m4

330 361

N91-19147

ADVANCES IN ATOMIC OXYGEN SIMULATION

M 1 4 11300

Joseph F. Froechtenigt and Lyle E. Bareiss
Martin Marietta Astronautics Group
Denver, Colorado

ABSTRACT

Atomic oxygen (AO) present in the atmosphere at orbital altitudes of 200 to 700 km has been demonstrated to degrade various exposed materials on Shuttle flights. The relative velocity of the AO with the spacecraft, together with the AO density, combine to yield an environment consisting of a 5 electron volt (eV) beam energy with a flux of 10^{14} to 10^{15} oxygen atoms/cm^2/s. An AO ion beam apparatus that produces flux levels and energy similar to that encountered by spacecraft in low-Earth orbit has been in existence at Martin Marietta Astronautics Group since 1987. Test data has been obtained from the interaction of the AO ion beam with materials used in space applications (carbon, silver, kapton) and with several special coatings of interest deposited on various substrates. The ultimate design goal of the AO beam simulation device is to produce neutral AO at sufficient flux levels to replicate on-orbit conditions. A newly acquired mass spectrometer with energy discrimination has allowed 5 eV neutral oxygen atoms to be separated and detected from the background of thermal oxygen atoms of $\approx$ 0.2 eV. Neutralization of the AO ion beam at 5 eV has been demonstrated in the Martin Marietta atomic oxygen facility. Research is in progress to increase the flux of the neutral beam to perform testing in a realistic exposure time. Neutral AO testing will be performed and the results compared to those obtained on materials exposed to the actual space environment.

INTRODUCTION

Much has been written in recent years about the phenomena related to spacecraft interactions with the ambient molecular environment at orbital altitudes (Ref 1). The subject phenomena include the effects of neutral AO on spacecraft materials and the emitted radiation (or "Shuttle Glow") observed on or near spacecraft surfaces in low-Earth orbit. These phenomena can result in extremely deleterious effects on spacecraft systems exposed to the environment through degradation of thermo-optical and physical properties of exposed materials and through the induced background radiation detectable by on-board optical sensors.

To address these obvious concerns by spacecraft and instrument designers, Martin Marietta developed the Oxidation/Materials Erosion and Glow Analysis (OMEGA) facility to simulate the high-velocity (8-km/s) AO "wind" experienced by low-Earth orbiting spacecraft (Fig. 1). The initial challenge in the development of OMEGA was to produce a clean AO beam at 5 eV (equivalent to 8 km/s) at sufficient uniform flux levels to simulate on-orbit conditions. This was achieved over 3 years ago for AO ions (i.e., O^+), however, concern arose within the technical community that a purely neutral beam was required to eliminate questions about ion vs neutral surface chemistry effects. It is interesting to note that essentially all other AO simulation systems in the industry today have at least one such major deficiency which limits their credibility (e.g., low beam energies, impure beams, flux rates that are too high or too low, etc). Recent research on OMEGA has, therefore, concentrated on: 1) O^+ ion surface chemistry, and 2) developing a neutral AO beam. We now have promising evidence that a neutral beam has been achieved.

ION GUN FACILITY

The ion gun facility at Martin Marietta is an ion beam device that utilizes electrostatic lenses and magnetic fields to control the kinetic energy and beam purity of the selected ion species (Ref 2). A schematic diagram of the ion beam optics is shown in Figure 2. The ion beam apparatus is divided into four subsystems: an ion source, an acceleration and focusing lens subsystem, a mass analyzer, and a decelerator lens subsystem. A neutralizer subsystem is being investigated to convert the beam of ions exiting from the decelerator into a beam of neutral atoms.

The ion source consists of an electron emitting filament, an anode to accelerate the electrons, and a magnet surrounding the ion source to increase the path length of the electrons for more efficient dissociation of the molecular oxygen (O_2) and subsequent ionization of the AO. A beam energy power supply is provided at the anode which allows the energy of the AO ions to be controlled to 5 eV above ground. Along with the AO ions, a mixture of various ions formed from the residual gases in the ion source chamber are extracted by the booster plate of the accelerating lens with an energy of approximately 6,000 eV. This beam of various ions immediately passes through a modified Einzel lens which decreases the energy of the ions to 3,000 eV and, thus, acts as a focusing lens. The energy of 3,000 eV is needed to transport the ions from the exit of the focusing lens, through the mass analyzer, to the entrance of the decelerator lens (a distance of $\approx$ 1 meter). As the beam passes through the mass analyzer, the magnetic field of the analyzer is adjusted so as to pass only the AO ions. This beam of AO ions is then transported through the decelerator where the beam energy is lowered from 3,000 eV to 5 eV at the exit lens of the decelerator.

