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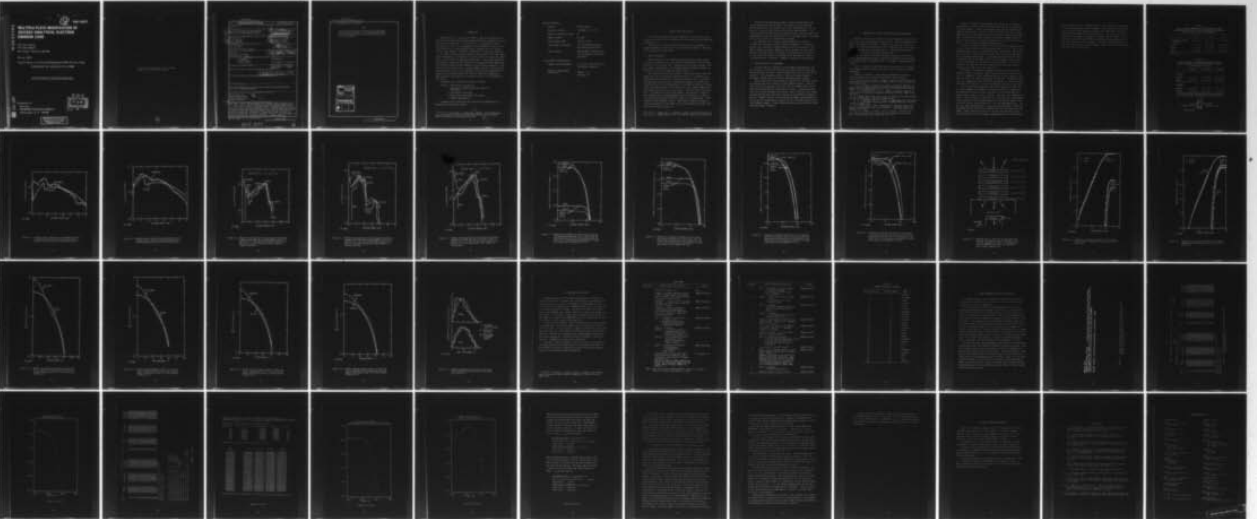
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# MULTIPLE-PLATE MODIFICATION OF QUICKE2 ANALYTICAL ELECTRON EMISSION CODE

IRT Corporation  
P.O. Box 80817  
San Diego, California 92138

15 July 1976

Topical Report for Period 8 September 1975-15 July 1976

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| 18. SUPPLEMENTARY NOTES<br>This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B323076464 R99QAXEB06963 H2590D. | 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>Electron Emission IEMP<br>Photo-Compton Currents SGEMP<br>QUICKE2 Computer Code Corp.<br>Photon Attenuation | 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>This report examines the performance of the QUICKE2 source code, authored by T.A. Dellin and C.J. MacCallum of Sandia Laboratories. The version referred to in this report contains an IRT modification to accommodate photon attenuation and electron emission for multiple layers. Numerous comparisons are made of QUICKE2 calculations with other computer codes and with experiments for a variety of conditions. Information of a practical nature, necessary for modeling problems with the code, is provided. Specific input requirements are listed and outputs are interpreted by means of a sample problem. |

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18. SUPPLEMENTARY NOTES (Continued)

NOTE

To distinguish between this modified version of QUICKE2 and the unmodified QUICKE2, it is requested that future references to the modified version described herein use the name "QUICKE2M".

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## 1. INTRODUCTION

QUICKE2 (Ref 1) is an analytical computer code which calculates bulk and vacuum emission currents produced when materials are subjected to x-rays. This code was developed by T. A. Dellin and C. J. MacCallum of Sandia Laboratories in 1974. As a refinement of earlier QUICKE2 versions, it has seen extensive use in the radiation effects community since its initial release. This report is intended as a descriptive extension to Reference 1. It reviews in some detail the analytical models used in the code, input/output requirements, and compares its solutions with the results from other codes as well as with relevant experimental data. The version examined in this document contains an IRT extension to the original QUICKE2 subroutines that permits the application of QUICKE2 to multiple-plate geometries. The calculations are carried out in a single computer run for a given spectrum and plate combination, and are expedited by the user-oriented features of simple free-field input formats and versatile output plot capabilities. These and other code features are described in detail in the remainder of this report.

Documentation is divided into sections as follows.

- Section 2 Description of the Physics
  - 3 Comparison of QUICKE2 with Other Codes and Experiments
  - 4 Description of the Input
  - 5 Sample Problem and Output Description
  - 6 Computer Requirements

A summary of the capabilities and limitations of QUICKE2 and its multiple-plate extension is shown.

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1. T. A. Dellin and C. J. MacCallum, "QUICKE2: A One-Dimensional Code for Calculating Bulk and Vacuum Emitted Photo-Compton Currents," Sandia Laboratories, SLL-74-0218, April 1974.

Physical Modeling:

|                              |  |
|------------------------------|--|
| Geometry                     | Infinite plates  |
| Materials available          | 25 elements, $1 \leq Z \leq 92$  |
| Number of elements per plate | $\leq 8$   |
| Number of plates             | No limit   |
| Photon energy range          | 1 keV to 10 MeV  |
| Photon angle of incidence    | 0 to $180^\circ$ measured from surface normal of each plate            |
| Typical outputs              | Photon spectra, electron spectra, and angular distributions and yields |

Computational Considerations:

|                                      |  |
|--------------------------------------|--|
| Computer time requirements           | 20 to 60 sec 7600 CPU per electron emission spectrum |
| Number of energy groups per spectrum | Photons: 50<br>Electrons: 34                         |

## 2. DESCRIPTION OF THE PHYSICS

A review of the physics employed in QUICKE2 is given in this section. Extensive descriptions of the formulation are given by Dellin and MacCallum in Reference 1.

QUICKE2 physics can be divided conveniently into the categories of photon attenuation, electron creation, and electron transport. Highlights of each segment are listed below.

### 2.1 PHOTON ATTENUATION

QUICKE2 calculates the attenuation of photon beams passing through materials, assuming that the flux decreases exponentially at the distance penetrated for each energy bin. Compton-scattered photons and other secondary photons are neglected. The energy-dependent attenuation lengths are taken from the tables of Biggs and Lighthill (Ref 2).

The calculation proceeds as follows. A photon spectrum is input into QUICKE2 as a set of coordinates ( $dN/dE$  or  $dE/dE$ ,  $E$ ). In addition, the composition and thickness of one or more attenuating layers is specified. For materials of one element, an attenuation length  $\lambda_E$  is interpolated from the tables for each photon energy  $E$ . The number of photons of energy  $E$  that leave the material is then calculated as the incident number times the attenuation factor  $[\exp(-\tau/\lambda_E)]$ , where  $\tau$  is the thickness of the material. For materials of two or more elements, the photons are assumed to pass through a series of monoelemental layers of thickness  $f_i\tau$ , where  $f_i$  is the fraction by weight of the  $i^{\text{th}}$  element of the compound and  $\tau$  is the thickness of the compound in  $\text{g/cm}^2$ . The number of photons of energy  $E$  leaving the material is then taken as the incident number times the attenuation factor  $[\exp(-\sum_i f_i/\lambda_{Ei})\tau]$ .

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2. G. L. Simmons and J. H. Hubbell, "Comparison of Photo-Interaction Data Set VII. Biggs-Lighthill (Rev.) and ENDF/B," NBSIS 73-241, July 1973.

Except near the photoelectric edges, log-log interpolation of the cross sections taken from the tables is accurate since the intervals between photoelectric edge energies are closely approximated by line segments for a log-log plot of cross-section versus photon energy. If an interval between two tabulated points contains both a spectral energy  $E$  and a photoelectric edge, the relationship of  $E$  to the edge energy is determined and the cross-section is interpolated accordingly.

The tabulated cross-sections include photoelectric absorption, coherent and incoherent scattering, and pair production. All of these processes are considered to remove photons from the incident beam. For photon energies relevant to QUICKE2 (1 keV to 10 MeV), the error introduced by including coherent scattering in the absorption cross section is small since this process is dominated by the photoelectric effect at low energies and by incoherent ( $\rightarrow$  Compton) scattering at high energies.

## 2.2 ELECTRON CREATION AND TRANSPORT

Electron creation in QUICKE2 is due to Compton, photoelectric, and Auger processes occurring more than an extrapolated electron range away from any material interface. Photon energies from 1 keV to 10 MeV can be specified. Electron emission due to a spectrum of photon energies is obtained by superposition of emissions from monoenergetic photons.

Electron angle and energy distribution functions for the bulk material are obtained from exact solutions to the transport equation. They are exact only for the regions of the target that are further than an extrapolated electron range from the material interfaces. Distribution functions for electrons emerging from infinite slabs of materials into vacuum are obtained from these exact bulk solutions using interpolative approximations. Complete emission electron energy and angular distributions can be obtained for normal photon incidence, and for non-normal photon sources with azimuthal symmetry. Angle-integrated spectra are available for other non-normal photon incidences.

### 3. COMPARISON OF QUICKE2 WITH OTHER CODES AND EXPERIMENT

QUICKE2 calculations of electron emission are compared with those of other codes and with experiment in this section. Specific comparisons are made to the SANDYL, POEM, GRAP2, and ETRAN codes (Refs 3-6) and to the experiments of Barlett and Weingart (Ref 7), Bradford (Ref 8), Denison et al (Ref 4), and Ebert and Lauzon (Ref 9). Photon attenuation results are compared to those of the FHUFF code (Ref 10).

Table 3-1 contains total reverse yields from Al, Cu, and Ta for a 50-keV bremsstrahlung spectrum as measured by Bradford and as calculated by the POEM, SANDYL, and QUICKE2 codes. This table is adapted from Reference 7.

Table 3-2 contains forward and reverse yields for 5-, 10-, and 15-keV blackbody spectra incident on 40 mils of Al as calculated by SANDYL and QUICKE2.

Figures 3-1 through 3-3 show energy distributions of the back-emitted electrons for the Bradford experiments and for QUICKE2.

3. H. M. Colbert, "SANDYL: A Computer Program for Calculating Combined Photon-Electron Transport in Complex Systems," Sandia Laboratories, SLL-74-0012 (1974).

4. W. L. Chadsey, "A Monte Carlo Photo-Current/Photo-Emission Computer Program," National Symposium on Natural and Man-Made Radiation in Space, Las Vegas, March 1971.

5. E. P. Wenaas and M. Williams, "GRAPUP: A Computer Code for Secondary Electron Emission from Plates," Gulf General Atomic, GAMD-10155, June 1970.

6. "ETRAN: Monte Carlo Code System for Electron and Photon Transport Through Extended Media," NBS reports 9836 and 9837.

7. C. J. MacCallum and T. A. Dellin, J. Appl. Phys. 44, 1878 (1973).

8. J. N. Bradford, "Radiation-Induced Electron Emission," AFCRL-TR-74-0583, November 1974.

9. P. Ebert and A. Lauzon, "Measurement of Gamma-Ray-Induced Secondary Electron Current from Various Elements," IEEE Trans. Nucl. Sci. NS-13, p. 735 (1966).

10. M. J. Nowak, M. R. White, and J. P. Wondra, "The FHUFF Code for X-Ray Energy Deposition with Fluorescent Heating and Fluorescent Fluxes," Gulf General Atomic, GAMD-9463, July 1969.

Figures 3-4 through 3-6 give energy distributions for reverse emission from Al, Ti, and Fe as measured by Denison et al. and as calculated by POEM and QUICKE2. Because the absolute yields for the experiment and POEM were not available, the curves were normalized to the same electron number densities as the QUICKE2 results at the peaks of either the K-photo edge or L-Auger contribution, whichever was greater. QUICKE2 yields are given on the figures, and various contributions to the electron spectra are labeled. These figures are adapted from Reference 4.

Figures 3-7 through 3-10 show the reverse and forward cumulative emission spectra from typical satellite materials for 2-, 5-, 10-, and 15-keV blackbody photon spectra as calculated by GRAP2 and QUICKE2. The reverse emission is from a quartz solar cell cover, while the forward emission is into an aluminum equipment box. The incident spectra used in the latter calculations are the blackbody spectra filtered through a typical solar cell and through the wall of the box, as shown in Figure 3-11. In these instances, the ordinate label "per calorie" always means "per calorie incident on the front face of the solar cell."

In Figures 3-12 through 3-15, photon attenuation predicted by the subroutine ATTEN is compared to FHUFF calculations for the cases of Figures 3-7 through 3-10. Here, the photon spectra are also compared as they leave the solar cell before entering the aluminum box. The quantity plotted is the cumulative fluence of photons with energy less than the energy indicated on the abscissa. Very minor differences are seen in the results.

For a hard-spectrum comparison, the forward and reverse yields and the forward angular distributions calculated by QUICKE2 are compared to the experimental results of Ebert and Lauzon for 1.25-MeV photons incident on thick targets of C, Al, Cu, and Pb. The results are summarized in Table 3-3 and in Figures 3-16 through 3-19. Note that, while the forward yields obtained by the two methods agree well, the QUICKE2 angular distributions are not as sharply peaked at  $\theta = 0$  as the experimental ones. Figure 3-20, taken from Reference 7, shows Dellin and MacCallum's comparison of QUICKE2 with the Ebert-Lauzon experiment and with the Monte Carlo code SANDYL. Their results are in units of electrons per unit angle rather than electrons per unit solid angles, emphasizing the fact that the solid

angle approaches zero as  $\theta$  approaches zero. Since this form is indicative of real spatial emission, the discrepancies in the results at small angles shown in Figures 3-16 through 3-19 probably have minor impact on calculations employing QUICKE2 electron emission data. The results in Table 3-1 through 3-3 and Figures 3-1 through 3-6 indicate that the QUICKE2 calculations agree quite well with SANDYL and POEM Monte Carlo calculations and with the experimental data of Bradford. The largest differences were for reverse emission due to low energy photons (Table 3-2) but the discrepancies were less than a factor of two.

Table 3-1

QUICKE2 RESULTS COMPARED WITH EXPERIMENT AND OTHER  
CALCULATIONS FOR REVERSE YIELDS FROM DIFFERENT MATERIALS<sup>a</sup>  
(Photons from 50-keV bremsstrahlung)

|                               | Aℓ                   | Cu                   | Ta                   |
|-------------------------------|----------------------|----------------------|----------------------|
| Bradford Experiment<br>(AFCL) | $1.9 \times 10^{-7}$ | $4.8 \times 10^{-7}$ | $1.2 \times 10^{-6}$ |
| QUICKE2                       | $1.5 \times 10^{-7}$ | $3.6 \times 10^{-7}$ | $1.0 \times 10^{-6}$ |
| SANDYL                        | $1.5 \times 10^{-7}$ | $3.2 \times 10^{-7}$ | $8.7 \times 10^{-7}$ |
| POEM                          | $1.5 \times 10^{-7}$ | $3.3 \times 10^{-7}$ | $8.8 \times 10^{-7}$ |

<sup>a</sup>From Ref. 7.

Table 3-2

QUICKE2 RESULTS FOR FORWARD AND REVERSE YIELDS  
FROM Aℓ COMPARED WITH SANDYL FOR DIFFERENT SPECTRA  
(Plate thickness 40 mils)

|                | 5-keV BB             | 10-keV BB            | 15-keV BB            |
|----------------|----------------------|----------------------|----------------------|
| <u>Reverse</u> |                      |                      |                      |
| QUICKE2        | $3.4 \times 10^{-7}$ | $9.2 \times 10^{-8}$ | $3.9 \times 10^{-8}$ |
| SANDYL         | $2.3 \times 10^{-7}$ | $6.6 \times 10^{-8}$ | $2.8 \times 10^{-8}$ |
| <u>Forward</u> |                      |                      |                      |
| QUICKE2        | $2.9 \times 10^{-8}$ | $2.9 \times 10^{-8}$ | $2.0 \times 10^{-8}$ |
| SANDYL         | $3.4 \times 10^{-8}$ | $3.1 \times 10^{-8}$ | $1.7 \times 10^{-8}$ |

5-, 10-, and 15-keV blackbody spectra are incident.  
All yields are in C/cal incident on front face of Aℓ.

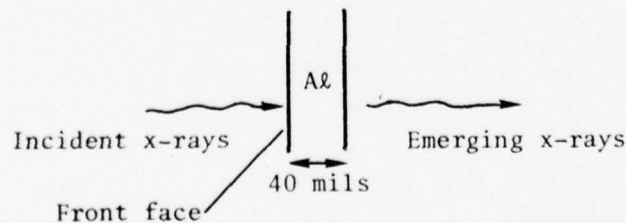


Table 3-3  
 QUICKE2 AND EXPERIMENTAL RESULTS COMPARED FOR HIGH-ENERGY PHOTONS

| Material                          | Thickness<br>(g/cm <sup>2</sup> ) | Experiment of<br>Ebert & Lauzon                     | QUICKE2   |
|-----------------------------------|-----------------------------------|---|---|
| <u>Forward Yields<sup>a</sup></u> |                                   |   |   |
| Carbon                            | 0.457                             | 3.0 x 10 <sup>-8</sup><br>(9.1 x 10 <sup>-3</sup> ) | 2.8 x 10 <sup>-8</sup><br>(8.4 x 10 <sup>-3</sup> ) |
| Aluminum                          | 0.614                             | 2.7 x 10 <sup>-8</sup><br>(8.0 x 10 <sup>-3</sup> ) | 2.3 x 10 <sup>-8</sup><br>(7.0 x 10 <sup>-3</sup> ) |
| Copper                            | 0.467                             | 1.8 x 10 <sup>-8</sup><br>(5.3 x 10 <sup>-3</sup> ) | 1.8 x 10 <sup>-8</sup><br>(5.5 x 10 <sup>-3</sup> ) |
| Lead                              | 0.591                             | 2.0 x 10 <sup>-8</sup><br>(6.1 x 10 <sup>-3</sup> ) | 1.7 x 10 <sup>-8</sup><br>(5.3 x 10 <sup>-3</sup> ) |
| <u>Reverse Yields<sup>a</sup></u> |                                   |   |   |
| Carbon                            |                                   | 1.1 x 10 <sup>-9</sup><br>(3.4 x 10 <sup>-4</sup> ) | 1.2 x 10 <sup>-9</sup><br>(3.6 x 10 <sup>-4</sup> ) |
| Aluminum                          |                                   | 1.1 x 10 <sup>-9</sup><br>(3.3 x 10 <sup>-4</sup> ) | 2.2 x 10 <sup>-9</sup><br>(6.6 x 10 <sup>-4</sup> ) |
| Copper                            |                                   | 4.3 x 10 <sup>-9</sup><br>(1.3 x 10 <sup>-3</sup> ) | 3.7 x 10 <sup>-9</sup><br>(1.1 x 10 <sup>-3</sup> ) |
| Lead                              |                                   | 7.3 x 10 <sup>-9</sup><br>(2.2 x 10 <sup>-3</sup> ) | 7.4 x 10 <sup>-9</sup><br>(2.2 x 10 <sup>-3</sup> ) |

<sup>a</sup>Yields without parentheses are in C/cal; yields in parentheses are in electrons/photon.

