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RACIC report

EFFECTIVENESS STUDY OF REFLECTIVE CLOUDS

Report RACIC-TR-57

February 28, 1967

Prepared for

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by

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PREFACE

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by ARPA/AGILE under Contract No. SD-171.

ACKNOWLEDGEMENT

The detailed programming on this project was performed by Christopher G. Davy and Fred G. Wise of the Computation Research Division of Battelle Memorial Institute, Columbus Laboratories.

EFFECTIVENESS STUDY OF REFLECTIVE CLOUDS

by

R. E. Hess

ABSTRACT

A computer program has been developed as a result of this project. For input data consisting of the spectral distribution of the incident energy, the composition of the scatterer, and the size distribution of the scatterer, this program computes the volumetric scattering intensity. Preliminary results obtained with the program indicate a very prominent degree of lateral scattering.

INTRODUCTION

To afford the reader a fuller understanding of this project, the application of radiant energy to fire spread, which is actually the main stimulus for this study, will initially be described. Following this description of fire spread, the history of the development of this project will be briefly chronicled, so that the reader may more fully appreciate why one particular small segment of the problem was taken out for study. Finally, somewhat in the nature of a summary, the history of the Mie problem will be considered.

SUMMARY

The accomplishments of this project have been:

(1) The preparation of a computer code by which numerical data for the volumetric scattering intensity can be obtained. Incorporated within the program is a plotting option by which the data may be portrayed graphically.

(2) Limited experience with the computer program has indicated tentative bounds for the convergence of the infinite summation, and has identified the computational steps that must be checked to ensure convergence.

(3) The output data obtained to date, presented as a plot of intensity against scattering angle, demonstrate the very strong degree of lateral scattering inherent in the Mie problem. Successful enhancement of fire spread will require serious consideration to both the gross configuration of the reflective cloud, and the minute aspects of the scatterer – composition and size.

CONCLUSIONS

As a result of this program, the following conclusions were reached:

(1) The Mie problem can be programmed with nominal difficulty, and for a computer operating interval of three minutes maximum will produce a curve of scattered intensity against scattering angle for a specified wavelength and scattering particle. If the problem is set up for multiple inputs, the running time is lengthened about one-half minute per curve.

(2) The versatility of the program should be capable of considerable extension; however, this is more of an engineering problem than a programming problem. A clearer definition of the fire-spread problem would stimulate improvements in the program.

RECOMMENDATIONS

Inherently an exploratory program such as this would allow the compilation of a rather large list of recommendations, and most of these recommendations would involve additional work to extend a particular aspect of the study. However, since there is no indication that an extension of this program is likely, only a few very general recommendations will be offered. For instance, optical data for the various candidate materials to be used for reflective clouds are not available in a form readily usable by the cloud designer. Some efforts leading to a more handy presentation would seem justified. Regarding the efforts here, several aspects of the computer program could be modified to extend the range and versatility of this program.

BACKGROUND

Application of Radiation to Fire Spread

In any analysis of mass fires as either an offensive or a defensive weapon, serious consideration must be given to ignition, the initiation of the fire, and to propagation of the fire, at least during the early stages. This consideration of ignition and propagation may be combined into the general term "fire spread". The use of mass fire as a weapon implies enhanced fire spread. A discussion of fire spread necessarily involves the energy balance associated with the fire. One very significant term in this energy balance is the radiant energy term, for radiant energy fills the role of a precursor in mass fire spread.

An early realization in any consideration of this radiant energy term is the fact that much, if not most, of the radiant energy associated with an open fire escapes skyward and is lost to the energy balance. It is then rather obvious that in any effort to enhance fire spread, an attempt should be made to return earthward a significant portion of this skyward-bound radiant energy. In a military situation, the attempted ignition will utilize incendiary bombs and here too much, if not most, of the radiant energy is lost skyward.

