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THE SAN MARCO III NEUTRAL ATMOSPHERE COMPOSITION EXPERIMENT

D. T. PELZ
G. P. NEWTON
W. T. KASPRZAK
T. D. CLEM

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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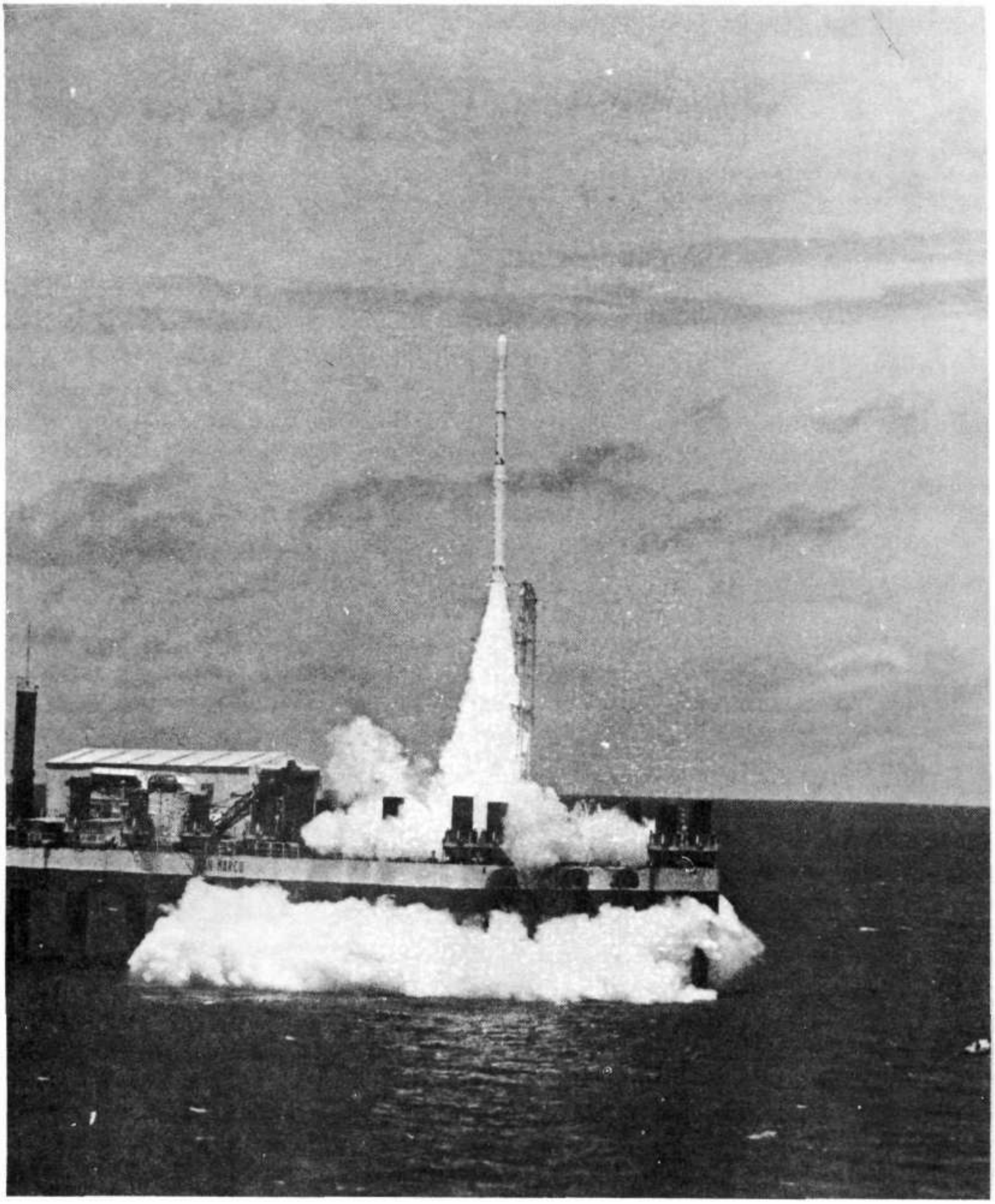

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THE SAN MARCO III NEUTRAL ATMOSPHERE

COMPOSITION EXPERIMENT

INTRODUCTION

The San Marco III Project is a cooperative space program between the Centro Ricerche Aerospazialia del' Universita Degli Studi di Roma, and NASA/ Goddard Space Flight Center. This aeronomy program is a study of the equatorial neutral thermosphere behavior resulting from solar and geomagnetic activity. The experimental objective of the San Marco III satellite is to obtain by direct measurement, a description of the equatorial atmosphere behavior in terms of neutral gas density, composition and temperature. A secondary objective is to determine the inter-relationships of three neutral density measurement techniques from the same satellite; i.e., in-situ mass spectrometric, instantaneous drag force, and orbital decay density measurements.

The San Marco III satellite shown in Figure 1 was constructed, integrated and tested in Rome, Italy, and was launched from the San Marco platform, Formosa Bay, Kenya, on 24 April 1971. The spacecraft, described by Ravelli et al. [1970], carried three aeronomy experiments in a 213 km perigee by 780 km apogee initial orbit at 3° inclination. The satellite operated successfully throughout orbital life and re-entry occurred on 28 November 1971. The experiment instrumentation included: (1) an Air Density Experiment [Broglio, 1971], to measure the instantaneous drag force and thus the neutral particle total mass density; (2) a Neutral Atmosphere Temperature Experiment (NATE) to determine the gas kinetic temperature by measuring molecular nitrogen density variations in an orificed spherical chamber as a function of angle of attack; and (3) a Neutral Atmosphere Composition Experiment (NACE), to measure the densities of helium, atomic and molecular oxygen, molecular nitrogen and argon. A cooperative analysis of the essentially simultaneous data obtained from these experiments, and a comparison with ground based orbital decay measurements is currently in progress.

