SCALABLE STANDARD OPTICAL SOURCES IN THE VUV: EMISSIONS FROM ELECTRON IMPACT ON METALS

Final Report

by

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January 1980

(NASA-CR-162562) SCALABLE STANDARD OPTICAL SOURCES IN THE VUV: EMISSIONS FROM ELECTRON IMPACT ON METALS Final Report (Arkansas Univ.) 12 p HC A02/MF A01 CSCL 20F

N80-14900

Unclas
G3/74 46541

Prepared for the

NATIONAL AERONAUTICS SPACE ADMINISTRATION

Under Grant No. NSG-7106

Final Report NSG-7106

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Abstract

A compact optical standard lamp in the vacuum ultraviolet is being developed at the University of Arkansas using electron impact on metals. Two different mechanisms are exploited, transition radiation and bremsstrahlung. Transition radiation will be used as a primary standard from 1200A to 3000A using 10-keV electron impact on tungsten. Bremsstrahlung will be used in the soft X-ray region below 1200A to less than 5A as an optical transfer standard from 4-keV electron impact on tantalum or tungsten.

Introduction

It is important to develop optical standards in the vacuum ultraviolet and soft x-ray regions. Electron impact on metals produce optical radiation which can be used for such standards. It has many advantages. (1) The light level is easily scalable by changing the electron beam current. (2) The light level is comparable to that encountered in atomic physics and space astronomy without any necessary attenuation. (3) The lamp operates in a hard vacuum without attenuation of the radiation by window materials. (5) Either bremsstrahlung or tansition radiation can be selected as the radiation mechanism by altering the energy of the electron beam (6) Transition radiation can, in principle, be calculated and used as a primary standard source. (7) The e-beam source, in principle, can be used for calibration at all VUV wave lengths since both radiation mechanisms produce continuous radiation.

Figures 1 and 2 show expected levels from electron impact on tungsten and tantalum respectively.

Experimental Results

Final design and testing are still not completed but the basic concepts and basic understanding of the mechanisms are essentially established.

High-field thermionic electron emission produces an intense well-focussed electron beam striking the anode normal to the surface. The viewing direction is 45^o to the beam direction. This viewing direction is chosen because transition radiation under these conditions has a spectral distribution that generally varies slowly with frequency.[1] (It is also near the direction for maximum intensity for bremsstrahlung.)

The intensity of both types of radiation can be non-linear with beam current below a certain threshold beam power level. It is suspected that the beam has to simultaneously clean the surface in order to realize full intensity.

In general cold-cathode field emission is not sufficient to generate enough beam power to provide the required cleaning threshold. However, a clean surface was once generated using zero cathode heat when the beam power of 6 watts was sufficient to heat the anode to incandescence. Heat transfer to the cathode apparently thermionically assisted the field emission. The required conditions for zero cathode heat have yet to be duplicated but simply reducing heat conductance at the anode should again provide the conditions for zero heat.

At the Physics Department, University of Arkansas, the radiation has been studied from 3500A to 1200A. It has been established that the emissions are not a strong function of surface roughness. Electron impact on metal films evaporated onto quarter-wave optical flats and on mill-surface foils all produced similar results. Studies of small current, high energy

(50 - 100 keV) impact produced transition radiation that scaled properly with energy but produced intensities that were too small by an order of magnitude or more in the VUV.

Apparatus using cold cathode field emission of electrons was built which produced erratic optical emission and again too small in magnitude. However, with a special knife edge cathode and thermonic assistance from a hot cathode produced strong bremsstrahlung from 2-keV impact on tungsten.

Parallel short term investigations were conducted at the University of Arkansas and at the Oak Ridge National Laboratory. External heating of the knife edge cathode was provided in both experimental apparatus. The Oak Ridge source was used to investigate radiation from 3-keV electron impact on tantalum and tungsten in the wave length range from 8A to 1300A while the Arkansas apparatus studied 5- to 9-keV impact on tungsten in the wave length range from 12A to 2000A. The Oak Ridge apparatus used a McPherson 247 grazing incidence spectrometer while the Arkansas apparatus used a Jarrell-Ash ½-m Seya-Namioka spectrometer.