In elementary terms, the escaping radiant energy may be returned earthward by spreading a reflective blanket above the fire zone. In military terms, this reflective blanket can be produced by spreading a reflective smoke screen or a reflective fog above the fire. Smoke generators, or fog generators, either earthbound or airborne, represent a reasonably well-developed technology, so suitable delivery means are within the current state of the art. The only remaining question is the effectiveness of the smoke cloud in returning energy earthward. It is to this question that the efforts represented by this report were directed.

History of RACIC/LWL Interchange

In September of 1965, a request was made by the Limited War Laboratory at Aberdeen Proving Ground to Battelle's RACIC-Washington office for information related to the reflective properties of smoke clouds. The response to this request initially took the form of a search of the RACIC-Columbus files. To supplement the RACIC holdings, a number of inquiries were made to investigators whose general scope of study suggested that they might be able to contribute pertinent information. The activities related to this initial request were concluded in late October 1965 and reported in a letter to LWL tabulating the bibliographical data and other information obtained.

From the onset, this problem was of a strong heuristic nature and generated many discussions regarding the probable implications. Further, the amount of data gathered during the literature search was rather small and of quite disappointing quantitative content. The extended needs of LWL were discussed and the availability of RACIC assistance was made known. Subsequently, LWL requested such assistance from RACIC, and in late January of 1966 this study was authorized.

During the time interval in which authorization of the project was considered, there was personal communication between LWL personnel and RACIC personnel. During these conversations the broad field of radiant energy in fire spread was sifted, to give one aspect which might be attacked with the resources at hand. The final mutual decision was to prepare a computer program which would provide an estimate of the volumetric scattering efficiency for any specified cloud. This decision was subsequently confirmed by correspondence*.

Statement of the LWL Problem

The field of radiant energy and its interaction with matter is exceedingly broad. Any given effort can at best attack only a limited region, as these efforts were designed to do. To enhance appreciation of the results stated in this report, the intended purpose will be clearly and rather restrictively drawn. One element in the planning of future work to develop a newly hypothesized smoke is the degree of expectation that the smoke would achieve the results postulated. The need which led to this program was for an established methodology which would quickly give a working estimate of the reflective effectiveness and thus assist in planning a development program. The intent here was to establish the methodology to give the working estimate by programming the Mie solution in a quite restrictive fashion.

*Reference teletype W-21 dated December 17, 1965, from F. J. Barone/RACIC-W to J. T. Brown/R. E. Hess/RACIC-C, and letter CRD-AM-5A dated December 13, 1965, from Lt. Col. J. F. Matteson, Chief, Operations and Analysis Division, Limited War Laboratory, to F. J. Barone/RACIC-W.

Description of the Physical Problem

The Mie scattering problem is the description of the interaction of a plane electromagnetic wave with a spherical scatterer. This problem is applicable to any portion of the electromagnetic spectrum and may be used to describe the scattering of radar waves, of thermal radiation, or of visible light. The application here is to thermal radiation as it might be scattered by a chemical smoke used in military operations.

The elementary definition of electromagnetic radiation employs an electric vector and a magnetic vector which oscillate perpendicularly to each other and which define a plane whose normal is the direction of propagation of the electromagnetic wave. Strictly this description fits only one wave train, and a beam of radiation would consist of many such wave trains. For an unpolarized beam, there is no preferred orientation so that the electric vectors, hence the magnetic field also, are randomly oriented with all directions equally probable. Under these circumstances, the electric field and magnetic vectors can be each represented by two perpendicular vectors of equal magnitude.

If this electromagnetic wave traverses an electron, the electron responds to the electric field of the wave and is forced into oscillation by this field. This moving electron now gives rise to a magnetic field and since the movement of the electron is accelerated motion, the resulting magnetic field has a timewise variation. Since a changing magnetic field gives rise to a changing electric field, the motion of the electron results in the propagation of a secondary electromagnetic wave. The electron, in responding to the incident electric field, oscillates in the plane of this electric field; the field generated by the movement of the electron is in a plane perpendicular to the plane of oscillation. Although this description is greatly oversimplified, it serves to demonstrate that the interaction of an incident field and a responsive electron removes energy from the original beam and scatters it in a plane perpendicular to the initial beam.