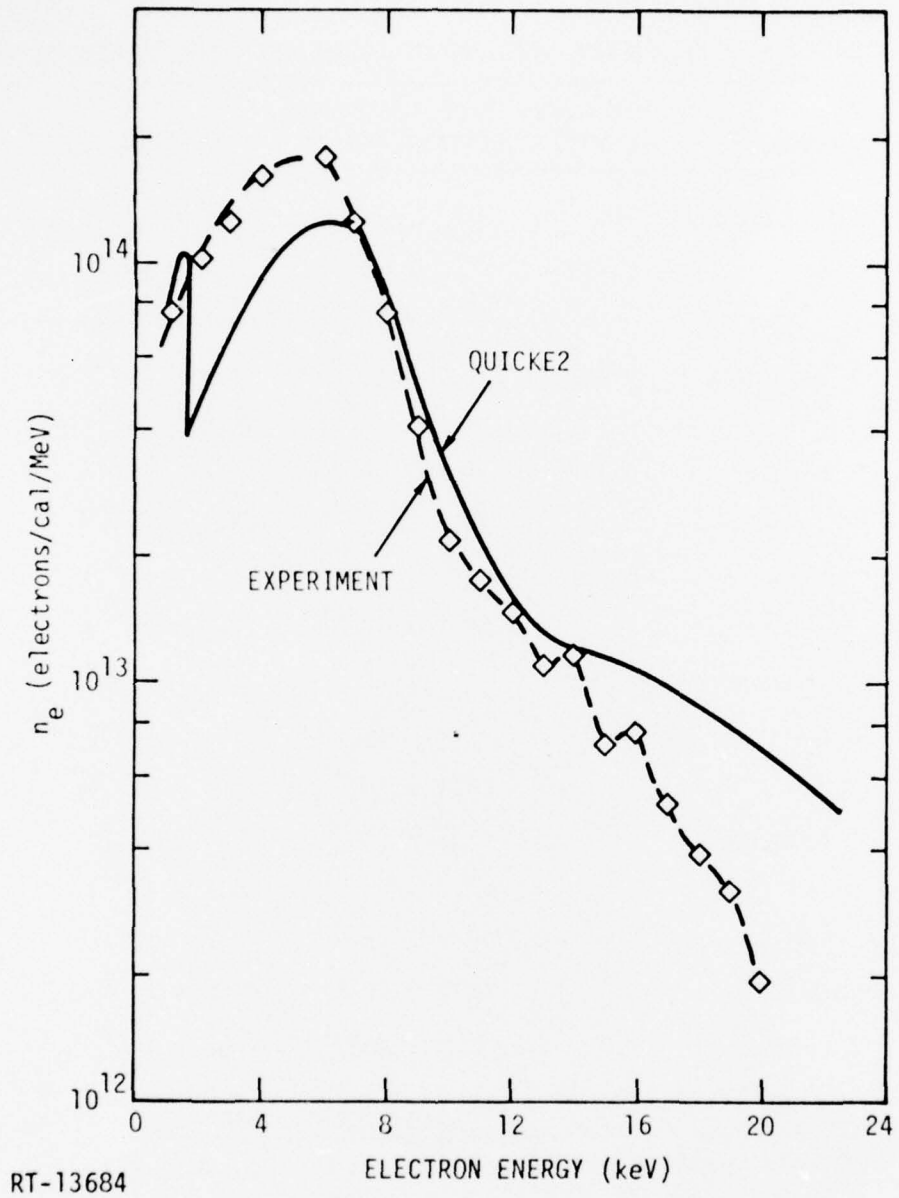


Figure 3-1. QUICKE2 results compared with experimental results of Bradford for reverse-emitted electron energy spectra obtained from 50-keV bremsstrahlung on Al

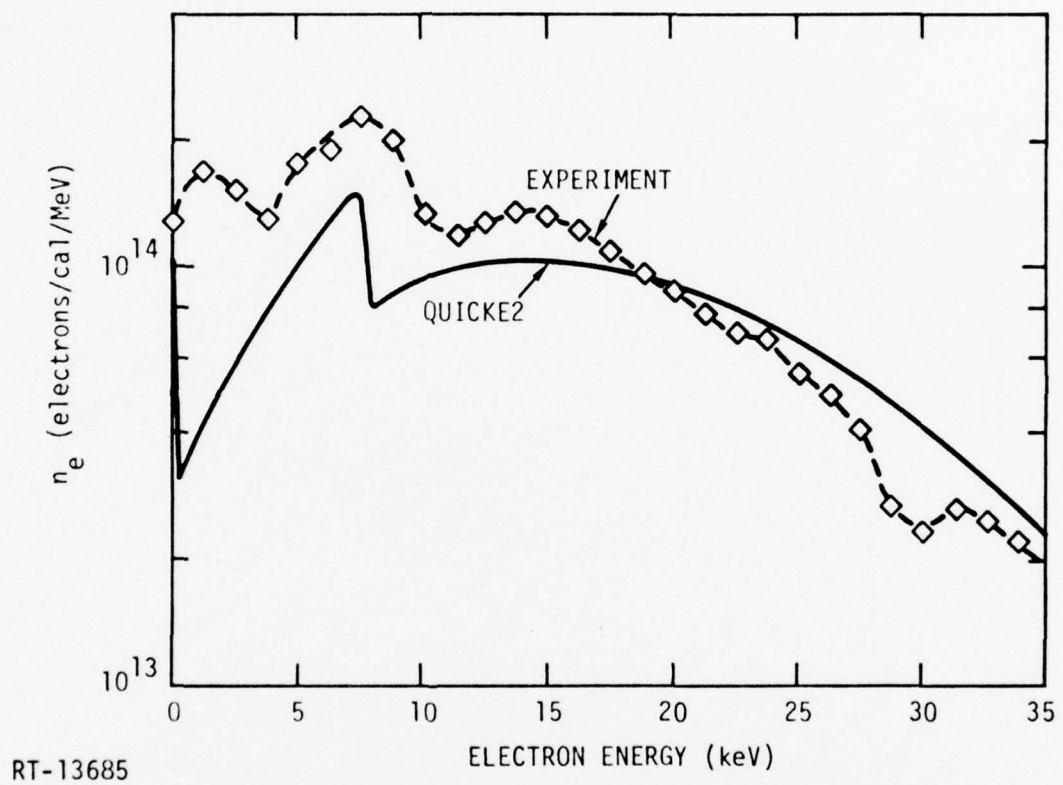


Figure 3-2. QUICKE2 results compared with experimental results of Bradford for reverse-emitted electron energy spectra obtained from 50-keV bremsstrahlung on Cu

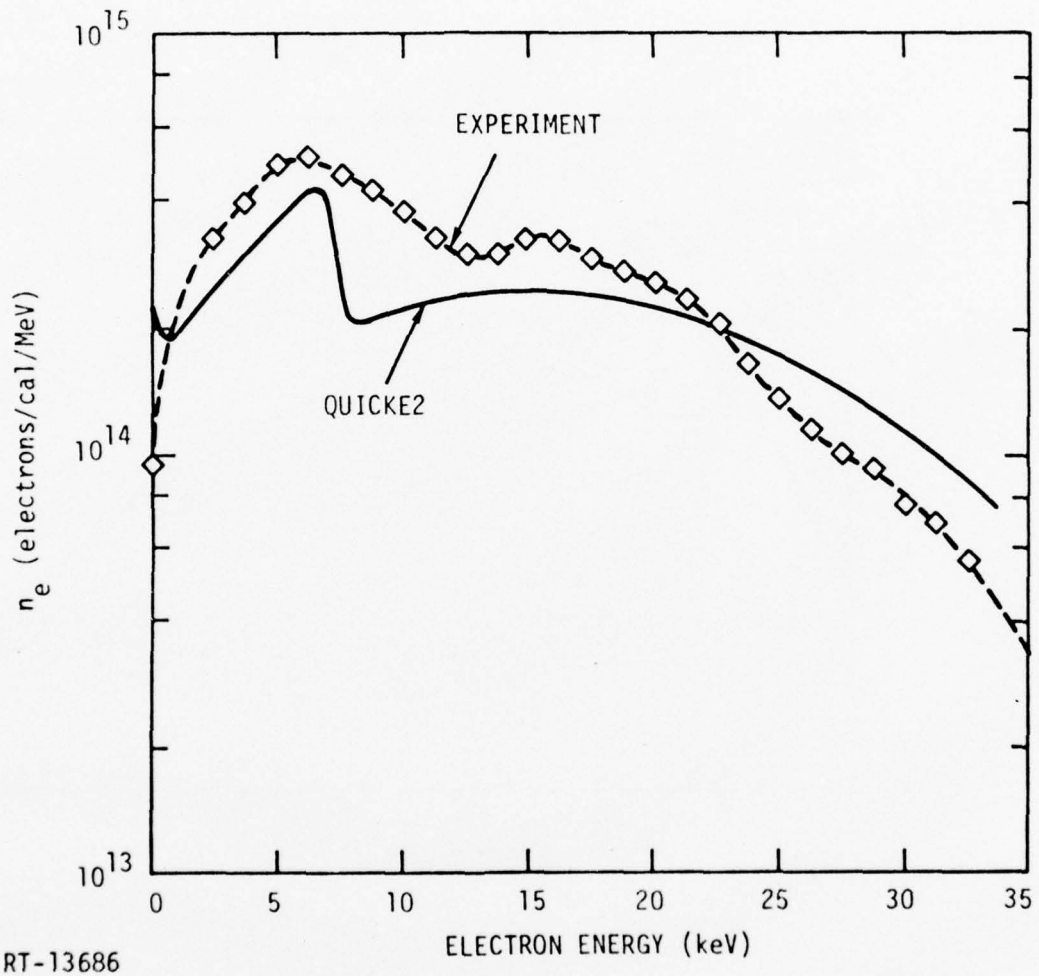


Figure 3-3. QUICKE2 results compared with experimental results of Bradford for reverse-emitted electron energy spectra obtained from 50-keV bremsstrahlung on Ta

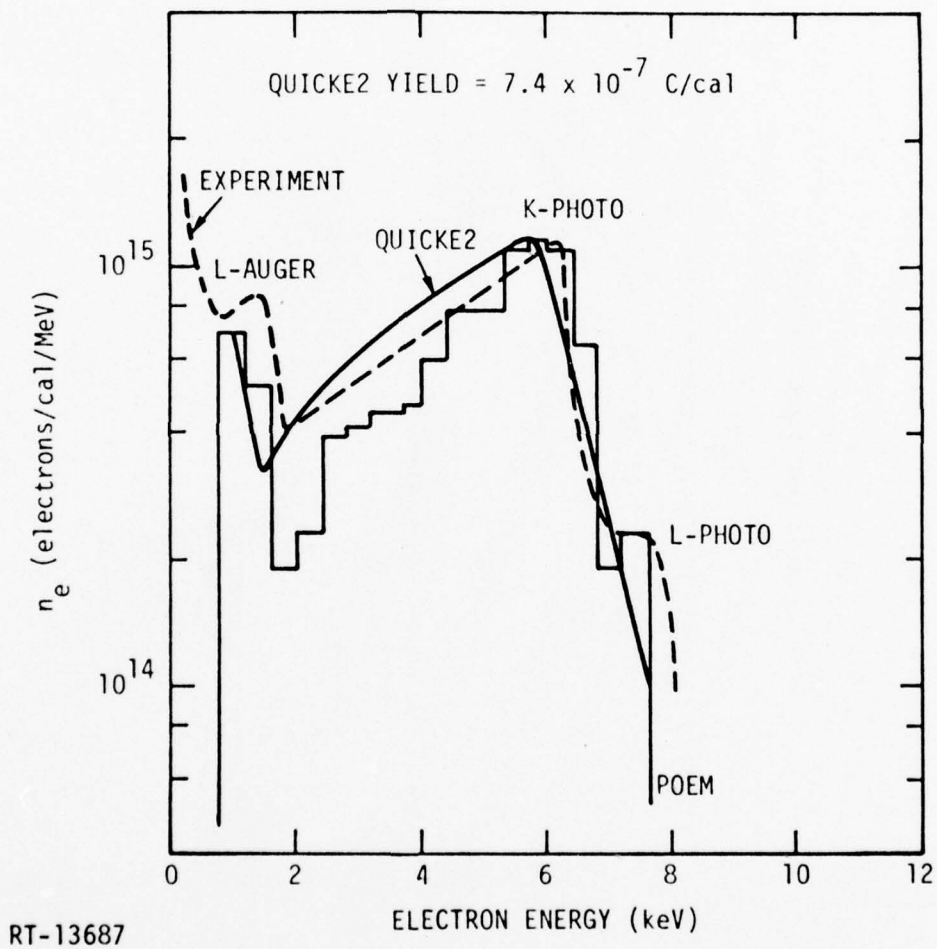


Figure 3-4. QUICKE2 reverse-emitted electron energy distribution compared with POEM code and experimental results of Denison et al. for 8-keV monoenergetic photons incident on Al; curves normalized to same heights at K-photo edge peaks

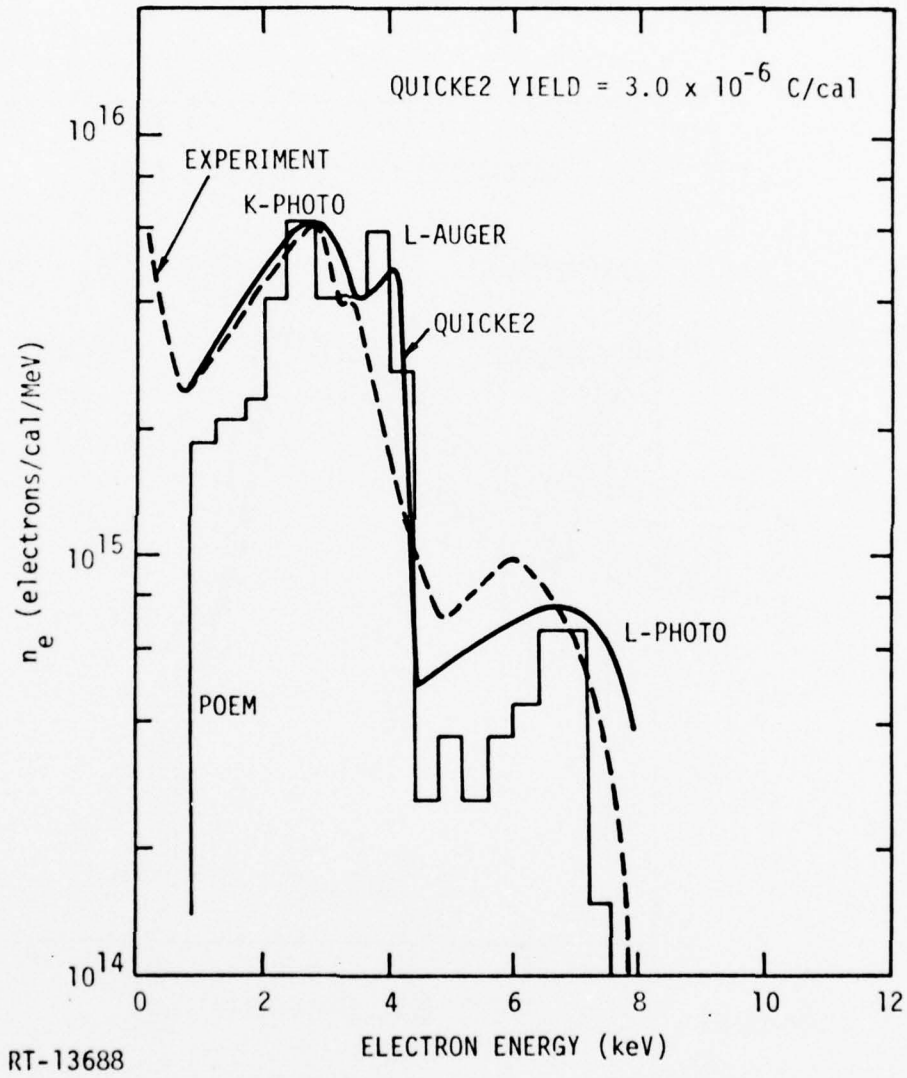


Figure 3-5. QUICKE2 reverse-emitted electron energy distribution compared with POEM code and experimental results of Denison et al. for 8-keV monoenergetic photons incident on Ti; curves normalized to same heights at K-photo edge peaks

