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FINAL REPORT

SUMMARY OF THE DEVELOPMENT OF THE SPECIALIZED QUADRUPOLE MASS SPECTROMETER-PHASE IV

May 1969

NASA Contract Number
NAS5-11045

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

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1. INTRODUCTION

During the past five years, mass spectrometer instrumentation for planetary atmospheric analysis has been under development by Perkin-Elmer Aerospace Systems for NASA-GSFC. Under Contract NAS5-3453, the development of a Specialized Quadrupole Mass Spectrometer has been documented.[1] This report covers the period since the conclusion of Contract NAS5-3453, and deals with the continued research and development performed to upgrade the instrumentation toward flight hardware. In general, the final configurations of the previous contract were modified to provide for more stable alignments and ease of manufacture. The analytical design, however, remained unchanged.

2. OBJECTIVES

This program was originally undertaken to fabricate and test a Specialized Quadrupole Mass Spectrometer having a dual filament ion source. These items are described in the final report [1] on Contract NAS5-3453 in the section covering Phase III. Additionally, a high pressure ion source was to be fabricated and tested. This ion source is described in another final report [2] generated for the NAS5-3453 complex. During the course of the original program, a study was added to evaluate the performance of a previously fabricated quadrupole analyzer when fitted with a set of hyperbolic surfaces in place of the previously used cylindrical rods. The results of this study effort have been documented and submitted as a final report [3] under Contract NAS5-11045.

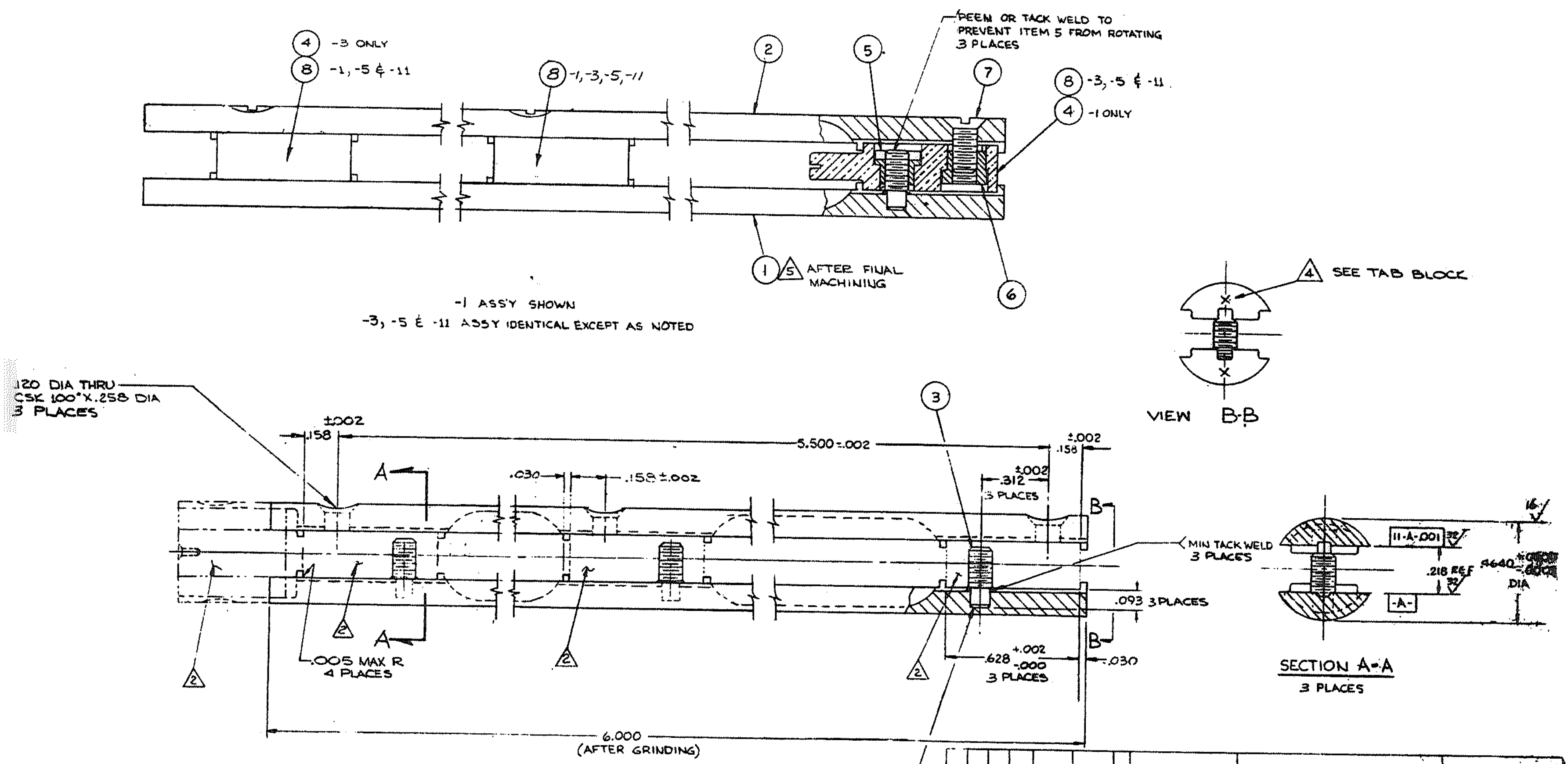
Further modifications to the original program consisted of the mechanical repair of the OGO-F Quadrupole Mass Spectrometer, serial number 1, which was damaged at GSFC when the vibration test table ran away during environmental testing of the instrument. Mechanical repair was also undertaken to completely safety wire all mounting screws within the Quadrupole Mass Analyzer originally built under this contract.

The final modification to the contract involved the fabrication and test of a Specialized Quadrupole Mass Spectrometer utilizing hyperbolically contoured rods and a high pressure ion source.

3. DESIGN-PHASE IVA

The basic design of the Specialized Quadrupole Mass Spectrometer was performed under Contract NAS5-3453. During the initial phase of this contract, no new design and development was generated. However, some effort was undertaken to improve the machinability, accuracy of alignment, and overall assembly of the instrument parts. Phase III testing of the NAS5-3453 mass spectrometer demonstrated that alignment of the quadrupole rods, with respect to each other, is a very critical control parameter, when attempting to achieve the theoretical performance of the analyzer. In order to improve this alignment, and improve the manufacture of the rods, a third support between the rod halves was added. This new support position is shown in Figure 3-1. The multiplier housing was redesigned to incorporate a welded plate to seal the end, rather than machining the complete housing from solid stock. This change was incorporated in order to reduce the probability of vacuum leaks occurring through the granular structure of the material. Utilization of an end plate changes the grain orientation such that it is not in the direction between the vacuum and atmospheric pressure sides, as was the case in the earlier design. Originally, a calibration grid system was installed in the multiplier housing as was done in the Phase III instrument of NAS5-3453. Under technical direction from GSFC, this grid system was removed, leaving only the einzel lenses placed between the quadrupole rods and the electron multiplier. The multiplier assembly then became virtually identical to those built under Contract NAS5-9328 for the Atmospheric Quadrupole Mass Spectrometer sensor of the OGO-F satellite.

Slight mechanical modifications were also incorporated in the design of the high pressure ion source. All but one of these modifications were made to improve the manufacturability of the parts. One major design change was the shortening of the length of the filament. This was done in order to reduce the degree of filament sag which was observed in the test model built under NAS5-3453. The filament length was reduced from 0.440 inch to 0.250 inch in order to maintain alignment in front of the 0.002 by 0.020 inch electron entrance aperture.



NOTES: UNLESS OTHERWISE SPECIFIED

2. USE TOOLING SPACERS S327387-1-F1A THRU S327387-1-F1AA and S327387-1-F24 THRU S327387-1-F2D FOR MACHINING AND GRINDING OPERATIONS.
ALL MACHINE AND WELDING OPERATIONS TO BE COMPLETED BEFORE GRINDING 4640 DIA. EXCEPT FINISH LENGTH.

3 CLEAN PER P-E SPEC A31760.

4. MARK PER 326455 CODE P, APPROX. .09 HIGH; PRIOR TO PLATING.

5. FINISH: NICKEL-FLASH, CYANIDE GOLD PLATE, .000200/.000250 REF. MIL-G-45204, CLASS 3 TYPE I.

.093 ±.001 DIA x DEPTH SHOWN 3 PLACES

TAB BLOCK	
DASH NO ASSY	X
-1	1
-3	2
-5	3
-11	4

-11	-5	-3	-1	ITEM OR SYM	CODE IDENT NO.	DWG SIZE	PART OR IDENTIFYING NO.	DESCRIPTION	MATERIAL AND SPECIFICATION
3	3	2	2	8		C	329223	SPACER, CERAMIC	
3	3	3	3	7				SCREW 100°FL HD 4-40x1/4	SST
3	3	3	3	6		B	328137	BUSHING, THREADED, KEYED	
3	3	3	3	5		B	328136	BUSHING, THREADED	
		1	1	4		C	328135	SPACER, CERAMIC	
3	3	3	3	3		B	329230	STUD	
1	1	1	1	2			-9	POLE HALF - OUTSIDE	.500 DIA BAR CRES 303 COML GRADE
1	1	1	1	1			-7	POLE HALF - INSIDE	

REQD/ASSY — LIST OF MATERIAL OR PARTS LIST

FIGURE 3-1. New Quadrupole Rod

4. TEST RESULTS-PHASE IVA

The test results for the original Quadrupole Mass Spectrometer built under this contract, hereafter referred to as the serial number 4A analyzer, were documented and shipped with the instrument, following acceptance tests witnessed by a GSFC representative. This instrument utilized the dual filament ion source.

Operation of this instrument was superior to that obtained in the earlier instruments built under NAS5-3453. In particular, the resolution and peak top-to-base ratios obtained indicated a higher degree of performance than could be obtained from the earlier instruments. A typical mass spectra obtained without the electron multiplier in operation is shown in Figure 4-1. This scan illustrates a resolution of $\Delta m/m = 1/33$ and a peak top-to-base ratio of 44 percent. This compares with resolutions of between 1/20 and 1/25 for comparable top-to-base ratios obtained from the NAS5-3453 Phase III and NAS5-9328 instruments. Operation with the electron multiplier showed large gliches across the top of the peak, which were due to the presence of the calibration grids in the multiplier housing. Following technical direction from GSFC, these grids were removed and further testing performed.

A typical scan of the m/e 28 and 32 spectra, following removal of the grids, is shown in Figure 4-2, giving a resolution of $\Delta m/m = 1/28$ and a top-to-base ratio of 46 percent.

From the data taken on the serial number 4A analyzer, the center rod support and alignment improvement gained, appeared to significantly increase the potential performance of the system over those previously built.

The high pressure ion source originally built under this contract was fully tested using the serial number 2A Quadrupole Mass Spectrometer built under the NAS5-3453 program. As with the serial number 4A analyzer testing, a data book including the test data taken was shipped with the instrument. This ion source demonstrated a sensitivity of about 3.5×10^{-9} amperes/torr for a nitrogen sample when monitoring the m/e 28 peak in the mass spectrometer. It was tested over the pressure range of 1×10^{-3} to 1×10^{-1} torr and maintained linearity as the original test model had indicated in the NAS5-3453 program. Difficulties were experienced during this test program, which were created by oil contamination of the ionizing region. This was due to oil diffusion pumping on the sample inlet system. This necessitated frequent cleaning of the ion source and created instabilities during the course of the test program. The new design, incorporating the shorter filament, improved the stability of the emission system whereby reliable and repeatable settings of the emission current reaching the anode could be maintained.

