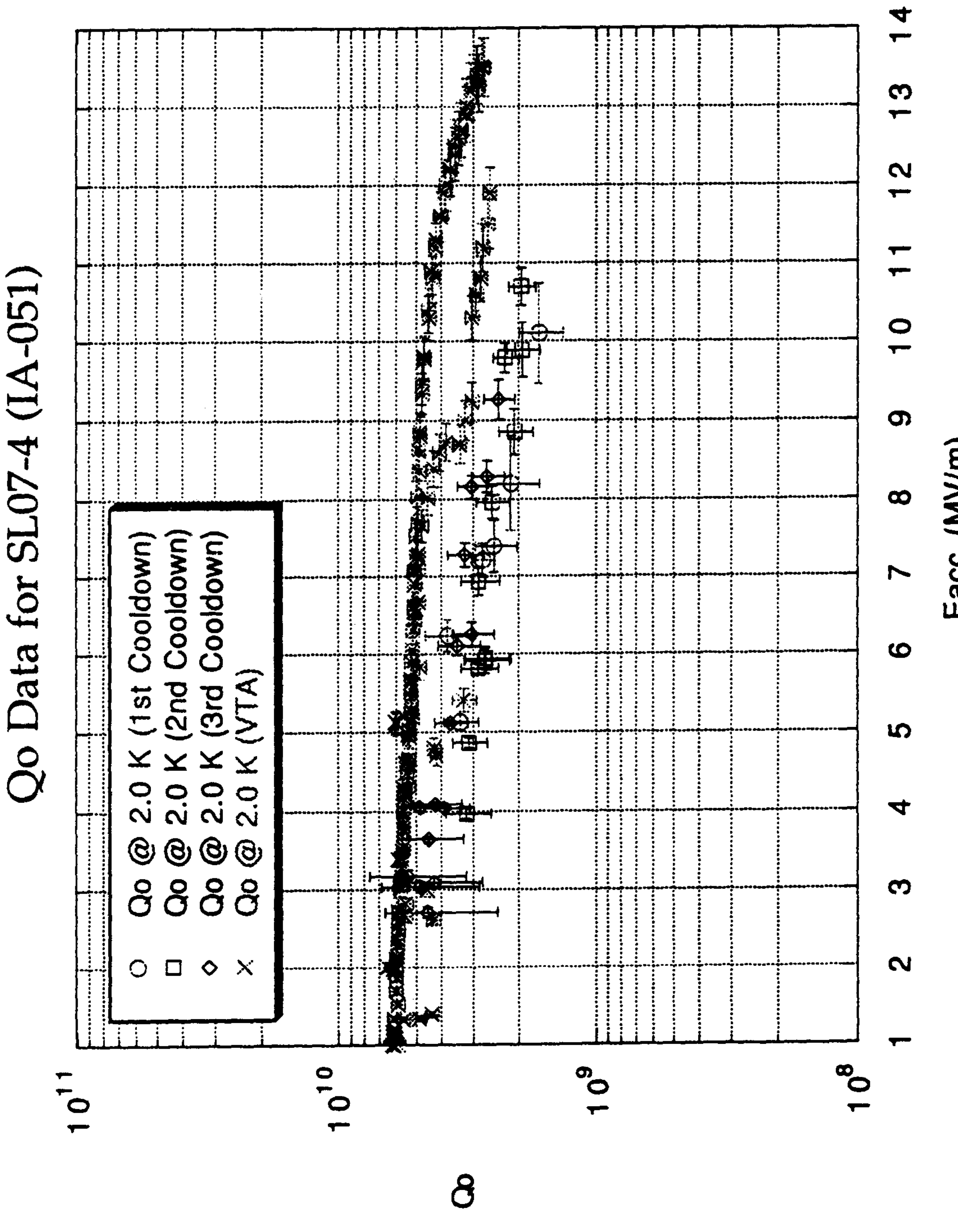

Qo Data for SL07-4 (IA-051)
Qo @ 2.0 K (1st Cooldown)
Qo @ 2.0 K (2nd Cooldown)
Qo @ 2.0 K (3rd Cooldown)
Qo @ 2.0 K (VTA)
Qo
10^{11}
10^{10}
10^{9}
10^{8}
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Eacc (MV/m)

