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A BRIEF DISCUSSION OF BERGER'S LATEST MONTE CARLO PROGRAM

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George C. Marshall Space Flight Center
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ABSTRACT

The computer program that is examined here was developed by Martin J. Berger and S. M. Seltzer of the National Bureau of Standards. The Monte Carlo program furnishes the user with a battery of information associated with the transport of electrons and photons through matter. Stochastic processes are used in arriving at the theoretical results. The data are then compared with the latest experimental data of D. H. Rester of Ling-Temco-Vought, Inc.

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TABLE OF CONTENTS

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INTRODUCTION

In recent months, M. J. Berger and S. M. Seltzer of the National Bureau of Standards completed their latest version of a computer program designed to trace both electrons and photons through matter. Upon receiving the program at Marshall Space Flight Center, comparison runs were initiated using existing experimental data. The experimental data were supplied by D. H. Rester[1] and W. E. Dance of Ling-Temco-Vought, Inc. The results of these comparisons are presented in this report along with a brief description of the Monte Carlo computer program.

GENERAL DESCRIPTION OF THE MONTE CARLO PROGRAM

Input Conditions

The Monte Carlo program depicts the following physical situation. Either electrons or photons are permitted to bombard a semi-infinite slab of material. Upon striking the target, the incident or primary particles interact with the material and produce secondary electrons and photons. These secondary particles are then followed through the target as are the primary particles. Since the target is finite in only one dimension (its thickness), the program must neglect lateral effects. This is a good approximation to the actual experimental situation if the beam area of the incident radiation is small compared to the target area. The energy spectrum of the incident particles may be read into the program as a list, or the incident radiation may simply be monoenergetic. In addition, the incident beam can be emitted from either a monodirectional source, an isotropic source, or a cosine-law source.

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[1]Private communication.

Output of Program

The program computes the energy spectra and the angular distribution for electrons and photons emerging from a target of given thickness. The output also contains the electron flux distribution, the energy and charge deposition, and the transmission and reflection coefficients. Only a representative sample of information provided by the Monte Carlo program has been mentioned. The complexity of the program is demonstrated by the fact that many of the secondary particle interactions in the target are included in the final results. To be more precise, electrons originating from such complicated interactions as Auger emission, pair production, Compton scattering, and the photoelectric effect are traced through the target material. Normally the program will follow naturally occurring bremsstrahlung and characteristic x-rays; however, to improve the statistics, artificial photons are generated, suitably weighted, and then traced.

Internal Structure

The internal structure of the Monte Carlo program is composed of three basic parts: the input datatape, datapac-4, and etran-15. The datatape contains various cross section data, including data related to the differential bremsstrahlung cross sections. Other parameters pertaining to the target material are also included on the tape. Three datatapes are now available for use, the only difference being the emprical correction factor that is applied to the Bethe-Heitler bremsstrahlung cross sections. For datatape 0, the correction factor is equal to one; for datatape 1, the correction factor is obtained from experimental data given by Koch and Motz; and, for datatape 2, the correction factor is deduced from experimental data collected by Aiginger, Rester, and Dance. Datatape 2 is usually preferred, since it is based on the latest experimental data.

Datapac-4 converts the data stored on the datatape into convenient tabular form. In particular, it produces tables of energy losses and range values for electrons, differential and cumulative multiple scattering distributions for electrons, and other distributions that relate to bremsstrahlung production. Etran-15 then samples these probability distributions in a random manner, and, in so doing, generates a large number of electron and photon histories. After these histories are accumulated and analyzed, the desired output is then tabulated so that the analytical results can be compared with the experimental results. The only real limitation of the Monte Carlo program is the restriction it places on the configuration of the experiment (semi-infinite slab). At the present time, the program is being run on the Univac 1108 Exec II computer. Additional information concerning either datapac-4 or etran-15 may be found in References 1 and 2, or may be obtained from the author.

COMPARISON OF ANALYTICAL AND EXPERIMENTAL RESULTS

The first experiment consisted of a monoenergetic beam of electrons, with an energy of 2.5 MeV normally incident on a target of aluminum. Data were taken for target thicknesses 0.2, 0.4, and 0.56, where the units of thickness are given in fractions of the mean electron range ($\rho = z/r_0$). A parallel Monte Carlo run was then compared with the experimental data. Some of the results are presented in Figure 1. A total of ten thousand primary histories were permitted to accumulate before the computer run was terminated. The theoretical and experimental results as a whole are in good agreement.

When comparing experiment with theory, one must be aware of the inherent statistical errors found in the Monte Carlo program. Since the data being considered are differential in both energy and solid angle, it follows that a large number of scattered electrons must be detected if the results are to be meaningful. This presents no special problem to the experimenter, but it can be a problem to the theoretician. The analyst has a limited amount of available computer time, and therefore must put an upper bound on the number of primary histories generated by the Monte Carlo program. This limitation could pose a serious threat to the accuracy of the theoretical calculations, particularly if the target is a thick high-Z material. At the present time there are six target materials that can be used in conjunction with our Monte Carlo program: beryllium ($Z=4$), aluminum ($Z=13$), iron ($Z=26$), copper ($Z=29$), tin ($Z=50$), and gold ($Z=79$).