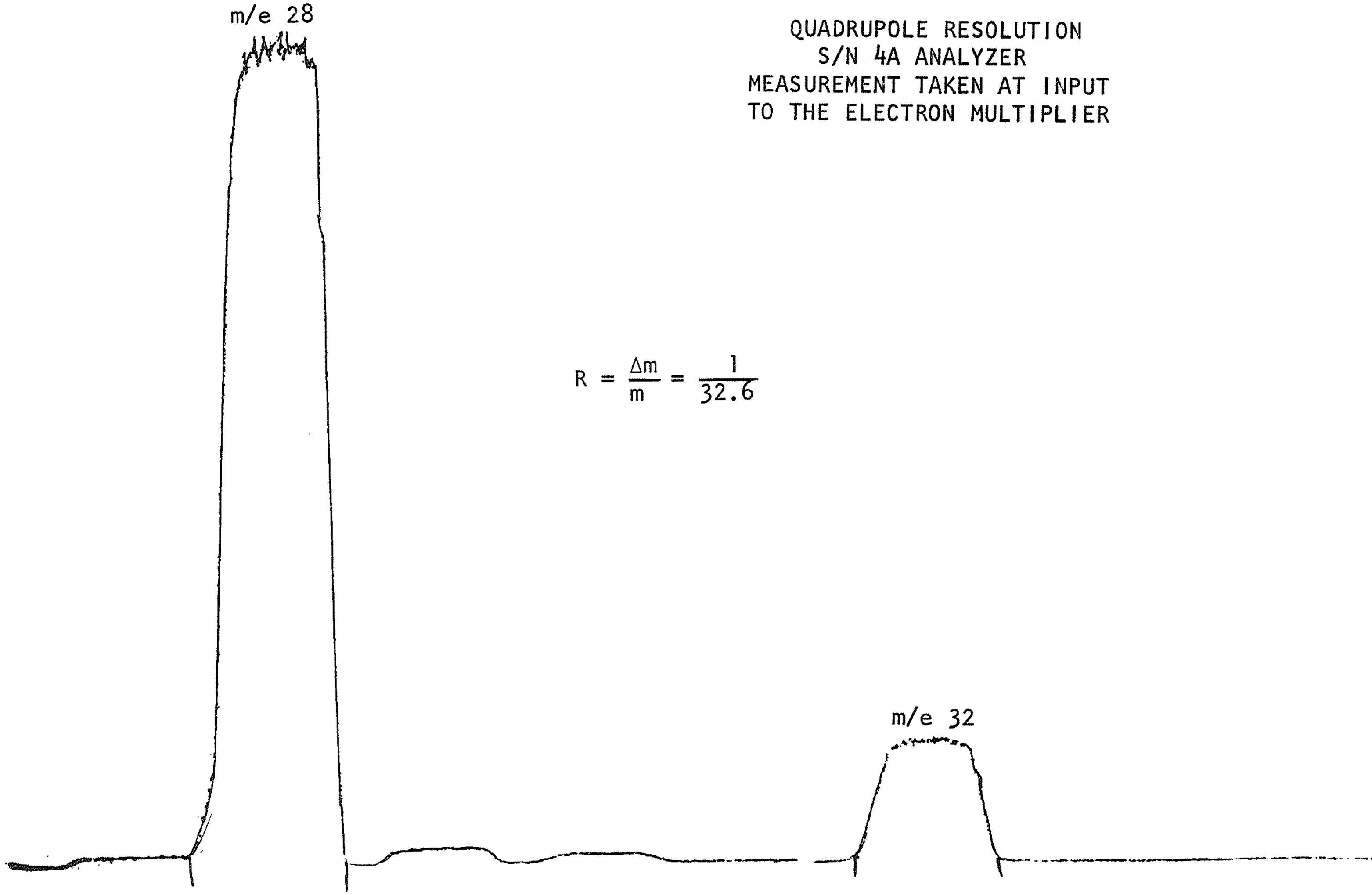


FIGURE 4-1. Quadrupole Resolution Without Multiplier.

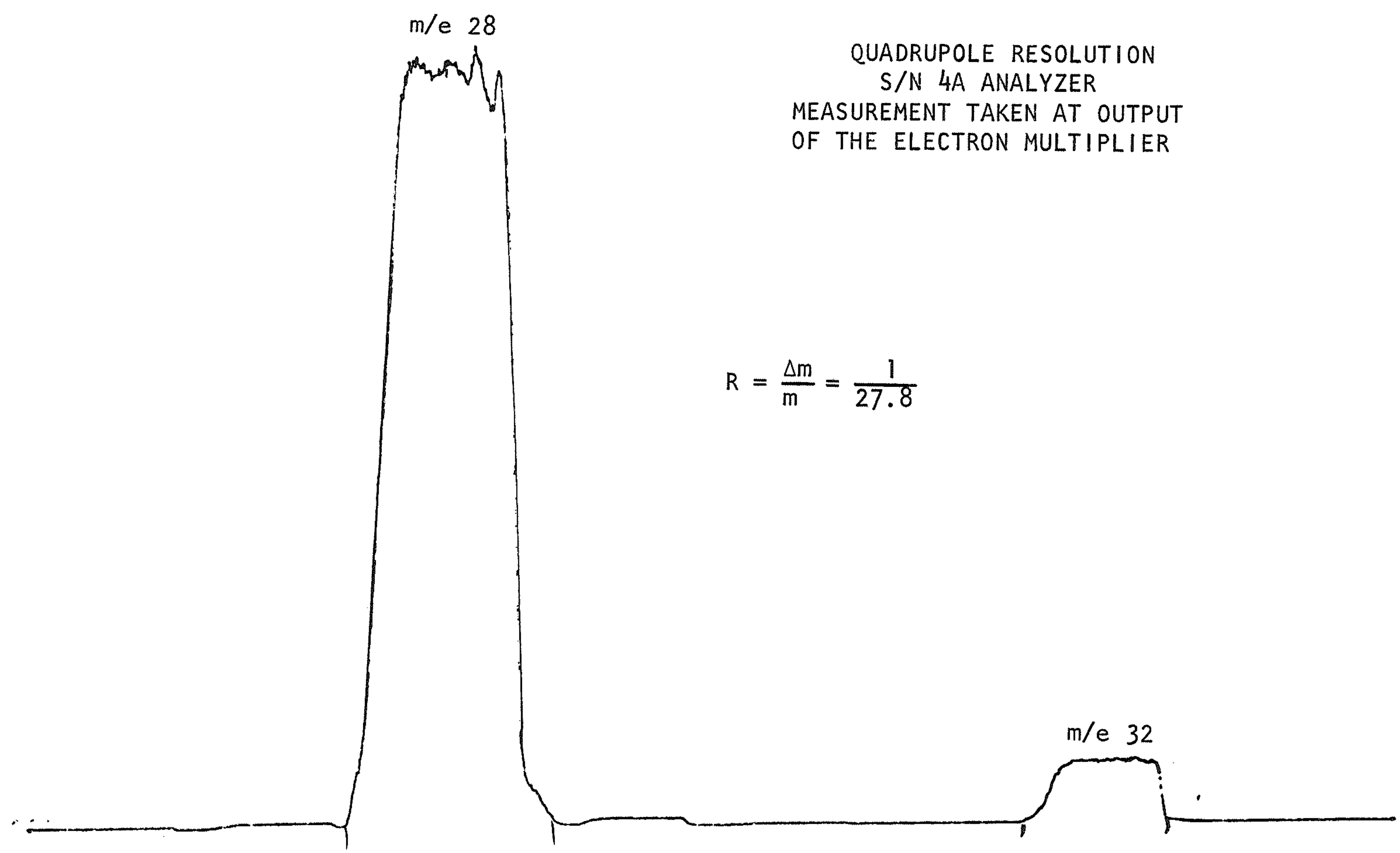


FIGURE 4-2. Quadrupole Resolution With Multiplier.

5. DESIGN-PHASE IVB

The design activity of the Phase IVB program was centered about designing a set of high precision hyperbolically contoured quadrupole rods which would be tested in a new instrument equipped with a high pressure ion source and an electron multiplier. These quadrupole rods would also be fabricated and assembled such that very precise alignment of the rods would be guaranteed.

The design of the hyperbolic rods and associated mounting was performed on the basis of interchangeability with the existing cylindrical rod design without modification of the quadrupole housing. No particular effort was made to obtain minimum weight.

The design requirements presented four major problem areas:

a. Investigation of materials that had the required physical and structural properties, long-term stability, and would be stable at elevated temperatures.

b. Design and mounting of the rods that assured achievement of the final alignment and manufacturability of the rods to the specified tolerances.

c. Locating a vendor who would be able to manufacture the rods.

d. Assembly and alignment of the rods.

5.1 MATERIAL INVESTIGATION

A metallurgist [4] was consulted to aid in the selection of a suitable material. The various properties required of the material are listed in Figure 5-1 which was used for evaluating typical alloys in several basic compositions of corrosion resisting alloys, stainless steels, binary alloys, and a list of elements which have low vapor pressures. Nonmetallic materials, plated with a conductive coating, were not considered because this approach could result in developmental problems not compatible with the urgency of the schedule commitment. A metallic material of proven performance, amenable to plating, if necessary, was considered the search objective.

It was established that the rods would not be a structural highly stressed member; the only stresses would result from attachments and the weight of the rods under gravitational and acceleration loading. In addition, the maximum thermal environment would be a 24 to 72 hour bakeout at 750°F in a vacuum for a maximum total of approximately 100 cycles.

X CAUSE OF REJECTION

MATERIAL \ PROPERTY REQUIREMENTS	MACHINABILITY	LOW % VOLATILES (LOW VAPOR PRESSURE ELEMENTS, GASES, COMPOUNDS)	DIMENSIONAL CHANGE AFTER 100 BAKEOUTS @ 750°F (24-72 HRS EACH)	ELECTRICAL CONDUCTOR	MODULUS OF ELASTICITY IN TENSION TO BE 25 TO 30 x 10^6 PSI	YIELD STRENGTH @ 750°F AFTER 100 BAKEOUTS	BRITTLE AT R.T.	LOW MELTING POINT	CONTAINS REACTIVE ELEMENTS OR CONSTITUENTS HAVING AFFINITY TO HOT GASES	COST EXCESSIVE	NONMAGNETIC AFTER FABRICATION AND STRESS RELIEF
INCONEL X-750									X		
HAYNES 25											X
316L CRES											
MONEL 404											
SILVER					X	X				X	
ALUMINUM					X	X		X			
COPPER-OFHC					X	X					
GOLD					X	X				X	
GERMANIUM						X					
COBALT											X
PALLADIUM										X	
URANIUM		X									
RHODIUM										X	
MOLYBDENUM		X									
RHENIUM		X									
NICKEL											X
BERYLLIUM	X	X			X						
TITANIUM		X									
VANADIUM		X									
PLATINUM										X	
CHROMIUM							X				
TANTALUM		X									
TUNGSTEN		X									

FIGURE 5-1. Materials Evaluation.

In assessing the time-temperature-stress conditions prevailing, it was established that relaxation by creep would not take place because the temperature was too low when considered in relation to the comparatively unstressed condition of the part. For example, to produce a 0.1 percent creep at 800°F in 316 stainless steel, a sustained stress of 40,000 pounds per square inch would have to be applied for 1,000 hours at 800°C.

It was found that Monel Alloy 404 (International Nickel Co.) will provide satisfactory service for the intended application in the subject part. Type 316L stainless steel is also satisfactory for the application; however, this low carbon variety was available only in the air melted stock. Therefore, the hyperbolic rods were fabricated from vacuum melt Monel 404.

Many more binary and ternary alloys could be reviewed; however, the two selected have a history of reliable service under conditions somewhat similar to the requirements, and the materials are readily available.

