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SOFT X-RAY PHOTOEMISSION

D. J. Strickland
SCIENCE APPLICATIONS, INC.
8400 Westpark Drive
McLean, Virginia 22101

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Test and Evaluation, 1 July 1977. Other requests for
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Hanscom A.F.B., Massachusetts 01731.

This research was sponsored by the DEFENSE NUCLEAR AGENCY
under Subtask Z99QAXTA040, Work Unit Code 01, entitled
"Electron Interaction Calculations".

ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441
This technical report has been reviewed and approved for publication.

APPROVED:

[Signature]
JOHN C. GARTH
Project Engineer
SOFT X-RAY PHOTOEMISSION

D. J. Strickland

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McLean, Virginia 22101

Final Report.
1 Oct 1976 - 15 Apr 1977

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JULY 1977

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Distribution Statement (of this Report)

Distribution Statement (of the abstract entered in Block 20, if different from Report)

This research was sponsored by the Defense Nuclear Agency under Subtask 299QAXTA040, Work Unit Code 01, entitled "Electron Interaction Calculations".

This work was undertaken to develop a capability to predict photoemission from materials for soft x-ray sources. By soft, we mean x-rays with energies of a few keV or less. The Boltzmann equation was solved for the electron flux - from this flux, other quantities of interest may be obtained, e.g., the photoemission yields. Three materials have been examined: aluminum, aluminum oxide, and silicon dioxide. Back photoemission yields are presented in this report for these materials. For aluminum, an extensive series of runs was made. In particular, results were obtained for a series of narrow Gaussian
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photon distributions from 0.5 to 10 keV and for blackbody spectra over a temperature range from 1 to 10 keV.
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Section 1
INTRODUCTION AND SUMMARY

This work was undertaken to develop a capability to predict photoemission from materials for soft x-ray sources. By soft, we mean x-rays with energies of a few keV or less. The electron transport description required for soft x-ray sources is significantly different than the standard multiple scattering - continuous slowing down approach used at higher photon energies. At low energies, the standard approach must be abandoned in favor of the more exact single scattering approach which requires detailed scattering energy loss information for each important electron interaction. Said another way, the two parameter description, the parameters being the stopping power and

---

multiple scattering formula, must be replaced by a multi-parameter description where the parameters are the differential inverse mean free paths for the various electron interactions. In terms of transport equations, a Fokker-Planck type equation is replaced by a Boltzmann type integro-differential equation.

We have chosen to solve the Boltzmann equation for the electron flux — from this flux, other quantities of interest may be obtained, e.g., the photoemission yields. In the brief time allotted, this work was made possible by the extensive amount of work previously carried out by Strickland on electron transport in gases. We have borrowed coding from that work wherever possible. Nevertheless, extensive code development was required. Coding, together with acquisition of needed atomic data, consumed the major portion of time available. In spite of this, a considerable number of results will be presented in this report. A word of caution must be given. The results are the first of their kind and have not been critically tested against measurements nor can they be critically tested against results of other existing methods. Furthermore, at this time, we do not know how sensitive the results are to gridding, uncertainties in cross section, etc. Fortunately, a sensitivity study is now underway as well as a comparison with available data under Defense Nuclear Agency (DNA) sponsorship.

We have examined three materials – aluminum, aluminum oxide, and silicon dioxide, all of which were mutually agreed upon by SAI, RADC, and DNA. Back photo-emission yields are presented in this report for these materials. For aluminum, an extensive series of runs was made. In particular, results were obtained for a series of narrow Gaussian photon distributions from 0.5 to 10 keV and for blackbody spectra over a temperature range from 1 to 10 keV. Where comparisons could be made with POEM, the results of this work were found to be higher, but within reasonable agreement.