Instrument Description

The NACE instrumentation, shown in block diagram in Figure 2, is a "closed" ion source double focussing magnetic mass spectrometer system. The NACE design is an extension and modification of the previously flown Explorer 17 and

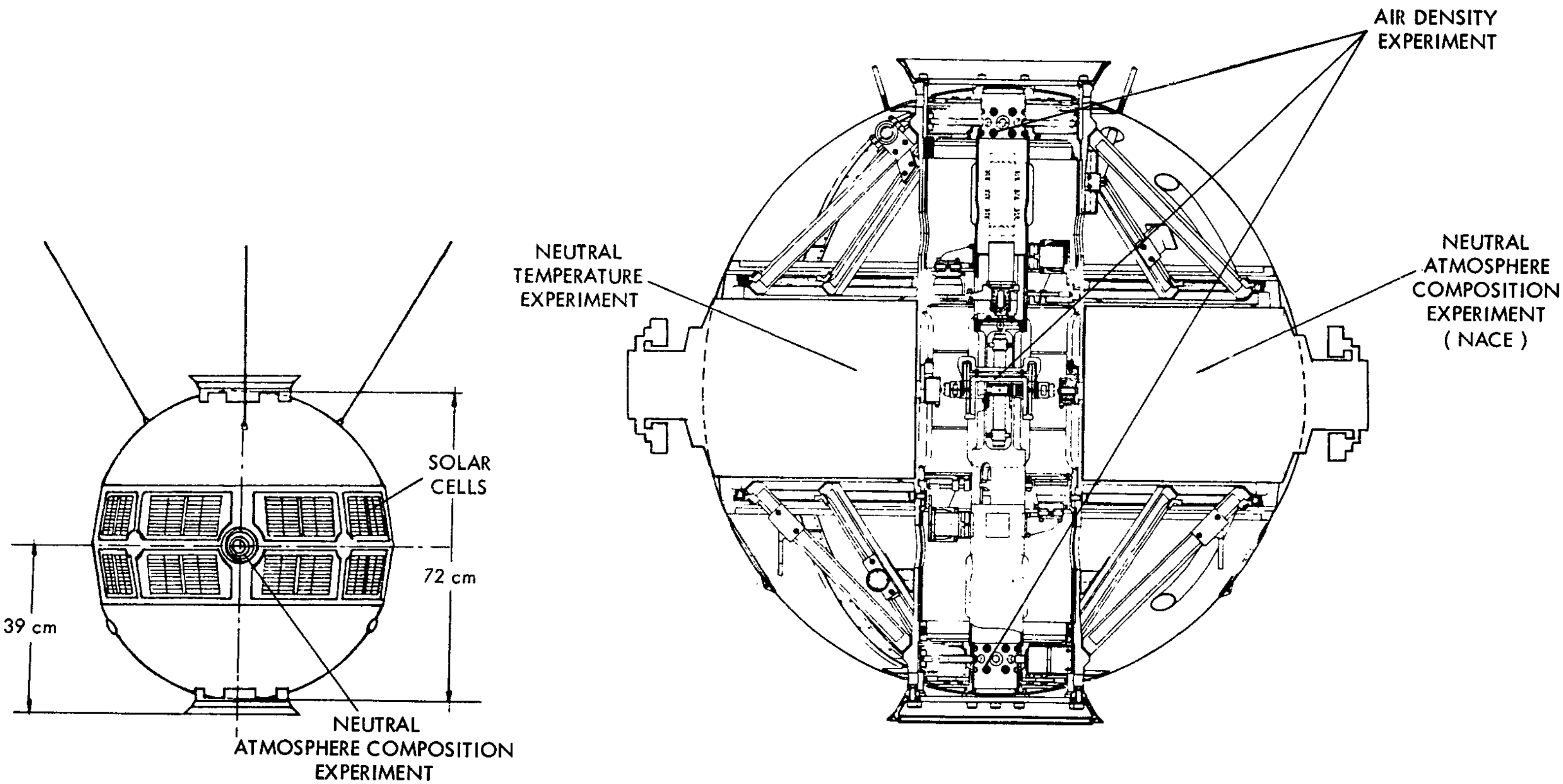

Figure 1. The San Marco III Aeronomy Satellite

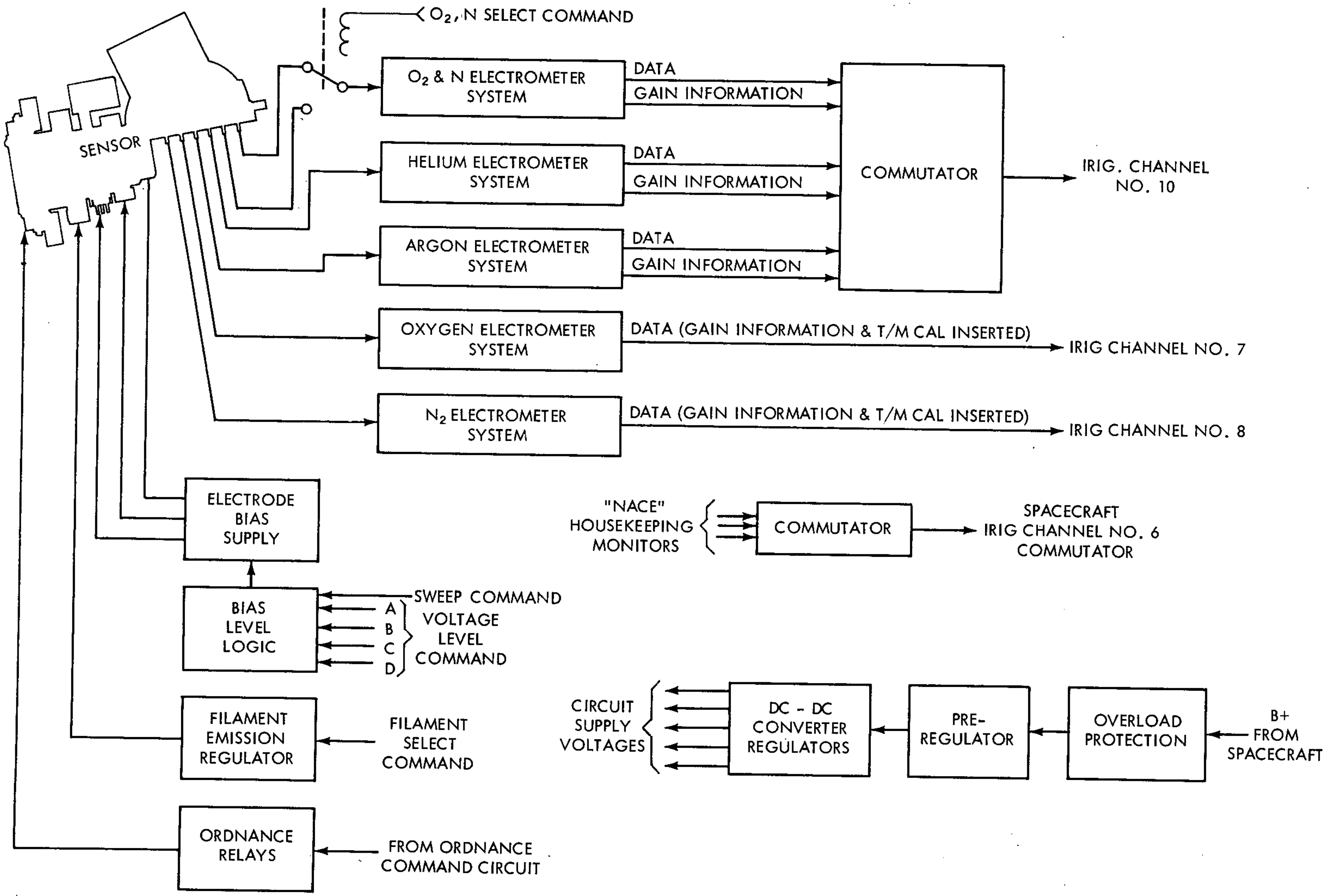

Figure 2. San Marco Neutral Atmosphere Composition Experiment (NACE) Block Diagram

32 satellite instruments [Spencer and Reber, 1964]. The instrumentation consists of a vacuum enclosure, antechamber, ion source, analyzer, detector, and electronics sub systems.

The NACE mass spectrometer sensor enclosure illustrated in Figure 3 consists of four stainless steel sections and a ceramic ring in the breakoff hat. Vacuum seals are accomplished using gold o-rings between the steel flanges and ceramic that is brazed into the breakoff hat. All housings are fabricated from 304 stainless steel except the ion source housing which is made from 410 stainless steel and acts as a magnetic shield for the ion source. The entire enclosure is sealed at high vacuum after final laboratory gas calibrations, and the ceramic ring is fractured in orbit using pyrotechnic linear actuators to effect separation of the breakoff hat. A titanium sublimation pump, shown in Figure 4, maintains low internal gas pressure and permits pre-launch ground testing of the full NACE system. The internal-pressure can be monitored by a miniature Bayard-Alpert ionization gauge in the titanium pump prior to turning on the mass spectrometer filaments. The titanium pump is valved off from the sensor after the last system check prior to launch and is thus isolated from the ion source in orbit.