Other experiments have been simulated on the computer by using Berger's Monte Carlo program. They include non-normal as well as normal incidence runs. There are two cases of non-normal incidence to be considered. In the first case, an electron beam of incident energy 1.0 MeV strikes an aluminum slab at an angle of 30 degrees (with respect to the target normal). In the second case, the first run is repeated with the angle of incidence being changed to 60 degrees. Twenty thousand primary histories were generated in each of the two cases.

The next set of Monte Carlo calculations used gold as the target material. Two runs were exectued, varying only in the incident energy of the electrons

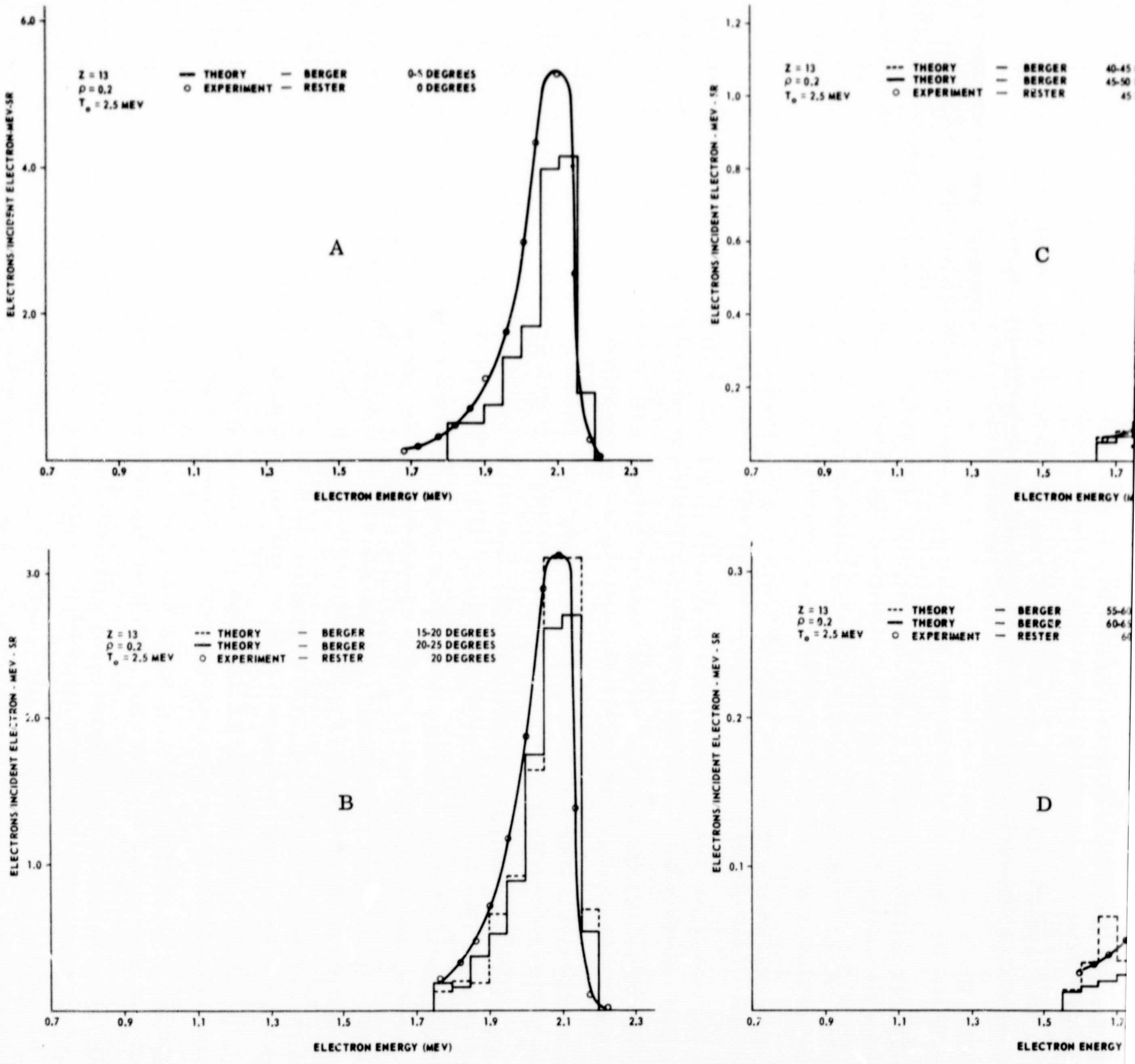
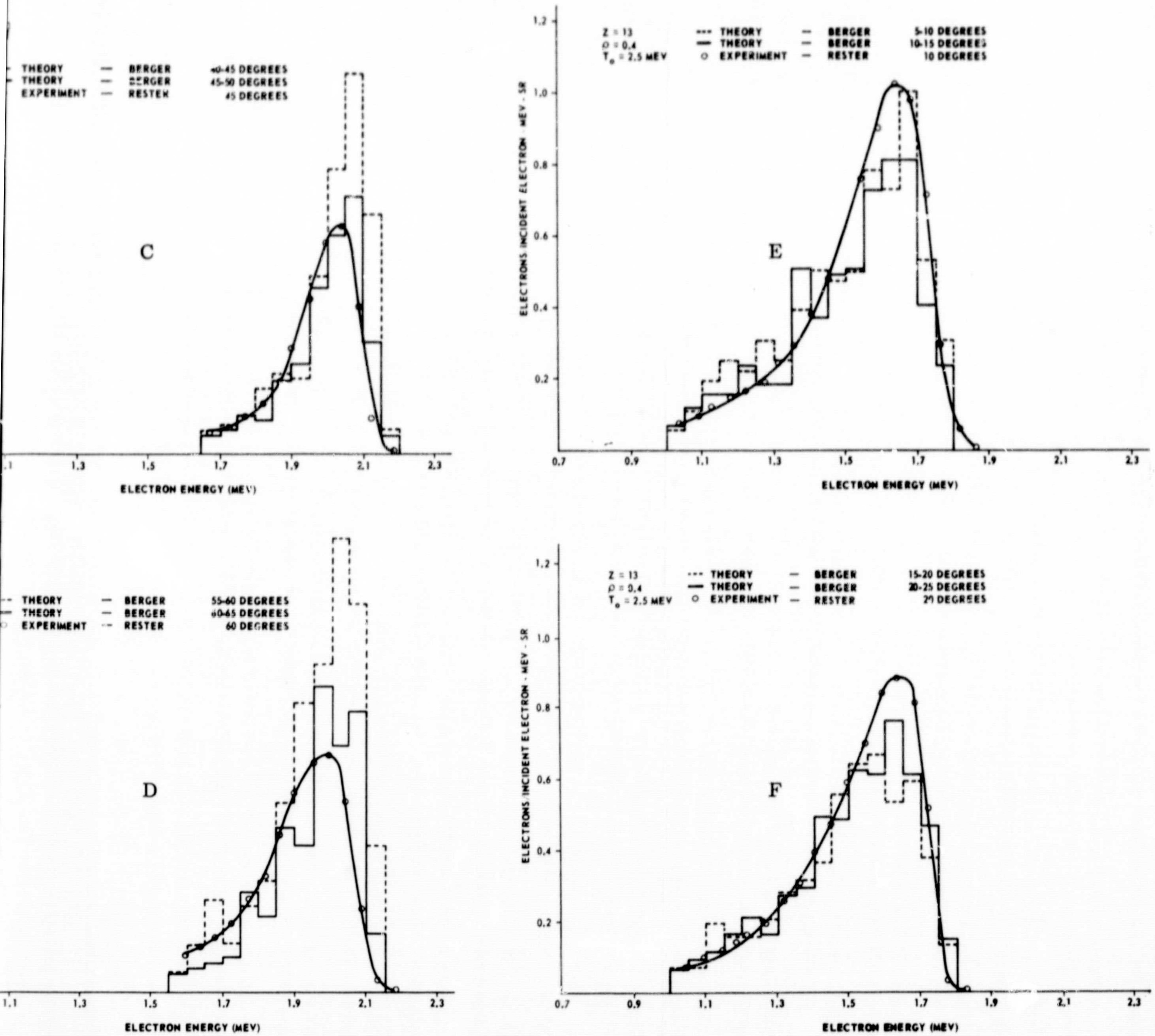