The basic task now is to relate this scattering to a three-dimensional geometry. For the very brief explanation permitted here, the earth will be taken as a flat surface defining the xy-plane and the perpendicular to this plane is the local vertical defined as the z-axis. The plane electromagnetic wave under discussion will, of course, be unpolarized and will be described by vectors E_{ox} and E_{oy} of equal magnitude. Associated with the electric vector E_{ox} is a magnetic vector H_{oy} and associated with the electric vector E_{oy} is a magnetic vector $-H_{ox}$. The one negative vector is necessary to give the same propagation direction to each pair of component vectors.

When this plane wave passes over an electron, the E_{ox} vector causes the electron to oscillate in the xy-plane along the x-direction while the E_{oy} vector causes the electron to also oscillate in the xy-plane but along the y-direction. The electric field variations are expressed in sinusoidal terms, so the motion of the electron is simple harmonic, at least in the ideal sense. In simple harmonic motion the moving particle has zero velocity at the ends of its travel and a maximum velocity at its midpoint. The strength of the magnetic field created by a current is proportional to the current, and the flux lines are circles centered on the conductor. The moving electron is a current, and since the velocity of the electron is changing sinusoidally, the current it

represents is also changing sinusoidally. Thus, the field strength is greatest when the electron is passing through its midpoint and this field strength decays to zero at the ends of its travel.

The oscillations of the electron due to the incident electric vector E_{ox} give rise to the scattered magnetic vectors H_{sy} and H_{sz}. By Lenz's Law the changing magnetic field resists the current variation. Thus, there is a scattered electric vector $-E_{sx}$ associated with each of the scattered magnetic vectors. The combination of vectors $-E_{sx}$ and H_{sy} has as its direction of propagation the minus z-direction; in other words, this combination represents the radiation scattered along – both forward and backward – the direction of the incident ray. The other combination of vectors $-E_{sx}$ and H_{sz} has as its direction of propagation the y-direction; in other words, this combination represents the radiation scattered laterally.

Similarly the oscillation of the electron due to the vector E_{oy} gives rise to scattered magnetic vectors H_{sx} and H_{sz}, and associated with each of these magnetic vectors is an electric vector $-E_{sy}$. The combination of vectors $-E_{sy}$ and H_{sx} has as its direction of propagation the z-direction, hence it represents the radiation scattered coincidentally with the incident ray. The combination of vectors $-E_{sy}$ and H_{sz} has as its direction of propagation the minus x-direction, so it represents the radiation scattered laterally.

Since the electron is in simple harmonic motion along the two axes in its plane of oscillation, there is symmetry about the midpoint of its excursion. Thus, the energy scattered along the direction of the incident ray is scattered equally in the earthward and skyward directions. Similarly for the laterally scattered energy, equal amounts are scattered to the right and to the left and equal amounts forward and aft. The accounting of this scattered energy is the task of this program.

History of the Mie Solution

Once the mathematical formalism related to the electromagnetic field had been developed by Maxwell in the middle of the nineteenth century, many attempts were made to solve the scattering problem as related to electromagnetic radiation. In principle, this problem requires solving the Maxwell equations, or more precisely, the wave equation describing the electromagnetic field, subject to the boundary conditions imposed by the geometry of the scatterer. The mathematical difficulties are extremely formidable, and except for extremely simple geometries, there is little hope for obtaining a solution.

Relatively speaking, the case of a plane electromagnetic wave incident upon a homogeneous spherical scatterer represents a simple geometry. The German physicist Gustav Mie obtained a solution for this problem in 1908. The solution is in the form of rather complex mathematical functions, and it is inconvenient for direct application and ordinary hand computations. The application of the solution remained relatively static until the advent of modern high-speed computers brought adequate computation within the realm of possibility. Since the Mie solution is general, it spans the range of optical phenomena and properties, thus leading to rather diverse applications. Although several tables of Mie functions have been generated, the use of such tables is reasonably involved. Further, the coverage by any given table is often inadequate for the specific needs of a given investigator.