The NACE antechamber is a right circular cylinder 2.0 cm in diameter and 4.6 cm long, with a 1.0 cm radius hemispherical dome. The antechamber-atmosphere interface is a .318 cm diameter orifice. The orifice edge is measured to be less than .01 mm in thickness. All internal antechamber surfaces are gold plated. The antechamber geometry forces complete thermalization of the ambient gas prior to measurement (approximately 50 surface collisions for each incoming particle prior to ionization) except when the vehicle velocity vector and orifice normal are essentially co-linear. The geometry correction factor used in the conversion of antechamber to ambient densities (see data analysis section) is shown in Figure 5 [Pearl and Vogel, 1972].

The antechamber exterior shown in Figure 3 includes a ram baffle to prevent ram pressure in the analyzer section and to vent the ion source "filament region" and analyzer volume to the atmosphere separately from the antechamber and ionizing region.

The NACE ion source is a dual-filament non-magnetic design, similar to that flown previously on the OGO-6-F04 satellite instrument [Carignan and Pinkus, 1968], with minor modifications to adapt from a quadrupole to a magnetic analyzer. All ion source surfaces are gold plated stainless steel. A section of one of two orthogonal electron guns is shown in Figure 6. The electron guns are operated in an anode-current regulation mode, with approximately 33 μA ionization current. The output of the ion source is nominally 2×10^{-5} ampere per Torr for nitrogen gas. The filaments are .025 mm diameter tungsten

