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WALL CONDITIONS IN ORMAK*

R. J. Colchin, L. A. Berry, G. R. Haste, G. G. Kelley, J. F. Lyon
J. R. McNally, M. Murakami, R. V. Neidigh, J. E. Simpkins, and W. R. Wing

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Abstract

ORMAK is a diffuse toroidal pinch with typical plasma currents of 100 kA, electron temperatures of 800 eV, and ion temperatures of 300 eV. The walls of the plasma region are made of stainless steel coated with an intermediate layer of platinum 0.05 μ thick and an outer 1 - 2 μ layer of gold. Tests with an Ion Microprobe Mass Analyser have shown that the platinum acts to decrease diffusion of impurities from the stainless steel to the surface. Gold was chosen to inhibit the surface chemical adsorption of gases. Studies with a movable limiter lead us to believe that electron energy is lost at the plasma edge mainly via line radiation and cooling on ions, while ions are lost from the plasma by charge exchange. Thus the walls are bombarded by energetic neutrals, line radiation and, in addition, bremsstrahlung x-rays. The flux of energetic neutrals is measured by a charge exchange analyser. Wall bombardment by such neutrals should cause sputtering, and gold has been observed spectroscopically near the limiter, increasing with time during a shot. However, analysis of impurities coated on a window by the discharge indicated very little gold sputtering and re-deposition. To measure the sputtering rate, a wall sample was coated with 105 Å of radioactive gold and bombarded with neutrals from ORMAK during a day's run. No measurable sputtering was found within the counting statistics of the measurement, but surface carbon contamination of the sample prevents us from any final conclusions.

Introduction

ORMAK is a tokamak-type plasma device. A top view of ORMAK is shown in Fig. 1. The plasma is the secondary of a transformer, and so carries large current pulses (or "shots") which cause resistive plasma heating. Typical hydrogen plasma currents are over 100 kA leading to electron temperatures around 700 - 800 eV and ion temperatures of 200 - 400 eV. Also shown in Fig. 1 are four ion sources for additional plasma

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heating by the injection of energetic hydrogen atoms. Two of these sources are presently in operation.

The plasma is formed inside a toroidal chamber of about 1000 liters volume and 7.8×10^4 cm^2 of surface area. With this large surface area there is ample room for plasma-wall interactions which can lead to contamination of the plasma by $Z > 1$ materials. The principal mechanisms of contamination are sputtering of the wall material and desorption of loosely attached impurities.

Desorption

Desorption of $Z > 1$ contaminants from the walls may occur when they are bombarded by particles or radiation from the plasma. It is thus highly desirable to keep $Z > 1$ materials from reaching the chamber walls. This section describes attempts to keep ORMAK's walls as clean as possible.

The walls are shielded from charged particle bombardment under most conditions by a circular tungsten limiter placed 1.9 cm into the plasma region. This charged-particle shielding may break down under conditions of violent instability, and motion pictures show corresponding flashes of light at the wall. Experiments under normal conditions with a movable limiter (inside the circular limiter) indicate that very little of the input power is deposited on it. Computer studies verify that electrons lose their energy mostly by line radiation and cooling on ions, rather than by power loss to the limiter. The ions near the wall in turn are lost mainly by charge exchange with the relatively large number of neutrals at the plasma surface. Thus wall bombardment is principally by neutral particles and by line radiation, as well as from bremsstrahlung x-rays originating within the plasma.

The limiter itself can, of course, be a source of tungsten contamination. However tungsten line radiation is observed with conventional spectroscopy in the plasma only under unusual conditions, such as when run-away electrons are present. The absence of characteristic tungsten line and x-ray radiation is another indication of low power deposition on the limiter.

In order to prevent outside impurities from invading the plasma region, it is desirable to have a low base pressure (i.e., a low partial pressure of impurities). Typical base pressures are $2 - 3 \times 10^{-8}$ torr in ORMAK. The walls are cleaned by heating to 150°C and by running intermittent (60 cycle) cathode-less discharges. The RMS energy deposition (3) by these discharges is typically 0.05 watts/cm^2. After an initial fast improvement, a slow clean-up is noted over a period of several weeks.