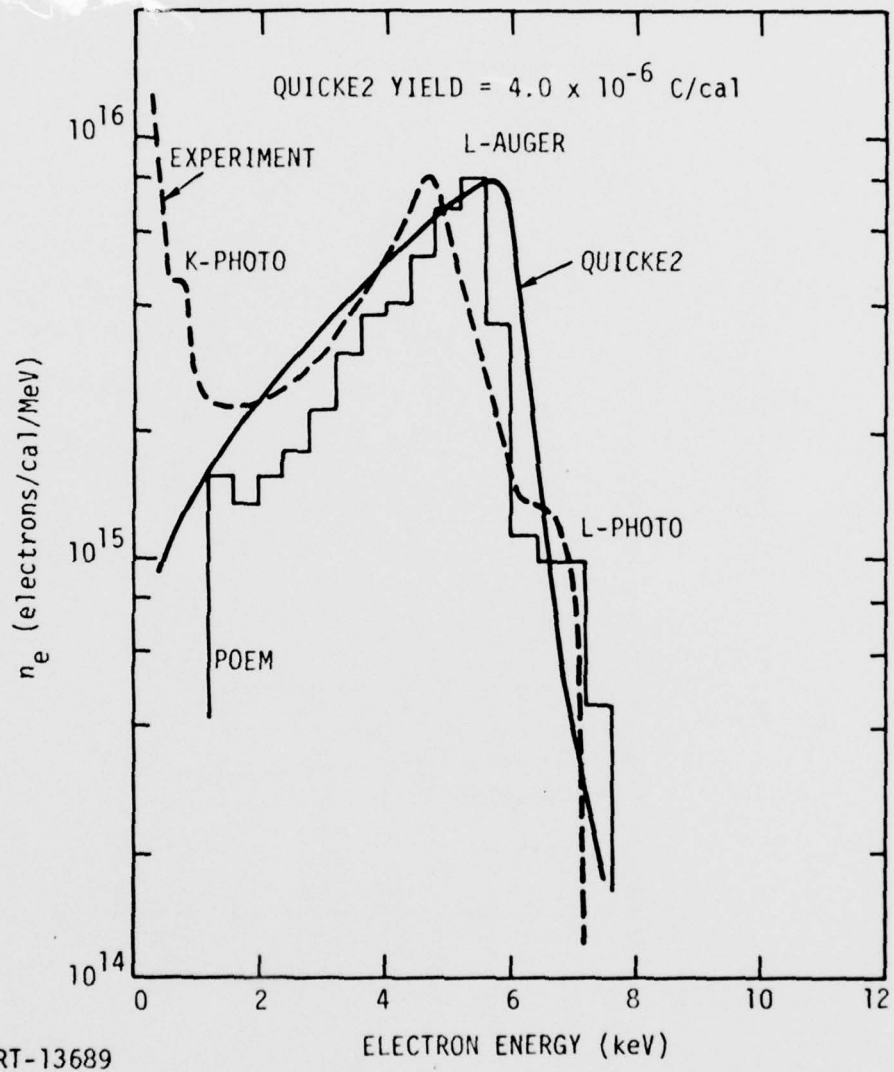


Figure 3-6. QUICKE2 reverse-emitted electron energy distribution compared with POEM code and experimental results of Denison et al. for 8-keV monoenergetic photons incident on Fe; curves normalized to same heights at L-Auger peaks

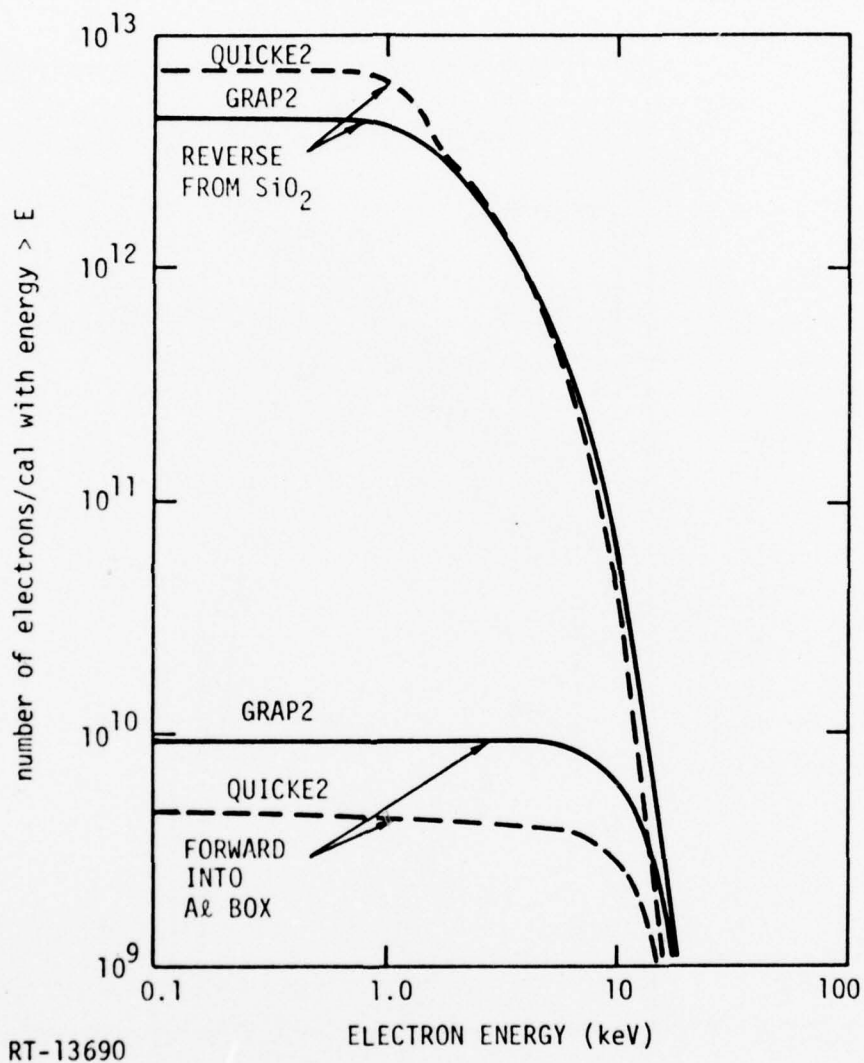


Figure 3-7. Comparison of QUICKE2 and GRAP2 electron spectra for reverse emission from a solar cell cover and forward emission from Al after attenuation by the solar cell; incident photon spectrum due to black-body radiator with temperature 2 keV

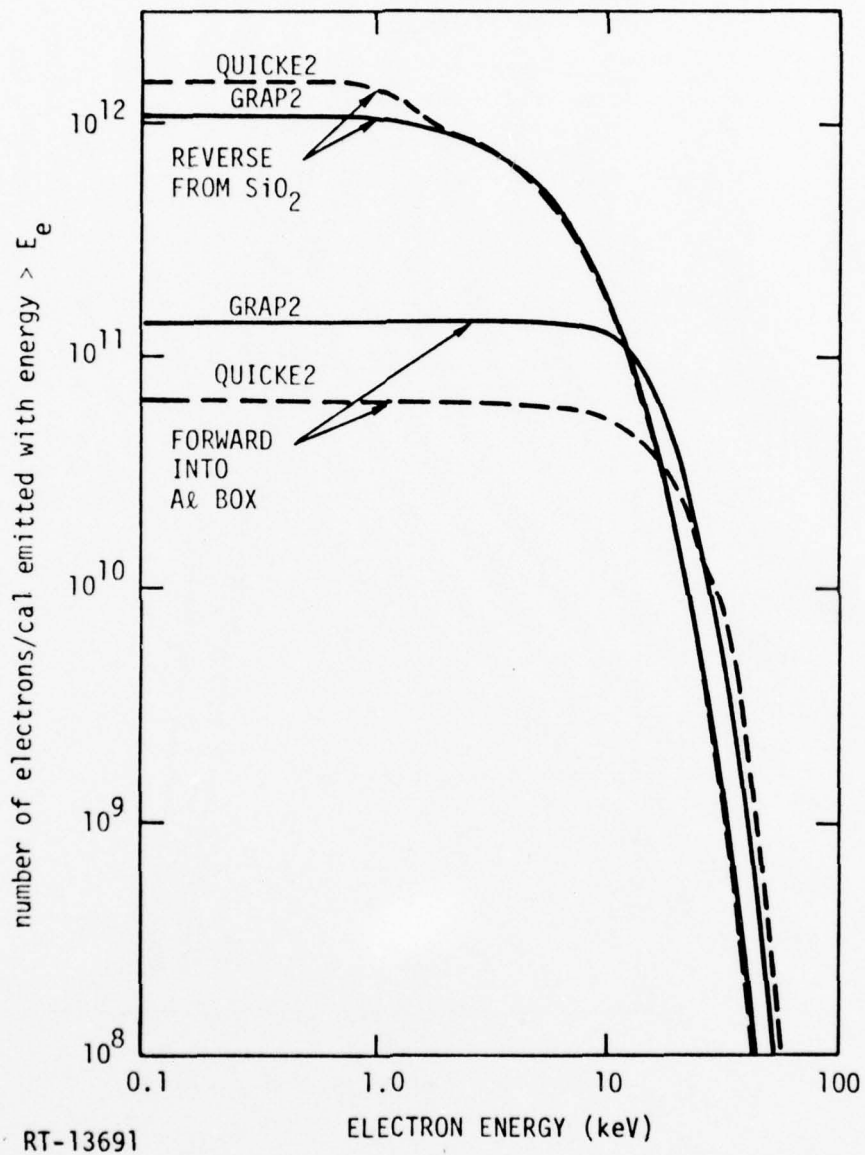
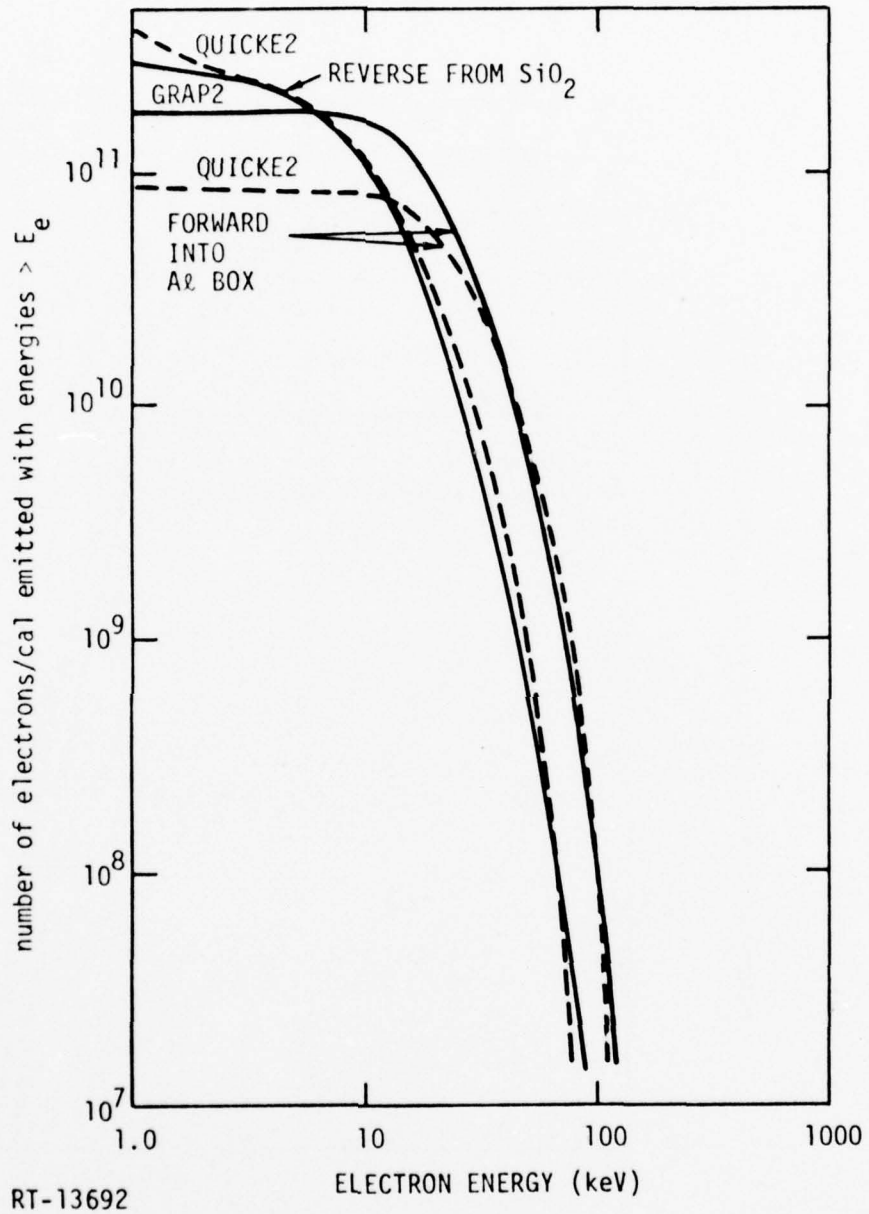
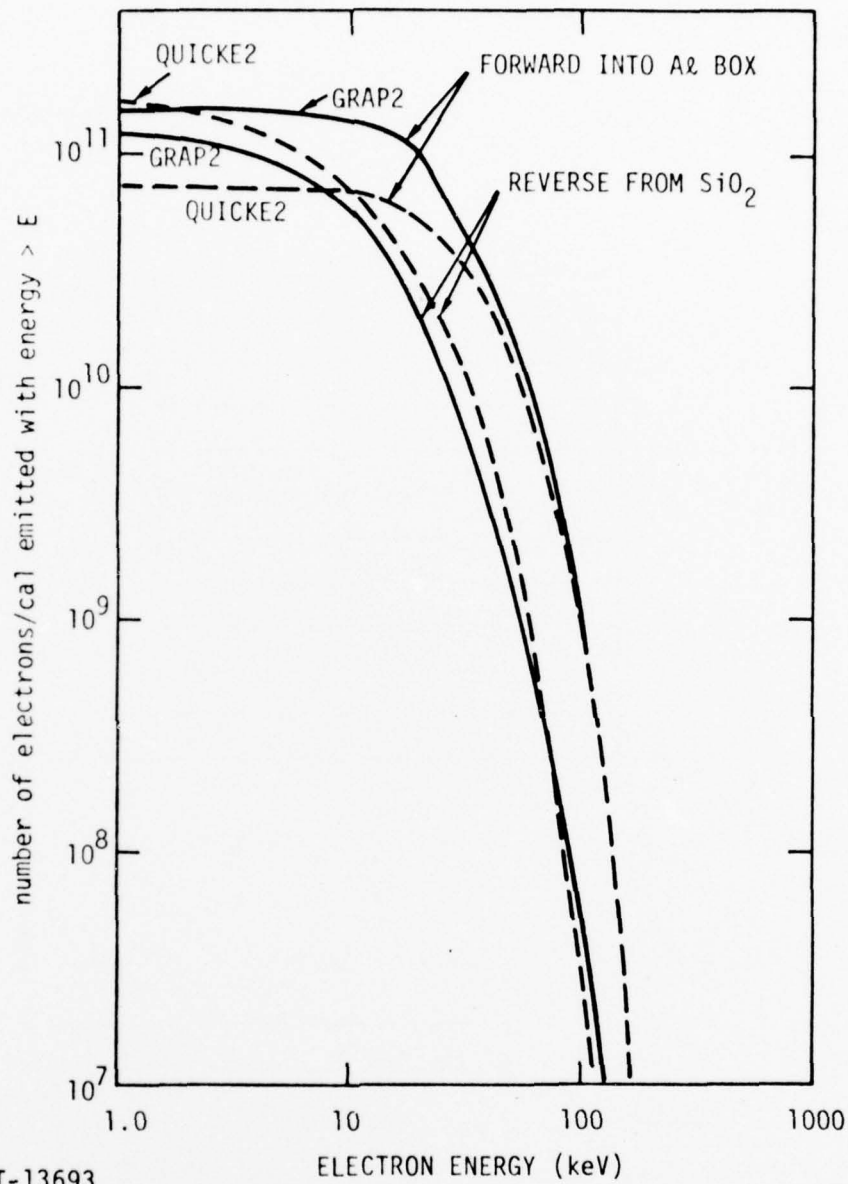


Figure 3-8. Comparison of QUICKE2 and GRAP2 electron spectra for reverse emission from a solar cell cover and forward emission from Al after attenuation by the solar cell; incident photon spectrum due to black-body radiator with temperature 5 keV



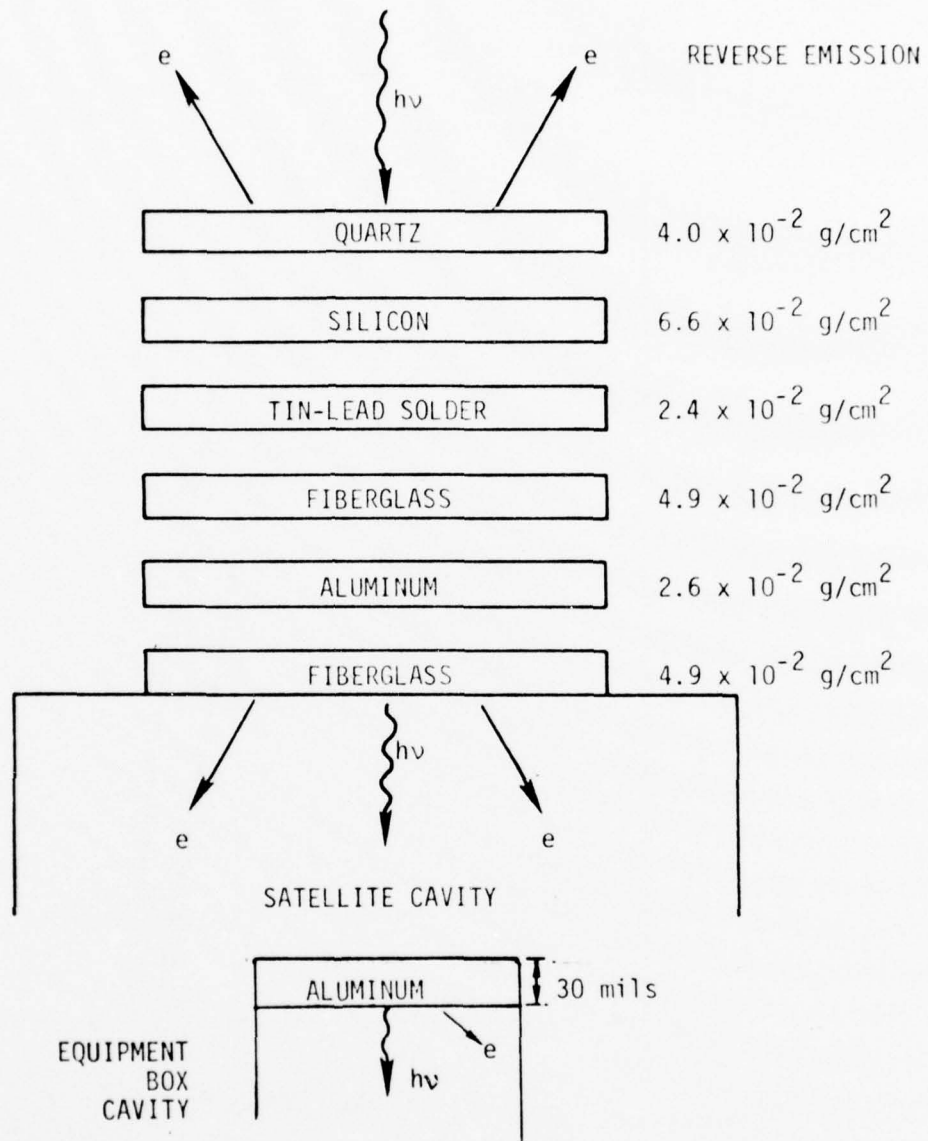
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Figure 3-9. Comparison of QUICKE2 and GRAP2 electron spectra for reverse emission from a solar cell cover and forward emission from Al after attenuation by the solar cell; incident photon spectrum due to black-body radiator with temperature 10 keV



RT-13693

Figure 3-10. Comparison of QUICKE2 and GRAP2 electron spectra for reverse emission from a solar cell cover and forward emission from Al after attenuation by the solar cell; incident photon spectrum due to black-body radiator with temperature 15 keV



RT-06431

Figure 3-11. Materials used in emission and attenuation calculations to represent typical satellite solar cell and equipment box cover. The QUICKE2 version described here performs the calculation with a single computer run.