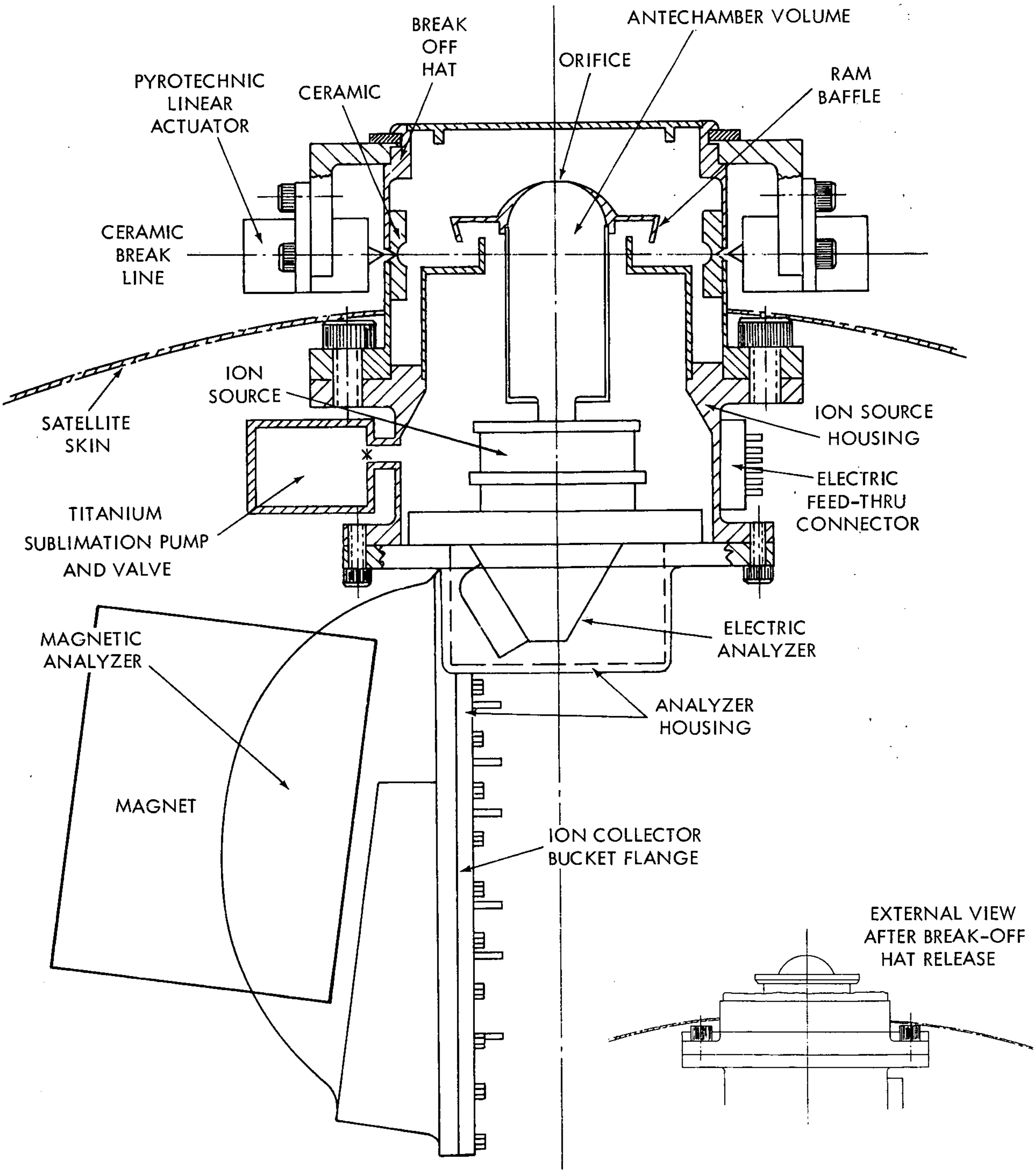

Figure 3. San Marco NACE Mass Spectrometer Sensor Vacuum Housing

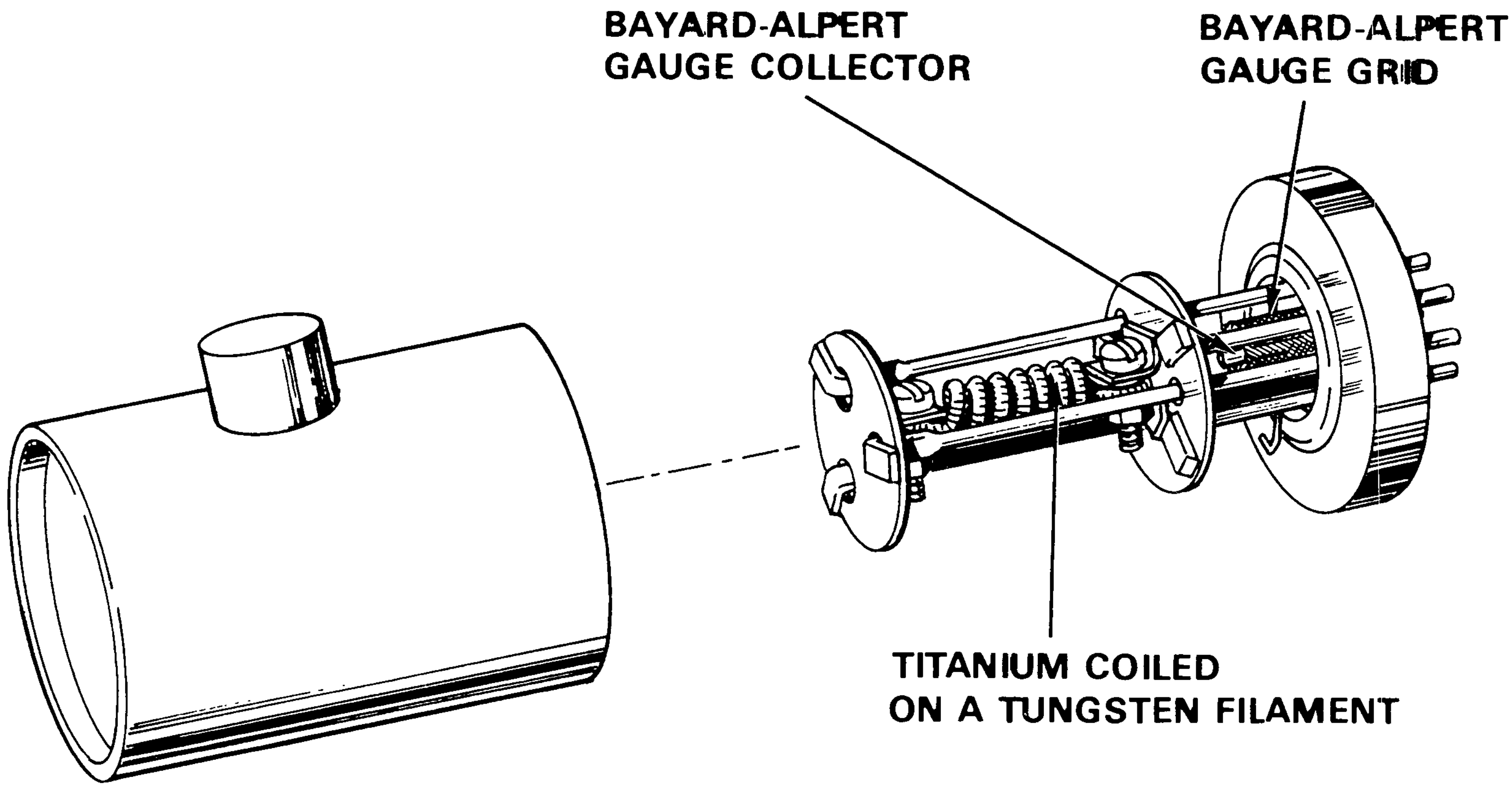

Figure 4. San Marco Titanium Sublimation Pump With Internal Bayard-Alpert Ionization Gauge