In considering the property requirements listed in Figure 5-1, the stability of the material after the 30 to 7,000 hours at 750°F was a primary consideration. Precipitation reactions, even at 750°F in alloys of complex chemistry, such as the heat resisting stainless varieties, could result in minor dimensional change.

The recommended alloy, Monel 404, is melted with pure metal additions, instead of the inclusion of scrap in the charge. Consequently, the trace elements, in addition to the basic chemistry listed, would be gold or platinum which are not reactive.

Considerable service data is available for 316 stainless steel at elevated temperatures, which reveals its long-term stability. The low carbon variety 316L was recommended to preclude precipitation of carbides at the grain boundaries during slow furnace cool following the 1650°F vacuum anneal required to remove 100 percent of the fabrication stresses.

The following processing procedures for the rods was established.

a. Technical Bulletin T-12 from the International Nickel Company provides specific machining data.

b. The part would be machined to within ±0.005 inch and then completely stress-relieved by thermal means, that is, suspending vertically in a vacuum furnace cooled slowly in the furnace with power-off but vacuum-maintained.

    (1) Monel Alloy 404, 1025°F ±25 - 2 hours

    (2) Type 316L Stainless Steel, 1650°F ±15° - 2 hours

5.2 DESIGN AND MOUNTING

The design utilizes the same r_o = 0.200 inch of the hyperbolic contour as used in the design under Contract NAS5-34533. The basic criteria was to design a rod assembly with a minimum tolerance buildup in the rod assembly. This was achieved by the following method. The rods were designed as shown in Figure 5-2.

The idea was to start out with precision-ground square rods to establish the mounting surfaces. The hyperbolic contour could then be generated at one of the corners. The corner opposite the hyperbola was machined off to remove unnecessary material.

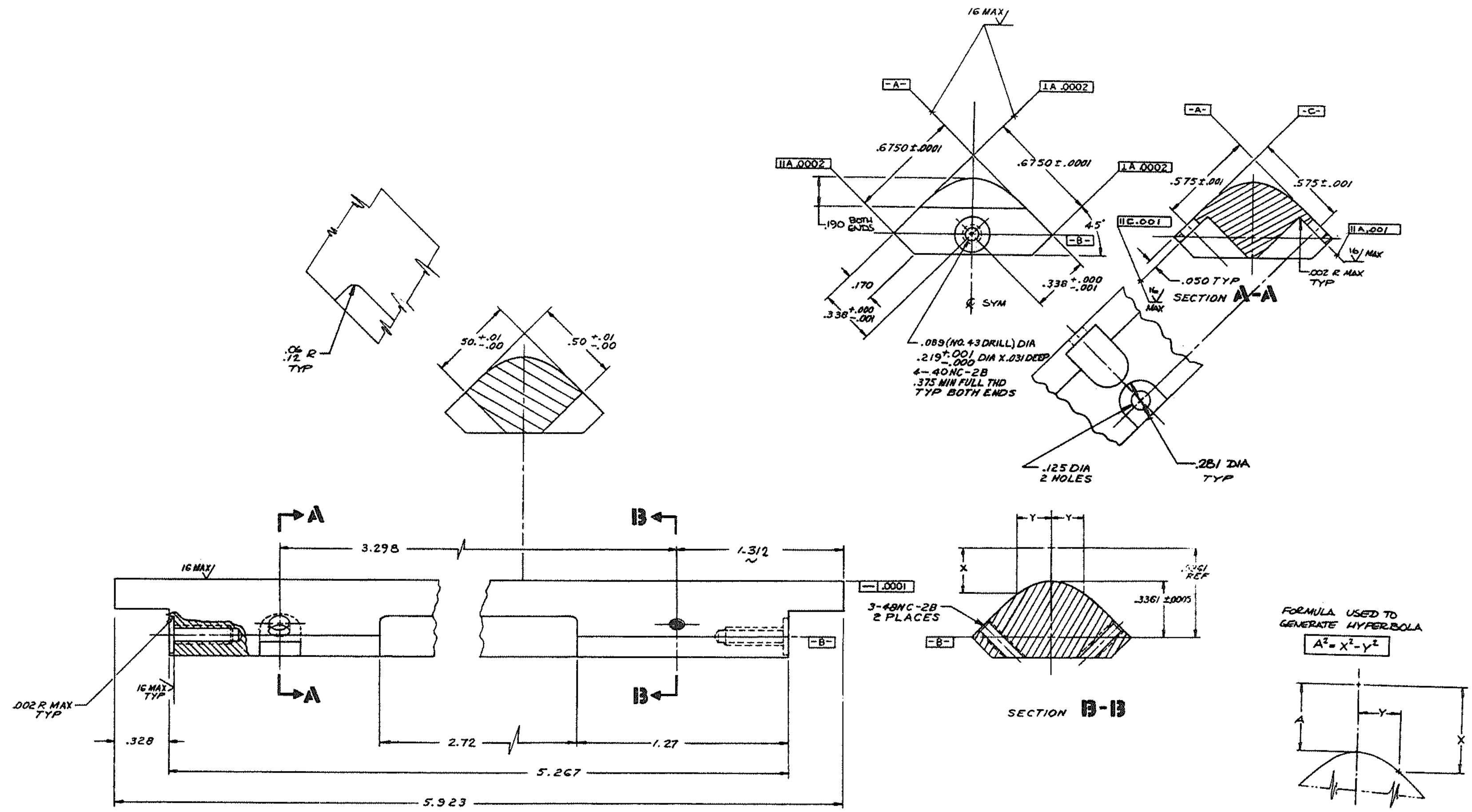
Precision Ruby washers were placed between the rods which allowed the hyperbolic contour of the rods to be spaced precisely as shown in Figure 5-3. A tolerance analysis revealed that a rod spacing within $\pm$0.00025 inch will be achieved after alignment, which will be discussed in a later paragraph. The four rods were mounted to each other with No. 3-48 NC screws.

This rod assembly was mounted between two mounting rings and isolated by ruby washers. One ring was hard-mounted to the mounting tabs of the existing quadrupole housing. The other ring was machined to match the housing bore for a good slipfit. This allowed the rod assembly to expand which is necessary due to the different coefficient of expansion of the rod and housing materials without introducing bending stresses to the rods. The ion source was attached to the free ring and the nozzle adjusted to the center of the rod assembly within 0.0002 inch as in the previous round rod design.

5.3 VENDOR SEARCH

A nationwide search was conducted to find a vendor who could machine the rods to the specified tolerances, which border on the state-of-the-art in machining. Out of 16 companies contacted, 14 no-bids were received. Two companies bid and each took exceptions to the flatness callout of 0.0001 inch over the full length of the rods. One vendor guaranteed a flatness of 0.0005 inch with best effort to achieve 0.0001 inch, and the other quoted flatness within 0.001 inch. It was decided to award each vendor a contract to build a set of six rods since the manufacturing approaches differed substantially.

The first vendor took the following approach: A 50:1 layout of the hyperbola was drawn with a very hard and sharp pencil onto a glass plate by using 128 X-Y coordinate points. This glass plate was mounted to the optical attachment of a visa-grinder. The premachined rod was attached on the back side to a precision gauge block to assure flatness. The gauge block was then attached to the table of the grinding machine. The rod and grinding wheel formed an image optically on the glass plate. The grinding wheel was adjusted visually to the 50:1 layout after each length cut until the hyperbolic contour was completed. Prior to removal of the last 0.010 inch material, a stress relief as described in the material investigation paragraph was performed. It was predicted that by removing the machining stresses a distortion of about 0.005 might occur. The actual deformation turned out to be 0.003 inch which was



COORDINATE DIMENSIONS

Y±.00010	X±.00010	Y±.00010	X±.00010
.000000	.200000	.160000	.256125
.005000	.200062	.165000	.259278
.010000	.200250	.170000	.262488
.015000	.200562	.175000	.265754
.020000	.200998	.180000	.269072
.025000	.201556	.185000	.272443
.030000	.202237	.190000	.275862
.035000	.203039	.195000	.279330
.040000	.203961	.200000	.282843
.045000	.205000	.205000	.286400
.050000	.206155	.210000	.290000
.055000	.207425	.215000	.293641
.060000	.208806	.220000	.297321
.065000	.210297	.225000	.301040
.070000	.211896	.230000	.304795
.075000	.213600	.235000	.308585
.080000	.215407	.240000	.312410
.085000	.217313	.245000	.316267
.090000	.219317	.250000	.320156
.095000	.221416	.255000	.324076
.100000	.223607	.260000	.328024
.105000	.225887	.265000	.332002
.110000	.228254	.270000	.336006
.115000	.230705	.275000	.340037
.120000	.233238	.280000	.344093
.125000	.235850	.285000	.348174
.130000	.238537	.290000	.352278
.135000	.241299	.295000	.356406
.140000	.244131	.300000	.360555
.145000	.247032	.305000	.364726
.150000	.250000	.310000	.368917
.155000	.253032	.310693	.369500

NOTES: UNLESS OTHERWISE SPECIFIED.

1. MATERIAL, MONEL ALLOY 404, AIR MELTED CERTIFICATION REQUIRED. (INTERNATIONAL NICKEL CO.)

2. TECHNICAL BULLETIN T-12, (AVAILABLE FROM INTERNATIONAL NICKEL CO.) PROVIDES SPECIFIC MACHINING DATA.

3. STRESS RELIEF, FOLLOWING PRELIMINARY MACHINING THE LOCKED IN FABRICATION STRESSES SHOULD BE REMOVED AS FOLLOWS.

   3.1 SUSPEND ROD VERTICALLY IN A VACUUM FURNACE AT 50 MICRONS OR LESS
   3.2 HEAT TO 1025° ±25°F FOR 2 HOURS
   3.3 COOL SLOWLY IN FURNACE TO ROOM TEMPERATURE WITH VACUUM MAINTAINED.

4. FINISH ROD TO FINAL DIMENSIONS

5. IF MORE THAN 0.010 OF MATERIAL IS REMOVED DURING FINAL FINISHING, ADDITIONAL STRESS RELIEVING IS REQUIRED PER 3.1, 3.2 and 3.3.

⚠6 HYPERBOLIC CONTOUR MAY DEVIATE FROM A TRUE HYPERBOLA WITHIN ±.0005 IF THE HYPERBOLAS IN A SET OF FOUR RODS ARE EQUAL WITHIN ±.0001.