Gold was chosen as the wall material so as to minimize chemical- and electron-induced absorption (1). The gold surface was formed by ion plating 2 μ of Au on a 10 mil 304L stainless steel backing. Trisone and Drobek (2) have observed interstitial diffusion in Au - Ti and Pt - Ti films, and we were thus concerned that impurities from the notably "dirty" 304L stainless steel backing could diffuse along grain boundaries and reach the gold surface.

Trisone and Drobek also observed that diffusion ceased on annealing the Pt - Ti sample with the subsequent formation of a Ti_3Pt diffusion barrier. So, it was decided to coat 500 Å of Pt between the stainless steel and the gold and to anneal this sandwich at 300°C for one hour.

Samples of stainless steel, stainless plus gold, and stainless plus platinum plus gold were investigated using an Ion Microprobe Mass Analyser. This analyser is capable of determining isotopic ratios with a detection limit of 0.1 ppm by ion bombardment and mass analysis of the positive and negative ions ejected. Results of the positive spectra are shown in Figs. 2 and 3. For the bare stainless steel sample, Fig. 2, the major peaks are iron, chromium, nickel, sodium, potassium, and calcium. The negative spectrum includes carbon, oxygen, fluorine, sulphur, and chlorine. The gold-stainless combination shown at the top of Fig. 3 indicates that many of these impurities have diffused through the gold, while Fig. 4 shows that the platinum layer acts to inhibit impurity migration quite effectively.

In spite of all the above precautions, spectroscopic studies show that plasma impurities are present. Although relative abundances are difficult to determine, the principal impurity seems to be carbon, followed by oxygen and nitrogen. Conductivity measurements based on neoclassical theory give $\langle Z \rangle \gtrsim 2$.

Sputtering

One disadvantage to using gold is its relatively high sputtering yield (3) (Fig. 4) under neutral particle bombardment. A first attempt to measure the sputtering rate is described below. Unfortunately, some carbon on the prepared sample restricts us from drawing any conclusions concerning the total amount of plasma sputtering.

To determine the sputtering rate in ORMAK, a 3/4 in. diameter sample of wall material was vacuum coated with 105 ± 10 Å of neutron-activated gold. The γ activity of the sample was counted by a photomultiplier and the sample was then inserted at the edge of the plasma flush with the wall. A control sample was likewise made and counted but kept in isolation. The original sample was bombarded by the plasma during a series of 80 shots and subsequently removed and re-counted.

It was expected that if there was appreciable sputtering, some of the activated gold would be removed causing a decrease in the expected count rate. The sample count was 57,458 counts, and the expected count rate (with no sputtering) differed from this by only 58 counts. The probable counting error was 162 counts, so that the observed difference is well within the statistical error of the experiment. Assuming a count rate difference less than or equal to the probable counting error, a thickness of

$$t \leq 4.5 \times 10^{-11} \text{ cm}$$

of gold was removed by sputtering per shot. This distance is much less than one atomic layer, so "thickness" is a term of convenience only. It does reflect the sensitivity of the measurement. This upper bound can be lowered several times by making the radioactive gold thinner and/or by increasing the exposure and counting time. To this end we have made a sample 34 Å thick with a more-than-ample counting rate.

From this thickness it would be possible to obtain a limit on the Franck-Condon density at the plasma edge, had not the surface been carbon contaminated. Franck-Condon neutrals are 2 - 4 eV atoms resulting from the dissociation of hydrogen molecules. Hogan and Clarke (4) have calculated the expected neutral flux to the wall Γ normalized by the Franck-Condon density N_{FC}. The conditions under which our experiments were run are shown in the hatched area of Fig. 5. Then

$$N_{FC} = \frac{t \cdot \rho(\text{atoms/cm}^3)}{\Gamma/N_{FC} \cdot f_s}$$

where f_s is the sputtering yield (Fig. 4). Typical numbers from present operating conditions show it should be possible to use this sputtering measurement to determine N_{FC}. Franck-Condon neutrals are important to tokamaks since they penetrate into the plasma causing ion energy loss via charge exchange.

There may be a local asymmetry in the neutral flux, and hence more gold sputtering, near the limiter. During one series of runs gold lines were observed spectroscopically upon looking tangentially through the plasma in the vicinity of the limiter. The line intensity was noted to increase during each shot. Recent attempts to look perpendicularly through the plasma near the limiter have revealed only a very weak gold line.