FIGURE 1. A COMPARISON OF THE EXPERIMENTAL TRANSM
BOTH ENERGY AND SOLID ANGLE WITH BERGER'S THEORE
ANGLE. (THE INCIDENT ELECTRON ENERGY WAS 2.5
THE THICKNESS WAS 0.2 THE RANGE IN A, B, C, AND



ERIMENTAL TRANSMITTED ELECTRON SPECTRA DIFFERENTIAL IN
H BERGER'S THEORETICAL VALUES FOR THE GIVEN SCATTERING
ON ENERGY WAS 2.5 Mev. THE TARGET WAS ALUMINUM, AND
GE IN A, B, C, AND D, AND WAS 0.4 THE RANGE IN E AND F.)

FOLDOUT FRAME 2

(1.0 MeV for the first run and 2.5 MeV for the second run). Both electron beams were normally incident to the gold target with fifteen thousand primary histories being traced out for each run.

All the Monte Carlo runs are being compared with the appropriate experiment and the results will be reported at a later date. In the near future, data provided by Gulf General Atomic will be analyzed. One of the main features of their experimental apparatus is that the incident energy of the electron beam can be set as high as 10 MeV.

In the experiments of Gulf General Atomic, data were taken for targets of beryllium, aluminum, and gold with incident electron energies of 4 MeV, 8 MeV, and 10 MeV. The corresponding calculations of Berger will be compared with this additional data, and the results will be published.

REFERENCES

1. Berger, M. J. and Seltzer, S. M.: Introduction and Notes on Program Datapac 4. National Bureau of Standards Report 9836, Contract R-80, June 10, 1968.

2. Berger, M. J. and Seltzer, S. M.: Notes on Program Etran 15. National Bureau of Standards Report 9837, Contract No. R-80, June 10, 1968.