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OPERATING CHARACTERISTICS OF A HOLLOW-CATHODE NEUTRALIZER FOR 5- AND 8-CENTIMETER-DIAMETER ELECTRON-BOMBARDMENT MERCURY ION THRUSTERS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1975

1. Report No. NASA TM X-3209	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle OPERATING CHARACTERISTICS OF A HOLLOW-CATHODE NEUTRALIZER FOR 5- AND 8-CENTIMETER-DIAMETER ELECTRON-BOMBARDMENT MERCURY ION THRUSTERS		5. Report Date March 1975
		6. Performing Organization Code
7. Author(s) Albert J. Weigand		8. Performing Organization Report No. E-8176
		10. Work Unit No. 506-22
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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17. Key Words (Suggested by Author(s)) Hollow cathode; Auxiliary propulsion; Ion thrusters		18. Distribution Statement Unclassified - unlimited; STAR category 18 (rev.)	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 17	22. Price* $3.25

* For sale by the National Technical Information Service, Springfield, Virginia 22151

OPERATING CHARACTERISTICS OF A HOLLOW-CATHODE NEUTRALIZER FOR 5- AND 8-CENTIMETER-DIAMETER ELECTRON-BOMBARDMENT MERCURY ION THRUSTERS

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SUMMARY

Thin-tip 0.3-centimeter-outside-diameter hollow-cathode neutralizers were used to investigate causes of neutralizer tip erosion experienced in thruster endurance tests. Bell-jar tests indicated that neutralizers with new rolled tantalum foil inserts coated with an emissive mixture eroded very little over the neutral flow rates investigated (3 to 10 mA) for simulated 5- and 8-centimeter-diameter thruster neutralizer conditions. Tip erosion rates of neutralizers operated with no insert or emissive mixture increased by two orders of magnitude for both configurations as the neutral flow rate decreased. Spectroscopic analysis of the discharge plasma from neutralizers operated with inserts coated with the emissive mixture detected tungsten at all neutral flow rates for both thruster neutralizer conditions. The only source of tungsten was the tip. Therefore, detection of tungsten indicated neutralizer tip erosion. Barium, an element of the emissive mixture, was detected at low neutral flow rates for the 5-centimeter-diameter thruster neutralizer operating condition only.

INTRODUCTION

Electron-bombardment mercury ion thrusters are attractive auxiliary propulsion devices for long-life geosynchronous satellites. There have been two flight tests of mercury ion thrusters SERT I (ref. 1) and SERT II (ref. 2), and auxiliary propulsion thrusters and their components have been extensively studied in ground tests. These ground tests have included a 9700-hour endurance test of a 5-centimeter-diameter ion thruster (ref. 3) and an ongoing life test of an 8-centimeter-diameter ion thruster which has operated for 7000 hours during 220 cycles (ref. 4). Post-test analysis of the 5-centimeter-diameter thruster revealed that the neutralizer tip orifice diameter had increased from

0.25 to 0.55 millimeter. In addition, it was necessary to increase the neutralizer tip heater power from 0 to 10 watts to maintain the magnitude of the thruster floating voltage below 25 volts and to keep the mercury (Hg) flow rate at about 3 milliamperes. Examination of the rolled tantalum (Ta) foil insert, which was coated with a mixture of barium oxide (BaO) and strontium oxide (SrO), indicated a deterioration of the downstream portion of the insert (closest portion to the tip) and a depletion of emissive mixture in this region (ref. 3). The results of the 9700-hour life test suggested an interdependence among neutralizer tip erosion, the presence of an emissive mixture, and neutral flow rate. Therefore, an investigation was undertaken to determine the relation among these parameters.

APPARATUS AND PROCEDURE

Two series of tests were run to define the important parameters that affect neutralizer lifetime. One series obtained direct measurements of neutralizer tip erosion with a variety of conditions simulating operation of 5- and 8-centimeter-diameter thrusters. The other series measured certain spectral emission lines from the neutralizer discharge plasma.