An exploding wire spectrum from a recent Physics International report was considered for obtaining results for all three materials. The total back yield was found to be sensitive to the material with aluminum providing the highest value and silicon dioxide the lowest.
Section 2

METHOD OF SOLUTION

To properly model the transport of electrons over an energy range which extends below \(\sim 1\) keV, a single scattering description is required. This entails consideration of all important scattering and loss mechanisms on an individual basis. One can choose to either use a single scattering Monte Carlo approach or solve a Boltzmann equation in its integro-differential form. The latter approach has been chosen here and is based on the earlier work by Strickland, et al.,\(^6\) for electron transport in gases. In this section, we present the transport equation, list the important photon and electron processes, give the matrix representation to the transport equation, and mention how the equation is solved. The discussion will be brief with emphasis placed on publications and reports where more details may be found.

The Boltzmann equation in its integro-differential form is:

\[
\mu \frac{d \phi}{dx} (x, E, \mu) = -K_T(x) \phi(x, E, \mu) + \int d\Omega' \int dE' \frac{4\pi}{4\pi} \delta(E' > E) 
\sum_k K_k (E, E', \theta) \phi(x, E', \mu') + P(x, E, \mu) \quad (1)
\]

The terms are:

\[
\begin{align*}
x & \quad \text{depth in cm}, \\
E & \quad \text{energy in eV}, \\
\mu & \quad \text{cosine of pitch angle with respect to back surface normal}, \\
\Theta & \quad \text{scattering angle}, \\
K_T & \quad \text{total inverse mean free path (IMFP) in cm}^{-1}, \\
K_x & \quad \text{differential inverse mean free path (DIMFP) for } x\text{th process in cm}^{-1}\text{eV}^{-1}\text{sr}^{-1}, \\
\phi & \quad \text{electron flux in electrons/cm}^2\text{sec-ev-sr}, \\
P & \quad \text{electron volume production rate in electrons/cm}^3\text{sec-ev-sr}.
\end{align*}
\]

One spatial (x) and two velocity (represented by E and \(\mu\)) variables are considered of the six possible phase space variables. The equation is thus one-dimensional with azimuthal symmetry about the surface normal and is appropriate to broad uniform photon sources normally incident on a material. No restrictions are placed on the description of scattering and energy loss in equation (1). In particular, scattering through any angle, discrete energy loss, and production of secondary electrons are permitted.

The electron volume production rate \(P\) contains electrons for the following photon processes:

(1) The photoelectric effect,
(2) Compton scattering, and
(3) Auger emission.
The incident photon spectrum is allowed to be attenuated in the calculations and thus leads to the depth dependence in $P$ expressed in equation (1). An angular dependence given by $1 - aP_2(\cos \theta)$ is assigned to the photoelectrons$^7$ where $P_2$ is the second Legendre polynomial and $\theta$ is the emission angle with respect to the incident photon direction. In this work, the parameter $a$ was set to unity. Isotropic angular dependence is assumed for Auger emission. The dependence for Compton electrons comes from the standard Compton expression — the Klein-Nishina formula (see Evans$^8$). For soft x-ray sources, the electron density inserted into this formula is for the electrons in the conduction and/or valence bands of the material. The particular value used is not important since Compton scattering provides relatively few electrons for soft photon sources. Each Auger feature is given a narrow triangular distribution over five equally spaced grid points in energy.

Electron processes modeled in the DIMFP's are:

(1) Elastic scattering,
(2) Plasmon excitation,
(3) Conduction/valence band ionization,
(4) Inner shell ionization, and
(5) Auger emission.


Assumptions concerning each process and the corresponding form of the DIMFP may be found in the 1977 RADC final report on x-ray photoemission. Briefly, elastic scattering is permitted through an angle of $180^\circ$, plasmon excitation is assumed to be a discrete energy loss process with no change in direction of the incident electron, the ionization processes describe both energy loss of the incident electron and secondary electron production, and, finally, Auger emission is assumed isotropic and triangular in energy as in the case of shell vacancy creation by photons. Angular dependences assigned to degraded primaries and secondaries in the ionization process are based on the laws of energy and momentum conservation.