A brief consideration of the Mie problem will demonstrate why this condition exists. In a very strict sense the designation Mie functions should be reserved for the quantities S_1 (μ, m, θ) which, in dimensionless form, are the amplitudes of the farfield electric vectors. If these quantities are divided by $k = 2\pi/\lambda$, where λ is the free-space wavelength of the radiation thus making k the free-space propagation constant, the resulting quantities are the amplitudes of the electric vectors:

$$A_1 = \frac{S_1 (\mu, m, \theta)}{k = \frac{2\pi}{\lambda}} \qquad A_2 = \frac{S_2 (\mu, m, \theta)}{k = \frac{2\pi}{\lambda}} .$$

Thus, so long as care is exercised in the usage of these quantities in a physical sense, S_1 and S_2 can be interpreted as electric amplitudes.

One of the difficulties encountered in attempting to tabulate these Mie functions can be appreciated from the three variable dependence of the quantities. Actually since the index of refraction is a complex quantity, this relation is more appropriately taken as a four variable dependence. The total number of values to be tabulated is the four-term product of the number of values assigned to each independent variable. If any appreciable range of values is assigned to the independent variables, the number of values to be tabulated soon becomes unwieldy.

There are several other quantities that can be understood when the description or designation Mie functions are made. Two of these are the normalized extinction and scattering cross-sections, also termed the efficiency factors. These quantities are the actual cross-sections divided by the geometrical cross-sections. Again these two quantities have a three parameter dependence upon the Mie number and the complex index of refraction, so again a tabulation covering any considerable range for one or more of the variables becomes quite voluminous and even modest-range coverage is unwieldy. The availability of computing facilities has made the direct approach of programming the problem a more feasible approach, and this has been so suggested in the literature. The investigator can then exercise complete flexibility in studying his specific case.

THE RESEARCH PROGRAM

The objective of this research program as described in the work statement was twofold. The primary objective of this study was to provide quantitative data from which first-order estimates of the reflective power of chemically induced clouds could be made. A secondary objective was to provide the means of making first-order estimates related to weapons effects in general.

As the program developed, the greater portion of our efforts was devoted to the primary objective. As a result of the program, a computational procedure – a computer program in being – is available for making first-order estimates of the reflective power of clouds. To date limited quantitative data have actually been produced. The quantity of data produced would rapidly increase were a stimulus for such activities to appear.

In principle the computer program has also fulfilled the secondary objective. It can be used for weapons effects in general, but to do so imposes upon the requesting engineer the burden of expressing, or re-expressing, his information in terms compatible with the computer program.

The Mie Solution

The complete mathematical development of the Mie solution is extremely complex. Since the purpose here is utilitarian, this mathematical development is not presented in detail.

The working equation describes the specific intensity of the monochromatic, scattered, radiant energy:

$$\mathcal{I}_\lambda(\theta) = \frac{\mathcal{F}\beta_{sc}}{4\pi} \mathbf{P}(\theta)$$

where

$\mathcal{F}$ = incident, monochromatic flux, cal/sec · cm^2

β_{sc} = total scattering cross-section, cm^2

$\mathbf{P}(\theta)$ = angular dependent phase function.

This relation gives the amount of energy scattered by a small volume element of a monodisperse medium when the volume element is illuminated by a parallel unpolarized flux. Since the scattering is done by a small volume element, $\mathcal{I}_\lambda(\theta)$ is expressed on a per unit volume basis, and since $\mathcal{I}_\lambda(\theta)$ is dependent upon the scattering angle, θ, the specific intensity is normalized by the factor $1/4\pi$ to a per-solid-radian basis:

$$\mathcal{I}_\lambda(\theta) = \mathcal{F}\beta_{sc}\frac{\mathbf{P}(\theta)}{4\pi} \quad \frac{\text{cal/sec}}{\text{cm}^3 \cdot \text{strd}} \quad .$$

The total scattering cross-section is given by:

$$\beta_{sc} = n(r)\,\sigma_{sc}(m, r, \lambda) \quad ,$$

where

$n(r)$ = number density of spherical particles having a radius r, particles/cm^3

σ_{sc} = the scattering cross-section, cm^2.