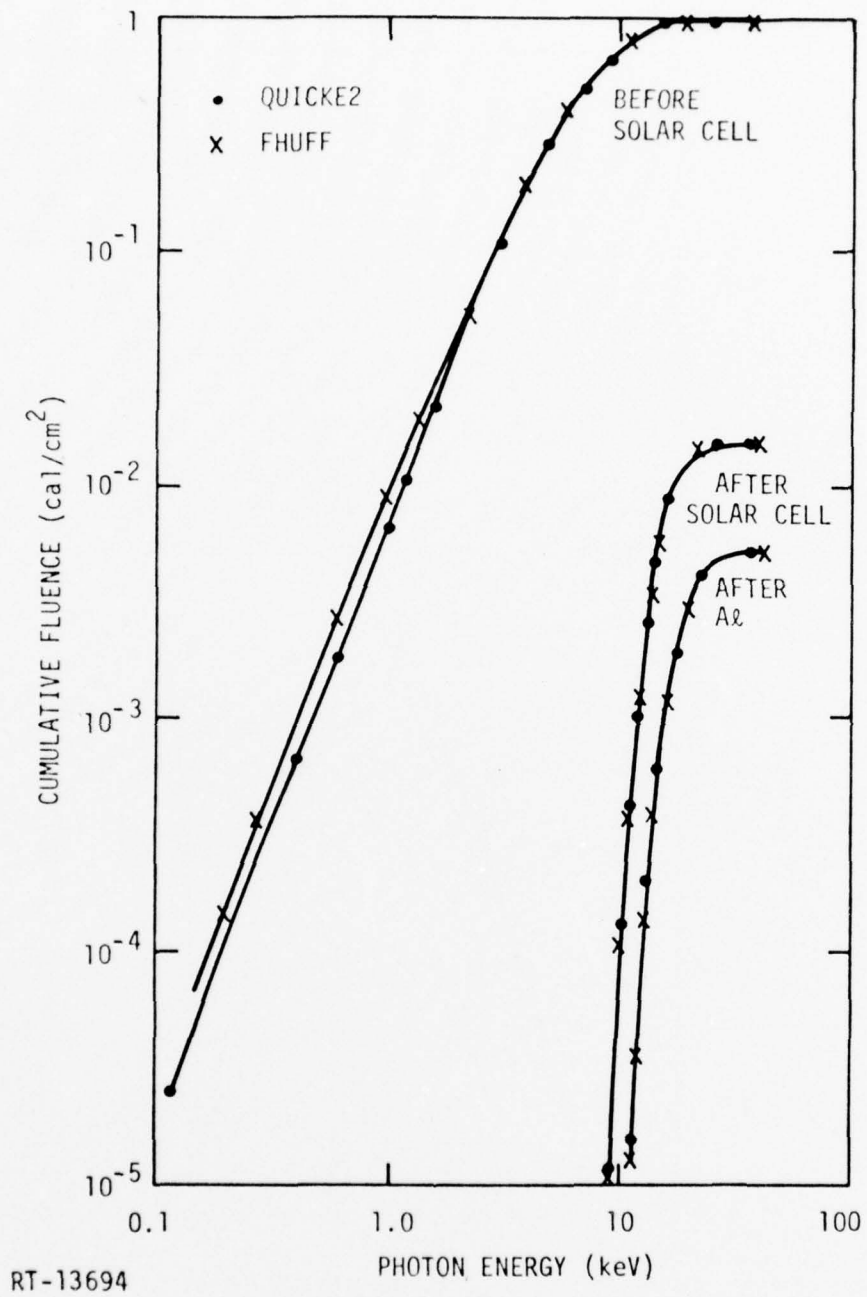


Figure 3-12. Comparison of QUICKE2 and FHUFF 2-keV blackbody photon spectra attenuated by solar cell and 30 mils of A<sub>2</sub>

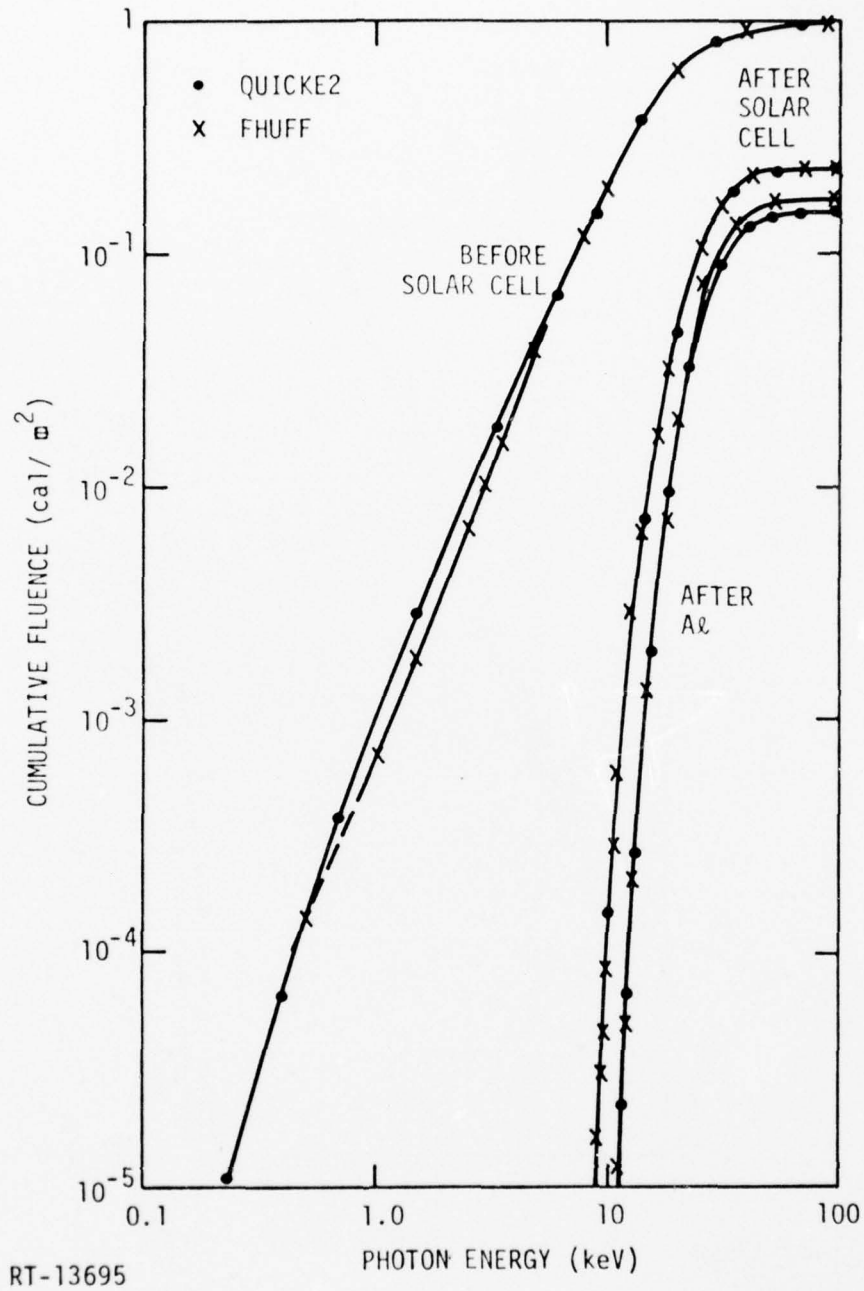


Figure 3-13. Comparison of QUICKE2 and FHUFF 5-keV blackbody photon spectra attenuated by solar cell and 30 mils of A $\lambda$

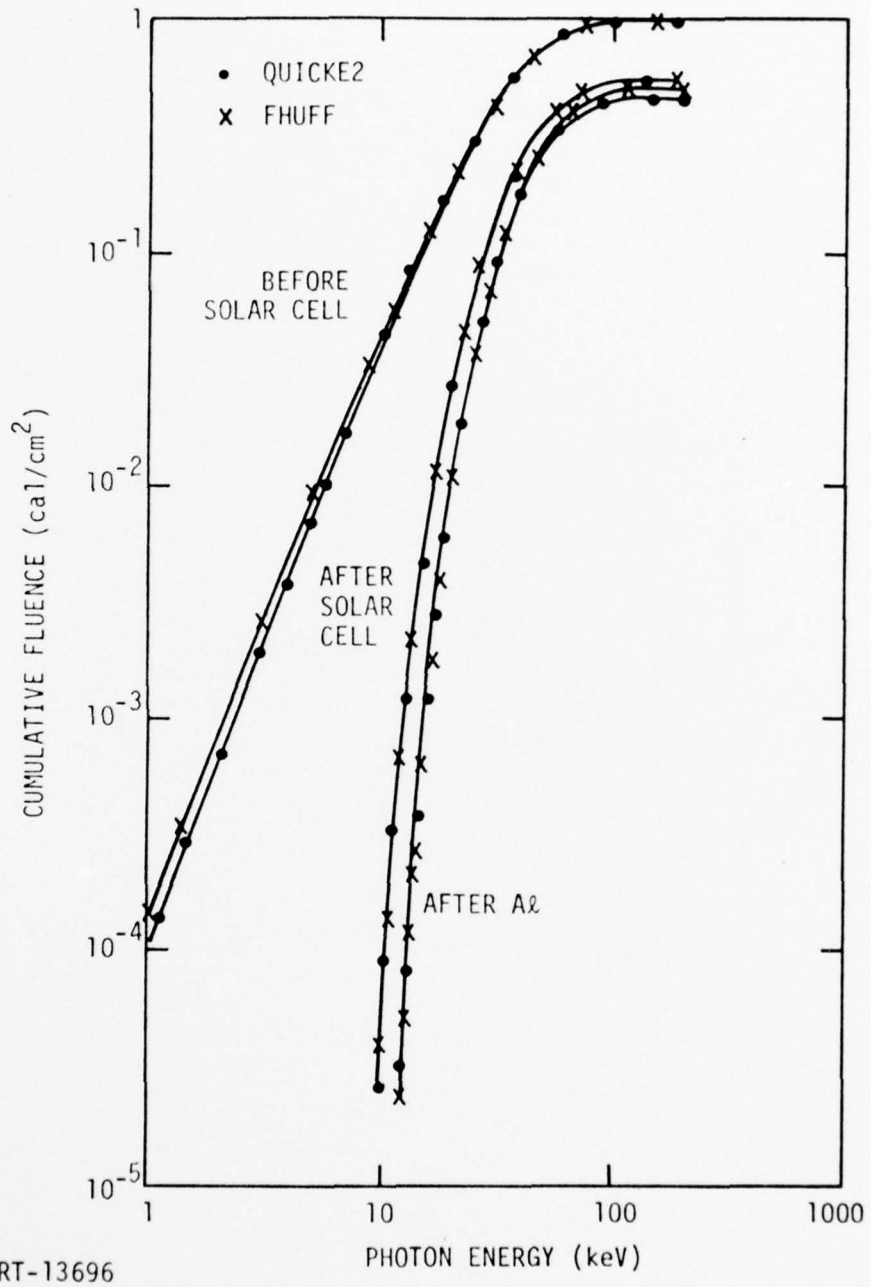


Figure 3-14. Comparison of QUICKE2 and FHUFF 10-keV blackbody photon spectra attenuated by solar cell and 30 mils of Al

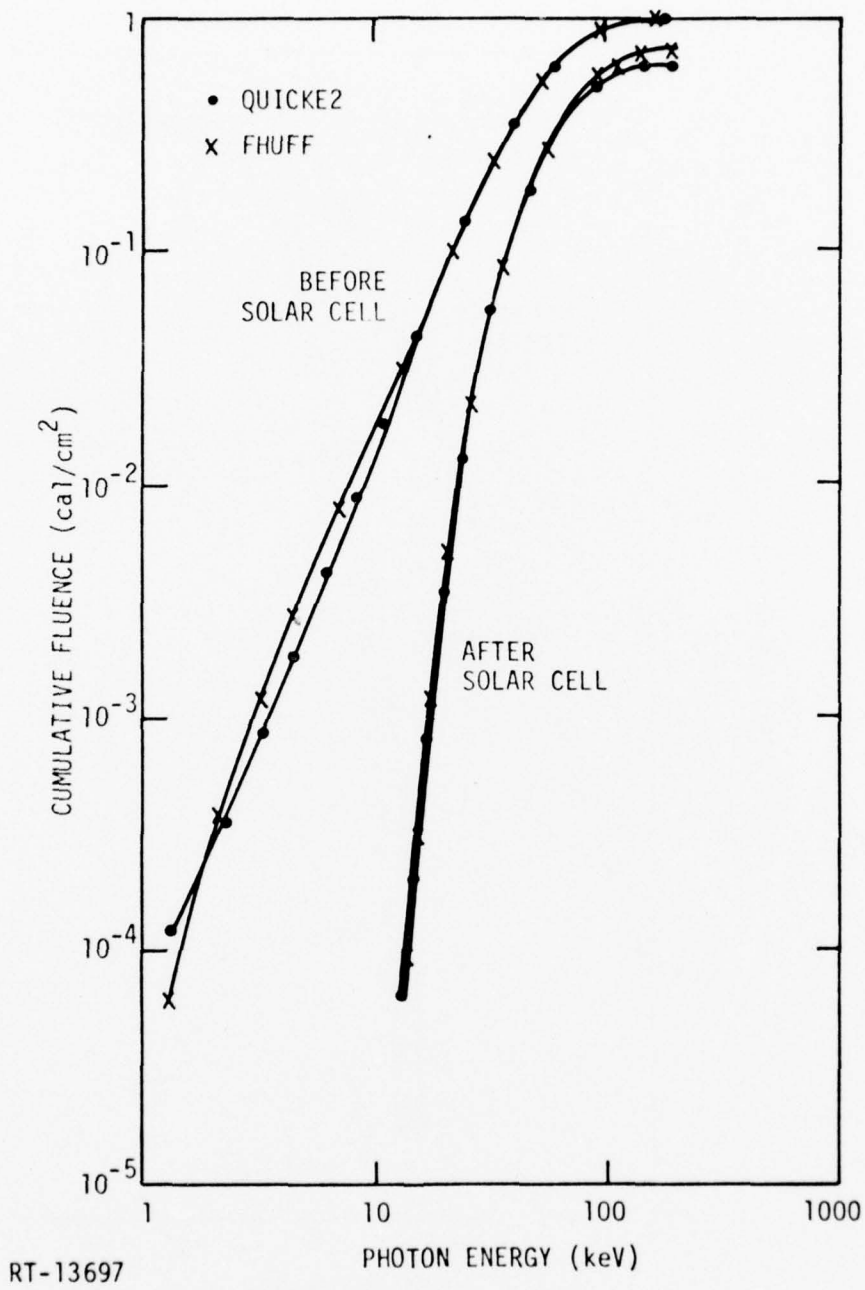


Figure 3-15. Comparison of QUICKE2 and FHUFF 15-keV blackbody photon spectra attenuated by solar cell and 30 mils of Al

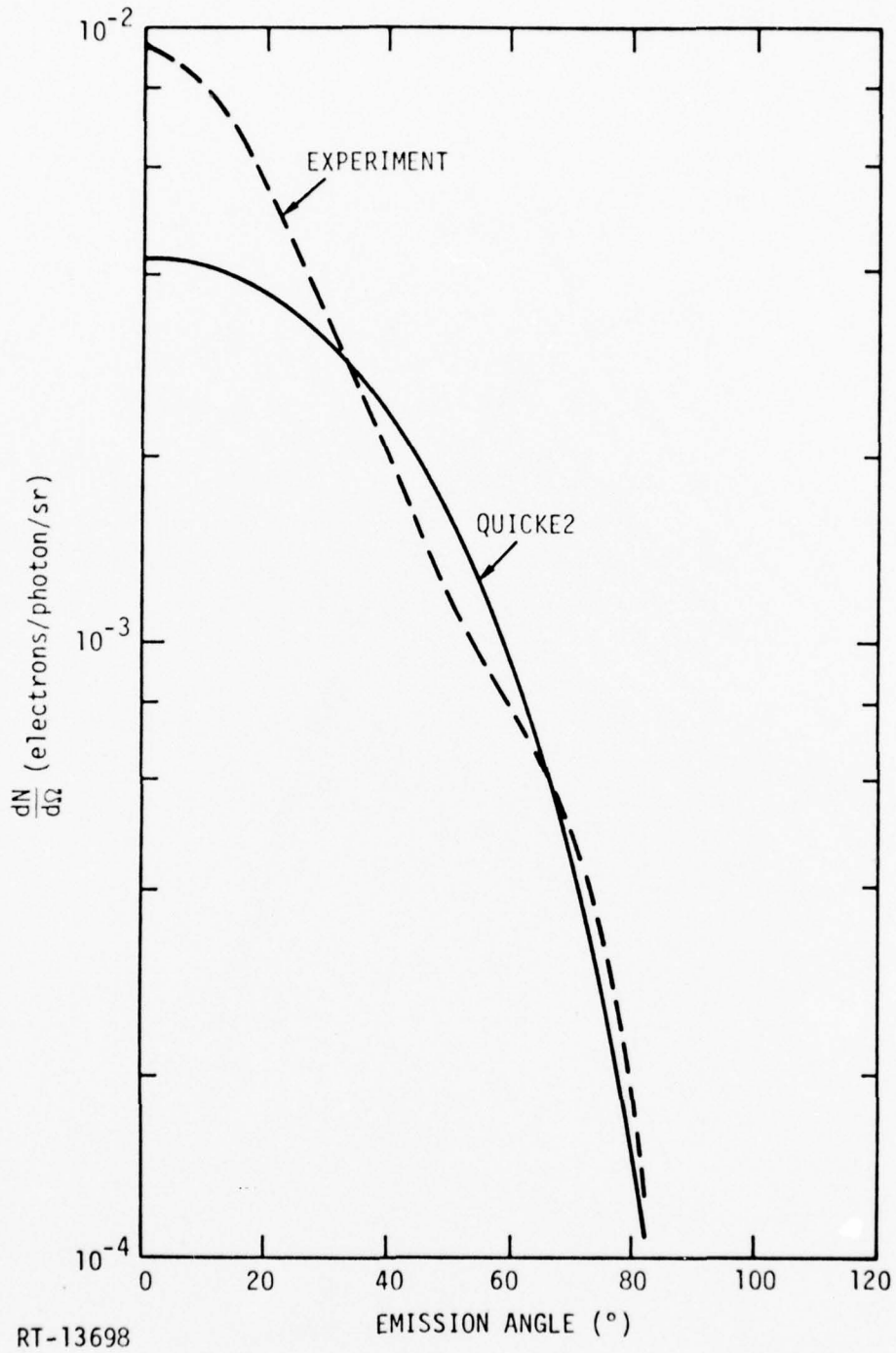


Figure 3-16. QUICKE2 and experimental results of Ebert and Lauzon compared for forward-emission electron angular distributions due to 1.25-MeV photons incident on C