Another evidence that sputtering is small comes from a spectroscopic analysis of impurities coated on a lens left in ORMAK for 2000 shots. Very little gold was observed to have been sputter-coated onto the glass. While these results are quite comforting for present experiments, an examination of Figs. 4 and 5 show Γ/N_{FC} and the sputtering yield increasing as ion temperatures are pushed up.

Summary

Because tokamak hydrogen plasmas are sensitive to $Z > 1$ contaminants, much care has been exercised to keep ORMAK's walls free from impurities. This care has included passivation of the 304L stainless steel wall by a thin layer of Pt to inhibit diffusion of impurities through a surface layer of gold. First measurements of the sputtering erosion of the gold wall by means of a radioactive probe show the potential power of this method.

References

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ORMAK WITH INJECTION HEATING

1 ION SOURCE
2 CHARGE EXCHANGE CELL
3 30 keV H° BEAM
4 PLASMA RING
5 LINER
6 VERTICAL FIELD COIL
7 CONDUCTING SHELL
8 PLASMA CURRENT PRIMARY COIL
9 TOROIDAL FIELD COIL

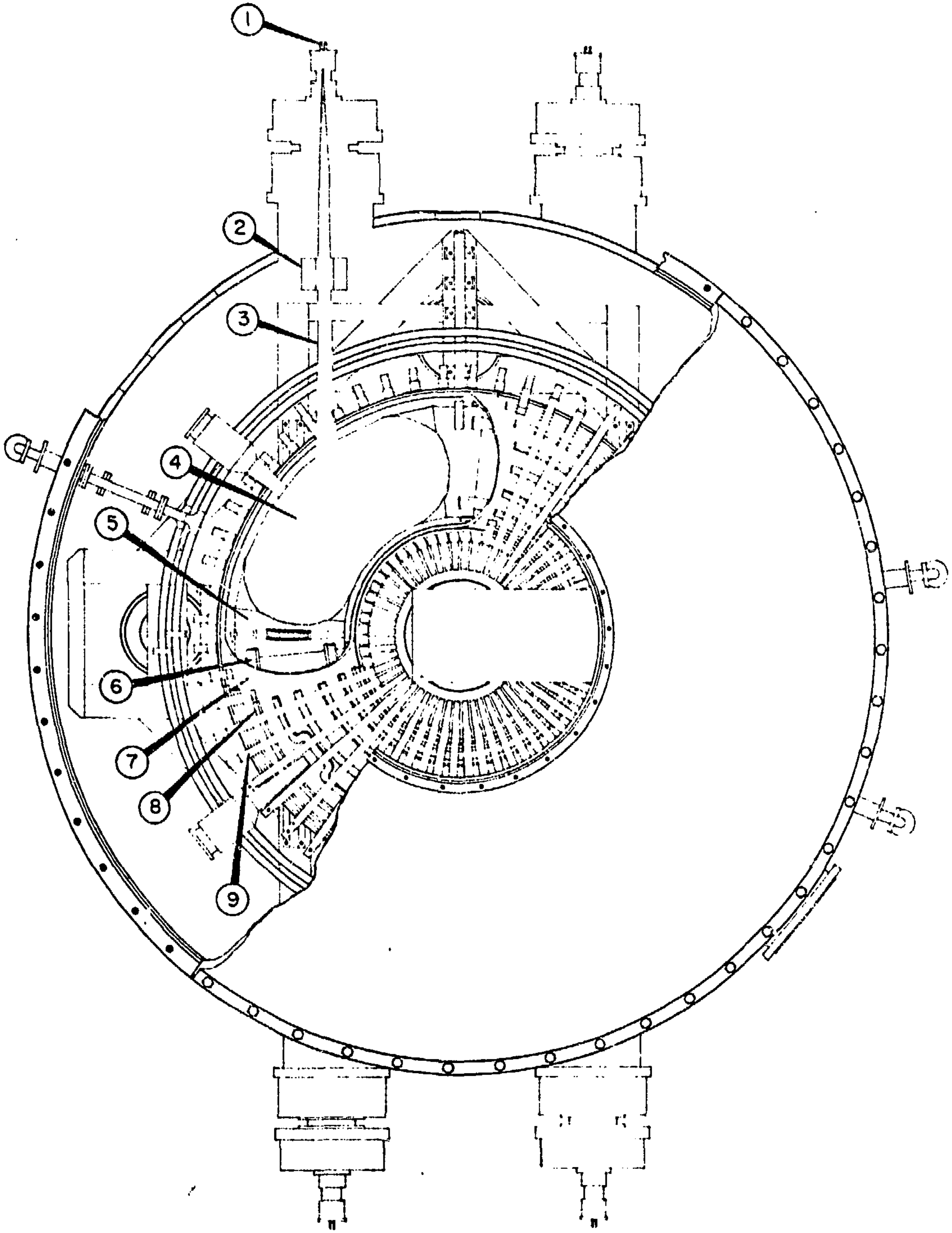
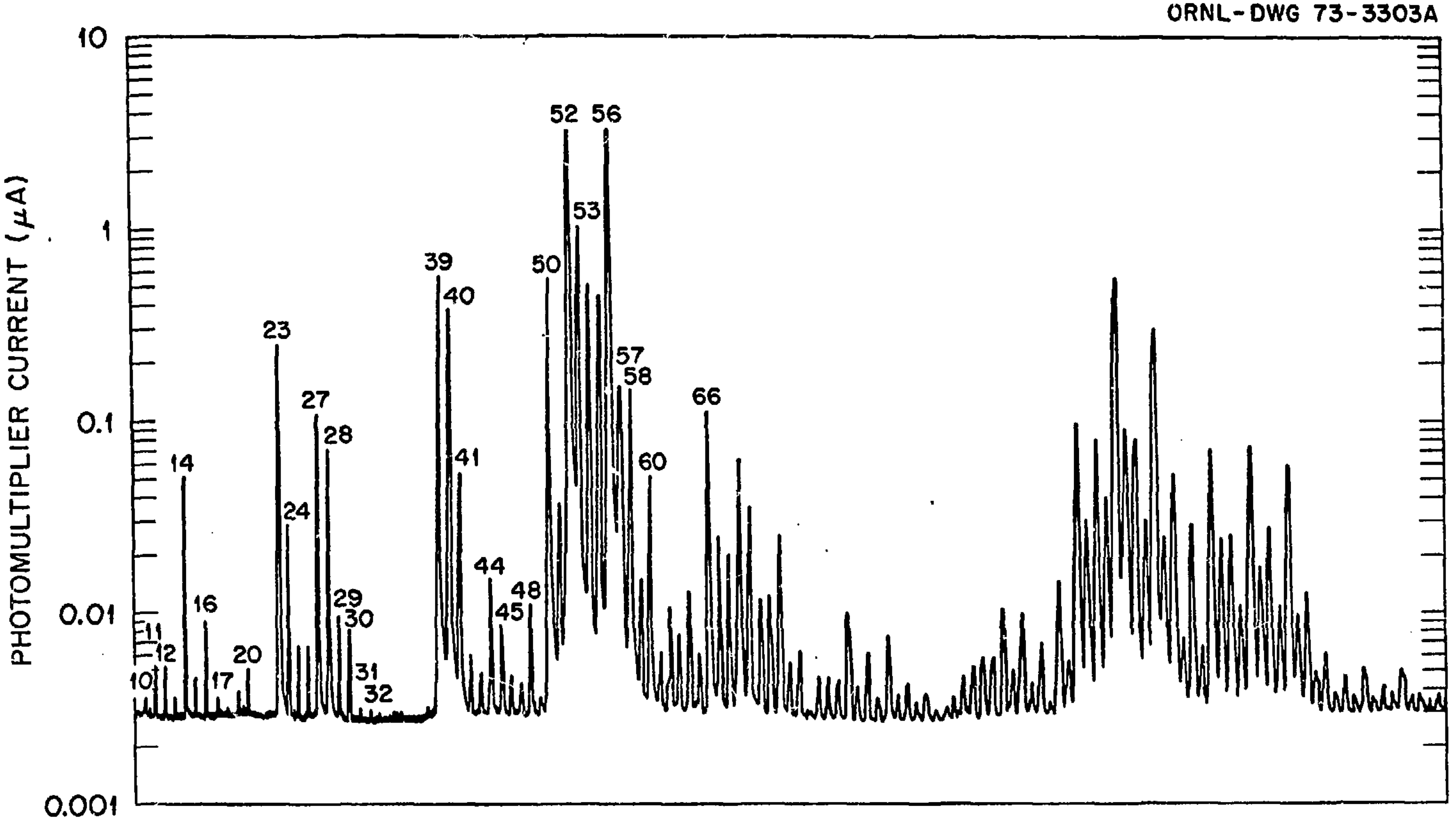