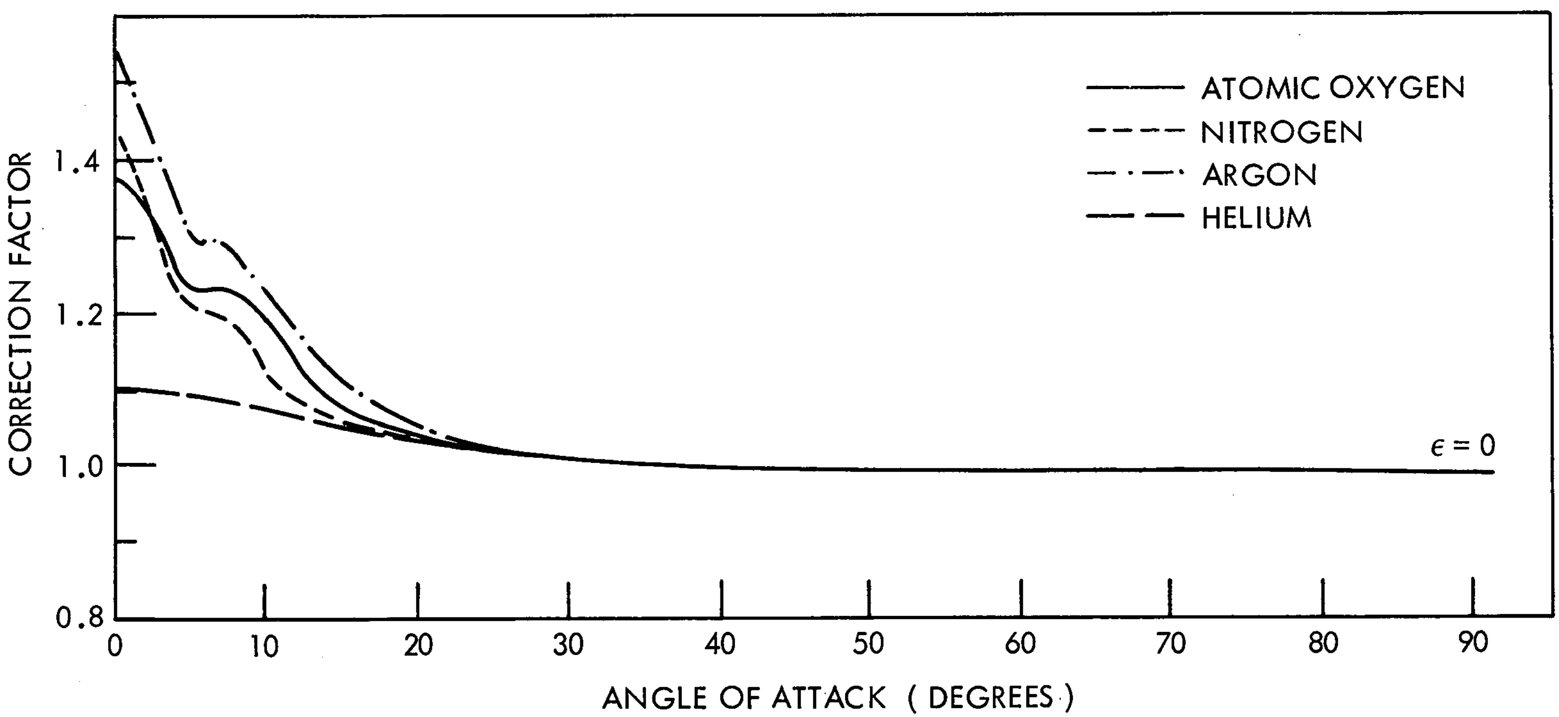

Figure 5. Correction factor to the F(s) Equation Relating Ambient and Ion Source Gas Densities, for the San Marco NACE Antechamber-ion Source Geometry

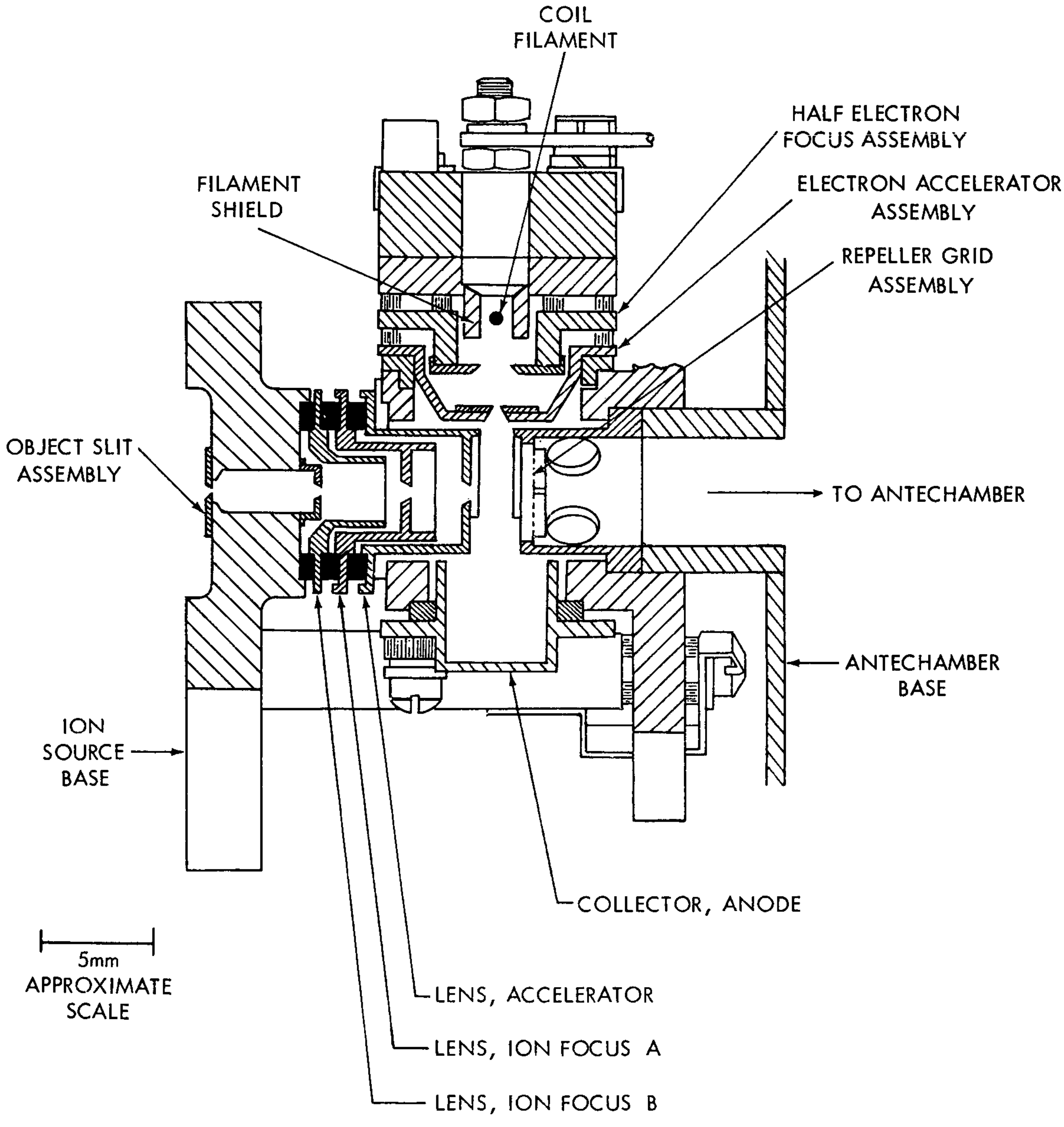

Figure 6. San Marco NACE Ion Source Section

wire coiled on a .35 mm mandrel. Laboratory test results in oxygen [Pelz et al., 1973a] indicate an expected filament lifetime of approximately nine months in the San Marco orbit, for each of the two redundant filaments.