Choosing a discrete set of energy and angular points, the Boltzmann equation may be transformed into the following matrix equation:

$$
\mu_i \frac{d\phi_{ni}(x)}{dx} = \sum_{m \leq n} \sum_{j} R_{nmij} \phi_{mj}(\xi) + P_{ni}(x) \quad (2)
$$

where indices $n$ and $m$ refer to energy and $i$ and $j$ refer to pitch angle. The index $m$ does not exceed $n$ in value since electrons cannot gain energy in our formulation. For details on the form of the matrix elements, see Strickland,

---

et al.,\(^6\) and the RADC x-ray photoemission final report.\(^9\)
It is convenient to define a new source term given by

\[
S_{ni}(x) = \sum_{m<n} \sum_j R_{nmj} \phi_{mj} + P_{ni}(x) \quad . \tag{3}
\]

Equation (2) is now

\[
\mu_i \frac{d\phi_{ni}(x)}{dx} = \sum_j R_{nnij} \phi_n(x) + S_{ni}(x) \quad . \tag{4}
\]

or without the explicit appearance of subscript \(n\),

\[
\mu_i \frac{d\phi_i(x)}{dx} = \sum_j R_{ij} \phi_j(x) + S_i(x) \quad . \tag{5}
\]

This equation is solved by an eigenvalue method, one energy at a time, beginning with the highest energy.\(^6\)

---


Section 3

CODE DEVELOPMENT

The following codes are required in this work for obtaining photoemission characteristics of materials:

(1) a source code,
(2) a matrix code, and
(3) a Boltzmann matrix equation solving code.

The source code generates the production rate $P(x,E,\mu)$ for a given normally incident photon source. The matrix code generates the matrix elements $R_{nmij}$ by carrying out detailed integrations of DIMFP's over energy and angle. Finally, the Boltzmann matrix equation solving code obtains the electron flux $\phi(x,E,\mu)$ for the given outputs of the first two codes. Given the solution $\phi$, this code further performs various integrations over $x$, $E$, and $\mu$ to obtain such quantities as differential and total yields, currents, and dose profiles.

The major part of the work performed was directed to developing the above codes. The source code is totally new whereas the matrix and Boltzmann codes are modified versions of codes used for electron transport in gases. Only minor modifications were needed on the Boltzmann code whereas an essentially new code was developed for obtaining the required matrix.
Following the basic development of these codes, further changes have recently been made so that the three codes may be run as multisteps in a single job. This has significantly increased efficiency in making production runs. A control statement program is now being used which does file manipulation and allows for new multistep runs by merely changing a few selected control and data statements.
Section 4
ATOMIC DATA

The three materials which were investigated are aluminum (Al), aluminum oxide (Al₂O₃), and silicon dioxide (SiO₂). In this section, the photoabsorption cross sections, Auger yields, and IMFP's used in the calculations are presented for these materials.

The energy levels considered for each material are designated in Tables 1-3. The energies assigned to the valance bands in Al₂O₃ and SiO₂ were taken from ORNL tabulations. ¹⁰,¹¹ Minor shifts that occur in inner shell binding energies in going from the atomic species (Al, Si, O) to the molecular species (Al₂O₃, SiO₂) have been ignored.

Information pertaining to Auger emission is given in Table 4. The description is simple, but adequate to account for conversion of potential energy of inner shell vacancies to kinetic energy of the emitted Auger electrons. For Al and Si, every K shell vacancy is

---


### TABLE 1. ENERGY LEVELS FOR ALUMINUM

<table>
<thead>
<tr>
<th>LEVEL DESIGNATION</th>
<th>ENERGY (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction Band</td>
<td></td>
</tr>
<tr>
<td>( L_{23} )</td>
<td>0.073</td>
</tr>
<tr>
<td>( L_1 )</td>
<td>0.114</td>
</tr>
<tr>
<td>( K )</td>
<td>1.56</td>
</tr>
</tbody>
</table>