Figure 1 shows a general cutaway view of a 0.3-centimeter-outside-diameter tantalum tube neutralizer cathode used for the tests. A heated porous tungsten (W) vaporizer plug was used to supply and control the flow of mercury vapor to the neutralizer. The insert in figure 1 is a standard rolled tantalum foil insert coated with a BaO-SrO emissive mixture (ref. 5). Another type of insert used was a porous tungsten plug impregnated with barium oxide (ref. 6). The location of both inserts was within 0.25 millimeter of the back surface of the cathode tip. A swaged tantalum heater was used to heat the neutralizer tip during startups and during operation when needed. The cathode tip had a 0.25-millimeter-diameter orifice for all tests. The keeper enclosures were made of ceramic and quartz for the tip erosion study and the discharge emission line analysis study, respectively. The tantalum keeper cap was slotted so that the discharge plasma in the region of the tip orifice could be observed (fig. 2). The keeper ignition voltages (ref. 7) for the neutralizer tip erosion study and the neutralizer discharge spectrographic analysis were 600 and 1000 volts, respectively. A collector screen was used to simulate the beam discharge. A more detailed description of the neutralizer construction can be found in reference 5. All tests were performed in 50-centimeter-diameter bell jars, and the vacuums ranged between 4×10^{-7} and 4×10^{-6} torr.

Direct Tip Erosion Measurements

A cross section of the neutralizer tip used for the 9700-hour endurance test is shown in figure 3(a); the figure illustrates the difficulty in the use of standard 1-millimeter-thick neutralizer tips to investigate neutralizer tip erosion. As can be seen, the erosion was a function of distance from the downstream surface of the tip. The erosion also produced irregular surfaces. Because of these effects, tests of several hundred hours would be required for each data point in order to obtain accurate measurements of volumetric losses.

Tests were run to determine if the use of thin tips would allow reliable erosion data to be obtained in relatively short tests. Pieces of tantalum foil 0.012, 0.025, and 0.076 millimeter thick were spot welded to 0.3-centimeter-outside-diameter cathode bodies. Each tip had a 0.25-millimeter-diameter orifice drilled in the center. A rolled tantalum foil insert coated with emissive mixture was put into each cathode. These special cathodes were tested at nominal 5-centimeter-diameter thruster operating conditions (table I). The resulting erosion was of the type shown in figure 3(b). This form of erosion allowed accurate erosion data to be obtained in test durations of about 150 hours by simply measuring the diameter of the orifice. The 0.025-millimeter-thick tip was the thinnest tip that could withstand the temperatures associated with neutralizer operating conditions. Therefore, in all tests to measure neutralizer tip erosion 0.025-millimeter-thick tantalum tips were used.

As shown in the section RESULTS the volume erosion rates observed for these thin tips were of the same order as those for the standard tips when operated under similar circumstances. The data from the thin-tip tests could then be used for parametric evaluations.

The tests were run over a variety of conditions in order to attempt to determine what parameters impacted lifetime. The range of conditions is shown in table II. The tests were run to simulate operation of both 5- and 8-centimeter-diameter thrusters. The basic differences between these two configurations were in the collector (simulated beam) current and keeper orifice diameter. Tests were run with and without inserts in order to explore the impact of the insert and the emissive mixture on lifetime. When a neutralizer was to be tested without an insert, a new tantalum tube was used to ensure that there was no emissive mixture present. Detailed listings of the operating conditions and configurations for the simulated 5- and 8-centimeter-diameter thruster neutralizer tests are given in tables III and IV, respectively.

A microscope with a magnification of 53 was used with a camera attachment to photograph each neutralizer tip before and after testing. The estimated uncertainty in the measurements of the diameter was 5 percent. The uncertainty in the volume calculations was then 10 percent.

Spectrographic Analysis of Discharge Plasma

The experimental arrangement for the neutralizer discharge emission line study is shown in figure 4. The spectrometer axis was perpendicular to the neutralizer axis and approximately in the plane of the tip orifice.

The optical spectrometer that was used for the tests was an Ebert mounted, plane-grating monochromator with a 0.5-meter focal length. The instrument dispersion was 16×10^{-10} meter per millimeter (16 Å/mm). The plane grating could be rotated, so that a wavelength range of 2000×10^{-10} to 8000×10^{-10} meter (2000 to 8000 Å) could be discerned. The entrance slit was set at 25 micrometers. The photon energy density (intensity) was detected by a photomultiplier tube and recorded on an x, y-recorder.

The emission lines that were analyzed included barium emission lines at 5535×10^{-10} and 4554×10^{-10} meter (5535 and 4554 Å) (BaI and BaII, respectively) and a tungsten emission line at 4294×10^{-10} meter (4294 Å). To obtain emission line intensity data the grating was first positioned to record one of these emission lines. The neutralizer was then started at a neutral flow rate of approximately 40 milliamperes. With the keeper current and collector current held constant, the neutral flow was slowly reduced to 3 milliamperes, whereupon the neutralizer discharge was extinguished. The grating was then reset to another emission line, and the procedure was repeated. Repeatability of the intensities of the emission lines was within 10 percent.

Table V shows the two neutralizer configurations that were investigated for emission lines. These neutralizers had standard tips (1 mm thick). Only neutralizers with rolled tantalum foil inserts were spectrographically analyzed.