The analyzer section of the NACE is a 60° electric sector followed by a 90° magnetic sector. The radius of curvature of the magnetic sector is 5.0 cm. A 3850 gauss Alnico V, C-magnet is mounted in a fixture (3-axis-independent motion) to allow maximum flexibility in precalibration set-up and tuning of the analyzer. The magnet is initially charged to approximately 4250 gauss. After the use of temperature cycling, magnetic field reversal and shock "knock-down" techniques, a stable field strength of approximately 3850 gauss is achieved. Routine laboratory measurements over a three year period have shown the NACE magnets to have constant field strengths within a measurement accuracy of 50 gauss.

The NACE detectors are five linear range switching electrometer amplifiers operating on the outputs of six independent ion collector buckets. The buckets are mounted on a "trolly-rail" type collector flange, shown in Figure 7. The bucket positions are adjusted to accept ions of e/m ratios 4, 14, 16, 28, 32 and 40. Three electrometers are MOSFET input devices designed to measure ion currents from 5×10^{-8} A to 5×10^{-14} A, and are connected to the 16, 28 and 32 amu collector buckets. The 32 amu electrometer is also connected to the 14 amu collector bucket through a switch to allow mass selection by command. The 4 and 40 amu detectors are balanced electrometer tube input devices, designed to measure helium and argon ion currents from 5×10^{-13} A to 5×10^{-16} A.

The MOSFET electrometers have automatic input range resistor switching circuits, designed to follow the peak ion current variations due to altitude changes. All electrometers employ high speed (1 msec) post amplifier "gain" switching, with gains of 1, 10, and 100, to follow ion current variations within each satellite spin. The tube electrometers contain fixed 10^{13} ohm input resistors. The electrometer band width is 10 Hertz and 5 Hertz for the MOSFET and TUBE electrometers respectively.

The nominal electrode voltages of the NACE are listed in Table 1. The power supply high voltage output is 760 volts. Special features of the NACE electronics system are: (1) in-flight sensor tuning verification; (2) contaminent gas measurement mode of operation; and (3) in-flight retune option in case of unforseen ion source charging or detuning effects. The NACE is normally operated in a fixed-tuned mode with ion beams centered in the appropriate collector buckets. For tuning verification the ion acceleration voltage is swept (on command) to produce an ion current versus acceleration voltage correlation. Any of sixteen acceleration voltages can be chosen in flight if the pre-launch selection is found to be inappropriate. The contaminent gas check is accomplished by commanding the acceleration voltage to a value which shifts the 18 and 44 amu ion beams into the 16 and 40 amu collector buckets, respectively. During the contaminent check, mass 32 and 16 amu ions are collected in the 28 and 14 amu buckets respectively, providing an in-flight detector system cross calibration.