The Oak Ridge apparatus provided sufficient cathode heating to establish linearity of the optical emission with electron current. The source could not deliver the same optical intensity per unit current when the current fell much below 1 mA. The source produced emissions linear with current from 1 to 6 mA. Figure 3 shows 3-keV bremsstrahlung from tantalum. Figure 4 shows bremsstrahlung from both Ta and W in the soft x-ray region.

The Arkansas apparatus produced transition radiation from 9-keV electron impact on tungsten that now begins to approach theory (See Fig 5). Unfortunately, the cathode heat was not sufficient to establish linearity with current. However, it was clear from optical emissions from 5, 6, and

8-keV impact that optical emission efficiency was increasing with increasing electron beam power. A cathode identical to the one used at Oak Ridge is being installed into the Arkansas apparatus. There is no physical reason why the transition radiation should not come up to the theoretical predictions. Thus the discovery of the apparent threshold effect gives some confidence that the source will finally produce transition radiation at the expected theoretical level.

When these expectations are realized, the results will be published and reprints will be forwarded to NASA.

Figure 1. Theoretically predicted optical emissions from electron impact on tungsten. It is assumed that the electron beam is directed normal to the surface and the viewing direction is 45° with respect to the electron beam. Optical constants from Juenker et al[2] are used in the calculations. Transition radiation calculations make full use of the expressions of Ritchie and Eldridge.[1] Optical bremsstrahlung without reflection losses is calculated using the Kramers theory as modified by Boersch et al.[3] This modification attempts to correlate electron energy loss, electron penetration, and optical absorption of the resulting bremsstrahlung on its way to the surface. Optical bremsstrahlung with reflection losses is a modification of the above using a reflection factor from Ritchie et al.[4]

Figure 2. Theoretically predicted optical emissions from electron impact on tantalum. Explanation regarding the curves follows that for Fig. 1.

Figure 3. Bremsstrahlung from 3-keV impact on tantalum, 18 watts of e-beam power. Spectra is taken with a McPherson 247 grazing incidence spectrometer at the Oak Ridge National Laboratory using a Ceratron photo detector. Grating blaze at 191A.

Figure 4. Bremsstrahlung from 3-keV impact on tungsten and tantalum. Spectra taken with the McPherson spectrometer and Ceratron detector. Grating blaze at 47.7A. The 45.6A feature implies an optical window in W at this wavelength.

Figure 5. Transition radiation from 9-keV impact on tungsten, 7.7 watts of e-beam power. Spectra taken with a ½-m Jarrell-Ash Seya-Nomioka spectrometer using an EMI G26H15 ultraviolet photomultiplier with a CsTe cathode. Grating blaze at 1200A. Loss of intensity at the short wavelength is due to loss in grating reflectivity and in detector sensitivity.

References

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3. H. Boersch, C. Radeloff, and G. Sauerbrey, Z. Phys. 165, 464 (1961).