FIGURE 5-2. Hyperbolic Quadrupole Rod Design

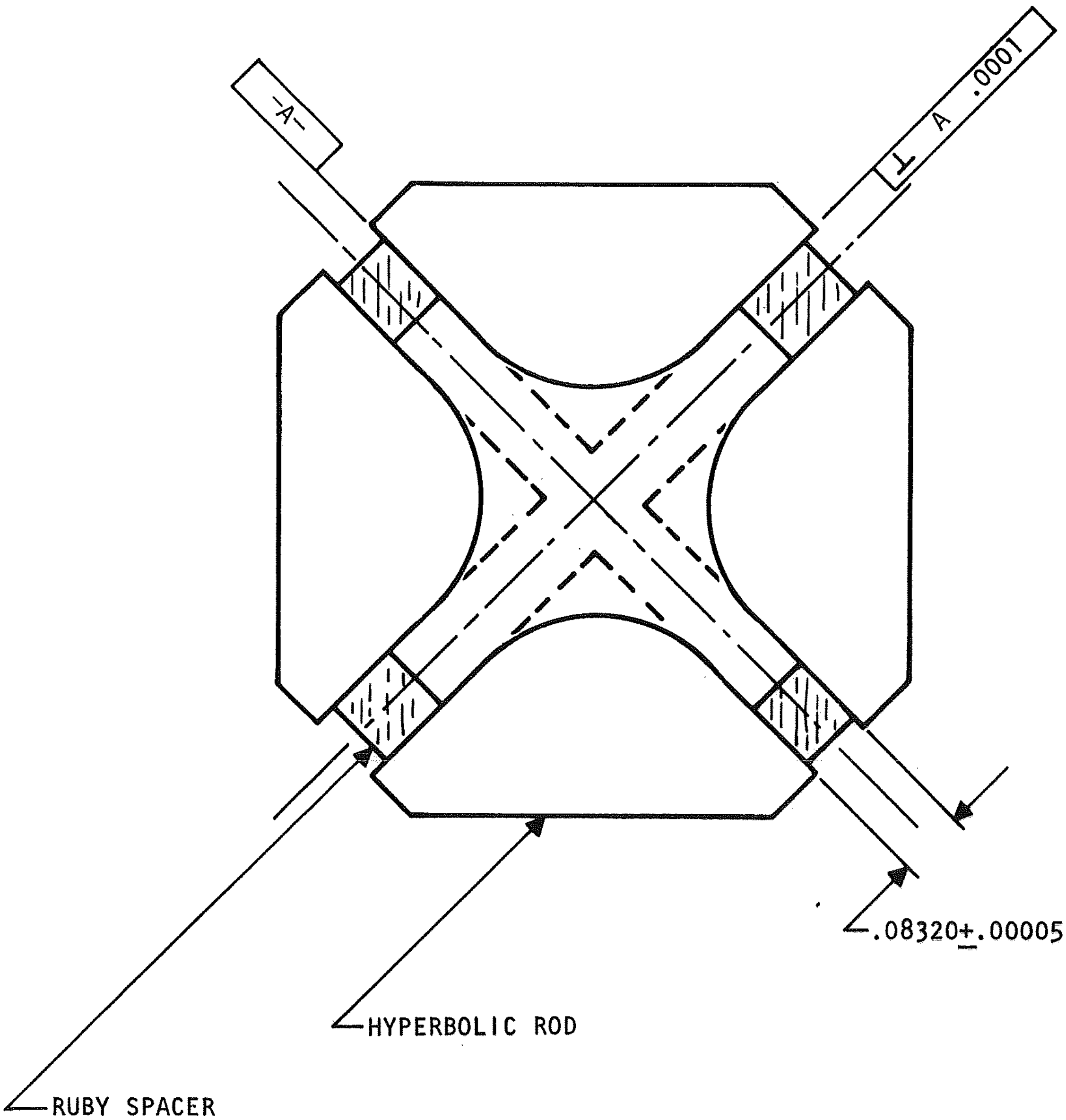


FIGURE 5-3. Quadrupole Rod Spacing

easily corrected by the final grinding. A lapping block was made from the 50:1 template which was used to handlap the hyperbolic surface to its final dimension. The flatness of the finished rods over its entire length was measured to be better than 0.00015 inch.

The second vendor manufactured the rods as follows: A crush roll or dressing tool was manufactured by using a 50:1 template of the hyperbolic contour. This crush roll was used to form a 24 inch diameter grinding wheel. With this grinding wheel the rods were ground on a temperature controlled crush grinding machine. The grinding wheel was periodically redressed by the crush roll to eliminate errors due to wheel wear. The same stress relief schedule was used as described before. The flatness of the finished rods by using this method was determined to be better than 0.0008 inch which is five times worse than the tolerance achieved by the method used by the other vendor. Consequently, the best four rods from the first vendor were selected and used for the quadrupole assembly.

5.4 ASSEMBLY AND ALIGNMENT

The first approach for aligning the rods relied upon using precision gauge blocks at each end of the rod assembly with a width and height of 2 r_o = 0.4000 inch. The rod mounting screws were tightened until the correct spacing of the rods determined by the gauge blocks were achieved. During the alignment check, an alignment of only 0.001 was achieved, indicating that the poor alignment was probably due to the fact that two rods can slide in parallel to the other set of rods and still maintain the desired r_o established by the square gauge blocks. A second attempt was made to improve the alignment as follows.

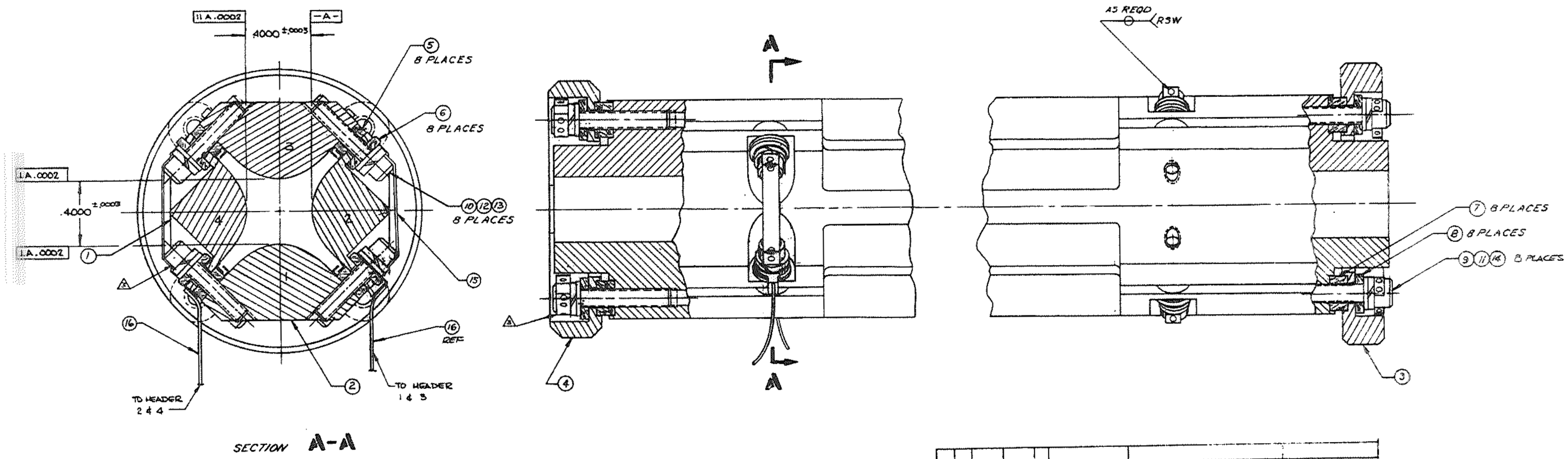
An alignment fixture in the form of a precision L-bracket was made. The four rods were assembled with Ruby washers and screws hand tight so that the individual rod could easily be moved. One rod was mounted to the L-bracket standing up. The high point of the hyperbola was determined under a high-powered microscope. Then the center line was established and the center of the rod assembly dialed on the traveling microscope by using the correct r_o dimension. The high point of the hyperbola on the adjacent rod was aligned perpendicular to the first centerline beginning at the rod assembly center by adjusting the table of the traveling microscope by the r_o dimension. The second rod was then secured to the first rod. The same method was repeated to align the third and fourth rod.

The rod assembly was then turned around and the alignment procedure peformed on the other end.

A check of the distance between one set of two opposing rods was found to be 0.4000 inch and the distance between the other two rods to be 0.4002 inch. This was true for both ends of the rod assembly. Since checking the rod distances over the full length of the rods was impossible with the available tooling, it was assumed that the specified spacing was achieved over the entire length because the flatness of the single rods was measured to be better than 0.00015 inch.

This rod assembly was attached to the two mounting rings, as shown in Figure 5-4. The ion source installed to the free mounting ring and the source nozzle aligned to the center of the rods. The combined rod and source assembly was installed in the quadrupole housing.

The system components as designed are shown in Figures 5-5, 5-6, 5-7, and 5-8. Figure 5-5 shows a photograph of two of the hyperbolic rods. Figure 5-6 shows a photograph of the rods as assembled prior to installation into the quadrupole housing. Figure 5-7 is a photograph of the high pressure ion source as utilized in this analyzer, and Figure 5-8 shows a photograph of the analyzer and electron multiplier housings, and internal components.



-/ REQD/ASSY	ITEM OR NO.	CODE IDENT. NO.	DWG SIZE	PART OR IDENTIFYING NO.	DESCRIPTION	MATERIAL AND SPECIFICATION
	17					
2	16		C	341455	LUG ASSY, PLAIN	
A/R	15		A	340153-2	SHIM STOCK, . . WIDE	304 CRES
8	14		-	NAS 620-4L	WASHER, FLAT #4, LIGHT	
8	13		-	NAS 620-3L	WASHER, FLAT #3, LIGHT	
8	12		-		WASHER, LOCK, #3, LIGHT	
8	11		-		WASHER, LOCK. #4, LIGHT	
8	10		-	NAS1352C03-8	SCREW, SOC. HD. CAP, 3-48 X 1/2 LG	
8	9		-	NAS1352C04-8	SCREW, SOC. HD. CAP, 4-40 X 1/2 LG	
8	8		C	341457 -4	WASHER, RUBY	
8	7		C	341457 -3	WASHER, RUBY	
8	6		C	341457 -2	WASHER, RUBY	
8	5		C	341457 -1	WASHER, RUBY	
1	4		C	341459	RING, REAR	
1	3		C	341458	RING, FRONT	
	2					
2	1		D	341453	HYPERBOLIC ROD ASSY	