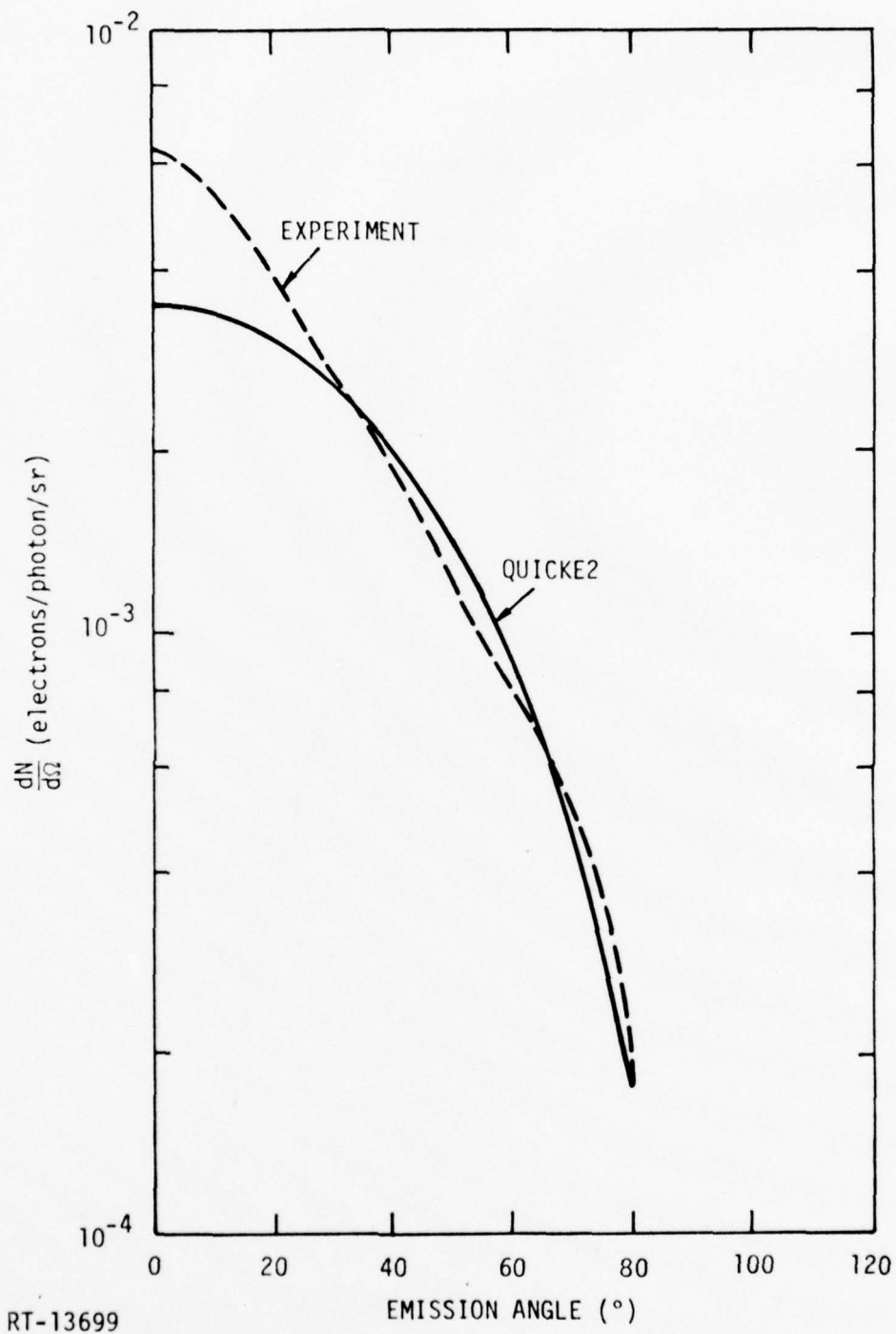


Figure 3-17. QUICKE2 and experimental results of Ebert and Lauzon compared for forward-emission electron angular distributions due to 1.25-MeV photons incident on Al

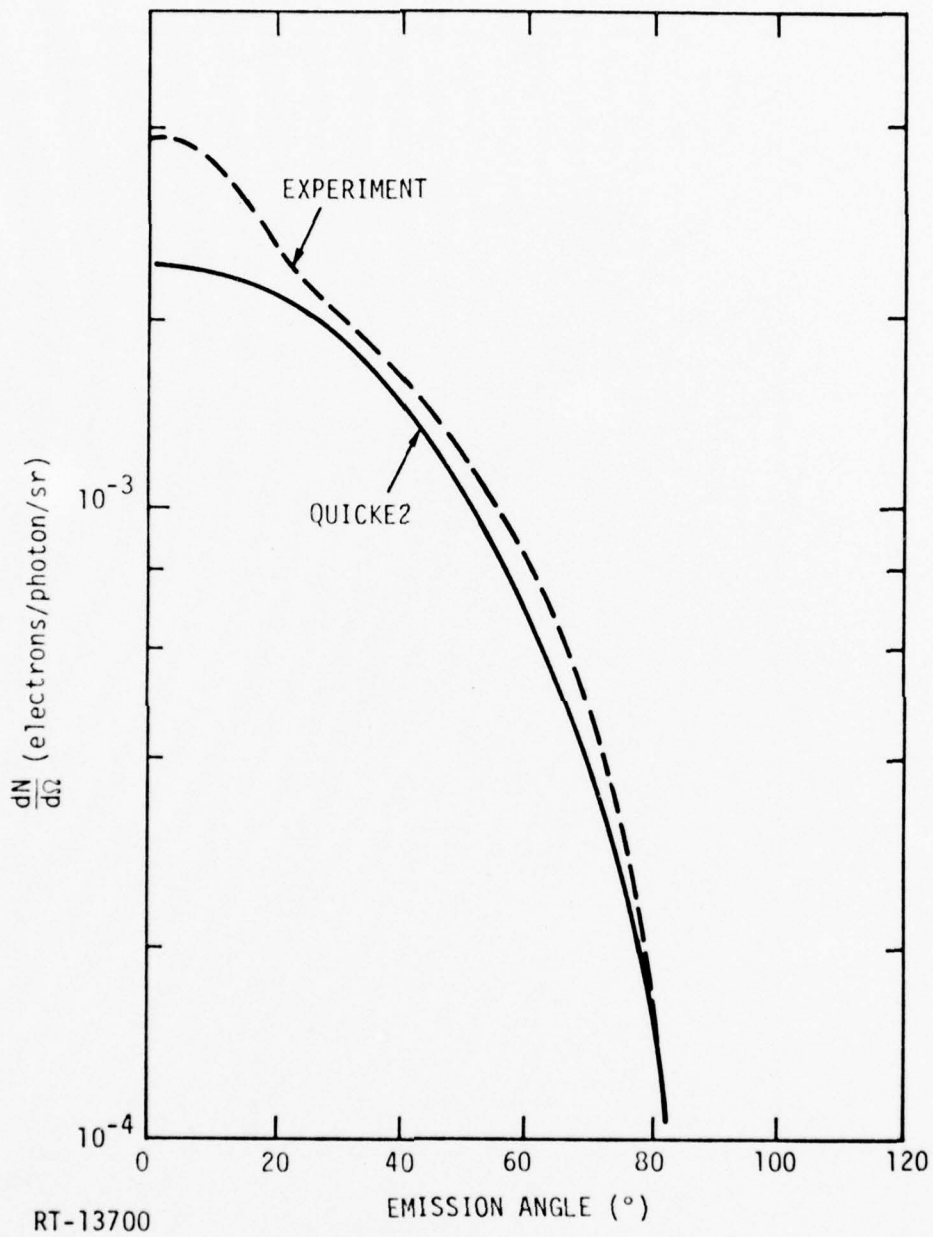


Figure 3-18. QUICKE2 and experimental results of Ebert and Lauzon compared for forward-emission electron angular distributions due to 1.25-MeV photons incident on Cu

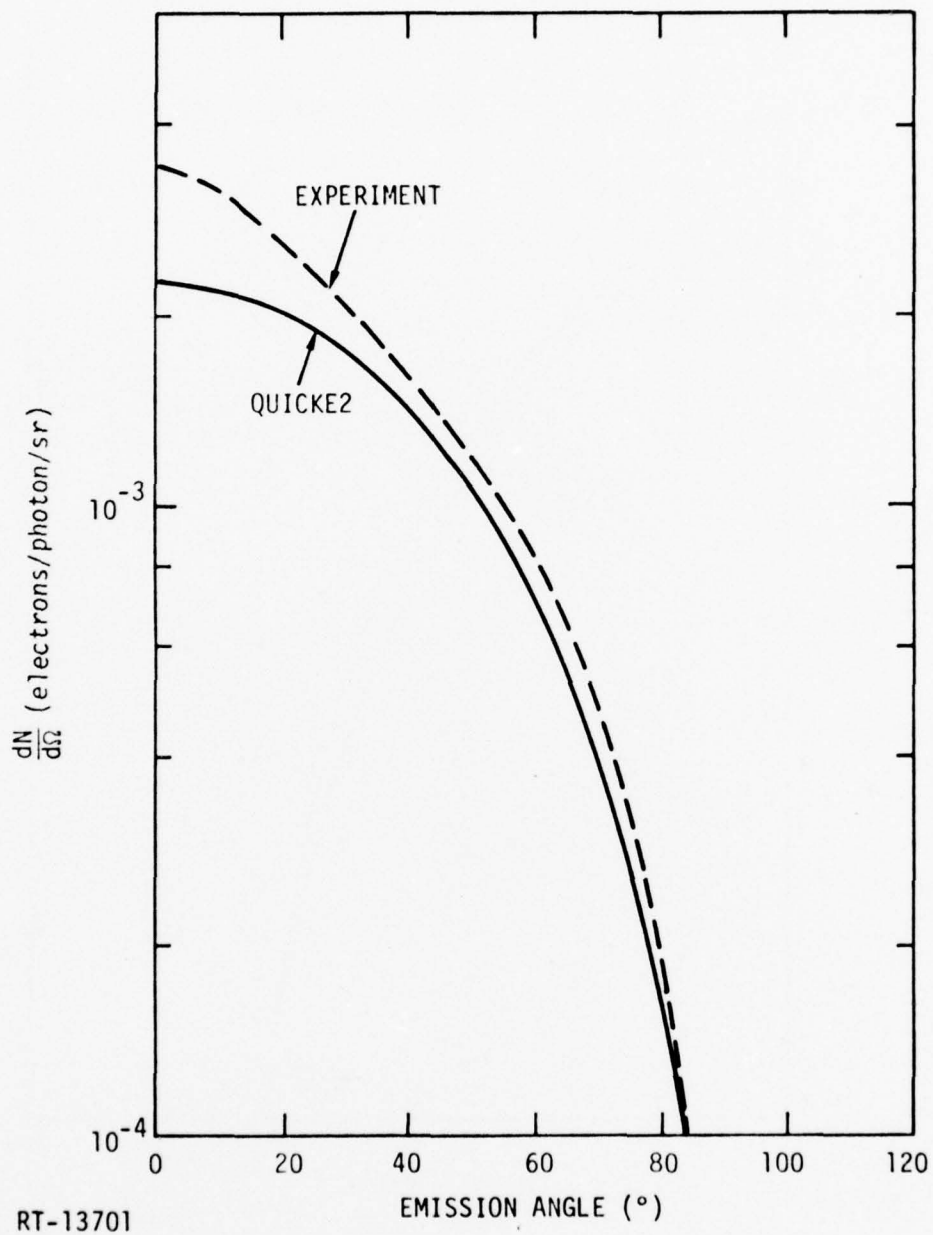
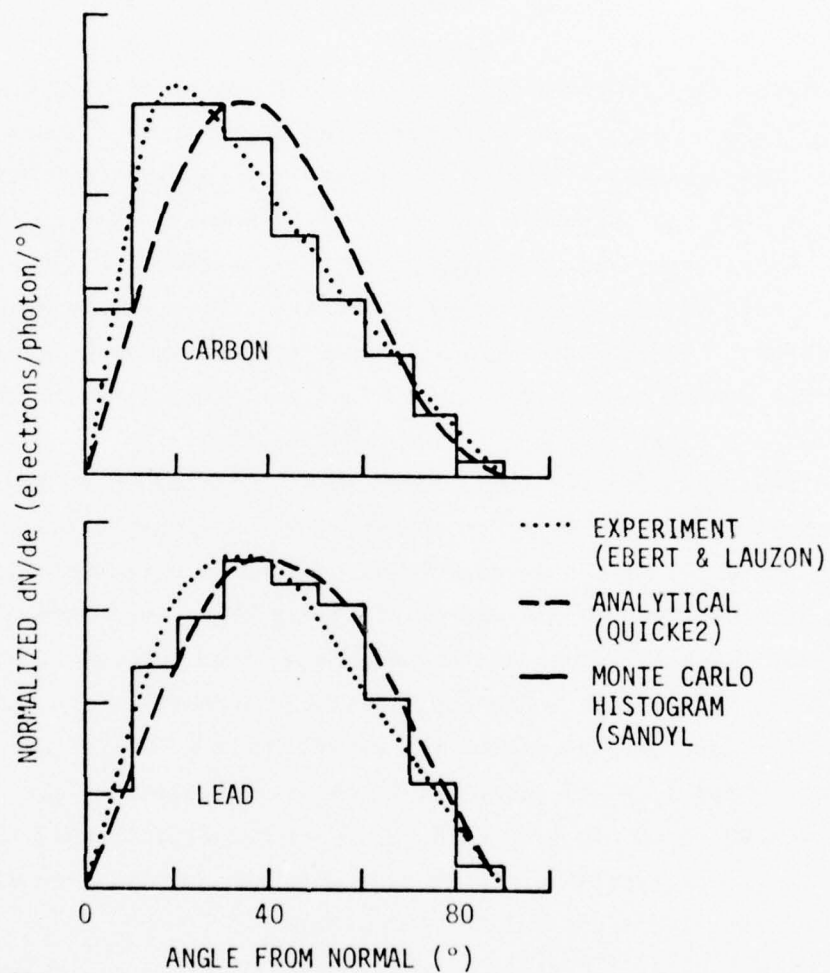


Figure 3-19. QUICKE2 and experimental results of Ebert and Lauzon compared for forward-emission electron angular distributions due to 1.25-MeV photons incident on Pb



RT-13702

Figure 3-20. Normalized angular distributions of electrons forward-emitted from C and Pb for  $Co^{60}$  radiation (from Ref 7)

#### 4. DESCRIPTION OF THE INPUTS

Detailed descriptions of the input cards required by QUICKE2 are given in this section. Variable names and physical or calculational significance are given, as well as the format for reading them into the code. Most of the variables are in NAMELIST format. These are specified in free form, separated by commas. The only restrictions are to begin the list with b\$NAME, leave column 1 blank on all cards, and end the list with b\$bEND. "b" indicates a blank space (necessary only in column 1) and "NAME" is the name of the NAMELIST given in the variable descriptions (see Figure 5-1 for a sample of the input deck).

In the input descriptions, arrays are indicated by an index following the variable name. If no index appears, only a single value is read in for the variable. The code counts the numbers of variables in cases where arrays are involved, so the number of values being read in need not be specified. Default values and maximum or minimum numbers of values are given where appropriate. Elements available in QUICKE2 are listed in Table 4-1. Elements not listed can be referenced.

The IOPT(27) option described in the table causes a file of data to be written which can be treated directly by the PLOTALL code (Ref. 11). This permits the overlay of photon and electron spectra from different plates or from different QUICKE2 calculations.

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11. A. J. Woods, T. N. Delmer, and M. A. Chipman, "The Arbitrary Body of Revolution (ABORC) Code for SGEMP/IEMP," INTEL-RT 8141-028, April 1976.