RESULTS

A plot of the tip volumetric erosion rate as a function of the neutral flow rate is shown in figure 5 for the 5-centimeter-diameter thruster conditions. Details of the individual test configurations and operating conditions are given in table III. For the thin-tip simulated 5-centimeter-diameter thruster neutralizers tested there was a definite correlation between tip erosion and the presence of an insert and an emissive mixture. Neutralizers operated with new inserts showed no measurable erosion after the nominal 150-hour tests over the extremes of neutral flow rates tested. After each test visual inspection of the insert indicated that there was no insert deterioration and that the emissive mixture was present on the downstream portion of the insert. In tests for neutralizers with no inserts the tip erosion rate increased by two orders of magnitude as the neutral flow rate decreased from 10 to 2.8 milliamperes.

The erosion rates of neutralizers with standard tips tested for 9700 and 5000 hours in a vacuum tank and a bell jar, respectively, are also shown in figure 5. Post-test inspection of both neutralizers showed the loss of emissive mixture on the downstream portion of both inserts. The time-averaged neutralizer tip erosion rates of these two tests corresponded closely to the thin-tip neutralizer data points taken with no inserts. This fact seemed to indicate that the technique of using thin-tip neutralizers to study tip erosion could be used with assurance that they follow the same trend as standard-tip neutralizers.

The results for thin-tip neutralizers operated at 8-centimeter-diameter thruster conditions are shown in figure 6. Details of the operating conditions of each data point are given in table IV. Neutralizers operated with new inserts showed no erosion (12 out of 17 tests) or very small quantities of erosion (4 out of 17 tests) over the extremes of neutral flow rate investigated. The one exception was the data point at 3.6 milliamperes with a measured erosion rate of 5.6×10^{-8} cubic centimeter per hour. This neutralizer was operated at an emission current two to three times higher than those for the other data points at low neutral flow rates. The neutralizers that were tested with no inserts showed a trend of increasing tip erosion rate as the neutral flow rate decreased. This trend was especially true for low neutral flow rates.

The differences between the simulated 5- and 8-centimeter-diameter neutralizers were the keeper orifice diameters and the collector currents. However, a similar correlation between tip erosion rates and the presence of an insert and an emissive mixture was evident. A comparison of the tip erosion rates of neutralizers operated at simulated 5- and 8-centimeter-diameter thruster conditions revealed that the dependence upon insert and emissive mixture is the same. Neutralizers operated with inserts showed relatively little or no erosion over the extremes of neutral flow rates. However, when a neutralizer was operated with no insert, the erosion rate increased by several orders of magnitude as the neutral flow rate decreased. In addition, the erosion rates of thin-tip neutralizers operated at approximately 3 milliamperes agreed with the erosion rates of standard-tip neutralizers operated for 9700 and 5000 hours in a vacuum tank and a bell jar, respectively.

Therefore, it can be concluded that if a neutralizer were operated with no insert or with a degraded insert at low neutral flow rates, the neutralizer tip would rapidly erode. The insert and its emissive mixture are essential for operation of a neutralizer with low tip erosion. Once the emissive mixture is depleted and the insert is deteriorated, neutralizer tip erosion accelerates, as observed in the 9700-hour thruster endurance test. The performance of the neutralizer will deteriorate, and the overall performance and life of the thruster will be reduced. Apparently, the only way to relieve this high tip erosion after insert deterioration is to increase the neutral flow rate.

The discharges from two hollow-cathode neutralizer configurations operated with inserts (table V) were spectrographically analyzed to determine the variation of certain emission line intensities as functions of neutral flow rate. The tip was the only neutralizer component composed of tungsten. Therefore, the 4294×10^{-10}-meter (4294-Å) (WI) line was observed in order to determine if the tip was being eroded. Figure 7 shows the intensity of WI as a function of neutral flow rate for both 5- and 8-centimeter thruster conditions. Although the signal level was low, the WI line was detected at all neutral flow rates investigated. The signal was constant except for the 8-centimeter thruster neutralizer at a neutral flow rate of 4 milliamperes, where it had a higher intensity. These low levels of intensity may be related to the low levels of tip erosion observed with neutralizers operated with inserts. It would be necessary to analyze a neutralizer system which erodes faster to see if spectrographic analysis of tungsten in the discharge could be used as a means of detecting levels of tip erosion.