The scattering cross-section can be looked upon in the sense of a fictitious parameter associated with a particle, or in the sense of an eff ctive value assigned to a parameter. To illustrate what is meant, consider first an ordinary rubber ball. As a sphere it has an unambiguous value for its diameter. Having an unambiguous diameter means that it also has an unambiguous cross-sectional area. As the size of the sphere shrinks, the meaning of the diameter is not so unambiguous and the operational approach, that is, definitions that apply strictly only under a specific set of circumstances, must be adopted. For instance, an estimate of the diameter of the particle made on the basis of an experiment concerning its volume may or may not correlate to the diameter determined by an optical experiment.

For a heterodisperse media, the total scattering cross-section can be expressed as a summation:

$$\beta_{sc} = \sum_i n(r_i)\, \sigma_{sc}\, (m,\ r_i,\ \lambda)\ \mathrm{cm}^2$$

giving

$$\mathcal{J}_\lambda(\theta) = \mathcal{F}\left\{ \sum_i n(r_i)\, \sigma_{sc}\, (m,\ r_i,\ \lambda)\right\} \frac{P\,(\theta)}{4\pi}\ \frac{\mathrm{cal/sec}}{\mathrm{cm}^3 \cdot \mathrm{strd}} \quad .$$

Next, for a given spherical particle, the phase function at any scattering angle, θ, is defined as:

$$P\,(\mathcal{m},\ m,\ \theta) = 2\ \frac{\left|S_1\,(\mathcal{m},\ m,\ \theta)\right|^2 + \left|S_2\,(\mathcal{m},\ m,\ \theta)\right|^2}{\mathcal{m}^2\ K_{sc}\,(\mathcal{m},\ m)} \quad ,$$

where

S_1 = dimensionless amplitude of one farfield electric vector – by convention S_1 is perpendicular to the scattering plane

S_2 = dimensionless amplitude of the second farfield electric vector – by convention S_2 is parallel to the scattering plane. By definition the scattering plane is that plane containing both the incident ray and the scattered ray; the scattering angle, θ, is measured in this plane.

$\mathcal{m} = 2\pi r/\lambda$ = Mie number

r = radius of spherical scatterer

λ = wavelength of the incident and scattered radiation.

The Mie number is a generalized, dimensionless parameter by which radiant energy effects may be correlated. Since it is essentially the ratio of the particle diameter to the wavelength, it subordinates both the individual effects and emphasizes the combined effect, the scattering event:

$$K_{sc} = \frac{\sigma_{sc}}{\pi r^2} = \text{normalized scattering cross-section or scattering efficiency}$$

$$= \text{ratio of scattering cross-section to the geometrical cross-section.}$$

This is a dimensionless parameter which relates the effectiveness of the scattering to the more familiar concept of physical size. Since S_1 and S_2 are complex quantities, the expression for the phase function may be written as:

$$P(\alpha, m, \theta) = \frac{S_1(\alpha, m, \theta) \cdot S_1^*(\alpha, m, \theta) + S_2(\alpha, m, \theta) \cdot S_2^*(\alpha, m, \theta)}{\alpha^2 K_{sc}(\alpha, m)} \quad .$$

The phase function may be looked upon as a partition function in the sense that it delineates what portion of the incident energy is scattered into a differential solid angle characterized by a particular scattering angle.

The expressions for S_1, S_2, and K_{sc} are infinite summations:

$$S_1(\alpha, m, \theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left\{ a_n \pi_n + b_n \tau_n \right\}$$

$$S_2(\alpha, m, \theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left\{ b_n \pi_n + a_n \tau_n \right\}$$

$$K_{sc}(\alpha, m) = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) \left\{ \left| a_n \right|^2 + \left| b_n \right|^2 \right\} \quad .$$

As described earlier, the efforts here were intended to provide a methodology by which working estimates could be quickly made. In line with this objective, the computer programs were written with a maximum value of n = 10.