### TABLE 2. ENERGY LEVELS FOR ALUMINUM OXIDE

<table>
<thead>
<tr>
<th>LEVEL DESIGNATION</th>
<th>ENERGY (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valance Bands</td>
<td></td>
</tr>
<tr>
<td>( A\ell(L_{23}) )</td>
<td>0.073</td>
</tr>
<tr>
<td>( A\ell(L_1) )</td>
<td>0.114</td>
</tr>
<tr>
<td>( O(K) )</td>
<td>0.533</td>
</tr>
<tr>
<td>( A\ell(K) )</td>
<td>1.56</td>
</tr>
</tbody>
</table>
**TABLE 3. ENERGY LEVELS FOR SILICON DIOXIDE**

<table>
<thead>
<tr>
<th>LEVEL DESIGNATION</th>
<th>ENERGY (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valance Bands</td>
<td></td>
</tr>
<tr>
<td>Si(L\textsubscript{23})</td>
<td>0.0094, 0.024</td>
</tr>
<tr>
<td>Si(L\textsubscript{1})</td>
<td>0.10</td>
</tr>
<tr>
<td>O(K)</td>
<td>0.151</td>
</tr>
<tr>
<td>Si(K)</td>
<td>0.533</td>
</tr>
<tr>
<td></td>
<td>1.84</td>
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TABLE 4. AUGER ENERGIES AND YIELDS FOR Al, Si, AND O

<table>
<thead>
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<th>VACANCY</th>
<th>AUGER ENERGY (keV)</th>
<th>YIELD</th>
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<tr>
<td>Al(K)</td>
<td>1.4</td>
<td>0.95</td>
</tr>
<tr>
<td>Al(L)</td>
<td>0.07</td>
<td>1.0</td>
</tr>
<tr>
<td>Si(K)</td>
<td>1.6</td>
<td>0.94</td>
</tr>
<tr>
<td>Si(L)</td>
<td>0.08</td>
<td>1.0</td>
</tr>
<tr>
<td>O(K)</td>
<td>0.50</td>
<td>1.0</td>
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assumed to first lead to a KLL Auger electron with probability given by the Auger yield. This leads to two L shell vacancies and, in turn, to two further Auger electrons with assumed probability of unity. For oxygen, only KLL Auger electrons are treated. Intra L-shell emission occurs at \( \geq 20 \) ev, below the region of interest in this work. Useful references to the Auger process for low-Z atoms are, e.g., McGuire, \(^{12}\) Yasko and Whitmoyer, \(^{13}\) and Walters and Bhalla. \(^{14}\)

The photoabsorption cross sections appear in Figures 1-3 and were taken from Biggs and Lighthill. \(^{15}\) No attempt was made to separate the L shell cross section into its \( L_1 \) and \( L_{23} \) components. The L shell binding energy was taken to be that for the \( L_{23} \) shell.

The IMFP's for electron processes listed in the previous section are shown in Figures 4-6. All inelastic IMFP's come from the work of the Health Physics Group at


The elastic IMFP's are based on the screened Rutherford cross section with the screening parameter of Moliéré. Below 0.1 keV, the elastic IMFP is allowed to become constant in a manner similar to that observed for \( \text{N}_2 \), \( \text{O}_2 \), and 0.18,19


Section 5
RESULTS

The basic quantity calculated in this work is the electron flux \( \phi(x, E, \mu) \). This gives the energy and angular dependence of photoelectrons throughout the slab of material being considered. The quantity of primary interest here is the cumulative back yield which is related to \( \phi \) by

\[
Y_B(E) = 2\pi \int_0^{E_{\text{max}}} dE' \int_{-1}^{0} d\mu \phi(x=0, E', \mu) / F
\]

(electrons/photon above electron energy \( E \))

where \( F \) is the total number of incident photons. The differential yield in energy \( \frac{dY_B}{dE} \) is also of interest:

\[
\frac{dY_B(E)}{dE} = 2\pi \int_{-1}^{0} d\mu \phi(x=0, E, \mu) / F
\]

(electrons/photon-keV).