The results of the investigation of the 5535×10^{-10}-meter (5535-Å) (BaI) line and the 4554×10^{-10}-meter (4554-Å) (BaII) line are discussed together. Detection of these lines would indicate depletion of the BaO-SrO emissive mixture coating on the insert. Figure 8 illustrates the results of the investigation. Lines for BaI and BaII were not detected at any flow rate for the 8-centimeter-diameter thruster condition and were detected only for neutral flow rates less than 5 and 3 milliamperes, respectively, for the 5-centimeter-diameter thruster condition. Although no definite conclusions can be drawn concerning barium depletion at high neutral flow rates, the detection of BaI and BaII at low neutral flow rates was positive evidence of depletion of the emissive mixture at low neutral flow rates.

SUMMARY OF RESULTS

Neutralizers operated at simulated 5- and 8-centimeter-diameter ion thruster conditions were tested to identify neutralizer operating parameters that affect neutralizer tip erosion. Thin-tip (0.025-mm-thick) neutralizers were used. The tip erosion was determined to be dependent on neutral flow rate for neutralizers with no inserts. As the neutral flow rate decreased, the tip erosion rate increased, especially at low flow rates. Increasing the neutral flow rate to 6 milliamperes or more reduced the tip erosion rate to a level which was compatible with the design life of the system. These results were true for both simulated thruster conditions, which indicated that increasing the keeper orifice diameter from 0.94 to 1.4 millimeters and increasing the collector current from 0.02 to 0.07 ampere had no effect on the tip erosion mechanism. Not only was the tip erosion rate trend the same for both 5- and 8-centimeter-diameter thruster conditions, but also the magnitudes of the erosion rates were similar. Neutralizers with inserts coated with the emissive mixture showed negligible tip erosion at these same operating conditions. A nondegrading insert was essential for long-life 5- and 8-centimeter-diameter thruster neutralizers. Once the insert was degraded and the emissive mixture was depleted, a higher neutral flow rate was necessary to reduce the tip erosion rate. A correlation between thin-tip neutralizer tip erosion data and standard-tip erosion data from 9700- and 5000-hour tests in a vacuum tank and a bell jar, respectively, substantiated the results of the thin-tip neutralizer study.

Spectrographic analyses of the discharge plasma of neutralizers with inserts operated at 5- and 8-centimeter-diameter thruster conditions were obtained. Tungsten was detected at all neutral flow rates investigated for both thruster conditions.

Barium was detected at low neutral flow rates for the 5-centimeter-diameter thruster conditions only. This result indicated that the emissive mixture was being depleted at low neutral flow rates.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 20, 1974,
506-22.

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TABLE I. - CONDITIONS FOR THIN-TIP FEASIBILITY TEST OF 5-CENTIMETER-DIAMETER THRUSTER NEUTRALIZER

Neutral flow rate, mA	4
Keeper current, A	0.4
Collector current, A	0.023
Keeper orifice diameter, mm	0.94
Tip orifice diameter, mm	0.25

TABLE II. - DIMENSIONS OF NEUTRALIZER COMPONENTS AND RANGES OF OPERATING PARAMETERS FOR NEUTRALIZER TIP EROSION STUDY

(a) Dimensions of 5- and 8-centimeter thrusters

Distance from tip to keeper, mm	1.5
Distance from keeper to collector, mm	6-10
Tip thickness, mm	0.025
Tip orifice diameter, mm	0.25
Keeper orifice diameter, mm	
5-cm thruster	0.94
8-cm thruster	1.40

(b) Operating parameters

Parameter	Diameter of thruster being simulated, cm	
	5	8
Neutral flow rate, mA	2.6-9.9	3.1-23.2
Keeper current, A	0.34-0.37	0.20-0.65
Keeper voltage, V	16-23	8-26
Collector (simulated beam) current, A	0.023	0.072
Collector voltage, V	12-100	28-99

TABLE III. - DATA FOR THIN-TIP NEUTRALIZERS OPERATING AT 5-CENTIMETER-DIAMETER THRUSTER CONDITIONS

[Keeper orifice diameter, 0.94 mm.]

Insert	Neutral flow rate, mA	Keeper current, A	Keeper voltage, V	Collector current, A	Collector voltage, V	Erosion rate, cm^3/hr	Tip heater power, W
None	2.9	0.34	22	0.023	100	3×10^{-8}	52.0
	6.9	.35	19	.025	12	8.4×10^{-10}	41.5
	9.6	.36	23	.024	28	(a)	42.3
	9.9	.37	19	.025	40	(a)	50.4
Ta foil	2.6	0.36	17	0.018	100	(a)	0
	5.0	.36	16	.025	70	(a)	0
	9.3	.36	18	.024	30	(a)	0

[a]Less than 10^{-10} cm^3/hr.