The mathematical complexity increases sharply in the expressions for a_n and b_n:

$$a_n = \frac{\left[\frac{A_n}{m} + \frac{n}{\mathcal{m}}\right] J_{n+1/2}(\mathcal{m}) - J_{n-1/2}(\mathcal{m})}{\left[\frac{A_n}{m} + \frac{n}{\mathcal{m}}\right]\left[J_{n+1/2}(\mathcal{m}) + i(-)^n J_{-n-1/2}(\mathcal{m})\right] - J_{n-1/2}(\mathcal{m}) + i(-)^n J_{-n+1/2}(\mathcal{m})}$$

$$b_n = \frac{\left[mA_n + \frac{n}{\mathcal{m}}\right] J_{n+1/2}(\mathcal{m}) - J_{n-1/2}(\mathcal{m})}{\left[mA_n + \frac{n}{\mathcal{m}}\right]\left[J_{n+1/2}(\mathcal{m}) + i(-)^n J_{-n-1/2}(\mathcal{m})\right] - J_{n-1/2}(\mathcal{m}) + i(-)^n J_{-n+1/2}(\mathcal{m})} \quad .$$

In these expressions

$$A_n = \frac{-n}{m\mathcal{m}} + \frac{J_{n-1/2}(m\mathcal{m})}{J_{n+1/2}(m\mathcal{m})} \quad .$$

Trying to give physical meaning to these coefficients would be an extremely difficult job at best, and to try to do so without a detailed derivation would be essentially impossible. The wisest course seems to be to merely accept these as expansion coefficients.

The expressions for π_n and τ_n are somewhat simpler in form and involve the Legendre polynomial:

$$\pi_n = \frac{d}{d\mu} P_n(\mu)$$

$$\tau_n = \mu \pi_n - (1-\mu^2) \frac{d\pi_n}{d\mu} \quad ,$$

where

$P_n(\mu)$ = Legendre polynomial

$\mu = \cos\theta \qquad -1 \leq \mu \leq 1 \quad .$

Actually, this rather lengthy discourse is really a quite abbreviated résumé of the mathematics involved.

The Computational Program

The equations summarized in the previous section were programmed for the Control Data 3400 computer. The program is referred to as PRØGRAM CLØUD. PRØGRAM CLØUD was written in 3400 FORTRAN, a superset of FORTRAN IV. Complex variables were used throughout. This program calls three subroutines BESSELC, LEGPD1, and PLOTXY1. The former two (for computation of Bessel functions and Legendre polynomials) are included. PLOTXY1 should be supplied by the user for the plots of $\mathcal{J}_\lambda(\theta)$ versus θ. The general flow chart for the program is shown in Figure 1. The discussion in this section is built around this flow chart and provides a general understanding of the computational scheme.