4. R. H. Ritchie, J. C. Ashley, and L. C. Emerson, Phys. Rev. 135A, 759 (1964).

Tungsten

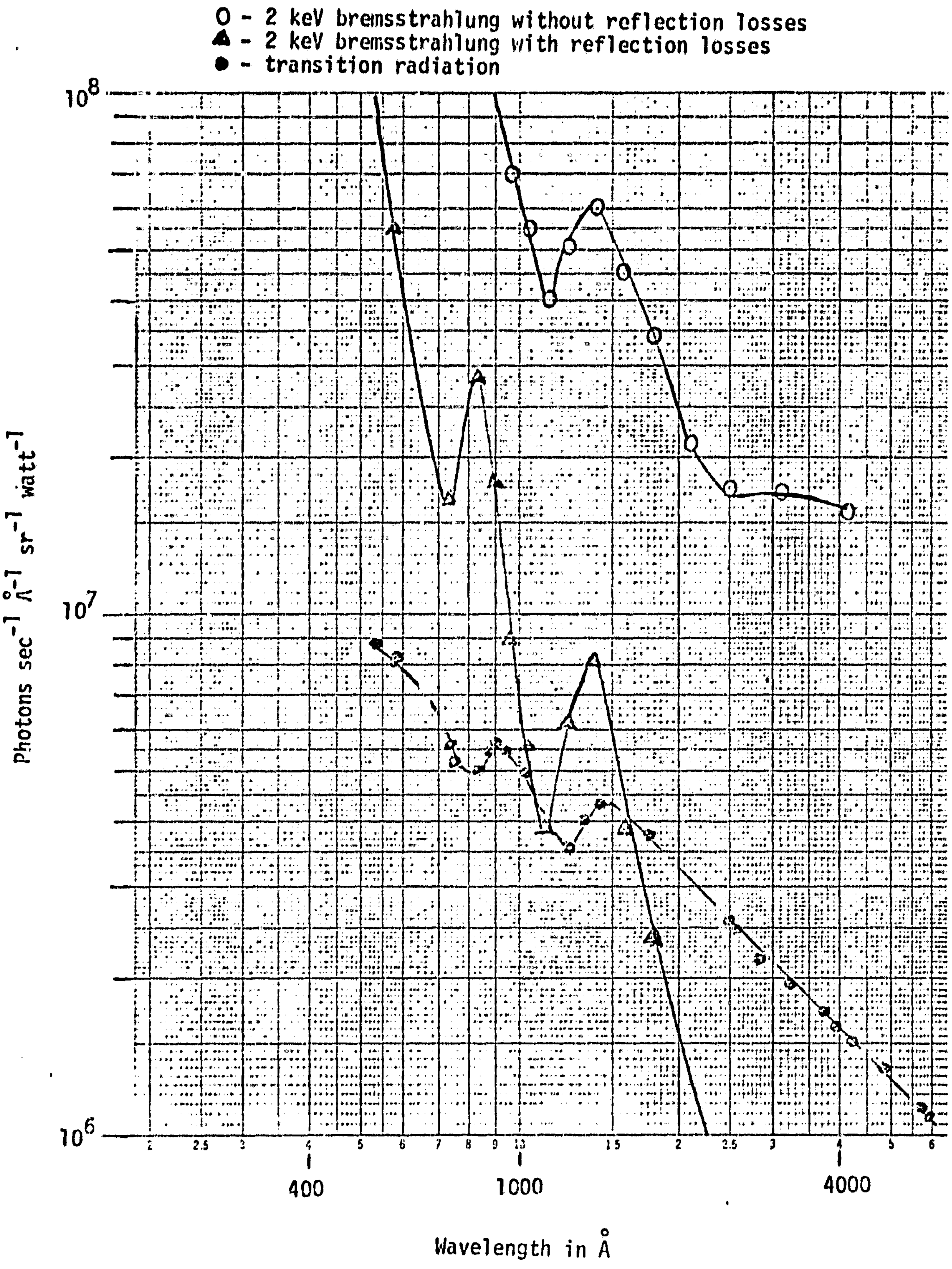


Figure 1.