TABLE IV. - DATA FOR THIN-TIP NEUTRALIZERS OPERATING AT

8-CENTIMETER-DIAMETER THRUSTER CONDITIONS

[Keeper orifice diameter, 1.4 mm.]

Insert	Neutral flow rate, mA	Keeper current, A	Keeper voltage, V	Collector current, A	Collector voltage, V	Erosion rate, cm^3/hr	Tip heater power, W
None	3.1	0.54	18	0.074	41	6.4×10^{-7}	56.0
	4.7	.48	21	.069	58	2.8×10^{-9}	61.2
	5.9	.45	20	.074	38	6.5×10^{-10}	61.9
	6.7	.65	22	.099	49	2.6×10^{-9}	19.7
	7.5	.39	26	.072	44	(a)	48.1
	9.6	.41	17	.071	31	7.9×10^{-10}	46.4
	12.6	.44	22	.074	32	8.8×10^{-10}	44.5
	23.2	.50	22	.074	30	1.6×10^{-10}	48.8
Ta foil	3.2	0.35	19	0.073	43	(a)	40.3
	3.6	.20	17	.067	82	(a)	51.0
	3.6	.62	16	.068	28	5.6×10^{-8}	39.2
	4.1	.20	16	.059	86	(a)	45.3
	4.6	.20	15	.058	77	(a)	47.6
	4.7	.30	16	.052	99	(a)	47.8
	5.0	.35	15	.070	57	7.9×10^{-10}	50.3
	5.4	.50	22	.072	41	(a)	44.6
W plug	6.0	0.45	10	0.058	59	(a)	76.7
Ta foil	6.0	0.35	18	0.073	39	(a)	44.0
	6.4	.47	20	.058	97	1.6×10^{-9}	0
	6.6	.40	18	.072	28	5.2×10^{-9}	45.1
	6.7	.35	18	.073	38	3.6×10^{-10}	48.7
W plug	7.6	0.45	9	0.073	47	(a)	65.7
Ta foil	8.0	0.40	16	0.076	70	(a)	30.7
	11.3	.46	8	.071	34	(a)	61.9
	13.0	.48	16	.073	27	(a)	47.4

[a]Less than 10^{-10} cm^3/hr.

TABLE V. - DIMENSIONS OF NEUTRALIZER COMPONENTS AND RANGES OF OPERATING PARAMETERS FOR SPECTROSCOPIC ANALYSIS STUDY

[Inserts, rolled Ta foil.]

(a) Dimensions of 5- and 8-centimeter thrusters

Distance from tip to keeper, mm	1.5
Distance from keeper to collector, mm	6-10
Tip thickness, mm	1.0
Tip orifice diameter, mm	0.25
Keeper orifice diameter, mm	
5-cm thruster	0.94
8-cm thruster	1.40

(b) Operating parameters

Parameter	Diameter of thruster being simulated, cm	
	5	8
Neutral flow rate, mA	3-40	3-40
Keeper current, A	0.3	0.3
Keeper voltage, V	20-29	21.5-28
Collector (simulated beam) current, A	0.023	0.072
Collector voltage, V	12-24	33-100