ATOMIC OXYGEN TESTS

Test Configuration

For the AO ion beam testing, the sample holder is situated approximately 0.32 cm (0.25 in.) in front of the exit lens of the decelerator. The sample holder is an aluminum block which has anodized surfaces to electrically insulate the test specimen from the holder. The AO ion beam at 5 eV impinges upon the test specimen through a well-defined aperture of 1.27 cm^2 (0.50 $in.^2$), and this current is continuously monitored to allow the AO ion fluence to be calculated.

Test Materials

The samples tested consisted of ten thermal control type coatings deposited on various substrates, an optical transmission filter, and a mirror sample. The shapes and dimensions of the substrates plus coatings were either 2.54 cm (1 in.) square or 2.54 cm (1 in.) diameter and 0.15 cm (0.06 in.) thick. The type of coating and substrate materials for the samples tested is shown in Table I.

Procedure for AO Ion Tests

Prior to testing, the solar absorptivity (α) and total normal emissivity (ε) were measured for each sample, and then a weight measurement was taken. The sample was then photographed and placed in the sample holder. With the test configuration in place, the system was evacuated to 6×10^{-7} torr. Oxygen gas flow was initiated, and the AO ion beam was selected and focused on the sample. The pressure during exposure increased to 2×10^{-6} torr. The current was monitored continuously with an electrometer and the data recorded. After exposure to the AO ion beam, the system was brought to ambient conditions and the sample removed. The same test procedure was followed for all samples. The posttest procedure consisted of photographs, weight measurements, solar absorptivity, and emissivity measurements. In addition, the filter sample had pre and posttest transmission measurements performed.

RESULTS AND DISCUSSION

The total fluence of AO ions was calculated using the time-averaged current during exposure and the 1.27 cm^2 (0.50 $in.^2$) aperture area. The reaction efficiency, R, for each sample was calculated from the mass change measurements and the time-averaged current using the expression:

$$R = \frac{\Delta m \, q}{\rho \, I \, \Delta t} \; cm^3/O^+ \qquad (1)$$

where Δm is the mass change, q is the electronic charge, ρ is the coating density, I is the average current, and Δt is the total exposure time.

The test results are given in Table I. The reaction efficiencies for the thermal coatings all appear to be somewhat high compared to similar test data (Ref 1 and 4). The apparent discrepancies may be attributed to differences in the surface chemistry experienced for ions and neutrals or possibly test sample preconditioning issues which are still under investigation. Most of the carbon compound coatings exhibit a low tolerance to the AO environment for mass loss with the exception of the SiC (C-C) sample. It was found out later that the $ZrSiO_4$ (Mo)-BN sample had been exposed to other environmental testing prior to this test and this may have influenced its results. The transmission filter and the silicon-coated mirror both performed excellent after the AO ion exposure. With regards to the thermo-optical absorptivity and emissivity measurements, the CaO/ZrO_2 (Mo) and the $ZrSiO_4$ (Mo)-BN samples both had substantial changes. Both of these samples were white coatings and were visibly discolored after exposure. Auger electron spectroscopy measurements indicated that the discoloration may have been caused by some carbon deposition during exposure.

With the persistent concern over the uncertainties induced between ion and neutral AO surface chemistry coupled with the apparent variations in materials reaction efficiencies with ion and neutral beams discussed herein, basic research into optimum beam neutralization techniques has continued at Martin Marietta.