LIST OF MATERIAL OR PARTS LIST

FIGURE 5-4. Quadrupole Rod Assembly Design

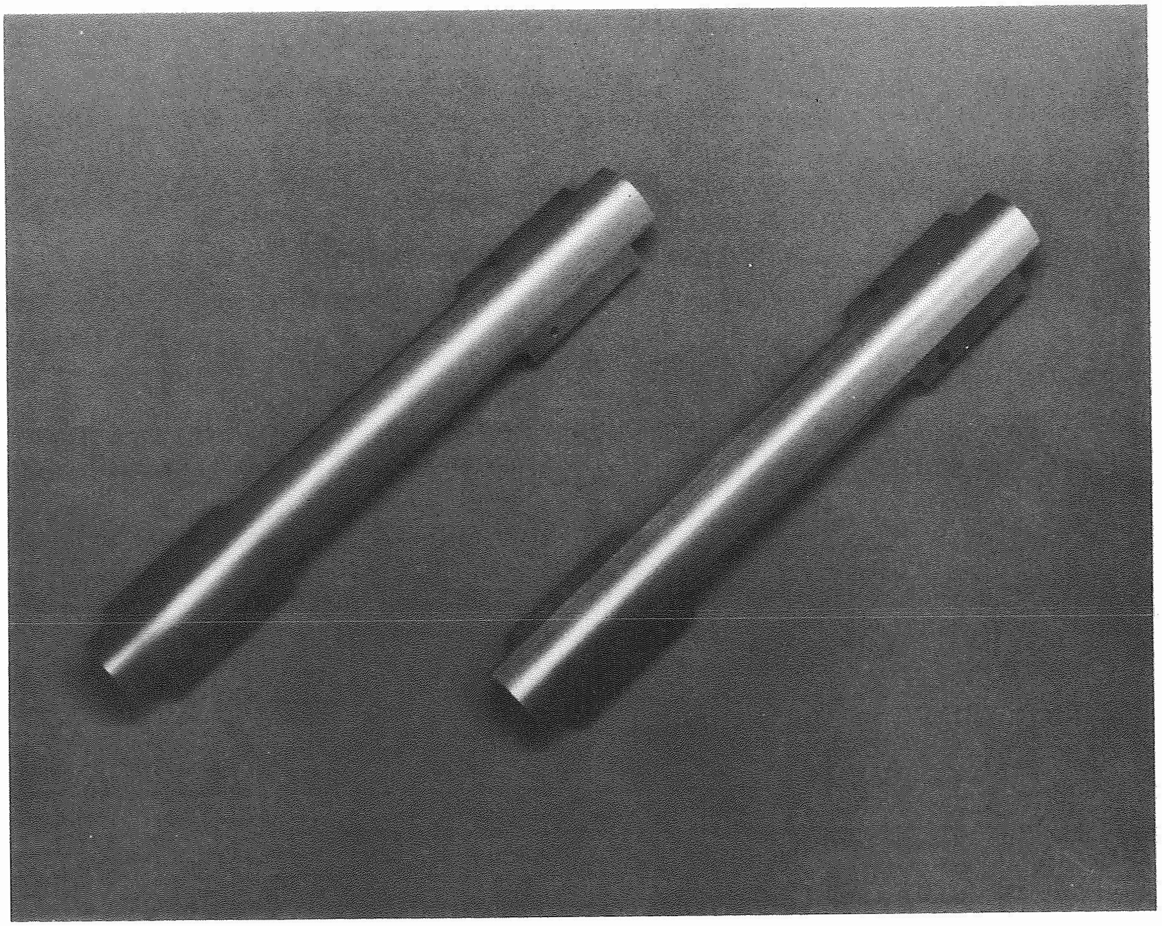


FIGURE 5-5. Hyperbolic Rods

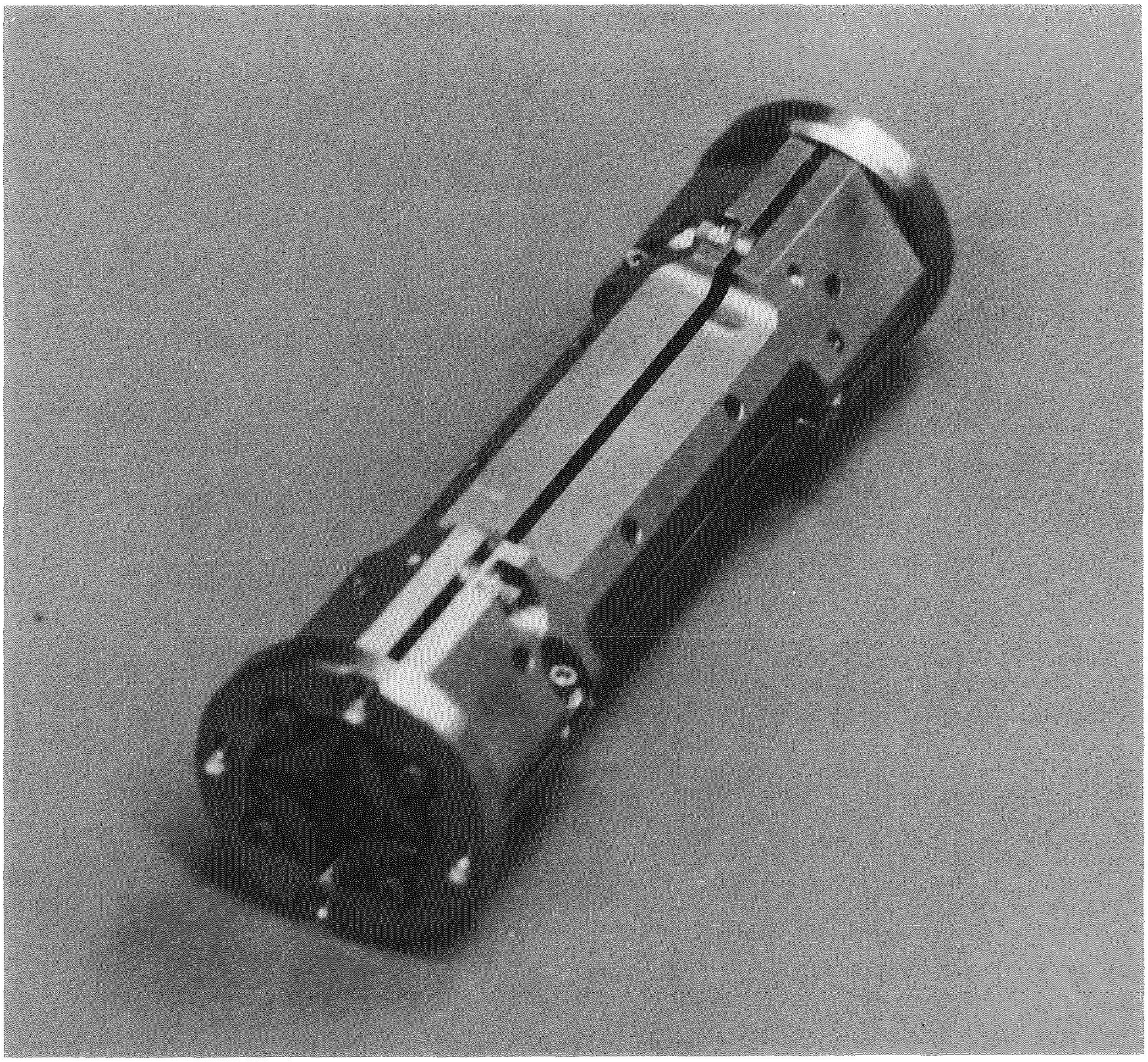


FIGURE 5-6. Hyperbolic Rod Assembly

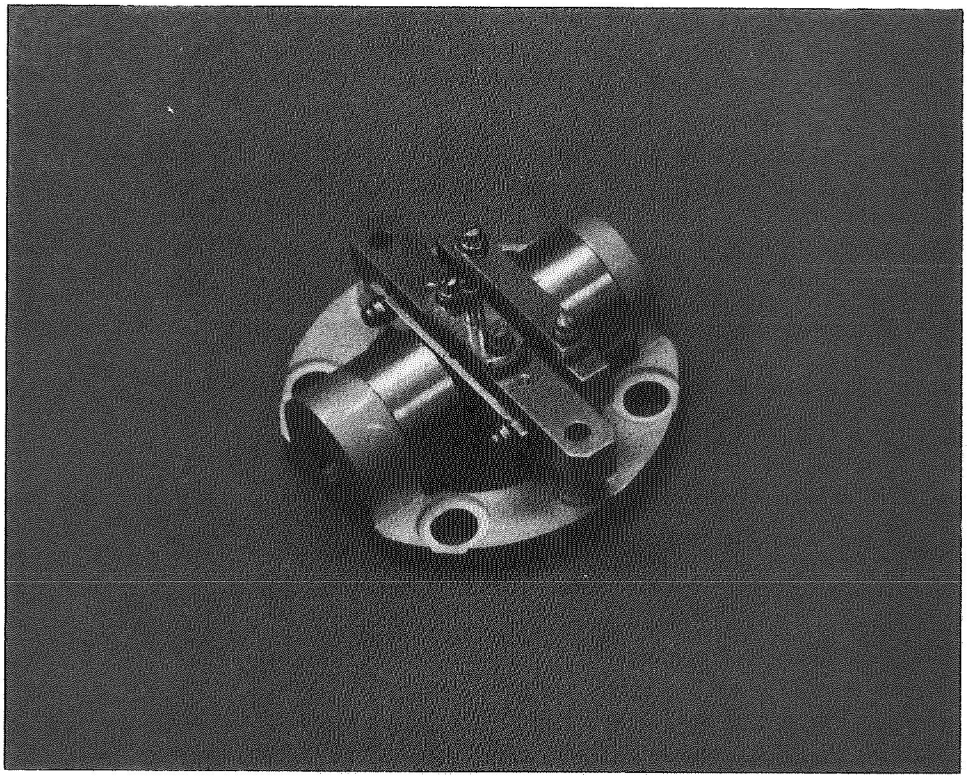


FIGURE 5-7. High Pressure Ion Source

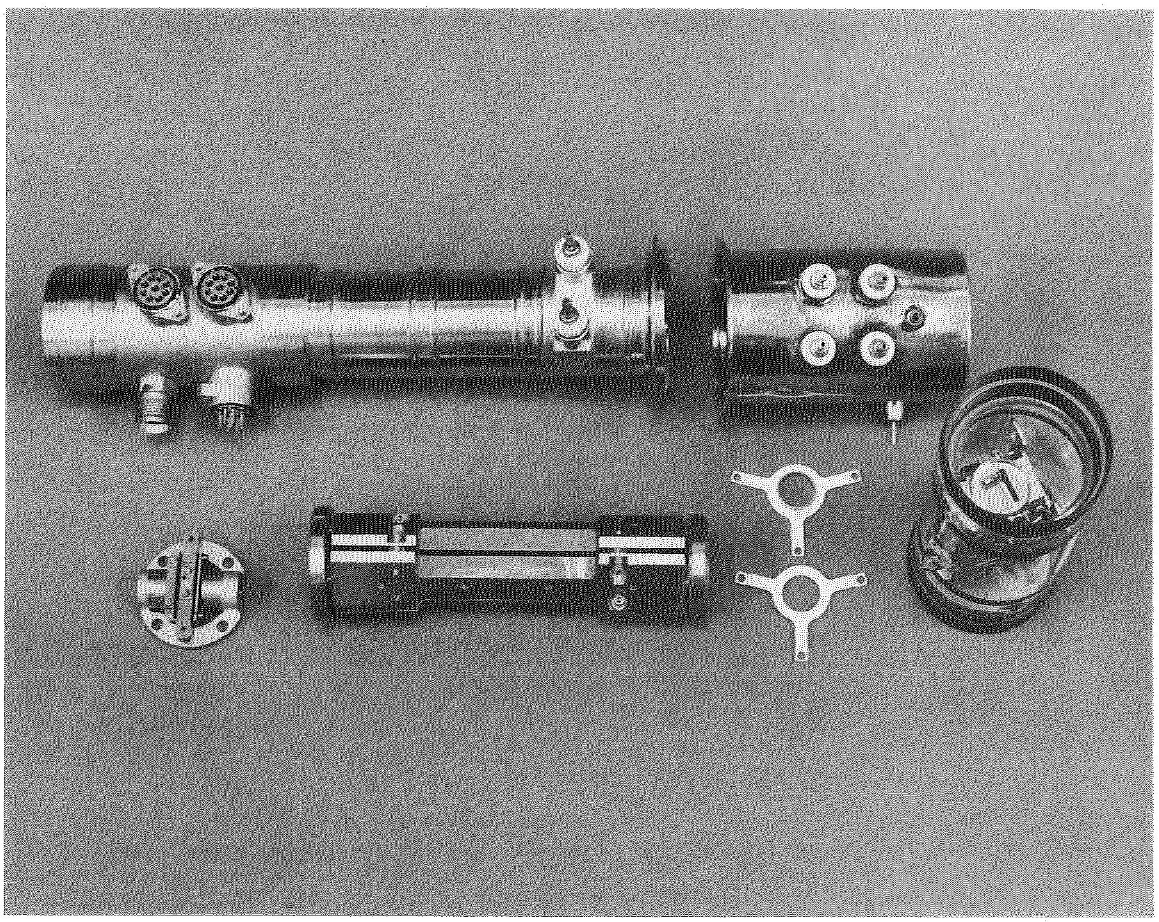


FIGURE 5-8. Quadrupole Analyzer Components

6. TEST RESULTS-PHASE IVB

The test program carried out on the Phase IVB analyzer (hereafter referred to as the serial number 4B instrument) was a minimal checkout to establish operating conditions for the instrument. Following this checkout, some investigations were carried out to analyze the performance capability of the hyperbolic quadrupole rods.

The initial tuneup of the high pressure ion source was carried out using a new sample inlet system to avoid the contamination problems which occurred during the Phase IVA testing. This inlet system was composed of a sorption pumping system to which a direct sample was introduced. The sample pressure was monitored using a Varian Millitorr ionization gauge, which operates between 1 x 10^{-6} and 1 torr. The ion source was then connected directly to this high pressure inlet system. A schematic of this inlet system is shown in Figure 6-1.