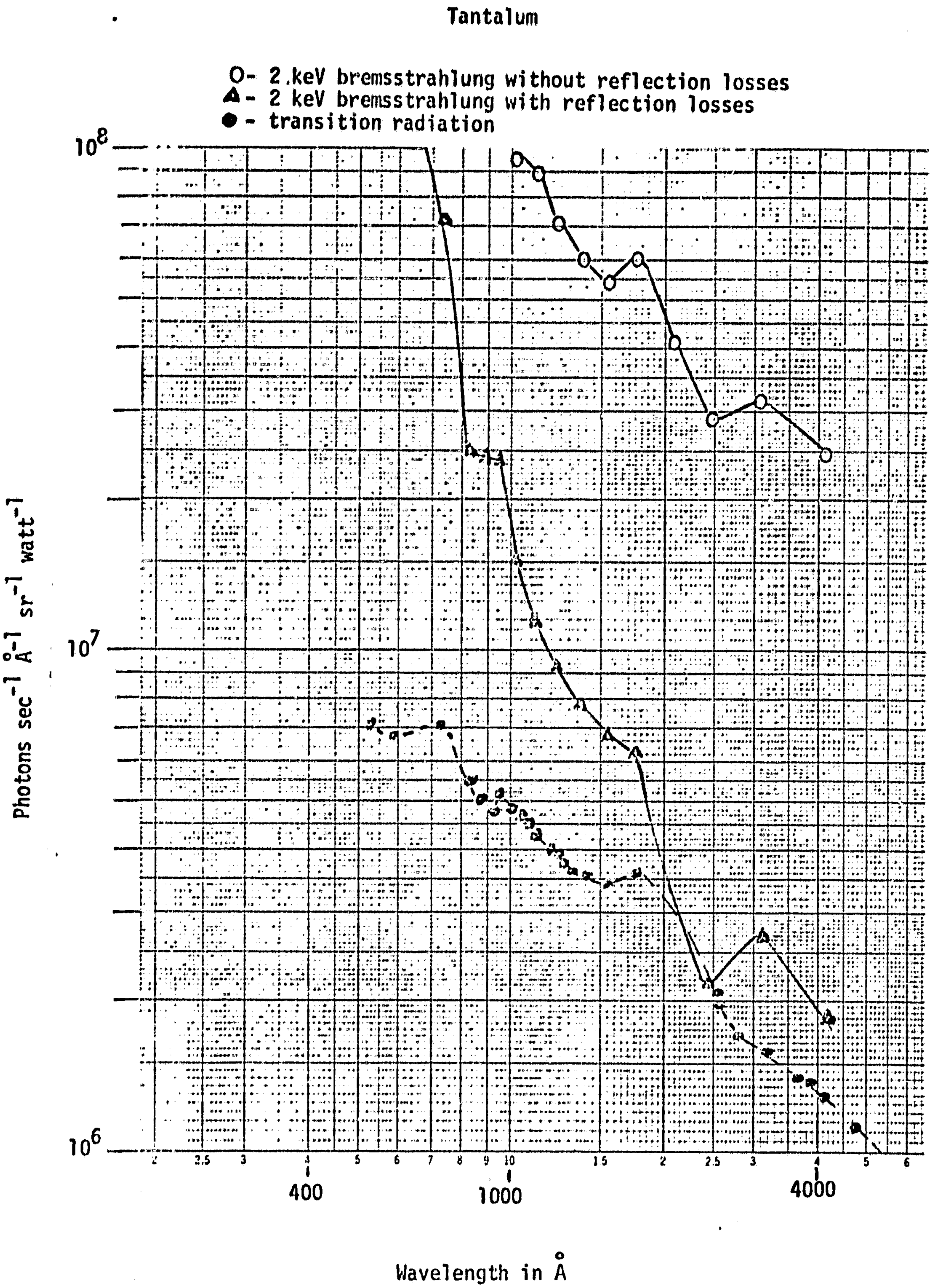