The emphasis in this section will be on these two quantities.
5.1 PHOTOEMISSION FROM A\% FOR GAUSSIAN SOURCES

The purpose in considering photon distributions which are Gaussian in energy is for the simulation of line sources. The simulation is effective provided the distribution is limited to an energy range over which the yield varies by only a few percent. This was achieved by using the Gaussian formula

\[ F(E) = \exp\left[\frac{(E-E_o)}{aE_o}\right]^2 \]

with \( a \leq 0.1 \). For most cases, an \( a \)-value of 0.05 was used. Smaller values were also considered, specifically, for energies close to the K-edge energy in aluminum.

Figure 7 gives the calculated back emission yield for A\% versus Gaussian photon energy \( E_o \) over a range from 0.5 to 10 keV. Electron emission was calculated down to \( \sim 0.1 \) keV. Several other results are shown in the figure for comparison. Measurements are provided by Eliseenko, et al.\(^{20}\) and Savinov, et al.\(^{21}\) Transport results are shown from the codes POEM\(^{22}\) and QUICKE\(^{2}\) and were obtained by running these codes specifically for this comparison.


Finally, the empirical result of Schaefer\(^{23}\) is shown which is based on the sum of products of the photon absorption coefficient at \(E_o\) and the penetration depths of the various types of electrons produced.

The agreement with the other available yields above the aluminum K-edge is encouraging considering the limited testing so far performed on the newly developed codes. The difference between our results and the measurements by Savinov, et al.\(^{21}\) below the K-edge remains to be determined. Based on the recent range calculations by Ashley, et al.,\(^{10}\) Schaefer's result at low energies will significantly increase using this new information in place of his low energy extrapolated range.

The next several figures serve to provide more detailed information on our results for Gaussian photon sources. Differential back yields \([dY_B(E)/dE]\) and cumulative back yields \([Y_B(E)\]) are shown in Figures 8-14 for \(E_o = 0.5, 1.0, 1.4, 1.7, 2.0, 4.0, \) and 10.0 keV. Table 5 gives the value of \(Y_B(E)\) for these \(E_o\) values for the lowest electron energy \(E\) treated in the calculations (either 0.1 or 0.05 keV). For \(E_o < 1.56\) keV (K-edge energy), the highest energy peak in \(dY_B/dE\) is due to L


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TABLE 5. CUMULATIVE YIELD $Y_B$ FOR SEVERAL GAUSSIAN SOURCES

<table>
<thead>
<tr>
<th>GAUSSIAN PEAK ENERGY $E_0$</th>
<th>$Y_B$ (e/phot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>$2.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>1.0</td>
<td>$9.9 \times 10^{-4}$</td>
</tr>
<tr>
<td>1.4</td>
<td>$8.6 \times 10^{-4}$</td>
</tr>
<tr>
<td>1.7</td>
<td>$7.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>2.0</td>
<td>$5.7 \times 10^{-3}$</td>
</tr>
<tr>
<td>4.0</td>
<td>$2.7 \times 10^{-3}$</td>
</tr>
<tr>
<td>10.0</td>
<td>$1.2 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
photoelectrons. The 0.07 keV feature is due to LMM Auger electrons. Starting with Figure 11, \( E_0 \) is greater than the K-edge energy and results in significant changes in both types of yields. In Figure 11, for example, the peaks in \( d\gamma_B/dE \) in order of decreasing energy are due to L-photo-, KLL Auger, K-photo-, and finally, LMM Auger electrons. For photon energies just above the K-edge, the spectra are seen to be dominated by KLL Auger electrons. At \( E_0 = 10 \) keV, however, Auger electrons provide only a minor contribution with the dominant source coming from K-photoelectrons.