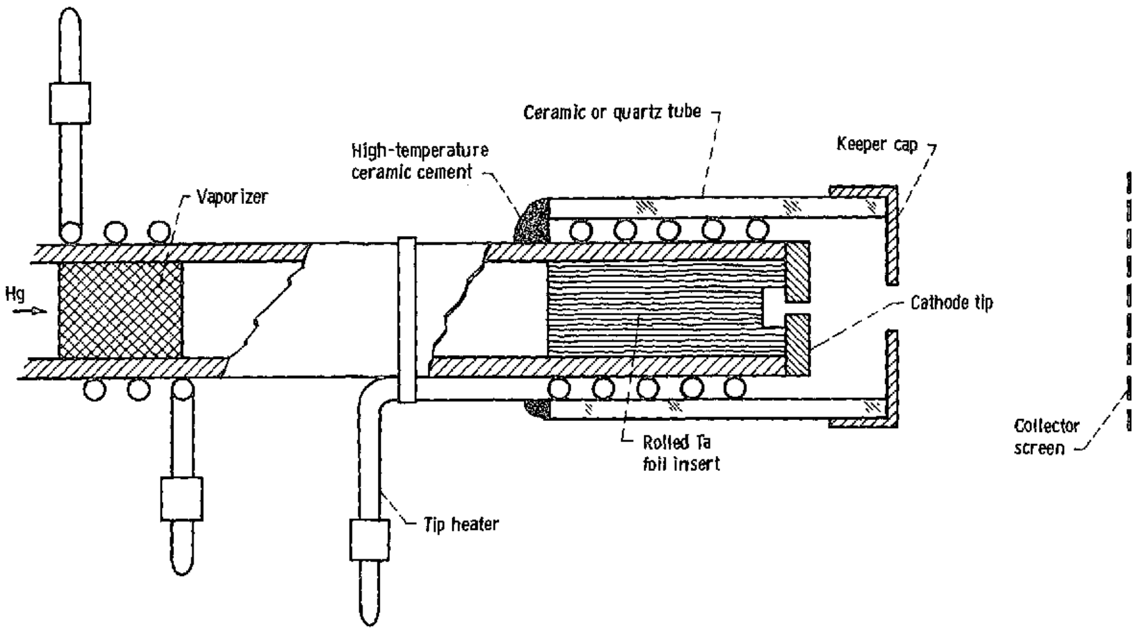


Figure 1. - Enclosed hollow-cathode neutralizer configuration.

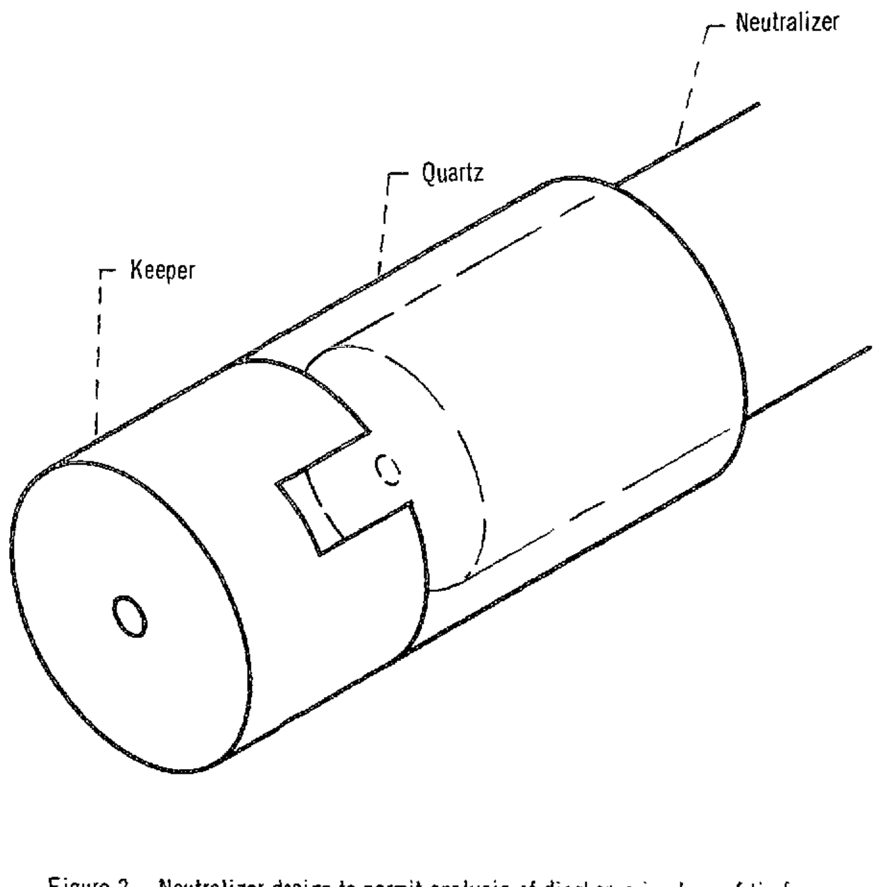
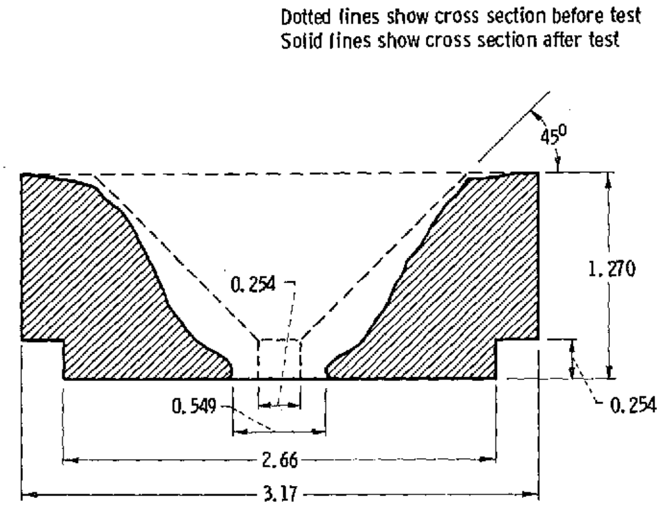
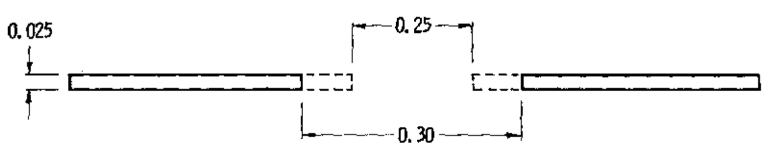


Figure 2. - Neutralizer design to permit analysis of discharge in plane of tip face.