FIGURE 5

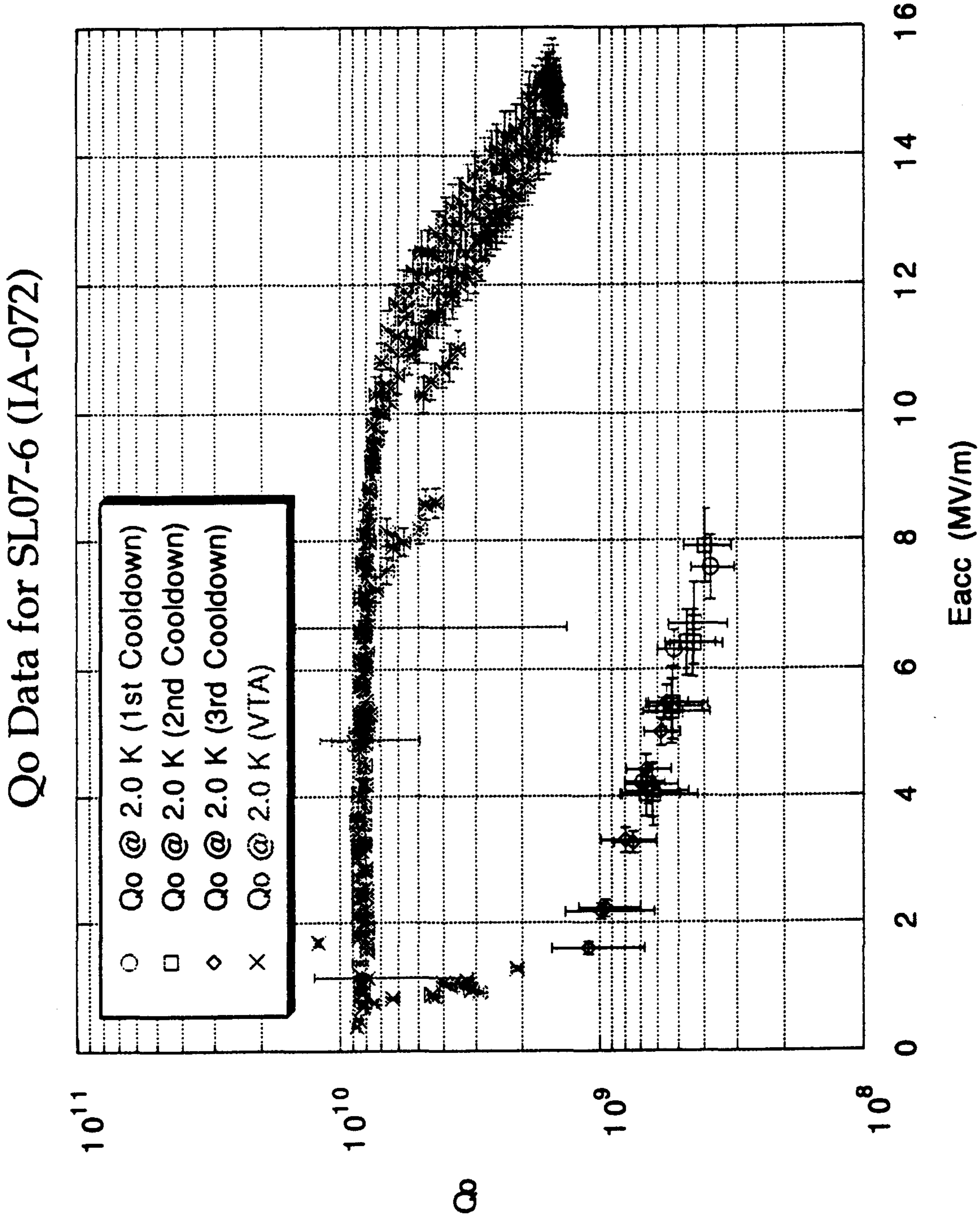

Qo Data for SL07-6 (IA-072)
Qo @ 2.0 K (1st Cooldown)
Qo @ 2.0 K (2nd Cooldown)
Qo @ 2.0 K (3rd Cooldown)
Qo @ 2.0 K (VTA)
Qo
10^11
10^10
10^9
10^8
0
2
4
6
8
10
12
14
16
Eacc (MV/m)