Tuneup data of the high pressure ion source proved to be much simpler and easier using this new inlet system. The control of the sample pressure was definite, and the pressure could read instantaneously off of a direct metered output.

Following initial filament burn-in and placement of nominal potentials on the lenses, ion focusing data was taken as a function of the ion extraction potential, ΔV_{R-A}. These data were taken using an N_2 sample with the quadrupole tuned to the m/e 28 peak. Collection of the m/e 28 current was then monitored at the input to the electron multiplier. A typical scan of the ion focusing results is shown in Figure 6-2. This scan is a plot of the m/e 28 ion current as a function of scanning the potential of one half of the ion focus split lens for various values of the potential on the other half of the lens. At the point of maximum sensitivity, where the output remains fairly flat, linearity plots of the I_{28}^{+} current versus pressure were then taken as a function of the ionizing electron energy. This was done to observe the linearity of the ion source with pressure for various electron energies. It was found that the linearity was nominally independent of electron energy, allowing a relatively high value in order to maximize the ionization probability and thereby the ion source sensitivity. A typical plot of the ion source linearity for N_2 is shown in Figure 6-3. The straight line at 45 degrees on the log-log plot corresponds to a linear change of output current versus sample pressure. As seen, the ion source linearity on this model extends to over 3 x 10^{-2} torr, and the ion source sensitivity is about 6 x 10^{-9} amperes/torr for N_2, using an ionizing electron current of 5 microamperes.

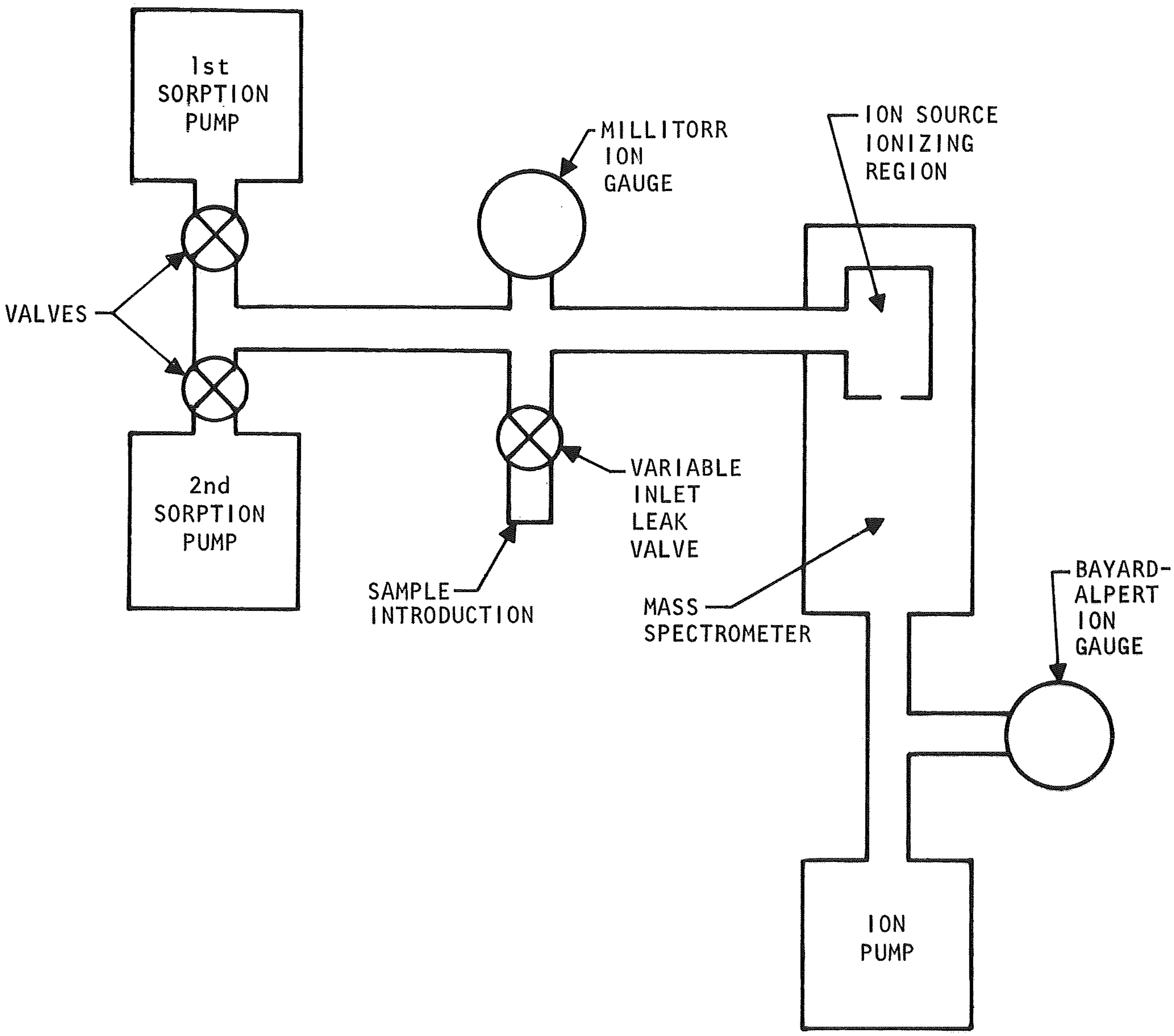


FIGURE 6-1. Sample Inlet System

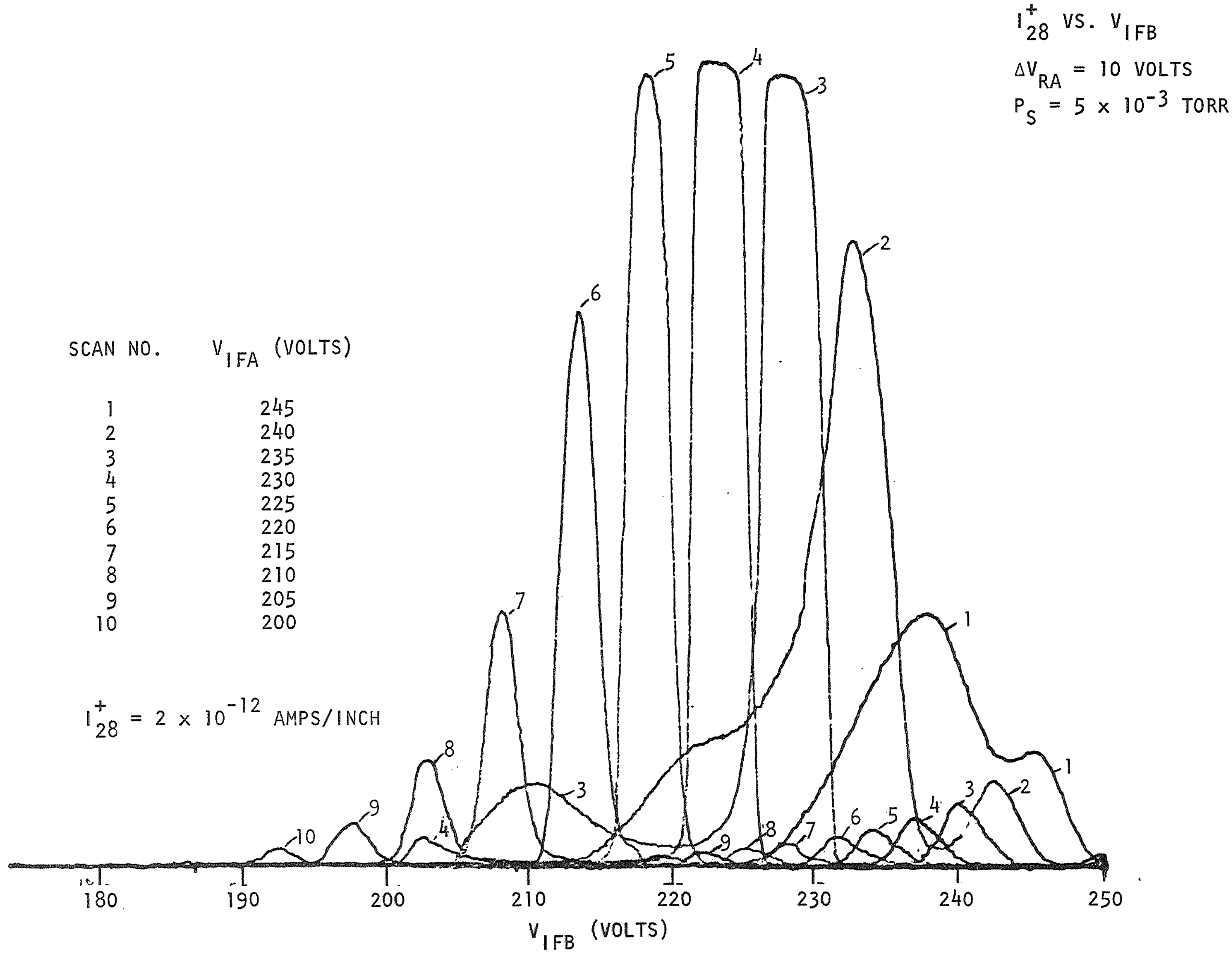


FIGURE 6-2. Ion Focusing Data

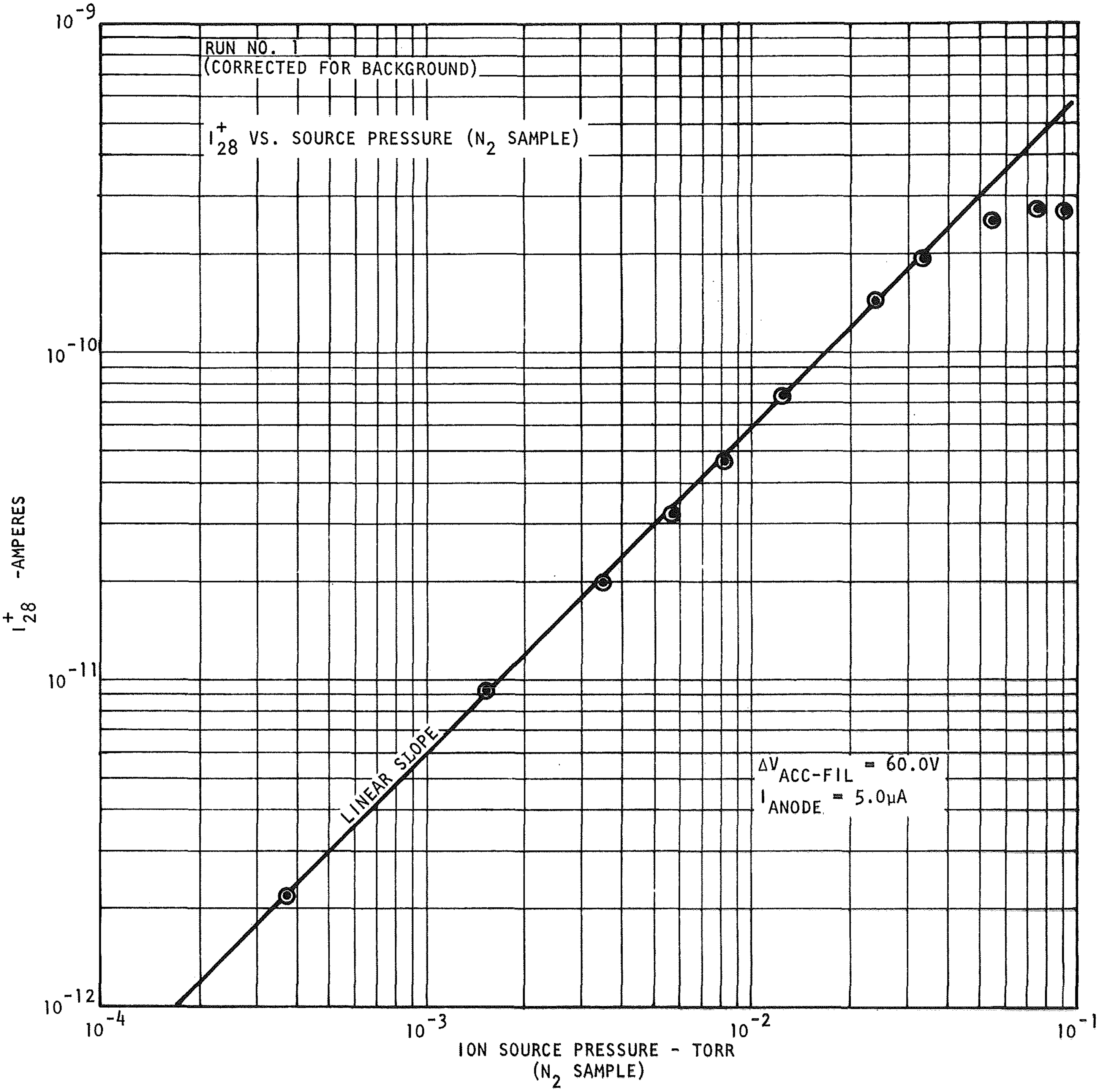


FIGURE 6-3. Ion Source Linearity

The ion source focal properties of the ion focusing system were also measured by computing the transmission efficiency of the ion current being focused through the nozzle. This transmission efficiency, Θ, is computed from