After investigating numerous approaches, the proposed method of neutralizing the AO ion beam is by a grazing incidence technique. The neutralization subsystem is shown in Figure 3. Figure 4 shows the neutralization subsystem in place in the target chamber. As the AO ions exit the last lens of its decelerator with an energy of 5 eV, the effect of space charge in the beam results in the beam expanding radially as it transverses the copper charge exchange cell longitudinally. As the positive AO ions approach the cylindrical surface of the cell at low grazing angles of incidence, free electrons available at the surface attach themselves to the AO ions resulting in partial neutralization of the AO ion beam. This technique is being investigated using nickel as the charge exchange material (Ref 3). Any positive AO ions that are not neutralized are removed from the longitudinal direction by using deflection plates as shown in Figure 3. The neutral AO beam is detected and the flux measured by a VG mass spectrometer which incorporates a cylindrical mirror analyzer (CMA) so that not only is the mass of the species determined but also its energy. This technique enables the oxygen atoms at 5 eV to be distinguished from the natural background of thermal oxygen atoms at 0.2 eV.

Although the results of the current beam neutralization research are quite preliminary at this writing, the data are indicating up to a 50% neutralization efficiency of the 5 eV O^+ beam. Further testing is currently underway to confirm these results, however, such a major breakthrough would provide the technical community with the only ground test facility capable of simulating all of the key AO environmental parameters simultaneously.

REFERENCES

1. Bareiss, L. E., R. M. Payton, and H. A. Papazian, "Shuttle/Spacelab Contamination Environments and Effects Handbook," MCR-85-583, December 1986.
2. Froechtenigt, J. F and E. B. Ress, "Ion Cleaning of Silicone-Based Contaminants," Proc. of 24th IECEE, August 1989, pp. 393-398.
3. Johnson, C. L. et al., "The Vanderbilt University Neutral O-Beam Facility," Report Written Under Contract A71052-A2.
4. Visentine, J. T. et al., "STS-8 Atomic Oxygen Effects Experiment," AIAA Paper 85-0415, 1985.

TABLE I. - ATOMIC OXYGEN TEST DATA FOR VARIOUS MATERIALS

Sample (Substrate)	Fluence O^+/cm^2	Reaction Efficiency cm^3/O^+	Thermal Properties			
			Before		After	
			α	ε	α	ε
C-C	1.3E18	3.4E-23	–	–	–	–
TiB_2 (Mo)	4.3E17	8.3E-22	–	–	–	–
B_4C (C-C)	3.5E17	1.65E-21	.96	.89	.97	.90
TiB_2 (C-C)	7.3E17	5.4E-22	.89	.78	.90	.82
C-C	1.7E18	4.0E-23	.86	.66	–	–
Al_2O_3 (Mo)	1.6E15	– – –	.37	.80	.51	.82
B_4C/SiC (C-C)	7.9E17	1.9E-22	.71	.71	–	–
SiC (C-C)	1.1E18	2.3E-24	.79	.82	.82	.82
CaO/ZrO_2 (Mo)	2.8E15	– – –	.56	.80	.59	.78
$Al_2O_3/BN/Cu/BN$ (SiO_2)	1.7E15	– – –				
$ZrSiO_4$ (Mo)-BN	6.7E14	1.3E-20	.45	.90	.44	.89
Al_2O_3/Ag (Si)	7.8E16	– – –				