FIGURE 6

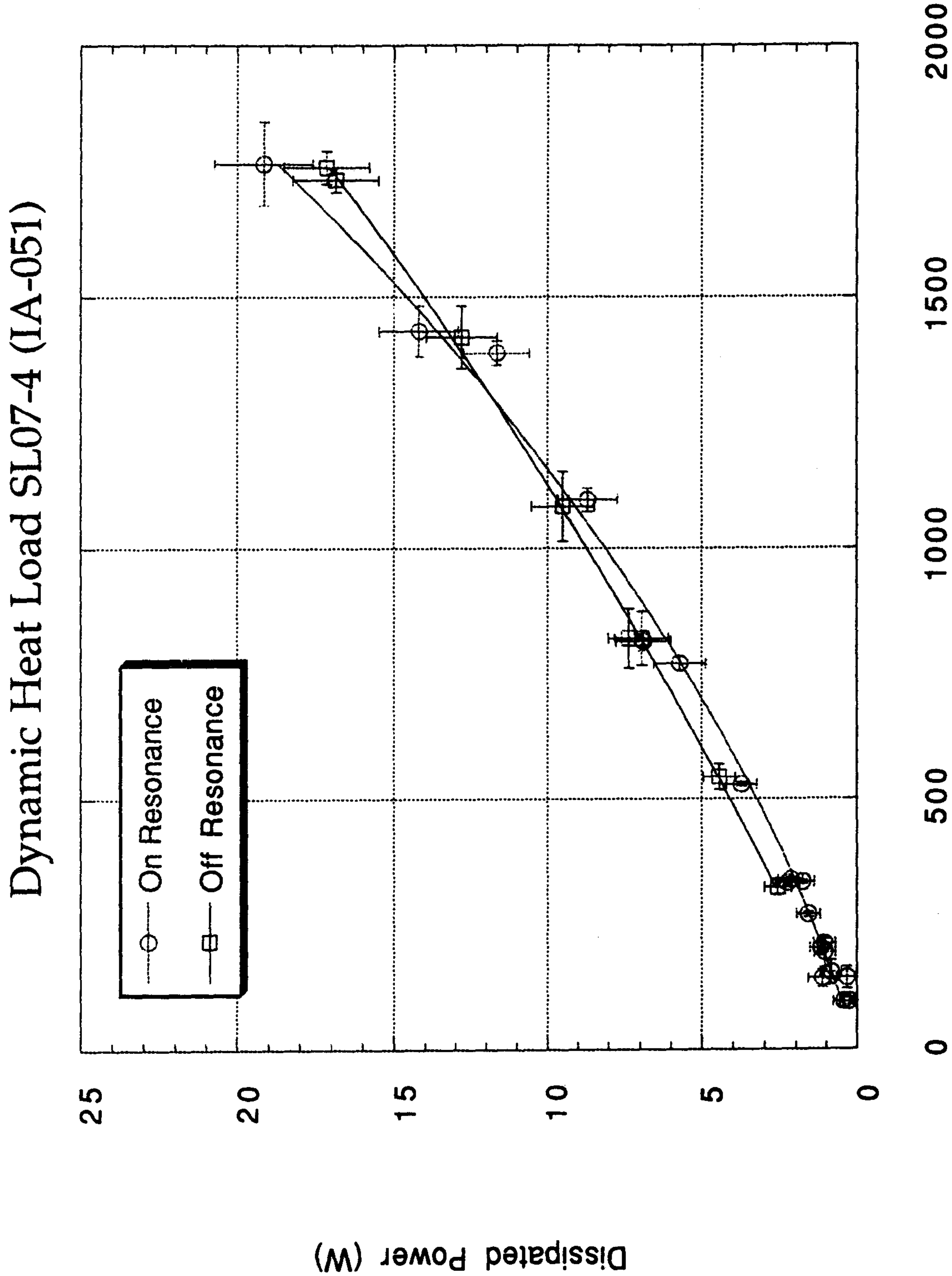
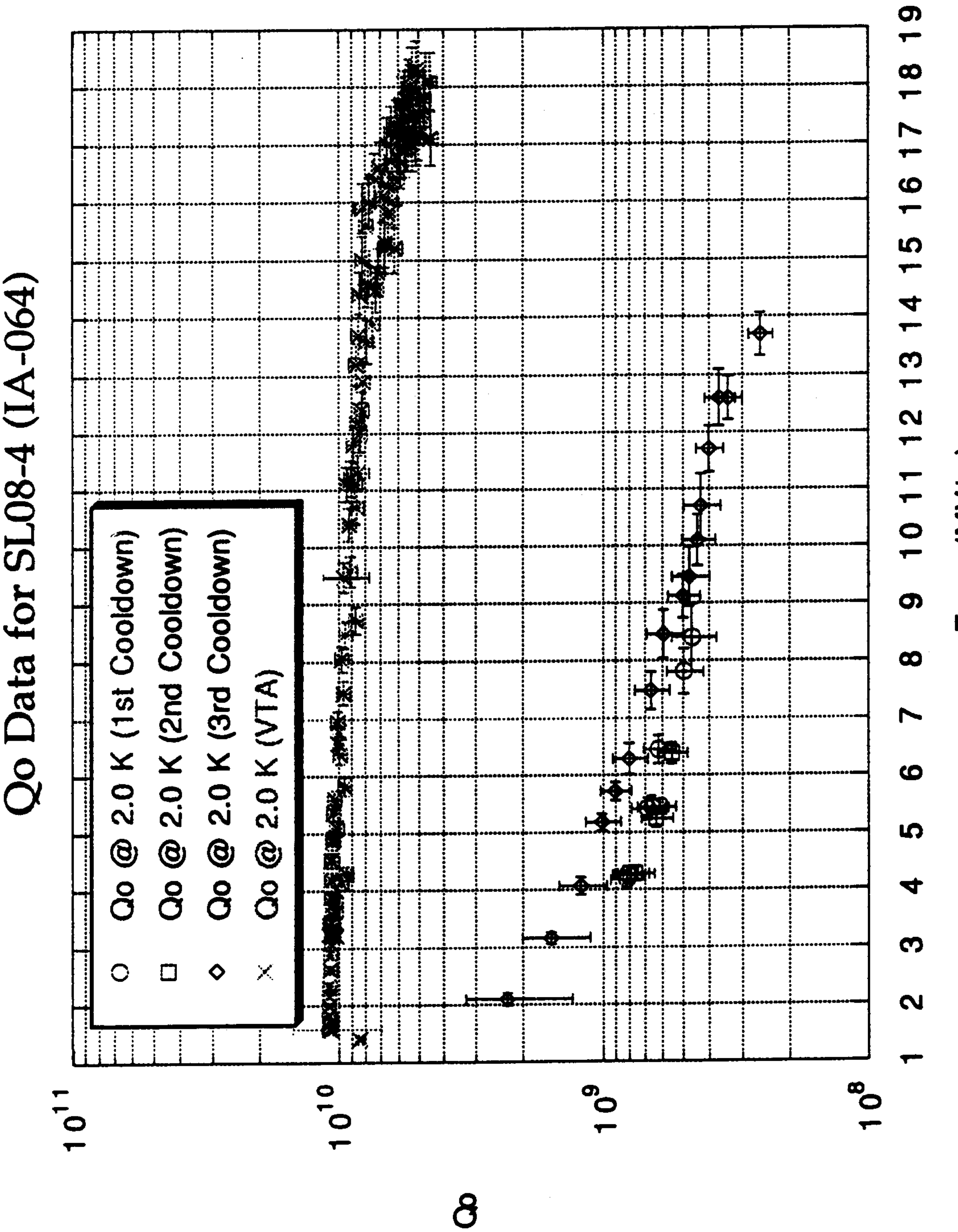

Dynamic Heat Load SL07-4 (IA-051)
On Resonance
Off Resonance
Forward Power (W)
Dissipated Power (W)
0
500
1000
1500
2000
0
5
10
15
20
25

FIGURE 7

FIGURE 8


Qo Data for SL08-4 (IA-064)
Qo @ 2.0 K (1st Cooldown)
Qo @ 2.0 K (2nd Cooldown)
Qo @ 2.0 K (3rd Cooldown)
Qo @ 2.0 K (VTA)
Qo
10^{11}
10^{10}
10^{9}
10^{8}
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Eacc (MV/m)