(a) Standard tip tested for 9700 hours.



(b) Thin tip tested for 150 hours.

Figure 3. - Cross sections of neutralizer tips before and after testing showing erosion. (Dimensions in millimeters.)

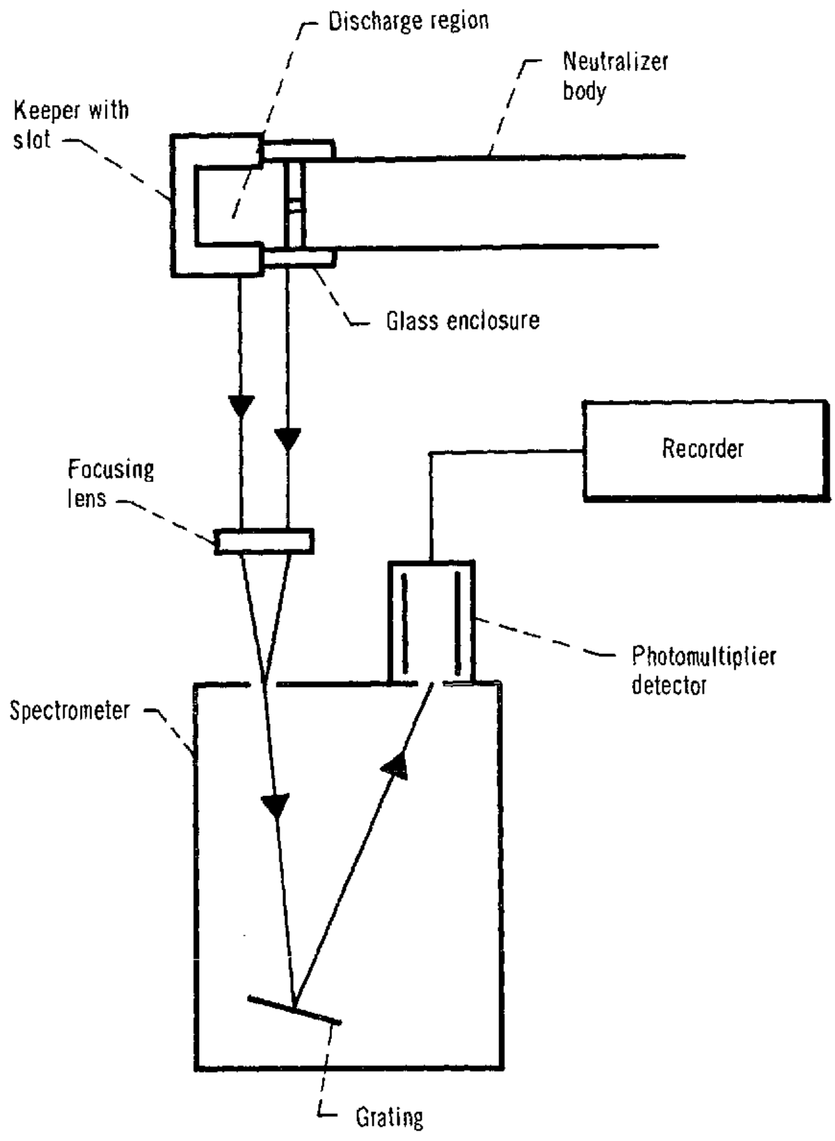


Figure 4. - Schematic of neutralizer discharge spectrographic analysis apparatus with spectrometer perpendicular to neutralizer axis in plane of tip.