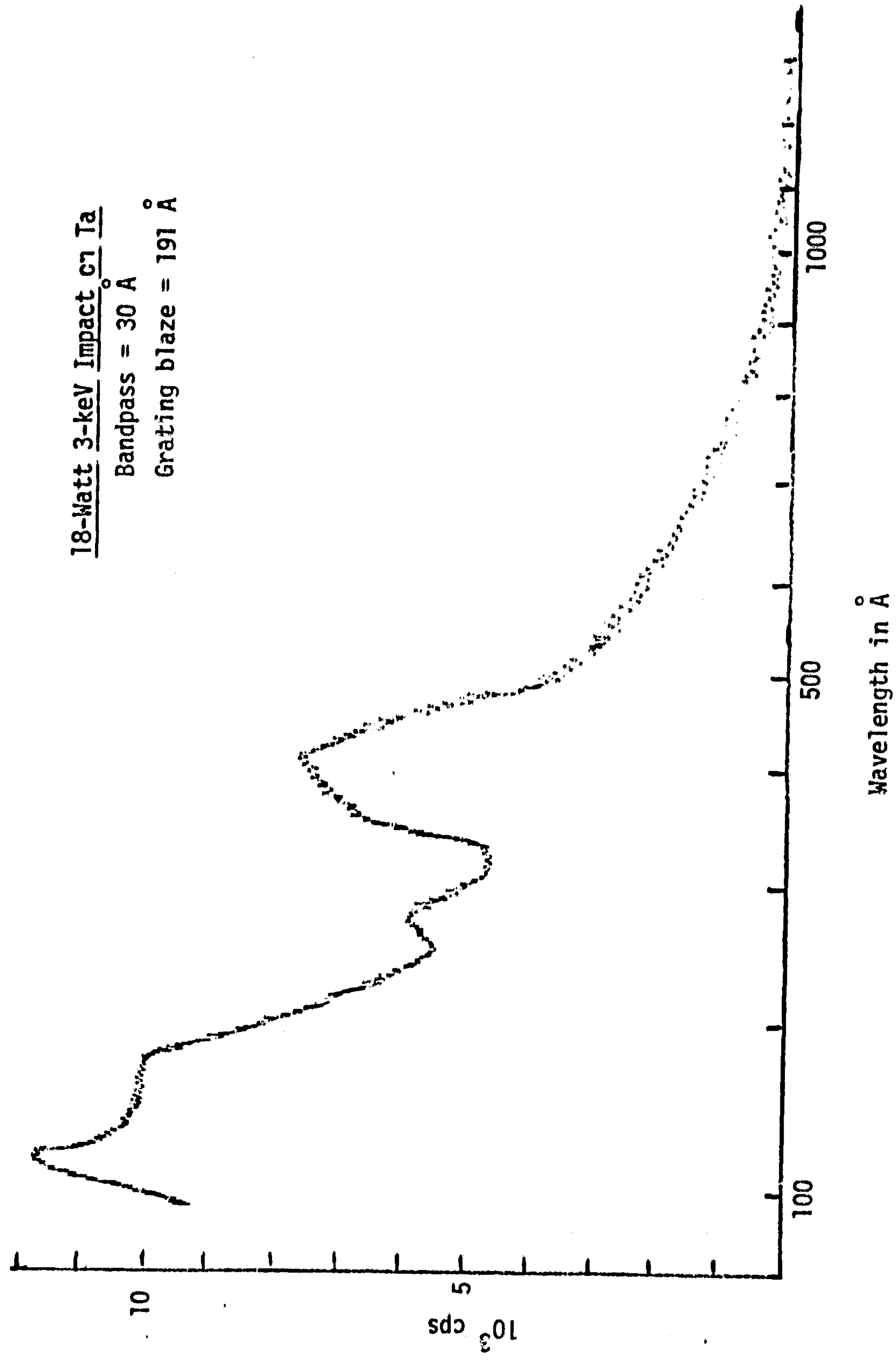