$$\Theta = \frac{S_T}{S_T + S_{Noz}}$$

Where S_T = ion source sensitivity of ions transmitted through the quadrupole

S_{Noz} = ion source sensitivity of ions striking the nozzle

For this ion source, the maximum transmission efficiency was found to be about 91.5 percent, indicating that almost all the ions exiting the ion exit aperture of the ionizing region were being transmitted.

The test program to evaluate the performance of the hyperbolic rods was then undertaken to establish the peak shape and resolving power. Initial tuning showed that poor peak shapes resulted, due to the ion source tuning. This showed that the angular output of the high pressure source is significantly higher than the dual filament ion source, so it was detuned in sensitivity to reduce its exit angles. Following this change, extensive tuning of the quadrupole was undertaken. These data have been submitted in the test data book accompanying the analyzer. Note, however, that a considerable improvement in analyzer performance resulted.

Figure 6-4 shows a plot of a mass spectrum taken on an air sample using a logarithmic electrometer amplifier to obtain a high output dynamic range. Figure 6-5 shows a similar plot using a krypton sample. Here it is seen that separation is occurring between the m/e 41, 41.5, and 42 peaks created by the doubly charge species of m/e 82, 83, and 84 of the krypton spectra. The mass spectra of krypton in the m/e 80's is shown in Figure 6-6. With a xenon sample admitted to the ion source, the resultant mass spectra is shown in Figure 6-7. The increased resolution gained by the use of hyperbolic rods is apparent as shown in Figure 6-8, where $\Delta m/m = 1/90$ was obtained. This contrasts with the previous values of $\Delta m/m = 1/33$ as shown in Figure 4-1 earlier. The improved rod alignment plus the utilization of hyperbolically contoured rods has thus shown a direct influence on the obtainable performance of a small flyable mass spectrometer.

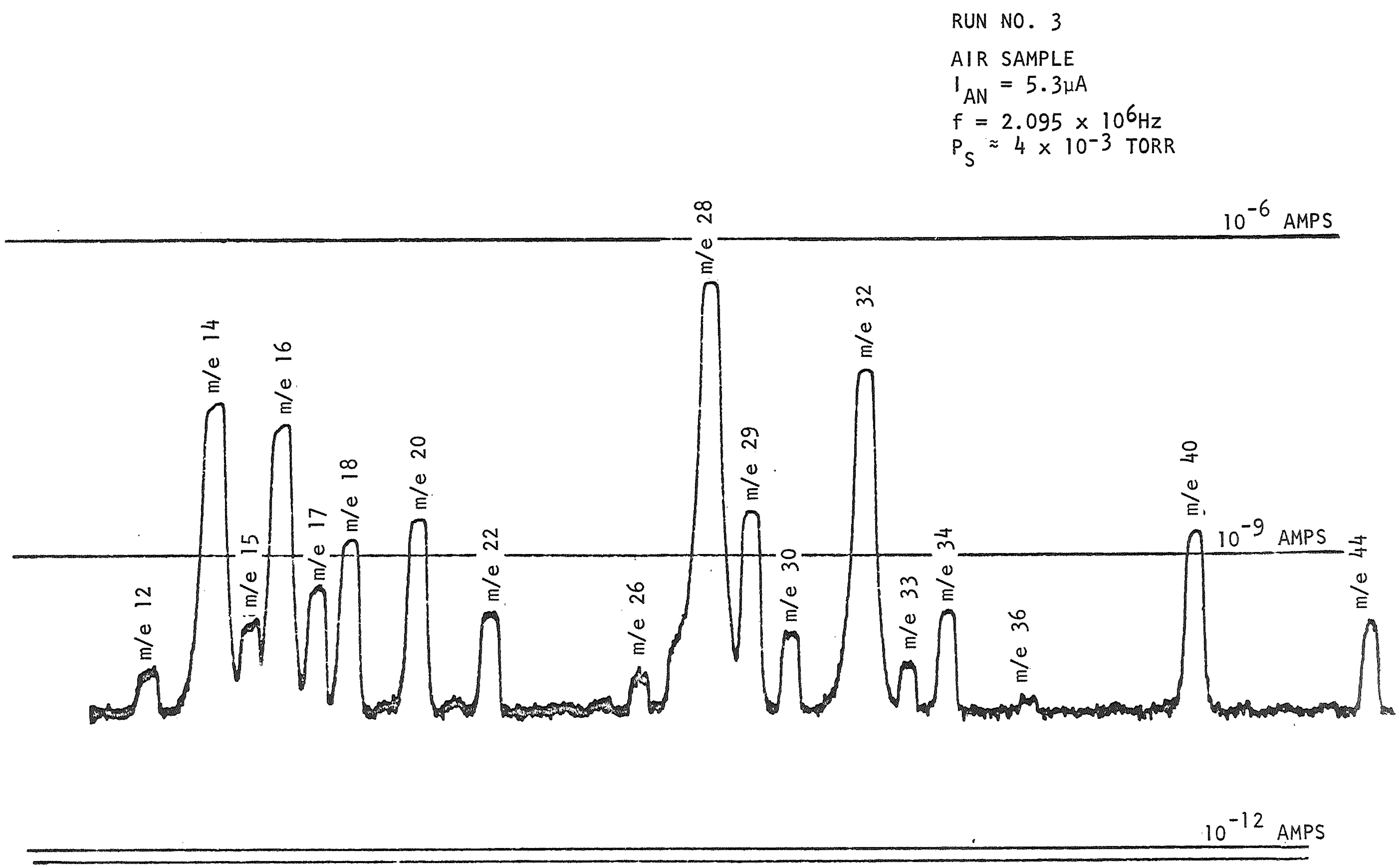


FIGURE 6-4. Mass Spectrum Scan (Air Sample)

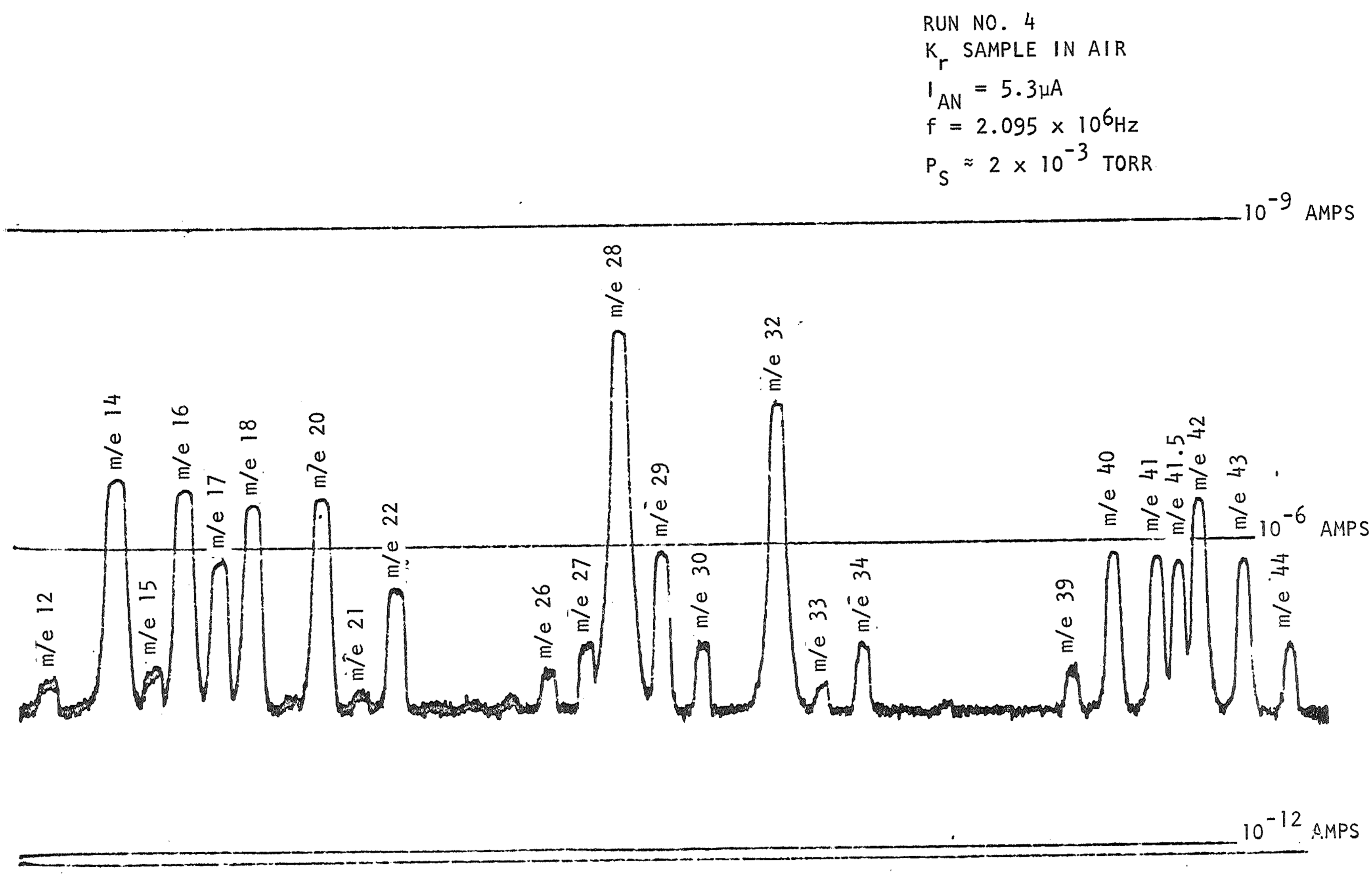


FIGURE 6-5. Mass Spectrum Scan (Kr Sample In Air)