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

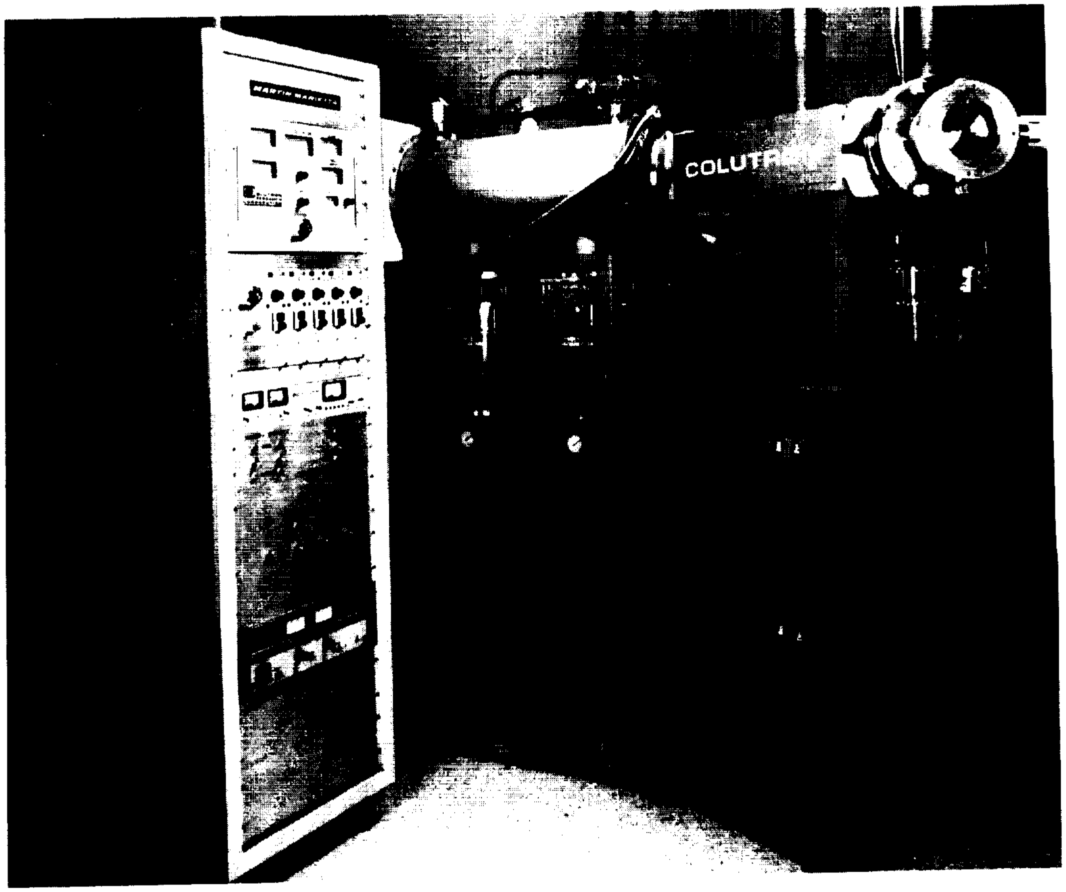

FIGURE 1. - OMEGA TEST FACILITY