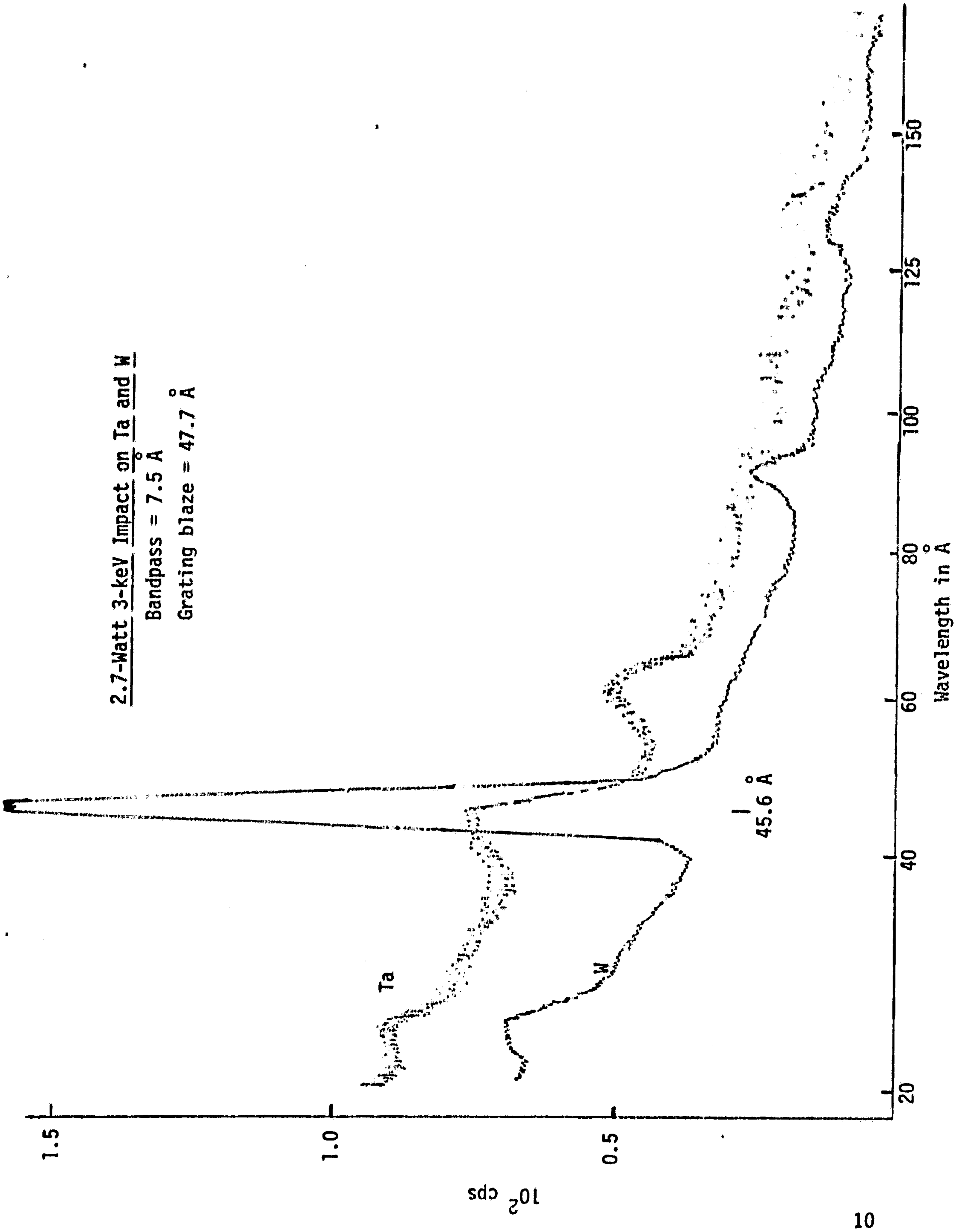