INPUT CARDS

| Card Type | Variable Name and Description   | Format            |
|-----------|---|-------------------|
| 1         | Title card (columns 1-72)   | 12A6              |
| 2         | ECALC(I) - electron emission energies in MeV. Minimum ECALC is 0.001 MeV. Up to 34 values. Calculated from photon energies if not read in.  | NAMelist/SPECTRA/ |
| 2         | HVSPECT(I) - energies in MeV for photon spectrum. Up to 50 values. Omit for blackbody spectrum.   | NAMelist/SPECTRA/ |
| 2         | DNDISP(I) - relative intensities (energy/energy or number/energy according to NSPECT) of photon spectrum. Up to 50 values. Omit for blackbody spectrum.   | NAMelist/SPECTRA/ |
| 2         | KBT = 0 (default) if an arbitrary spectrum is input<br>> 0 to generate an incident blackbody spectrum with a temperature of KBT keV.  | NAMelist/SPECTRA/ |
| 2         | IOPT(I): 40 values<br>IOPT(26) = 1 to punch all emission electron energy distributions on cards in free-field format (default = 0)<br>IOPT(27) = 1 to put photon and electron spectra on file TAPE7 for treatment by PLOTALL (default = 1)                      | NAMelist/SPECTRA/ |
| 2         | NSPECT = 0 (default) for DNDISP(I) in energy/energy<br>= -1 for DNDISP(I) in number/energy  | NAMelist/SPECTRA/ |
| 3         | INDEXX-QUICKE2 internal table number for test detector element for dose calculation. Must specify an element from Table 4-1.<br>WARNING: DO NOT USE ATOMIC NUMBERS HERE. SPECIFY THE APPROPRIATE NUMBER FROM THE COLUMN LABELED "INTERNAL NUMBER" IN TABLE 4-1. | I5 (columns 1-5)  |

NOTE: Must input separate NAMelist/PLATE/ cards for each plate. There is no limit on the number of plates.

| Card Type | Variable Name and Description  | Format          |
|-----------|--|-----------------|
| 4         | NPCT = 0 (default) for plate elements in fraction by number<br>= 1 for plate elements in fraction by weight  | NAMelist/PLATE/ |
| 4         | IPRINT = 0 (default) no cross-section print<br>= 1 to print cross sections from input tape   | NAMelist/PLATE/ |
| 4         | KOPT = 0 (default)<br>= 1 to print detailed information about electron production by photons   | NAMelist/PLATE/ |
| 4         | NTYPE = 0 (default)<br>= 1 to calculate bulk current at forward edge of plate  |                 |
| 4         | NEL(I): atomic numbers of elements comprising plate. See Table 4-1. Maximum number = 8 per plate.  | NAMelist/PLATE/ |
| 4         | F(I): respective fractions of elements (see NPCT). Default = 1. Maximum number = 8 per plate.  | NAMelist/PLATE/ |
| 4         | IOPT(I): 40 values. No values need to be read in here at present.  | NAMelist/PLATE/ |
| 4         | IEM = 0 no emission from plate<br>= 1 forward emission from plate (default)<br>= 2 reverse emission from plate<br>= 3 forward and reverse emission from plate  | NAMelist/PLATE/ |
| 4         | TAU: thickness of plate in $\text{g}/\text{cm}^2$  | NAMelist/PLATE/ |
| 4         | HVDEG: angle in degrees between surface normal of plate and direction of photon beam. Default = 0.<br>WARNING: THIS ANGLE IS NOT INCLUDED IN PHOTON ATTENUATION CALCULATION. ALSO, WHEN NON-ZERO VALUE IS USED, RESULTING ELECTRON YIELDS ARE GIVEN IN UNITS OF $\text{C}/\text{cm}^2$ NORMAL TO MATERIAL SURFACE PER $\text{cal}/\text{cm}^2$ PERPENDICULAR TO PHOTON BEAM. | NAMelist/PLATE/ |
| 4         | QUIT = 0 (default)<br>= 1 signifies last plate   | NAMelist/PLATE/ |
| 4         | DENSITY: density of plate ( $\text{g}/\text{cm}^3$ )   | NAMelist/PLATE/ |

Table 4-1  
ELEMENTS AVAILABLE IN QUICKE2

| Atomic Number (Z) | Internal Number | Name      |
|-------------------|-----------------|-----------|
| 1                 | 1               | Hydrogen  |
| 4                 | 2               | Beryllium |
| 6                 | 3               | Carbon    |
| 7                 | 4               | Nitrogen  |
| 8                 | 5               | Oxygen    |
| 9                 | 6               | Fluoride  |
| 12                | 7               | Magnesium |
| 13                | 8               | Aluminum  |
| 14                | 9               | Silicon   |
| 17                | 10              | Chlorine  |
| 18                | 11              | Argon     |
| 20                | 12              | Calcium   |
| 22                | 13              | Titanium  |
| 26                | 14              | Iron      |
| 28                | 15              | Nickel    |
| 29                | 16              | Copper    |
| 32                | 17              | Germanium |
| 41                | 18              | Niobium   |
| 47                | 19              | Silver    |
| 50                | 20              | Tin       |
| 60                | 21              | Neodymium |
| 73                | 22              | Tantalum  |
| 79                | 23              | Gold      |
| 82                | 24              | Lead      |
| 92                | 25              | Uranium   |

## 5. SAMPLE PROBLEM AND OUTPUT DESCRIPTION

The QUICKE2 output is best illustrated by sample problems. Sample calculations are discussed here, giving the physical and calculational significances of the major quantities.

The first problem involves the emission generated when a 15-keV blackbody photon spectrum is incident on 40 mils of Al. The input card images for this problem are as shown in Figure 5-1, and the output as in Figure 5-2. On the first page of output is the title, followed below by a description of the first material, or "plate," since the problem is one-dimensional. This description gives the number of elements in the material and the name, fraction by number, and atomic number of each element. The data file location where the cross sections for each element are stored is given (here, "8" indicates that the information for Al is stored on file 8 of the data tape), and the thickness of the material is printed. The quantity labeled "input fluence" is simply a convenience output of the code. It gives the total fluence in  $\text{cal/cm}^2$  of the photon spectrum as input to the code. The code renormalizes this fluence to  $1 \text{ cal/cm}^2$ .

An important point regarding QUICKE2 output should be understood when interpreting results from other than normally incident photon beams. Quantities given in terms of unit area differ in definition, depending on whether they pertain to photons or electrons. Photon densities are always per unit area perpendicular to the beam, whereas electron densities are always per unit area perpendicular to the surface. Thus, for a non-normal incidence problem, the correct yield is obtained by simply emitting the number of electrons per unit area on the skewed surface obtained directly from QUICKE2 and, of course, multiplying by the fluence in  $\text{cal/cm}^2$  perpendicular to the photon beam.

```

1588,AL,REV
$SPECTRA KBT=15, ECALC= .001,.0012,.0014,.0016,.0018,.002,.0022,.0025,
.0035,.0045,.0055,.0065,.0075,.0085,.0095,.0125,.0175,.0225,.0275,.0325,.0375,
.045,.055,.07,.09,.105,.11,.12,.13,.14,.15,.16,.17,.18,$END
|
$PLATE NELE=13, TAUS=.272,IEM=3,QUIT=1., DENSITY=1., SEND

```

Figure 5-1. QUICKE2 sample problem input for 15-keV blackbody spectrum incident on a 40-mil Al plate causing both forward and reverse electron emission

15BH,AL KEV

PLATE NO. OF ELEMENTS ELEMENT FRACTION BY NO. ATOMIC NO. ELEMENT NO. ELEMENT NO. THICKNESS(GM/CM<sup>2</sup>)

1 1 ALUMINUM 1.0000 13 8 2.72E-01

INPUT FLUENCE= 9.7209E+02 CAL/CM<sup>2</sup>

F L U X S P E C T R U M I N C I D E N T O N P L A T E 1

| POINT | ENERGY (MEV) | FLUX (CAL/CM**2/MEV) | CUMULATIVE FLUX (CAL/CM**2) | POINT | ENERGY (MEV) | FLUX (CAL/CM**2/MEV) | CUMULATIVE FLUX (CAL/CM**2) |
|-------|--------------|----------------------|-----------------------------|-------|--------------|----------------------|-----------------------------|
| 1     | 1.500E-03    | 9.7719E+02           | 1.465794E+04                | 26    | 6.375E-02    | 1.141444E+01         | 6.650408E-01                |
| 2     | 3.000E-03    | 5.713504E+01         | 7.035751E+04                | 27    | 6.750E-02    | 1.052428E+01         | 7.025098E-01                |
| 3     | 4.500E-03    | 7.931240E+01         | 1.495201E+05                | 28    | 7.125E-02    | 9.612658E+00         | 7.365544E-01                |
| 4     | 6.000E-03    | 1.337118E+00         | 3.499939E+05                | 29    | 7.500E-02    | 8.715422E+00         | 7.712324E-01                |
| 5     | 7.500E-03    | 1.980497E+00         | 6.469651E+05                | 30    | 7.875E-02    | 7.844908E+00         | 8.006559E-01                |
| 6     | 9.000E-03    | 2.699931E+00         | 1.019588E+06                | 31    | 8.250E-02    | 7.016532E+00         | 8.267676E-01                |
| 7     | 1.050E-02    | 3.476919E+00         | 1.613486E+06                | 32    | 8.625E-02    | 6.238516E+00         | 8.503620E-01                |
| 8     | 1.200E-02    | 4.293909E+00         | 2.257595E+06                | 33    | 9.000E-02    | 5.515448E+00         | 8.710470E-01                |
| 9     | 1.350E-02    | 5.153671E+00         | 3.027645E+06                | 34    | 9.375E-02    | 4.855092E+00         | 8.892461E-01                |
| 10    | 1.500E-02    | 5.981575E+00         | 4.373500E+06                | 35    | 9.750E-02    | 4.249796E+00         | 9.051629E-01                |
| 11    | 1.650E-02    | 7.654728E+00         | 6.469942E+06                | 36    | 1.0125E-01   | 3.705062E+00         | 9.190769E-01                |
| 12    | 2.100E-02    | 9.230331E+00         | 9.439031E+06                | 37    | 1.050E-01    | 3.217923E+00         | 9.311441E-01                |
| 13    | 2.400E-02    | 1.064761E+01         | 1.265332E+07                | 38    | 1.088E-01    | 2.783180E+00         | 9.415811E-01                |
| 14    | 2.700E-02    | 1.187065E+01         | 1.619451E+07                | 39    | 1.125E-01    | 2.334424E+00         | 9.506604E-01                |
| 15    | 3.000E-02    | 1.286758E+01         | 2.005474E+07                | 40    | 1.163E-01    | 1.961691E+00         | 9.584117E-01                |
| 16    | 3.300E-02    | 1.365440E+01         | 2.414631E+07                | 41    | 1.200E-01    | 1.765693E+00         | 9.652458E-01                |
| 17    | 3.600E-02    | 1.417244E+01         | 2.839816E+07                | 42    | 1.2375E-01   | 1.264703E+00         | 9.776790E-01                |
| 18    | 3.900E-02    | 1.449144E+01         | 3.274559E+07                | 43    | 1.350E-01    | 9.249457E+00         | 9.841704E-01                |
| 19    | 4.200E-02    | 1.460450E+01         | 3.712694E+07                | 44    | 1.425E-01    | 6.544232E+00         | 9.87651E-01                 |
| 20    | 4.500E-02    | 1.452435E+01         | 4.146979E+07                | 45    | 1.500E-01    | 4.666040E+00         | 9.932646E-01                |
| 21    | 4.800E-02    | 1.430645E+01         | 4.578173E+07                | 46    | 1.575E-01    | 3.276561E+00         | 9.957236E-01                |
| 22    | 5.100E-02    | 1.394673E+01         | 4.996575E+07                | 47    | 1.650E-01    | 2.281632E+00         | 9.974348E-01                |
| 23    | 5.400E-02    | 1.347396E+01         | 5.400794E+07                | 48    | 1.725E-01    | 1.562754E+00         | 9.986218E-01                |
| 24    | 5.700E-02    | 1.294899E+01         | 5.788034E+07                | 49    | 1.800E-01    | 1.069424E+00         | 9.994349E-01                |
| 25    | 6.000E-02    | 1.227146E+01         | 6.202217E+07                | 50    | 1.875E-01    | 7.481080E+00         | 1.000000E+00                |

TOTAL ENERGY CONTENT OF SPECTRUM IS 1.000E+00 CAL/CM<sup>2</sup>.

AVERAGE PHOTON ENERGY IS 4.050E-02 MEV

TOTAL NUMBER OF PHOTONS IS 6.445E+14

Figure 5-2. Sample problem output for 15-keV blackbody spectrum incident on 40 mils of Al

REVERSE YIELD FROM PLATE 1 IS  $4.22E-08$  COULOMBS/ (CAL INCIDENT ON PLATE 1),  
 THE CORRESPONDING EMISSION CURRENT FOR A 10 NSFC FWHM PULSE IS  $4.22E+00$  AMPS/(CAL INCIDENT ON PLATE 1)  
 THE VALUES PER CAL INCIDENT ON PLATE 1 ARE  $4.22E-08$  COULOMBS/CAL AND  $4.22E+00$  AMPS/CAL, RESPECTIVELY.

REVERSE-EMITTED ELECTRON ANGULAR DISTRIBUTION INTEGRATED OVER ENERGY

| ANGLE (DEGREES) | ELECTRONS/CAL/DEG. | ELECTRONS/CAL/STERAD. | NUMBER /GT. A | A (DEGREES) |
|-----------------|--------------------|-----------------------|---------------|-------------|
| 180.0           | 0.                 | 6.962E+10             | 2.577E+11     | 175.0       |
| 170.0           | 1.326E+09          | 6.964E+10             | 2.577E+11     | 165.0       |
| 160.0           | 2.601E+09          | 6.934E+10             | 2.444E+11     | 155.0       |
| 150.0           | 3.714E+09          | 6.774E+10             | 2.184E+11     | 145.0       |
| 140.0           | 4.485E+09          | 6.362E+10             | 1.815E+11     | 135.0       |
| 130.0           | 4.706E+09          | 5.602E+10             | 1.304E+11     | 125.0       |
| 120.0           | 4.242E+09          | 4.467E+10             | 6.937E+10     | 115.0       |
| 110.0           | 3.120E+09          | 3.028E+10             | 4.695E+10     | 105.0       |
| 100.0           | 1.574E+09          | 1.458E+10             | 1.574E+10     | 95.0        |
| 90.0            | -1.094E+04         | -9.980E+04            | -1.094E+05    | 85.0        |

REVERSE-EMITTED ELECTRON ENERGY DISTRIBUTION INTEGRATED OVER ANGLE

| ENERGY (MEV)  | TOTAL         | PER BIN       | NUMBER/MEV    | MIDPOINT (MEV) |
|---------------|---------------|---------------|---------------|----------------|
| 9.0000000E-04 | 2.4551628E+11 | 9.2011421E+09 | 4.6005710E+13 | 1.0000000E-03  |
| 1.1000000E-03 | 2.3631514E+11 | 1.0662030E+10 | 5.3310149E+13 | 1.2000000E-03  |
| 1.3000000E-03 | 2.2565311E+11 | 1.2153675E+10 | 6.0768374E+13 | 1.4000000E-03  |
| 1.5000000E-03 | 2.1349944E+11 | 2.4562437E+09 | 1.3281218E+13 | 1.6000000E-03  |
| 1.7000000E-03 | 2.1084319E+11 | 2.9487024E+09 | 1.4743512E+13 | 1.8000000E-03  |
| 1.9000000E-03 | 2.0789449E+11 | 3.2379402E+09 | 1.6189701E+13 | 2.0000000E-03  |
| 2.1000000E-03 | 2.0465655E+11 | 4.4317449E+09 | 1.7726949E+13 | 2.2000000E-03  |
| 2.3000000E-03 | 2.0022480E+11 | 1.3000835E+10 | 2.0001285E+13 | 2.4000000E-03  |
| 3.0000000E-03 | 1.8722396E+11 | 1.5298187E+10 | 1.5298187E+13 | 3.5000000E-03  |
| 4.0000000E-03 | 1.7192577E+11 | 1.2400960E+10 | 1.2400960E+13 | 4.5000000E-03  |
| 5.0000000E-03 | 1.5952481E+11 | 1.5133185E+10 | 1.5133185E+13 | 5.5000000E-03  |
| 6.0000000E-03 | 1.4439164E+11 | 1.2115728E+10 | 1.2115728E+13 | 6.5000000E-03  |
| 7.0000000E-03 | 1.3227590E+11 | 1.0003941E+10 | 1.0003941E+13 | 7.5000000E-03  |
| 8.0000000E-03 | 1.2227196E+11 | 1.1318334E+10 | 1.1318334E+13 | 8.5000000E-03  |
| 9.0000000E-03 | 1.1095362E+11 | 1.8548088E+10 | 4.2990440E+12 | 9.5000000E-03  |
| 1.1000000E-02 | 9.2355407E+10 | 2.8614271E+10 | 7.1535642E+12 | 1.2500000E-02  |
| 1.3000000E-02 | 6.3741263E+10 | 2.2232640E+10 | 4.4465291E+12 | 1.7500000E-02  |
| 2.0000000E-02 | 4.1508617E+10 | 1.2793904E+10 | 2.5587809E+12 | 2.2500000E-02  |
| 2.5000000E-02 | 2.8714712E+10 | 1.0119979E+10 | 2.0239958E+12 | 2.7500000E-02  |
| 3.0000000E-02 | 1.8594733E+10 | 6.1700914E+09 | 1.2340183E+12 | 3.2500000E-02  |
| 3.5000000E-02 | 1.2424642E+10 | 4.6768991E+09 | 7.4830385E+11 | 3.7500000E-02  |
| 4.1250000E-02 | 7.7477428E+09 | 3.9336284E+09 | 4.4955753E+11 | 4.5000000E-02  |
| 5.0000000E-02 | 5.8141143E+09 | 2.6450454E+09 | 2.1160363E+11 | 5.5000000E-02  |
| 6.2500000E-02 | 1.1640689E+09 | 9.1577207E+08 | 5.2329832E+10 | 7.0000000E-02  |
| 8.0000000E-02 | 2.5329683E+08 | 1.8428713E+08 | 1.0416407E+10 | 9.0000000E-02  |
| 9.7500000E-02 | 6.4009695E+07 | 3.1805780E+07 | 3.1805780E+09 | 1.0500000E-01  |
| 1.0750000E-01 | 3.2205915E+07 | 1.6874778E+07 | 2.2499704E+09 | 1.1000000E-01  |
| 1.1500000E-01 | 1.5329136E+07 | 8.3315280E+06 | 8.3315280E+08 | 1.2000000E-01  |
| 1.2500000E-01 | 6.4978080E+06 | 4.0803793E+06 | 4.0803793E+08 | 1.3000000E-01  |
| 1.3500000E-01 | 2.9172295E+06 | 1.9203767E+06 | 1.9203767E+08 | 1.4000000E-01  |
| 1.4500000E-01 | 9.9685278E+05 | 6.3241907E+05 | 6.3241907E+07 | 1.5000000E-01  |
| 1.5500000E-01 | 3.6443371E+05 | 2.8357703E+05 | 2.8357703E+07 | 1.6000000E-01  |
| 1.6500000E-01 | 1.0085668E+05 | 8.8472235E+04 | 8.8472235E+06 | 1.7000000E-01  |
| 1.7500000E-01 | 1.2384444E+04 | 1.2384444E+04 | 1.2384444E+06 | 1.8000000E-01  |

AVERAGE ELECTRON ENERGY IS  $1.147E-02$  MEV, TOTAL EMITTED CHARGE IS  $3.92E-08$  COULOMBS/CAL ON PLATE 1

Figure 5-2 (cont.)