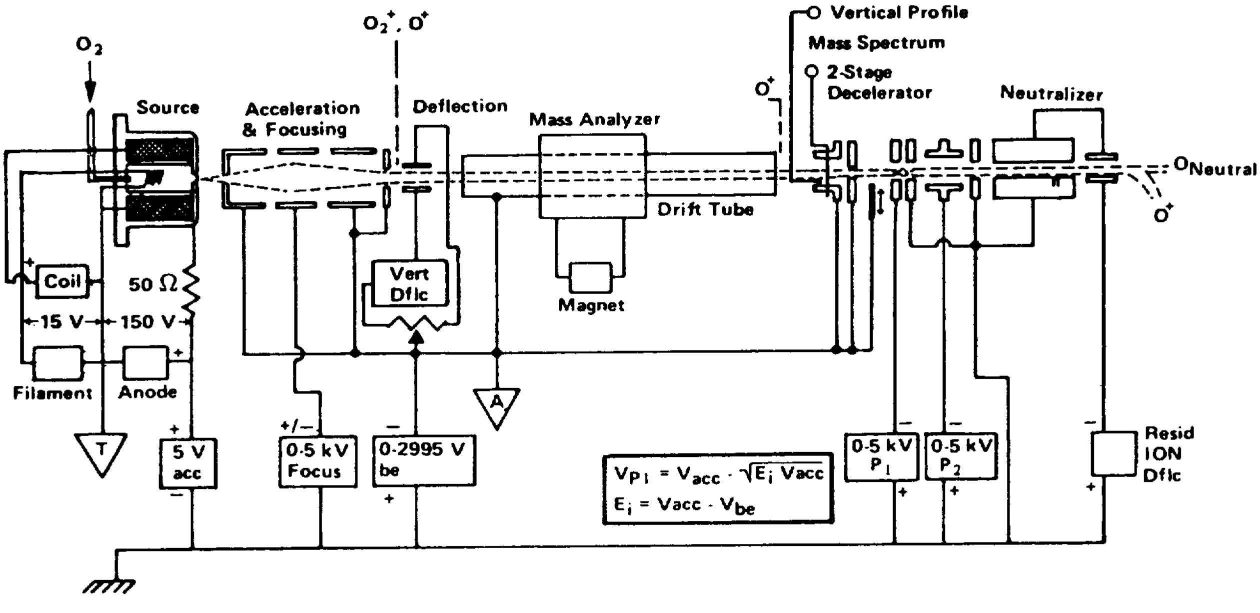

FIGURE 2. - MAJOR ELEMENTS OF ATOMIC OXYGEN BEAM APPARATUS

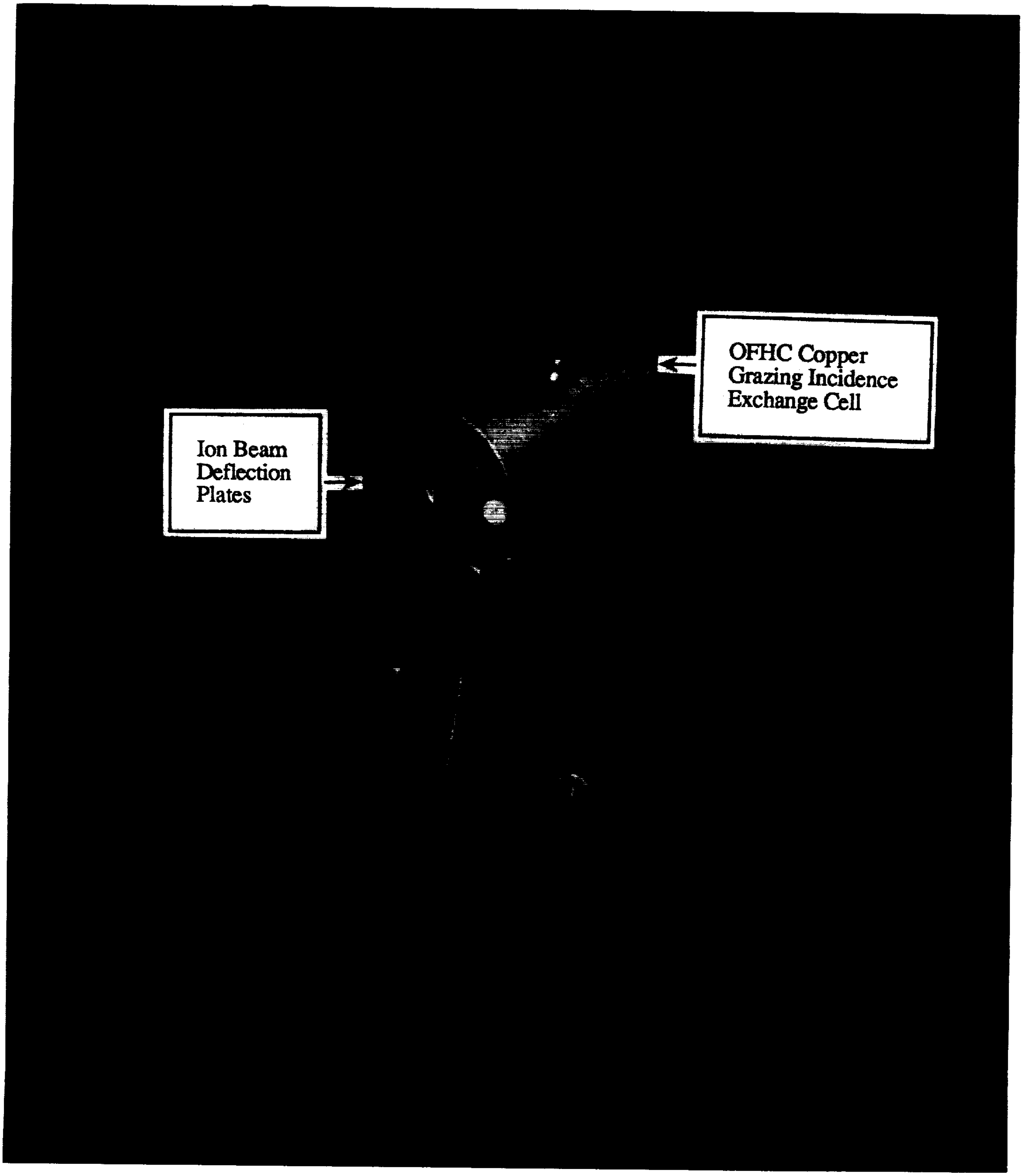

FIGURE 3. - NEUTRALIZATION SUBSYSTEM