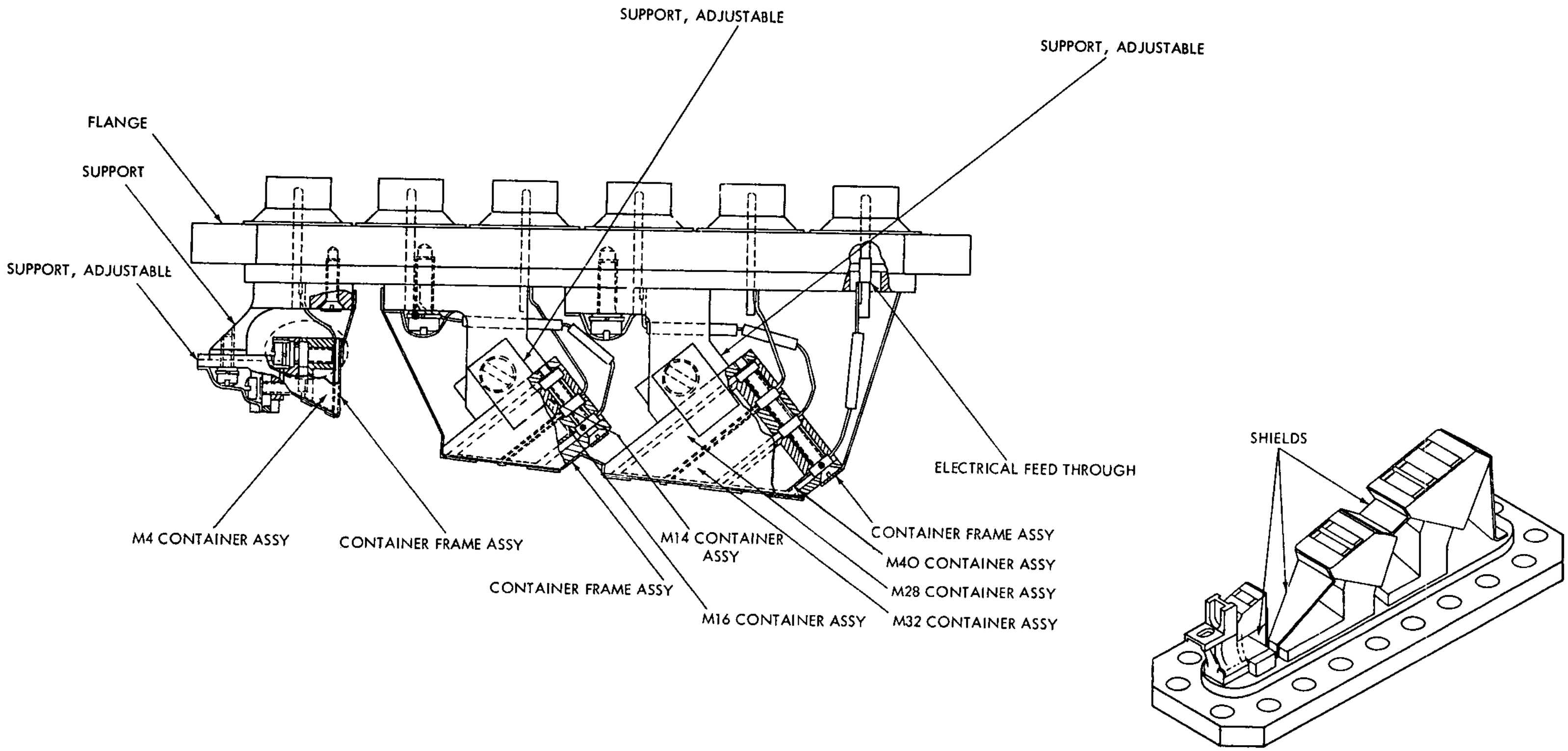

Figure 7. San Marco NACE Ion Collector Bucket Flange

Table 1

Nominal NACE Electrode Potentials (Volts)

	Gun 1-on	Gun 2-on
Ion Repeller	+463	
Ion Accelerator	+433	
Ion Focus A	+421	
Ion Focus B	+364	
Positive Sector	+206	
Negative Sector	-200	
Rails	- 26	
Z Focus A	0	
Z Focus B	0	
Filament Shield – 1	+349	
Filament Shield – 2	+357	
Filament – 1	+364	
Filament – 2	+364	
Electron Focus A	+480	+482
Electron Focus B	+479	+480
Electron Accelerator – 1	+495	+535
Electron Accelerator – 2	+522	+525
Anode – 1	+520	+521
Anode – 2	+522	+520
Exit Slit	0	

Operation

The NACE was operated in "real-time" from the Mobile Italian Telemetry Station (MITS) located at the San Marco Range on the coast of Kenya at Formosa Bay (3° north latitude) and the NASA, STADAN Station at Quito, Equador. A team of Experiment personnel were located at MITS, the primary spacecraft control station, to evaluate and control experiment operations. Telemetry data for all satellite passes at altitudes below 450 km were routinely recorded throughout the 9 month orbital lifetime.

Following the San Marco III launch on 24 April 1971, a period was allowed for spacecraft outgassing, to avoid possible contamination of interior antechamber and ion source surfaces from the initial spacecraft outgassing cloud. The NACE breakoff hat was separated on command in the 19th orbit. A further period of four days was allowed for spacecraft venting prior to NACE turn on, to insure against an internal pressure which could induce arcing or corona from the NACE high voltage.

Successful NACE operation was achieved from 29 April throughout the satellite life, on filament #1. Tune and contaminent checks were performed routinely and no detuning occurred. The mass peak at 44 amu, presumably conversion of atomic oxygen to carbon dioxide in the NACE ion source, decreased to a negligible value after two weeks of in-orbit exposure and operations. No mass 18 peak was observed at any time.

Calibration

The NACE absolute gas calibrations for molecular nitrogen and oxygen, helium, argon, and carbon monoxide and dioxide were performed on the vacuum system illustrated in Figure 8. Primary pumping during calibrations is provided by liquid helium cooled surfaces. Additional pumping is supplied by a noble ion-getter pump during helium calibrations. A titanium sublimation pump and the ion pump are normally valved off from the chamber during calibrations to provide high purity of the calibration gas. These pumps maintain low system pressure during non-calibration operation, and pump the gases released from the liquid helium pump following calibration runs. The calibration system is completely "oil-free," as are all vacuum systems on which the NACE was operated. Primary pressure reference is to Bayard-Alpert ionization gauges calibrated by Kern [1966] at NASA Langley Research Center. Cross calibration comparisons were made to the Explorer 32 pressure gauge calibrations and to the OGO-6-F04 mass spectrometer pressure reference gauges.

Extended exposure of the flight mass spectrometer to an atomic oxygen environment was obtained on the atomic beam system described previously by Niemann [1970], (Figure 9). Approximately thirteen hours of NACE operation were obtained at flux densities simulating atomic oxygen exposure at San Marco III perigee altitudes. Initially no atomic oxygen or carbon monoxide and dioxide enhancements were observed, presumably due to oxygen pumping at the antechamber and ion source surfaces. After a few hours increasing carbon dioxide pressures were observed in the ion source. The oxygen exposure tests were terminated after 13 hours because of pre-launch schedule demands. Details of these tests and a comparison of laboratory test results with the flight measurements are to be reported elsewhere [Pelz, et al., 1973b].