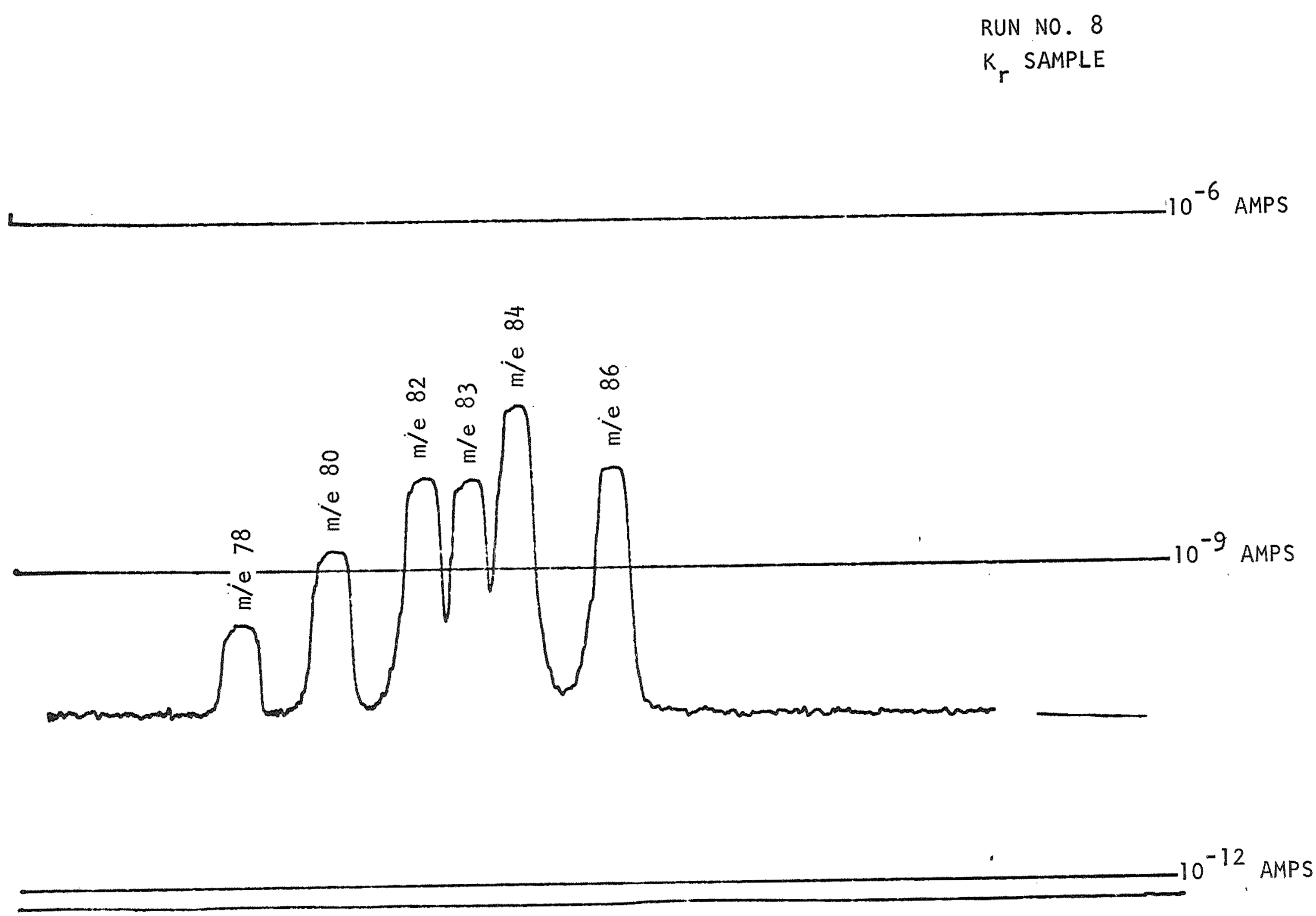


FIGURE 6-6. Krypton Spectrum Scan

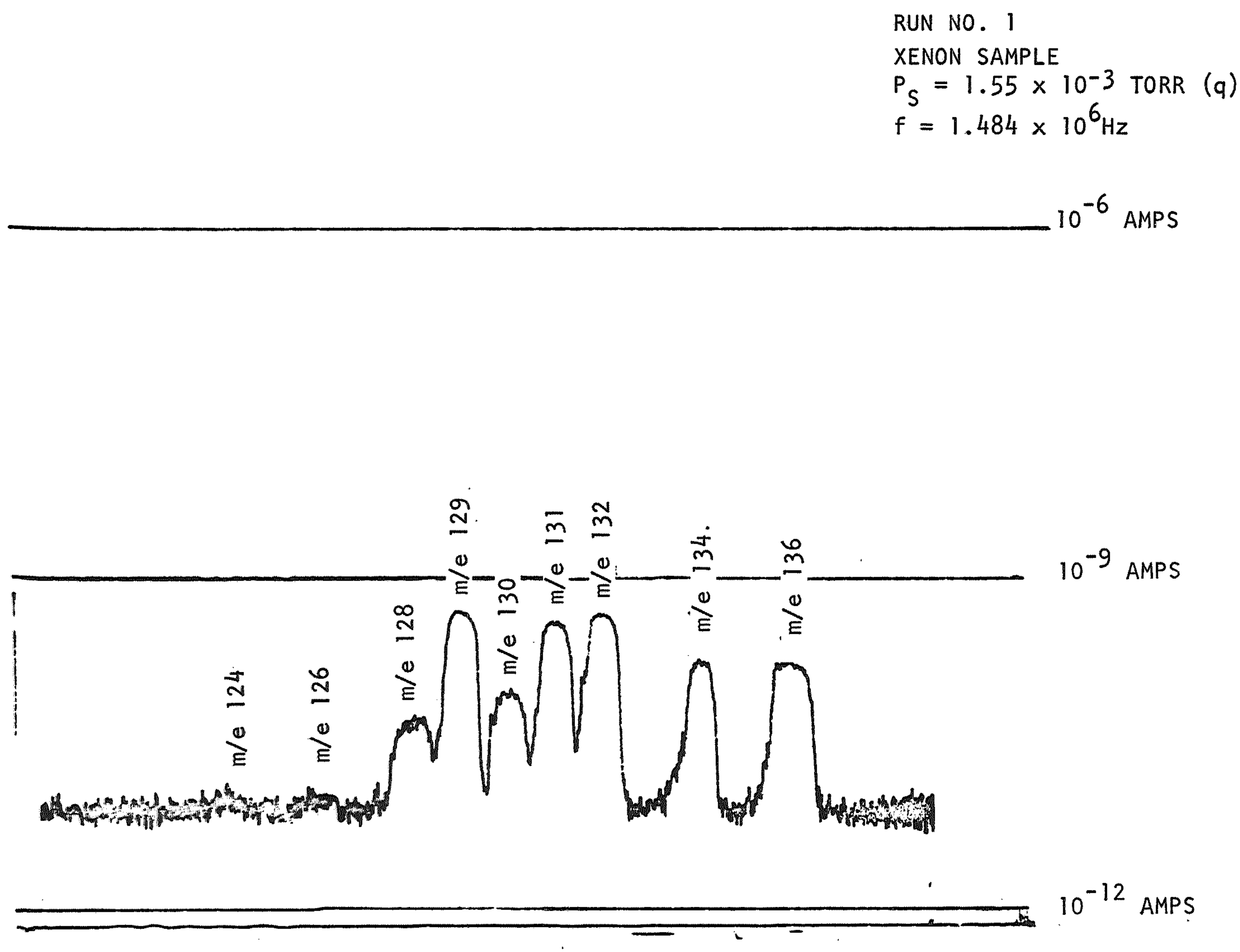


FIGURE 6-7. Xenon Spectrum Scan

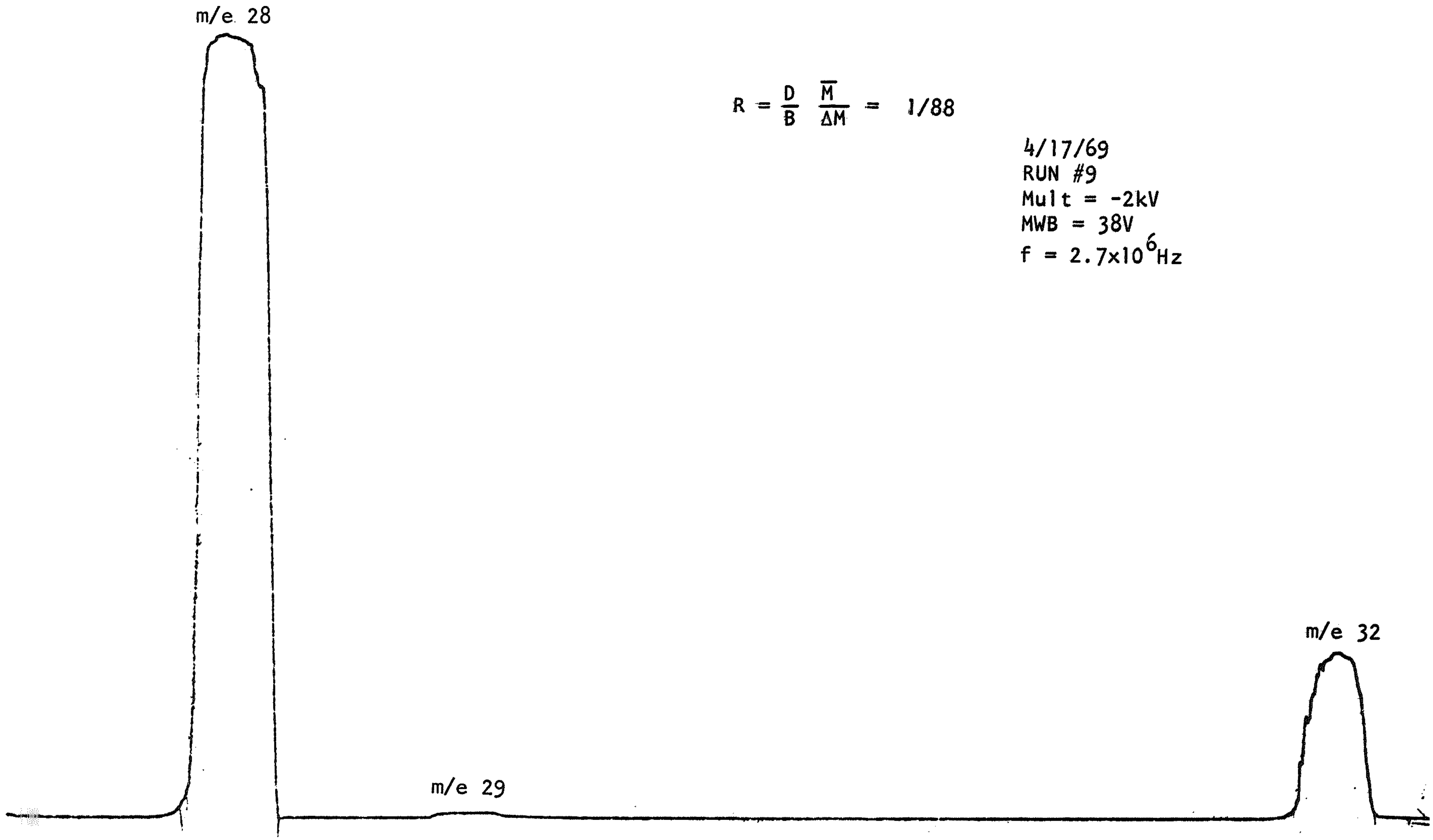


FIGURE 6.8 Quadrupole Resolution

7. CONCLUSION

The development program described in this final report has resulted in extensive improvements in the performance which can be realized from a miniaturized quadrupole mass spectrometer system. This Phase IV program has shown the results which can be gained with precision alignment of quadrupole rods, and the use of hyperbolic surfaces on the field-forming quadrupole electrodes. The resulting performance has been verified by test analyses.

The hardware which has been developed has demonstrated the necessary performance to be employed for the analysis of planetary atmospheres on entry vehicles and in particular for the analysis of the Martian atmosphere on board the Viking entry capsule. The remaining task of designing this instrument into a more optimum mechanical configuration for this mission has been undertaken on contract NAS5-11185 and the results will be reported at the conclusion of that effort.

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