ORIGINAL PAGE IS
OF POOR QUALITY

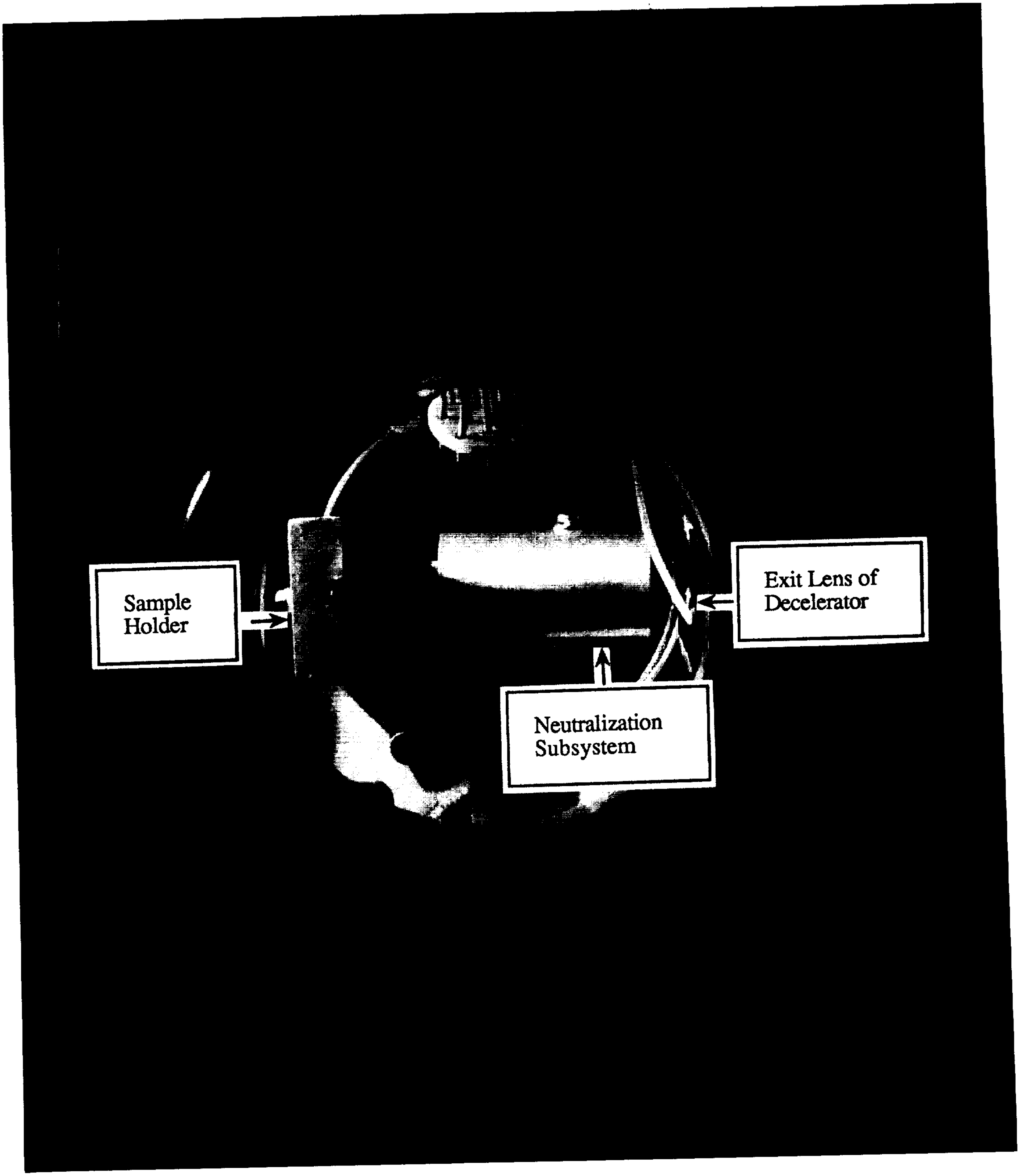

FIGURE 4. - NEUTRALIZATION SUBSYSTEM IN TARGET CHAMBER