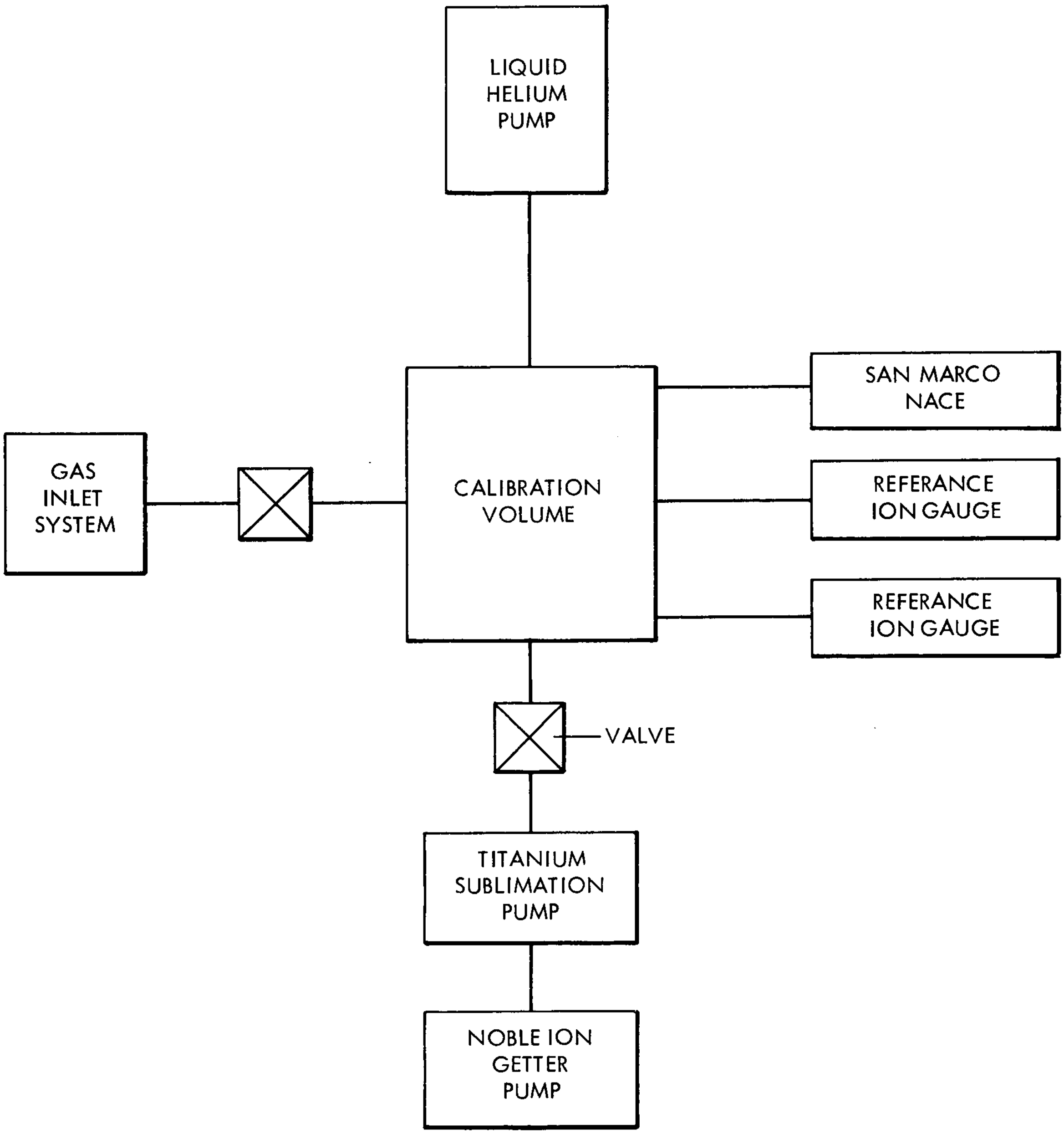

Figure 8. San Marco Non-reactive Gas Calibration System

Data Analysis

The NACE telemetry data will be converted to ion source densities using laboratory calibrations. For argon and helium, the source densities will be converted directly to ambient densities using the F(s) equation [Schultz, et al., 1948], modified for ion source and antechamber geometry effects [Pearl and

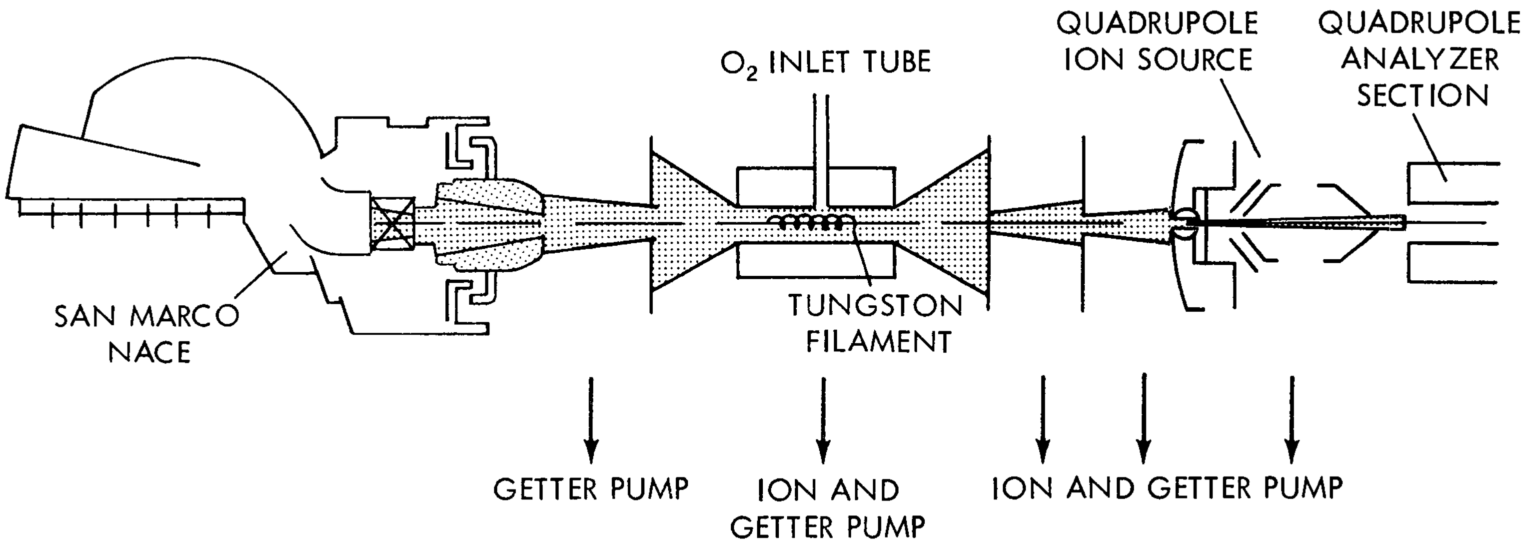

Figure 9. Atomic Oxygen Beam System

Vogel, 1972]. For oxygen and nitrogen, conversion to ambient densities will include additional analyses for gas-surface effects similar to those developed for the OGO-6 "closed" source spectrometer [Hedin, et al., 1972].

The NACE oxygen measurement is a "total" atmospheric oxygen measurement, i.e. the sum of the ambient atomic and molecular oxygen. Ambient atomic oxygen entering the antechamber has many surface collisions, and is expected to completely recombine, and be detected as molecular oxygen in the mass spectrometer ion source. Over most of the San Marco III altitude range ambient molecular oxygen densities are negligible in comparison with those of the ambient atomic oxygen. Thus, the molecular oxygen measurements are readily interpreted to give ambient atomic oxygen number densities. Only at altitudes below 200 km (late in the satellite lifetime) will separation of ambient atomic and molecular oxygen be required.

ACKNOWLEDGMENT

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The authors wish to acknowledge the many contributions of the late J. Schaffert to the NACE electronics system.

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