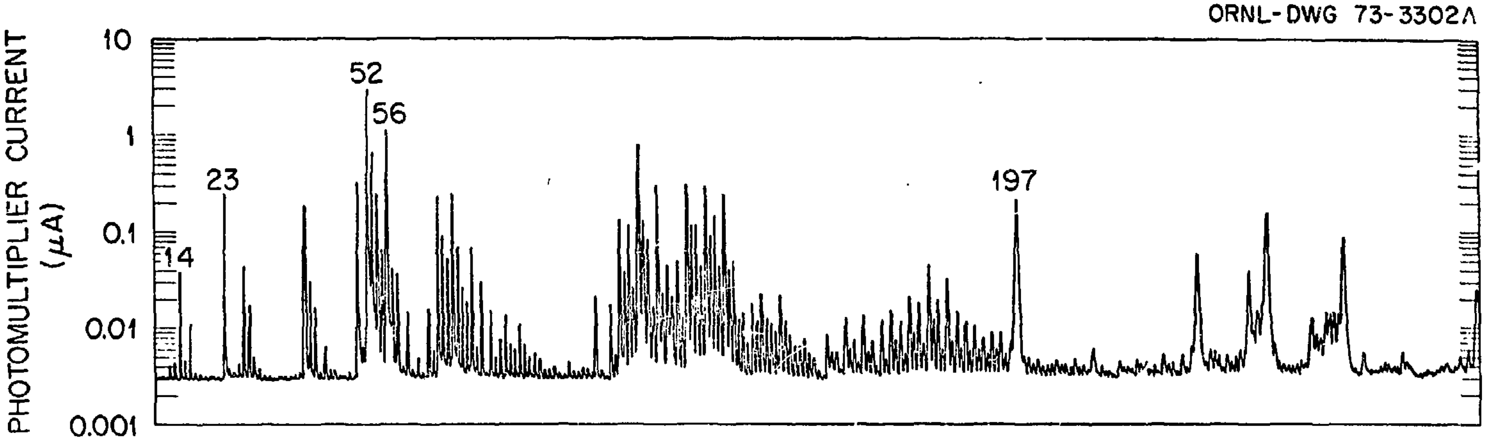
Figure 1

Figure 2

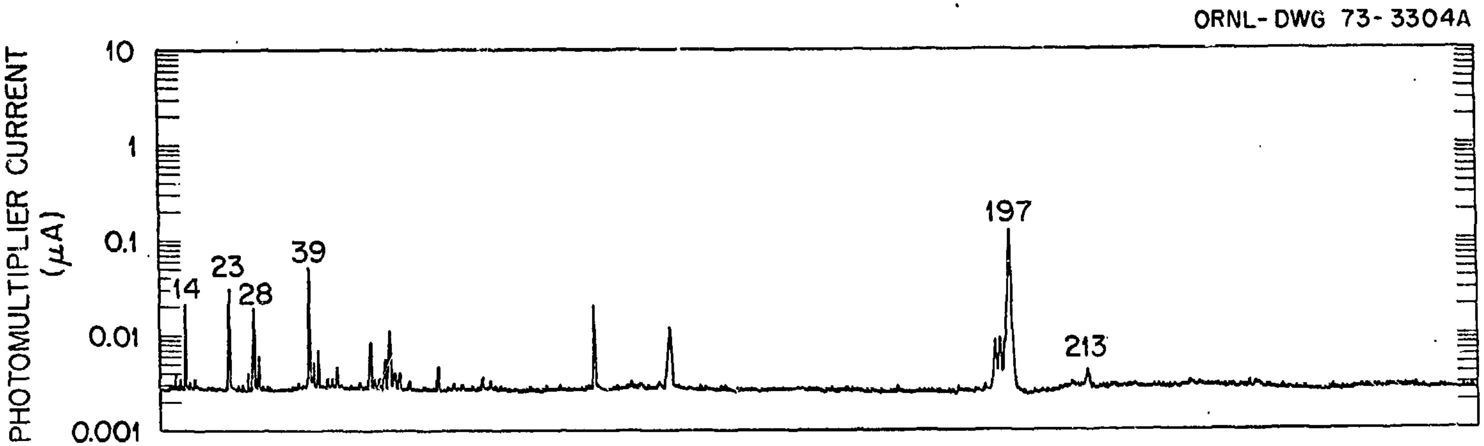


Mass Scan of Bare Stainless Steel Surface.
Mass Range: 0-150 amu.