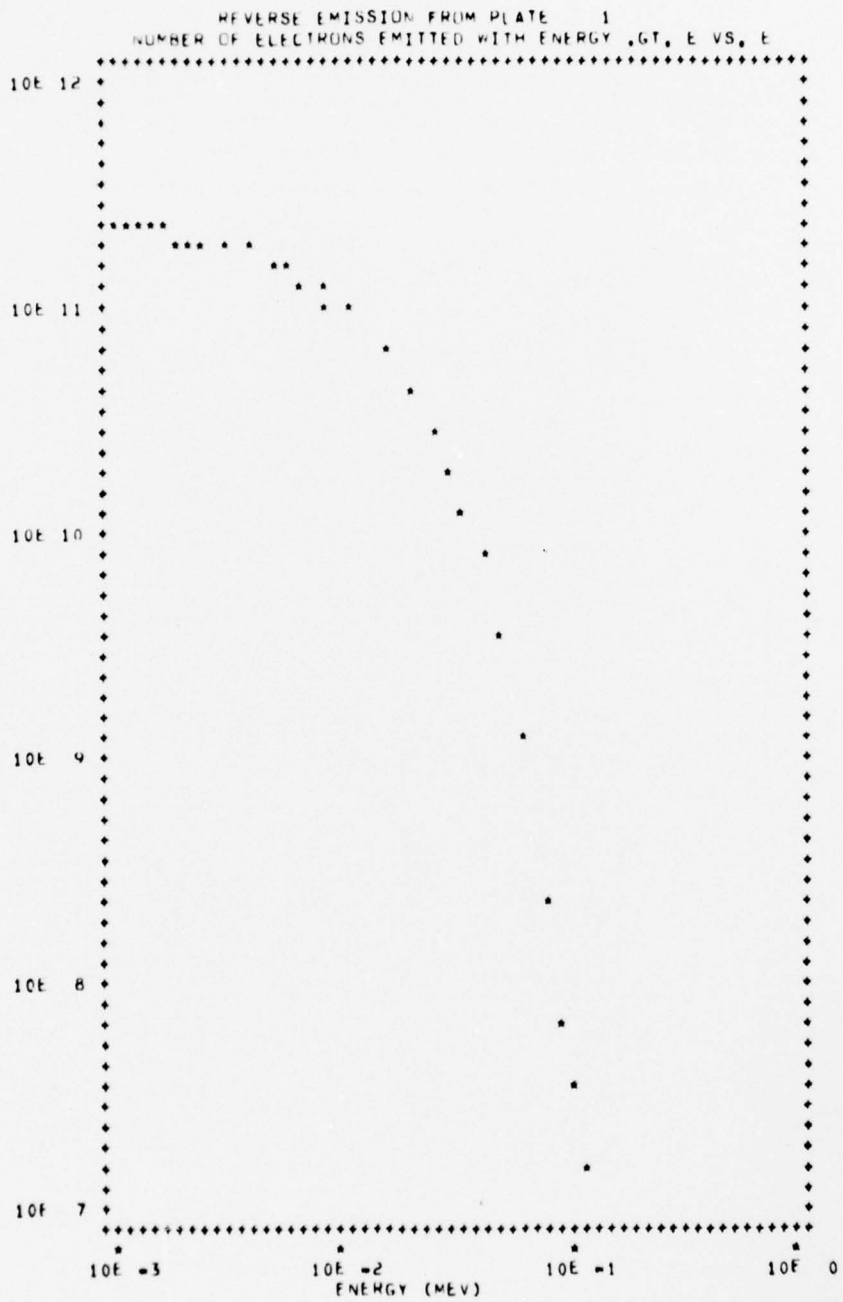


Figure 5-2 (cont.)

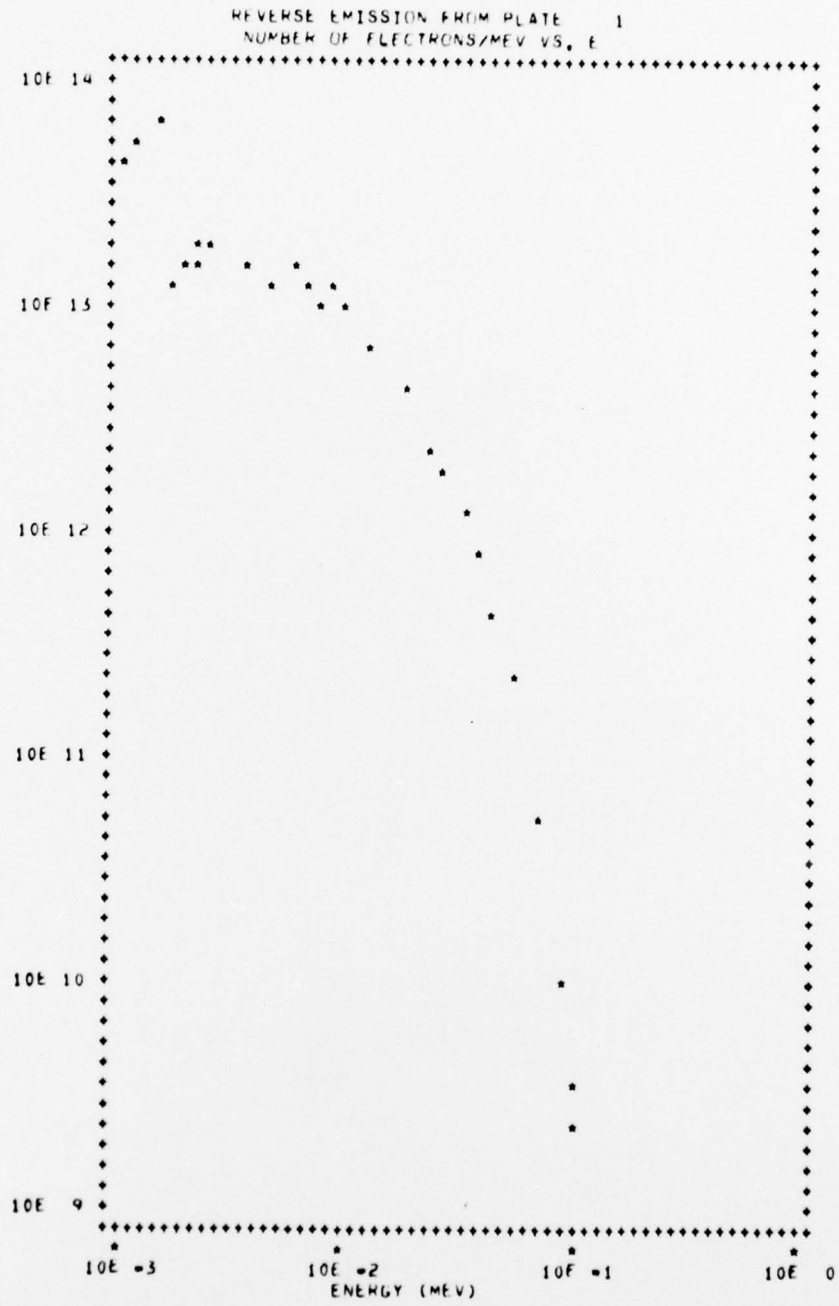


Figure 5-2 (cont.)

F L U X S P E C T R U M I N C I D E N T O N P L A T E 2

| POINT | ENERGY<br>(MEV) | FLUX<br>(CAL/CM <sup>2</sup> /MEV) | CUMULATIVE<br>FLUX<br>(CAL/CM <sup>2</sup> ) | POINT | ENERGY<br>(MEV) | FLUX<br>(CAL/CM <sup>2</sup> /MEV) | CUMULATIVE<br>FLUX<br>(CAL/CM <sup>2</sup> ) |
|-------|-----------------|------------------------------------|--|-------|-----------------|------------------------------------|--|
| 1     | 1.500E-03       | 3.784008E+09                       | 3.784008E+09                                 | 26    | 6.375E-02       | 1.084025E+01                       | 4.942283E+01                                 |
| 2     | 3.000E-03       | 5.840004E+09                       | 9.624012E+09                                 | 27    | 6.750E-02       | 9.834371E+00                       | 5.361822E+01                                 |
| 3     | 4.500E-03       | 4.059160E+09                       | 1.368372E+10                                 | 28    | 7.125E-02       | 9.035618E+00                       | 5.700657E+01                                 |
| 4     | 6.000E-03       | 6.054430E+09                       | 2.073802E+10                                 | 29    | 7.500E-02       | 8.220599E+00                       | 6.008930E+01                                 |
| 5     | 7.500E-03       | 1.967332E+07                       | 2.093475E+10                                 | 30    | 7.875E-02       | 7.422559E+00                       | 6.287275E+01                                 |
| 6     | 9.000E-03       | 2.026187E+04                       | 3.022231E+07                                 | 31    | 8.250E-02       | 6.631450E+00                       | 6.516779E+01                                 |
| 7     | 1.050E-02       | 8.105634E+03                       | 1.244268E+05                                 | 32    | 8.625E-02       | 5.926025E+00                       | 6.759005E+01                                 |
| 8     | 1.200E-02       | 7.407997E+02                       | 1.186623E+04                                 | 33    | 9.000E-02       | 5.248179E+00                       | 6.955612E+01                                 |
| 9     | 1.350E-02       | 2.793604E+01                       | 5.377356E+04                                 | 34    | 9.375E-02       | 4.624405E+00                       | 7.129227E+01                                 |
| 10    | 1.500E-02       | 7.034488E+01                       | 2.120493E+05                                 | 35    | 9.750E-02       | 4.052216E+00                       | 7.281298E+01                                 |
| 11    | 1.650E-02       | 2.164414E+00                       | 8.615735E+03                                 | 36    | 1.012E-01       | 3.519600E+00                       | 7.414033E+01                                 |
| 12    | 2.100E-02       | 4.087199E+00                       | 2.087533E+02                                 | 37    | 1.050E-01       | 3.076794E+00                       | 7.529413E+01                                 |
| 13    | 2.400E-02       | 6.053398E+00                       | 5.903553E+02                                 | 38    | 1.088E-01       | 2.663252E+00                       | 7.629285E+01                                 |
| 14    | 2.700E-02       | 7.887761E+00                       | 8.269881E+02                                 | 39    | 1.125E-01       | 2.281162E+00                       | 7.715466E+01                                 |
| 15    | 3.000E-02       | 9.474292E+00                       | 9.112169E+02                                 | 40    | 1.163E-01       | 1.915774E+00                       | 7.795568E+01                                 |
| 16    | 3.300E-02       | 1.087004E+01                       | 1.231827E+01                                 | 41    | 1.200E-01       | 1.633293E+00                       | 7.844605E+01                                 |
| 17    | 3.600E-02       | 1.162529E+01                       | 1.580545E+01                                 | 42    | 1.237E-01       | 1.231594E+00                       | 7.917325E+01                                 |
| 18    | 3.900E-02       | 1.230322E+01                       | 1.944682E+01                                 | 43    | 1.275E-01       | 8.492338E-01                       | 8.044017E+01                                 |
| 19    | 4.200E-02       | 1.286572E+01                       | 2.330554E+01                                 | 44    | 1.312E-01       | 6.350049E-01                       | 8.091643E+01                                 |
| 20    | 4.500E-02       | 1.286779E+01                       | 2.716567E+01                                 | 45    | 1.350E-01       | 4.445010E-01                       | 8.125355E+01                                 |
| 21    | 4.800E-02       | 1.264382E+01                       | 3.101902E+01                                 | 46    | 1.387E-01       | 3.160715E-01                       | 8.149060E+01                                 |
| 22    | 5.100E-02       | 1.266304E+01                       | 3.481795E+01                                 | 47    | 1.425E-01       | 2.201135E-01                       | 8.165569E+01                                 |
| 23    | 5.400E-02       | 1.233445E+01                       | 3.851828E+01                                 | 48    | 1.462E-01       | 1.527900E-01                       | 8.177028E+01                                 |
| 24    | 5.700E-02       | 1.190127E+01                       | 4.208666E+01                                 | 49    | 1.500E-01       | 1.052310E-01                       | 8.184921E+01                                 |
| 25    | 6.000E-02       | 1.138450E+01                       | 4.593046E+01                                 | 50    | 1.537E-01       | 7.230336E-02                       | 8.190343E+01                                 |

TOTAL ENERGY CONTENT OF SPECTRUM IS 8.190E+01 CAL/CM<sup>2</sup>.

AVERAGE PHOTON ENERGY IS 5.079E-02 MEV

TOTAL NUMBER OF PHOTONS IS 4.209E+14

DOSE IN SILICON DETECTOR AT FRONT END OF PLATE 1 = 1.26025E+06

DOSE IN SILICON DETECTOR AT BACK END OF PLATE 1 = 2.23415E+05

DOSE IN CARBON DETECTOR AT FRONT END OF PLATE 1 = 1.96581E+05

DOSE IN CARBON DETECTOR AT BACK END OF PLATE 1 = 6.68855E+04

DOSE IN MATERIAL AT FRONT END OF PLATE 1 = 9.96840E+05

DOSE IN MATERIAL AT BACK END OF PLATE 1 = 1.83096E+05

AVERAGE DOSE IN LAYER 1 = 2.78102E+05

DOSE IN HYDROGEN TEST DETECTOR AT FRONT END OF PLATE 1 = 1.38892E+05

DOSE IN HYDROGEN TEST DETECTOR AT BACK END OF PLATE 1 = 1.11755E+05

Figure 5-2 (cont.)

FORWARD YIELD FROM PLATE 1 IS  $2.215E+08$  COULOMBS/ (CAL INCIDENT ON PLATE 1).  
 THE CORRESPONDING EMISSION CURRENT FOR A 10 NSEC PPM PULSE IS  $2.215E+00$  AMPS/ (CAL INCIDENT ON PLATE 1).  
 THE VALUES PER CAL INCIDENT ON PLATE 2 ARE  $2.705E+08$  COULOMBS/CAL AND  $2.705E+00$  AMPS/CAL, RESPECTIVELY.

FORWARD-EMITTED ELECTRON ANGULAR DISTRIBUTION INTEGRATED OVER ENERGY

| ANGLE (DEGREES) | ELECTRONS/CAL/DEG. | ELECTRONS/CAL/STERAD. | NUMBER .GT. A | A (DEGREES) |
|-----------------|--------------------|-----------------------|---------------|-------------|
| 0.              | 0.                 | $4.775E+10$           | $7.422E+10$   | 0.          |
| 10.0            | $3.918E+08$        | $2.058E+10$           | $7.422E+10$   | 5.0         |
| 20.0            | $7.642E+08$        | $2.037E+10$           | $7.030E+10$   | 15.0        |
| 30.0            | $1.083E+09$        | $1.975E+10$           | $6.266E+10$   | 25.0        |
| 40.0            | $1.297E+09$        | $1.840E+10$           | $5.183E+10$   | 35.0        |
| 50.0            | $1.350E+09$        | $1.607E+10$           | $3.886E+10$   | 45.0        |
| 60.0            | $1.209E+09$        | $1.273E+10$           | $2.536E+10$   | 55.0        |
| 70.0            | $8.836E+08$        | $8.575E+09$           | $1.327E+10$   | 65.0        |
| 80.0            | $4.436E+08$        | $4.108E+09$           | $4.436E+09$   | 75.0        |
| 90.0            | $-3.071E+05$       | $-2.800E+04$          | $-3.071E+04$  | 85.0        |

FORWARD-EMITTED ELECTRON ENERGY DISTRIBUTION INTEGRATED OVER ANGLE

| ENERGY (MEV)    | TOTAL            | PER BIN          | NUMBER/MEV       | MIDPOINT (MEV)   |
|-----------------|------------------|------------------|------------------|------------------|
| $9.0000000E-04$ | $1.3311724E+11$  | $2.5045306E+08$  | $1.2522653E+12$  | $1.00000000E-03$ |
| $1.1000000E-03$ | $1.32866789E+11$ | $2.86809392E+08$ | $1.43404696E+12$ | $1.20000000E-03$ |
| $1.3000000E-03$ | $1.32574980E+11$ | $3.23856871E+08$ | $1.61928436E+12$ | $1.40000000E-03$ |
| $1.5000000E-03$ | $1.32256123E+11$ | $1.34046736E+08$ | $6.70233678E+11$ | $1.60000000E-03$ |
| $1.7000000E-03$ | $1.31922076E+11$ | $1.45305730E+08$ | $7.26528649E+11$ | $1.80000000E-03$ |
| $1.9000000E-03$ | $1.31497677E+11$ | $1.55514470E+08$ | $7.77572352E+11$ | $2.00000000E-03$ |
| $2.1000000E-03$ | $1.31821256E+11$ | $2.07974558E+08$ | $8.31918233E+11$ | $2.20000000E-03$ |
| $2.3000000E-03$ | $1.31613277E+11$ | $5.89952365E+08$ | $9.07619023E+11$ | $2.40000000E-03$ |
| $2.5000000E-03$ | $1.31023324E+11$ | $1.16174275E+09$ | $1.16174275E+12$ | $2.60000000E-03$ |
| $2.7000000E-03$ | $1.29861582E+11$ | $1.41491541E+09$ | $1.41491541E+12$ | $2.80000000E-03$ |
| $2.9000000E-03$ | $1.28446666E+11$ | $1.67808062E+09$ | $1.67808062E+12$ | $3.00000000E-03$ |
| $3.1000000E-03$ | $1.26768586E+11$ | $1.95572893E+09$ | $1.95572893E+12$ | $3.20000000E-03$ |
| $3.3000000E-03$ | $1.24812857E+11$ | $2.25467221E+09$ | $2.25467221E+12$ | $3.40000000E-03$ |
| $3.5000000E-03$ | $1.22558184E+11$ | $2.57478918E+09$ | $2.57478918E+12$ | $3.60000000E-03$ |
| $3.7000000E-03$ | $1.19983395E+11$ | $5.80960315E+09$ | $2.90480158E+12$ | $3.80000000E-03$ |
| $3.9000000E-03$ | $1.14173792E+11$ | $1.55125554E+10$ | $3.87813884E+12$ | $4.00000000E-03$ |
| $4.1000000E-03$ | $9.86612367E+10$ | $2.20296453E+10$ | $4.40592906E+12$ | $4.20000000E-03$ |
| $4.3000000E-03$ | $7.66315915E+10$ | $1.72427495E+10$ | $3.44854990E+12$ | $4.40000000E-03$ |
| $4.5000000E-03$ | $5.93888420E+10$ | $1.66811352E+10$ | $3.55622703E+12$ | $4.60000000E-03$ |
| $4.7000000E-03$ | $4.27077066E+10$ | $1.15879168E+10$ | $2.31758336E+12$ | $4.80000000E-03$ |
| $4.9000000E-03$ | $3.11197900E+10$ | $9.52880775E+09$ | $1.52460924E+12$ | $5.00000000E-03$ |
| $5.1000000E-03$ | $2.15909823E+10$ | $9.46301875E+09$ | $1.08148785E+12$ | $5.20000000E-03$ |
| $5.3000000E-03$ | $1.21279635E+10$ | $7.72793182E+09$ | $6.18234545E+11$ | $5.40000000E-03$ |
| $5.5000000E-03$ | $4.40003171E+09$ | $3.12408899E+09$ | $1.78519371E+11$ | $5.60000000E-03$ |
| $5.7000000E-03$ | $1.27594272E+09$ | $8.68709718E+08$ | $4.96405555E+10$ | $5.80000000E-03$ |
| $5.9000000E-03$ | $4.07233006E+08$ | $1.79287381E+08$ | $1.79287381E+10$ | $6.00000000E-03$ |
| $6.1000000E-03$ | $2.27945625E+08$ | $1.06739211E+08$ | $1.42318947E+10$ | $6.20000000E-03$ |
| $6.3000000E-03$ | $1.21206415E+08$ | $5.38075026E+07$ | $5.38075026E+09$ | $6.40000000E-03$ |
| $6.5000000E-03$ | $6.73989122E+07$ | $3.33776688E+07$ | $3.33776688E+09$ | $6.60000000E-03$ |
| $6.7000000E-03$ | $3.40212434E+07$ | $2.07056349E+07$ | $2.07056349E+09$ | $6.80000000E-03$ |
| $6.9000000E-03$ | $1.33156086E+07$ | $6.69782838E+06$ | $6.69782838E+08$ | $7.00000000E-03$ |
| $7.1000000E-03$ | $6.61778021E+06$ | $3.95851720E+06$ | $3.95851720E+08$ | $7.20000000E-03$ |
| $7.3000000E-03$ | $2.65926300E+06$ | $2.24640888E+06$ | $2.24640888E+08$ | $7.40000000E-03$ |
| $7.5000000E-03$ | $4.12854124E+05$ | $4.12854124E+05$ | $4.12854124E+07$ | $7.60000000E-03$ |

AVERAGE ELECTRON ENERGY IS  $2.617E-02$  MEV. TOTAL EMITTED CHARGE IS  $2.130E+08$  COULOMBS/CAL ON PLATE 1

Figure 5-2 (cont.)