Tantalum
O- 2.keV bremsstrahlung without reflection losses
▲- 2 keV bremsstrahlung with reflection losses
● - transition radiation
10^8
10^7
10^6
Photons sec^{-1} $Å^{-1}$ sr^{-1} $watt^{-1}$
400
1000
4000
Wavelength in Å

Figure 2.



18-Watt 3-keV Impact on Ta
Bandpass = 30 Å
Grating blaze = 191 Å
10^3 cps
10
5
100
500
1000
Wavelength in Å

Figure 3.



2.7-Watt 3-keV Impact on Ta and W
Bandpass = 7.5 Å
Grating blaze = 47.7 Å
Ta
W
45.6 Å
1.5
1.0
0.5
10^2 cps
20
40
60
80
100
125
150
Wavelength in Å

Figure 4.

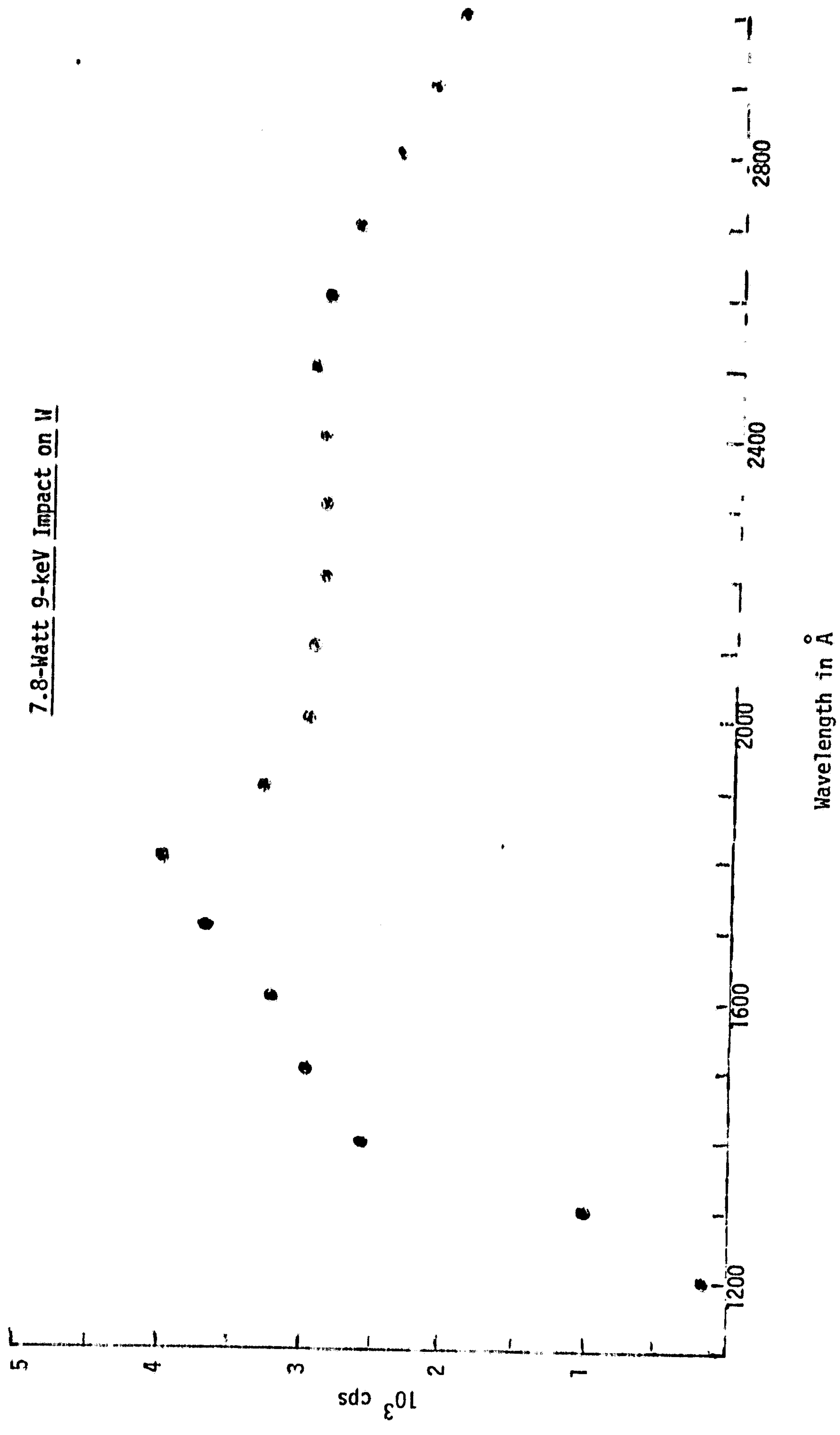

7.8-Watt 9-keV Impact on W
Wavelength in Å
1200
1600
2000
2400
2800
10^3 cps
1
2
3
4
5

Figure 5.