Figure 3

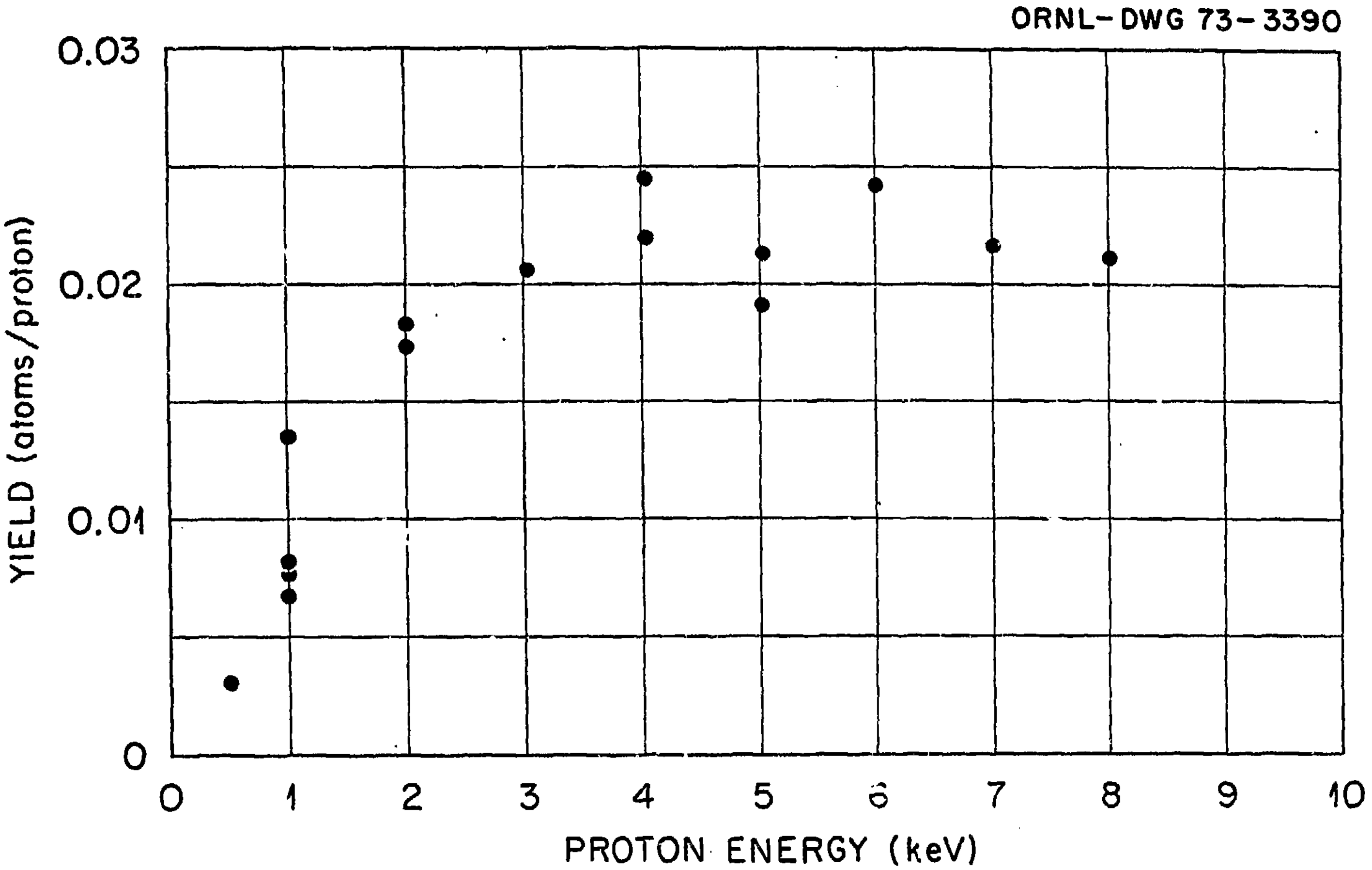


Mass Scan of Gold Surface, Gold/Stainless Sample.
Mass Range 0-300 amu.