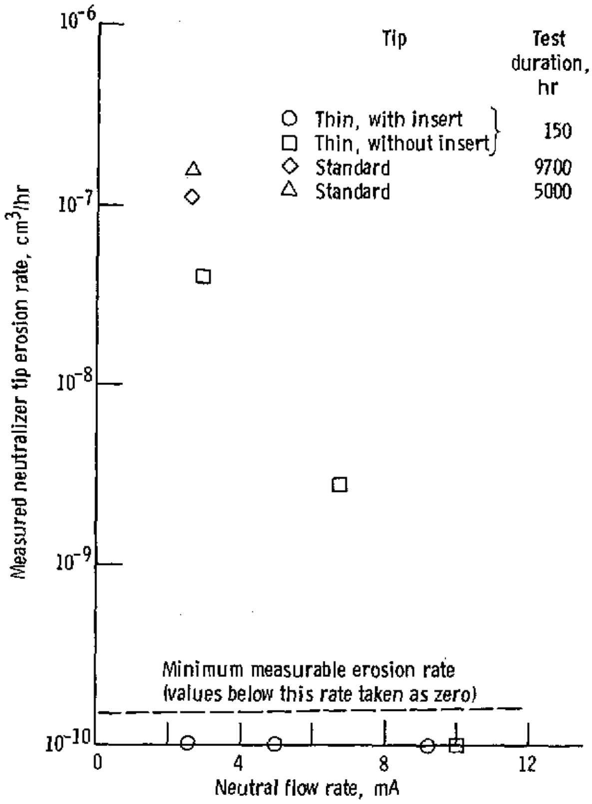


Figure 5. - Neutralizer tip erosion rate as function of neutral flow rate (1 mA = 7.5 mg/hr) for 5-centimeter-diameter thruster condition. Test duration, 150 hours.

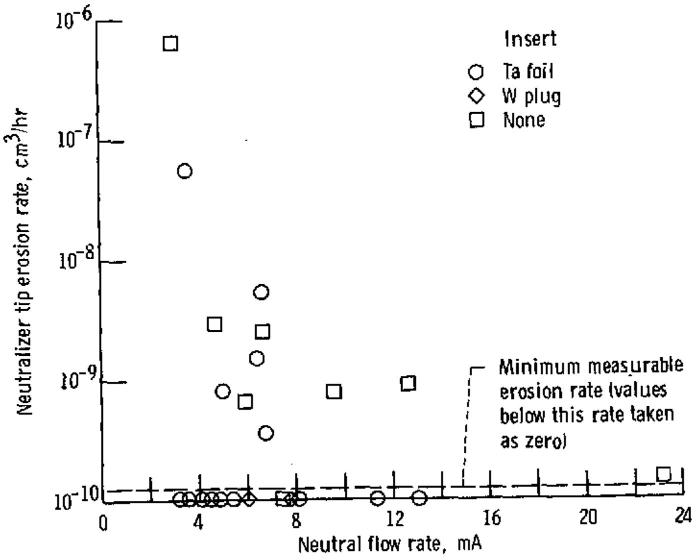


Figure 6. - Neutralizer tip erosion rate as function of neutral flow rate (1 mA = 7.5 mg/hr) for 8-centimeter-diameter thruster condition. Test duration, 150 hours.

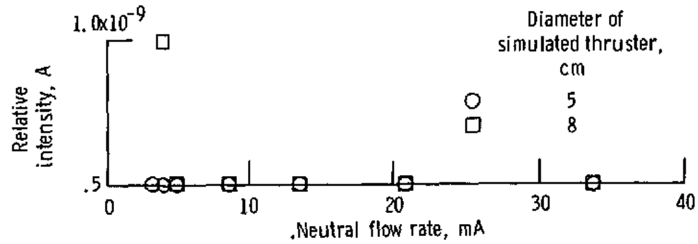


Figure 7. - Intensity of 4294×10^{-10}-meter (4294-Å) (WI) line as function of neutral flow rate (1 mA = 7.5 mg/hr) for simulated 5- and 8-centimeter-diameter thruster conditions.

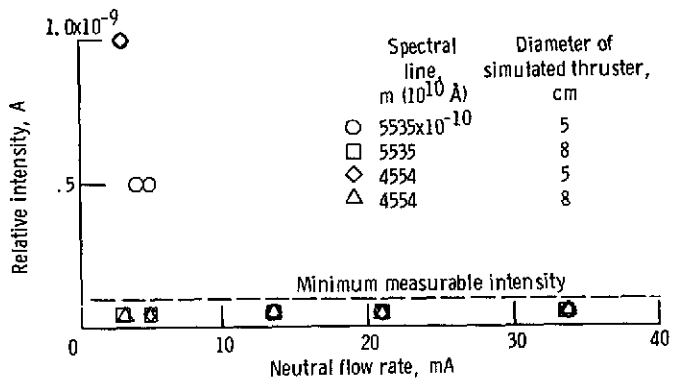


Figure 8. - Intensity of 5535×10^{-10}- and 4559×10^{-10}-meter (5535- and 4554-Å) (Ba I and Ba II) lines as function of neutral flow rate for 5- and 8-centimeter-diameter thruster conditions.

NASA-Langley, 1975 E-8176