5.2 PHOTOEMISSION FROM Al FOR BLACKBODY SOURCES

We next present results for a series of blackbody spectra incident on Al. Five spectra with temperatures of 1.0, 2.0, 5.0, 7.5, and 10 keV were considered. The yield \( \gamma_B \) is shown in Figure 15, and is tabulated in Table 6, versus temperature in keV. For comparison, available POEM results are also shown and, as with the previous comparison, are found to be below the results of this work. The difference increases with decreasing source temperature, as expected, since sub-kilovolt electrons are becoming increasingly important.

Figures 16-19 provide further information for the results in Figure 15. Shown in each of these figures are \( d\gamma_B(E)/dE \) and \( \gamma_B(E) \) versus electron energy \( E \) for a different blackbody temperature. The temperatures selected for these results are 1.0, 2.0, 4.0, and 10.0 keV. The differential

TABLE 6. CUMULATIVE YIELD $Y_B$ FOR SEVERAL BLACKBODY SOURCES

<table>
<thead>
<tr>
<th>TEMPERATURE (keV)</th>
<th>$Y_B$ (e/phot) (This work)</th>
<th>$Y_B$ (e/phot) (POEM)</th>
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yields shown have some noticeable differences compared with those shown in Figures 8-14 for narrow Gaussian photon sources. Here, a broad K-photoelectron continuum typically dominates the spectrum. As before, we observe the KLL and LMM Auger features starting at ~1.4 and 0.07 keV. With the exception of T=1 keV, photoelectrons, rather than Auger electrons, dominate the photoemission spectrum.

5.3 PHOTOEMISSION FROM Al, Al_2O_3, and SiO_2 FOR AN EXPLODING WIRE SPECTRUM

The primary goal of work begun under the given DNA/RADC contract is to develop a predictive capability in soft x-ray photoemission for making comparisons with photoemission data and providing physical insight into the photoemission process itself in the DNA sponsored exploding wire radiation program (EWR). As a beginning in the study of photoemission for EWR sources, we have run our transport codes for the photon spectrum shown in Figure 20, which is based on information appearing in a January 1977 Physics International report. The spectra in this report show that ~50% of the energy resides in the line features occurring at 1.6 and 1.7 keV. The Gaussian feature peaking at 1.65 keV in Figure 20 has been substituted for these lines and itself contains ~50% of the total energy. One should not necessarily interpret this figure to mean that no photons are present at lower energies for actual wires spectra in the test chamber. We are using data available

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to us at this time which covers the range from 1.3 to 3.4 keV. Over this range beginning at 3.4 keV, reported cumulative energy distributions reach 100% at 1.6 keV.

The yields $d\gamma_B/dE$ and $\gamma_B$ for Al and Al$_2$O$_3$ are shown in Figure 21 for the source spectrum in Figure 20. The results for SiO$_2$ appear in Figure 22. The dominant feature starting at $\sim$1.4 keV and continuing to lower energies in both spectra in Figure 21 is Auger electron emission arising from Al K-shell vacancies. The dominance by Auger electrons is due to the abundance of photons lying just above the 1.56 keV K-edge of aluminum. The minor contribution above 1.5 keV in both spectra is due to L photoelectrons which weakly reflect the source spectrum. Below 0.2 keV, the spectra rise and peak at 0.07 keV as a result of both K-photoelectron and Auger electron emission. Here the Auger electrons arise from L-shell vacancies in aluminum. The additional feature in the Al$_2$O$_3$ spectrum at 0.5 keV is due to Auger emission arising from K-shell vacancies in oxygen.