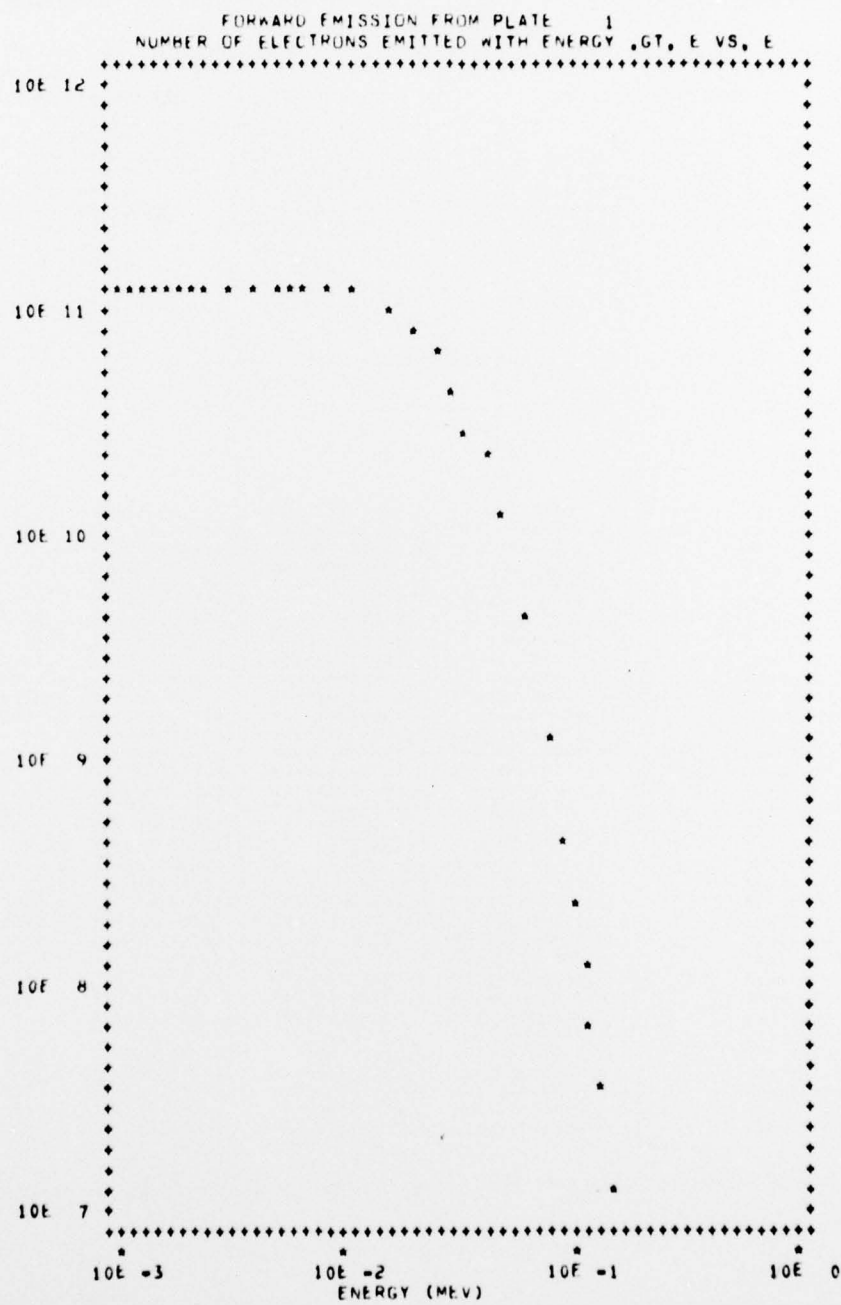


Figure 5-2 (cont.)

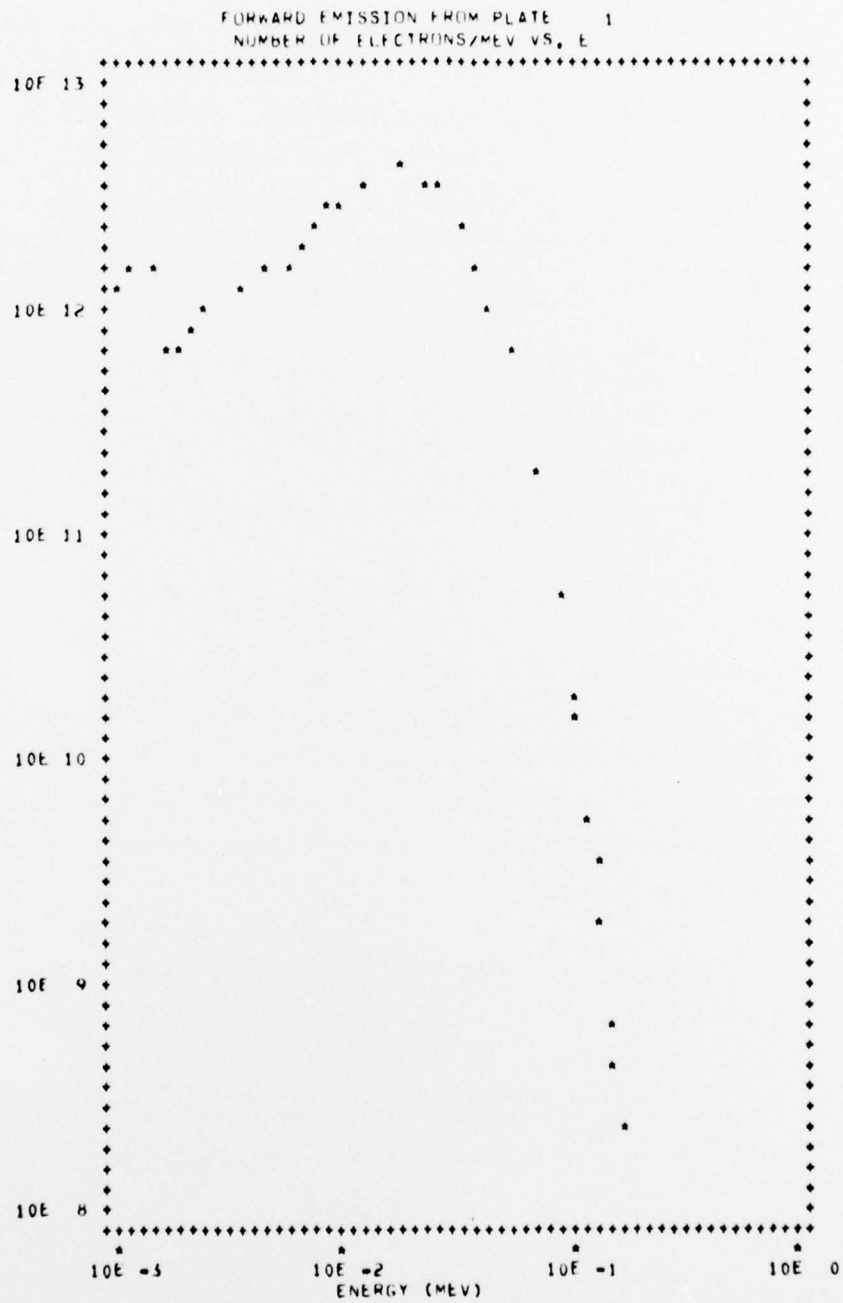


Figure 5-2 (cont.)

[When reverse emission only (emission code 2) or forward and reverse emission (emission code 3) is asked for from a plate, the bulk currents just inside the plate face closest to the source are printed out. Unfortunately, in some versions of the code, the plate index number for reverse emission is low by 1. In later versions, this error has been corrected and the legend says "Bulk currents in layer = \_\_\_\_ at entry face."]

```
BULK CURRENTS IN LAYER =      1 FOR EMISSION CODE =      1
BULK CURRENTS ALONG THE NORMAL DIRECTION
NET BULK CURRENTS ALONG THE NORMAL DIRECTION=  8.24140E-09
FORWARD CURRENT=  2.58326E-08
REVERSE CURRENT=  1.75912E-08
BULK CURRENTS PERPENDICULAR TO THE NORMAL DIRECTION
FORWARD CURRENT =  2.22836E-08
REVERSE CURRENT =  2.22836E-08
```

[When forward emission is requested from a plate, either by itself (emission code 1) or with reverse current, the bulk currents in the plate near the face farthest from the source are printed out. The layer index is correct. In later versions, the legend says "Bulk currents in layer = \_\_\_\_ at exit face."]

```
BULK CURRENTS IN LAYER =      0 FOR EMISSION CODE =      3
BULK CURRENTS ALONG THE NORMAL DIRECTION
NET BULK CURRENTS ALONG THE NORMAL DIRECTION=  1.66168E-08
FORWARD CURRENT=  7.32769E-08
REVERSE CURRENT=  5.66601E-08
BULK CURRENTS PERPENDICULAR TO THE NORMAL DIRECTION
FORWARD CURRENT =  6.79640E-08
REVERSE CURRENT =  6.79640E-08
```

Figure 5-2 (cont.)

In the next section of output, the incident photon spectrum normalized to a total incident fluence of  $1 \text{ cal/cm}^2$  is printed out, followed by the total energy content of the spectrum, the average photon energy, and the total number of photons/ $\text{cm}^2$  corresponding to the total energy content. (Here, the total number of photons is 1 calorie's worth of photons with the spectral energy distribution indicated.) The average photon energy is taken as that energy,  $h\nu$ , which gives the total energy content when multiplied by the total number of incident photons. The total number of incident photons is useful in that results from other codes expressed in electrons/photon can easily be converted to coulombs/calorie by multiplying them by this total number and the electronic charge:

$$\text{Yield in C/cal} = \text{yield in e/photon} \times (\text{photon/cal}) \times (C/e) .$$

The next page of output contains electron emission information. The first line indicates the type of yield (here, reverse), the material number from which the electrons are being emitted (here, 1 indicates the first material), and the yield in C/cal incident on plate 1. This yield corresponds to the "quantum efficiency." The yields in C/cal incident on plate N are also provided in case the user is interested in the yield per calorie for a filtered spectrum.

Next, the breakdown of the electron emission into angular and energy distributions is given. The "emitted electron angular distribution integrated over energy" is meant to provide the angular distribution only roughly. The "emitted electron energy distribution integrated over angle" should be a more precise function, provided the energy bins are close enough together. This printout is derived from the "energy distribution" described in Section 2.2. The column TOTAL contains the number of electrons emitted with energies greater than the corresponding entry in the column ENERGY. The column PER BIN is the total number of electrons in a given energy bin bounded by the energies in the column ENERGY and centered on the corresponding energy in the column MIDPOINT. NUMBER/MEV is the number of electrons/MeV emitted at the corresponding energy under MIDPOINT. Printed below the energy distribution is the average electron energy (calculated in the same way as the average photon energy) and the total emitted charge. The latter number is the result of integrating the energy

distribution  $dN/dE$  over energy. It should agree with the yield at the top of the page to within about 20 percent. Agreement is generally good except for back emission produced by low-energy photons (about 5 to 10 keV). In these cases, results should be used cautiously.

The next two pages are printer plots of TOTAL versus ENERGY and NUMBER/MEV versus MIDPOINT, described above. These plots are exactly the size of standard 5 x 3 log-log paper and may be xeroxed or used with a light table to save needless hours of hand-plotting.

The cycle repeats again with a printout of the photon spectrum emerging from the first material (and incident on the second). In the sample problem, the low-energy photons have been absorbed by the aluminum, reducing the total energy content from 1.0 to  $0.82 \text{ cal/cm}^2$ , raising the average photon energy from 40.5 to 50.8 keV, and reducing the total number of photons from  $6.44 \times 10^{14}$  to  $4.21 \times 10^{12} \text{ cm}^{-2}$ .

Dose information is printed at this point. The energy depositions are in units of rads of the particular material indicated (1 rad = 100 erg/g). Silicon and carbon are always given, and a third material is specified in the inputs from among those available in QUICKE2 (see Table 4-1). Doses at the fronts and backs of the plates are given.

The forward electron emission results are in the same format as the reverse ones, but the spectrum used is that incident on the second material - i.e., the spectrum seen by all material within a few electron ranges of the emitting surface. The yield from plate 1 "per cal incident on plate 2" is higher than the yield from plate 1 "per cal incident on plate 1" since the latter number is calculated for a total spectral energy content of  $0.82 \text{ cal/cm}^2$  - i.e., the energy remaining after the incident photons have been filtered through 40 mils of aluminum. The total yields at the top and bottom of the page agree to 4 percent, so in this sense, the results are trustworthy.

Bulk current information is also given. These currents are in units of electrons/ $\text{cm}^2$ -sec, photons/ $\text{cm}^2$ -sec, or electrons/photon. They pertain to regions greater than the largest electron range away from any interface. The quantities are described in some detail in Section 2.

Finally, for extra information, there are two printing options. If the parameter KOPT is set to 1 (see Section 4), the code will generate the original QUICKE2 output. If IPRINT is set to 1, information from the data tape will be printed. Information on these printouts is available in Reference 1.

## 6. QUICKE2 COMPUTER REQUIREMENTS

QUICKE2 is a FORTRAN IV computer program of approximately 2000 cards in length, operational on a CDC 7600 computer. No machine language is employed. The code requires a tape containing the tabulation of a considerable amount of data for material properties for the 25 elements available. This file is about 300,000 numbers in length.

One additional file is also required for plot information. Memory requirements are about 34,000<sub>10</sub> words of small core and no large core.

Typical run times are about 20 sec CDC 7600 time per electron emission spectrum. No additional computer programs are required by QUICKE2, but the PLOTALL code (Ref. 11) is very helpful in analyzing results of QUICKE2 calculations.

A present idiosyncrasy of the QUICKE2 version described here is that it is restricted to the CDC FTN FORTRAN extended compiler, version 1. Minor programming features do not permit its use on the more up-to-date FTN4 compiler available currently.

#### REFERENCES

1. T. A. Dellin and C. J. MacCallum, "QUICKE2: A One-Dimensional Code for Calculating Bulk and Vacuum Emitted Photo-Compton Currents," Sandia Laboratories, SLL-74-0218, April 1974.
2. G. L. Simmons and J. H. Hubbell, "Comparison of Photo-Interaction Data Set VII. Biggs-Lighthill (Rev.) and ENDF/B," NBSIS 73-241, July 1973.
3. H. M. Colbert, "SANDYL: A Computer Program for Calculating Combined Photon-Electron Transport in Complex Systems," Sandia Laboratories, SLL-74-0012 (1974).
4. W. L. Chadsey, "A Monte Carlo Photo-Current/Photo-Emission Computer Program," National Symposium on Natural and Man-Made Radiation in Space, Las Vegas, March 1971.
5. E. P. Wenaas and M. Williams, "GRAPUP: A Computer Code for Secondary Electron Emission from Plates," Gulf General Atomic, GAMD-10155, June 1970.
6. "ETRAN: Monte Carlo Code System for Electron and Photon Transport through Extended Media," NBS reports 9836 and 9837.
7. C. J. MacCallum and T. A. Dellin, J. Appl. Phys. 44, 1878 (1973).
8. J. N. Bradford, "Radiation-Induced Electron Emission," AFCRL-TR-74-0583, November 1974.
9. P. Ebert and A. Lauzon, "Measurement of Gamma-Ray-Induced Secondary Electron Current from Various Elements," IEEE Trans. Nucl. Sci. NS-13, p. 735 (1966).
10. M. J. Nowak, M. R. White, and J. P. Wondra, "The FHUFF Code for X-ray Energy Deposition with Fluorescent Heating and Fluorescent Fluxes," Gulf General Atomic, GAMD-9463, July 1969.
11. A. J. Woods, T. N. Delmer, and M. A. Chipman, "The Arbitrary Body of Revolution Code (ABORC) for SGEMP/IEMP," INTEL-RT 8141-028, April 1976.

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