Mass Scan of Gold Surface, Gold/Platinum/Stainless Sample.
Mass Range 0-300 amu.

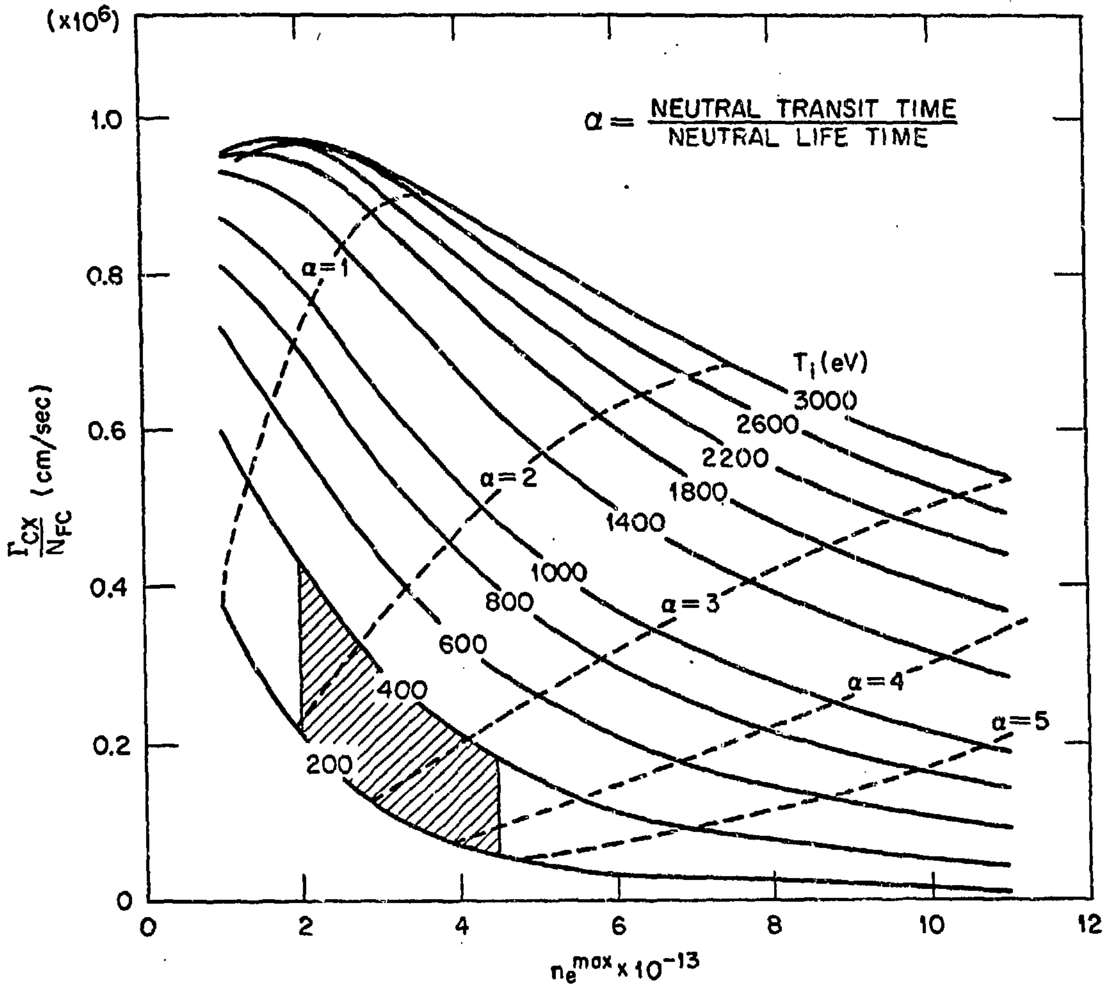
Figure 4



Yields as a Function of Energy for H^+ on Gold. A.K. Furr and C. R. Finfgeld, *J.A.P.*, 41, 1739, 1970.

Figure 5

ORNL-DWG 73-8979A



ORMAK/HFO: Charge Exchange Flux.