Significant differences are seen between photo-emission from Al and Al$_2$O$_3$. The most striking difference is in Auger photoemission for the Al KLL transition. We expect the decrease shown in Al$_2$O$_3$ since over the same mean free path distance in either material, the available number of aluminum atoms has decreased by more than a factor of two in Al$_2$O$_3$. We see that the cumulative yield at 0.05 keV is about twice as large for Al.
The photoemission spectrum for SiO$_2$ in Figure 22 is noticeably different compared to Al and Al$_2$O$_3$, due primarily to the K-edge of silicon being situated above the 1.65 keV Gaussian feature in the source spectrum. The Si K-edge occurs at 1.84 keV. The primary contribution to the 1.55 keV feature is Si KLL Auger electrons although Si L-photoelectrons arising from the 1.65 keV Gaussian photon feature also contribute. The peak at 1.1 keV is due to O K-photoelectrons, that at 0.5 keV comes from O KLL Auger electrons, and, finally, the low energy feature results from Si K-photoelectrons and Si LMM Auger electrons. Unlike Al or Al$_2$O$_3$, KLL Auger electrons do not dominate the emission spectrum which is a result of the Si K-edge lying above an important energy region of the source spectrum. For this same reason, SiO$_2$ has the smallest total yield of the three materials. Its value is $2.1 \times 10^{-3}$ electrons/photon compared with $7.1 \times 10^{-3}$ and $3.8 \times 10^{-3}$ for Al and Al$_2$O$_3$. 
REFERENCES


REFERENCES (Continued)


FIGURE 1. Photoabsorption Cross Section for Al
Taken from Biggs and Lighthill\textsuperscript{15}

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Taken from Biggs and Lighthill \cite{15}
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Back Yields for Al and Al₂O₃
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# METRIC SYSTEM

## BASE UNITS:

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</tr>
<tr>
<td>mass</td>
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</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
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</tr>
<tr>
<td>electric current</td>
<td>ampere</td>
<td>A</td>
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<td>thermodynamic temperature</td>
<td>kelvin</td>
<td>K</td>
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<tr>
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<tr>
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## SUPPLEMENTARY UNITS:

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<td>Solid angle</td>
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## DERIVED UNITS:

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<td>m/s</td>
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<tr>
<td>Activity (of a radioactive source)</td>
<td>disintegration per second</td>
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<tr>
<td>Angular acceleration</td>
<td>radian per second squared</td>
<td>rad/s</td>
</tr>
<tr>
<td>Angular velocity</td>
<td>radian per second</td>
<td>rad/s</td>
</tr>
<tr>
<td>Area</td>
<td>square metre</td>
<td>m</td>
</tr>
<tr>
<td>Density</td>
<td>kilogram per cubic metre</td>
<td>kg/m</td>
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<tr>
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<td>farad</td>
<td>F/A/s/V</td>
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<tr>
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<td>A/V</td>
</tr>
<tr>
<td>Electric field strength</td>
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<td>V/m</td>
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<tr>
<td>Electric inductance</td>
<td>henry</td>
<td>V/A</td>
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<td>Electric potential difference</td>
<td>volt</td>
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<tr>
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<tr>
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<tr>
<td>Energy</td>
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<tr>
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<tr>
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<tr>
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<tr>
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<tr>
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<tr>
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<td>W/l</td>
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<td>Pa/Nm</td>
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<tr>
<td>Quantity of heat</td>
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<tr>
<td>Radiant intensity</td>
<td>watt per steradian</td>
<td>W/str</td>
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<tr>
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<td>joule per kilogram-kelvin</td>
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<tr>
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<td>volt</td>
<td>V/W/A</td>
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## SI PREFIXES:

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* To be avoided where possible.
MISSION
of
Rome Air Development Center

RADC plans and conducts research, exploratory and advanced
development programs in command, control, and communications
(C3) activities, and in the C3 areas of information sciences
and intelligence. The principal technical mission areas
are communications, electromagnetic guidance and control,
surveillance of ground and aerospace objects, intelligence
data collection and handling, information system technology,
ionospheric propagation, solid state sciences, microwave
physics and electronic reliability, maintainability and
compatibility.