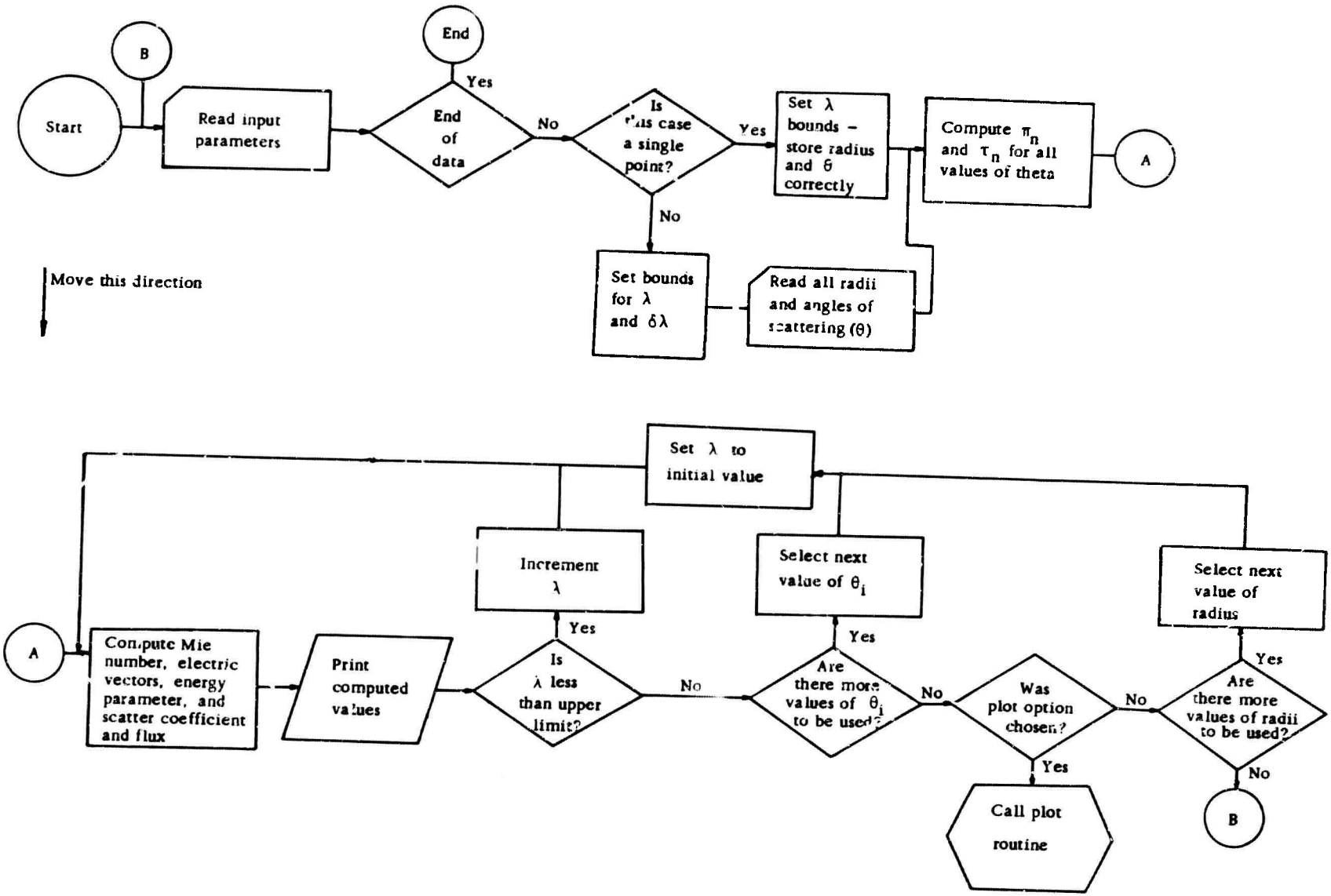

FIGURE 1. PROGRAM CLOUD FLOW CHART

The intent of this program was to provide two computational options referred to as a single-point computation and a many-point computation. In the single-point case, attention is confined to one value for each of the significant parameters: radius of scatterer, scattering angle, and incident wavelength. In the many-point case, at least one of these variables spans a range of values.

The Input Parameters

The input parameters to this program are the radius of the spherical scatterer, the complex index of refraction of the scatterer, and the scattering angle. With these input parameters and for individual values of the wavelength of the incident radiation, PRØGRAM CLØUD computes the first electric amplitude, the second electric amplitude, the scattering efficiency, the phase function, and the scattered intensity. With the radius of the particle and the specified wavelength, PRØGRAM CLØUD computes the Mie number, m, as a generalized parameter for discussing the interaction of radiant energy with a scatterer.

The input to the program is contained on three input cards, and the presentation of information on these cards differs according to the decision required from the program. The decision-making capability of PRØGRAM CLØUD is based upon a variable designated as KEY. The decision is raised in the question "Is this case only a single point calculation?". The answer "YES" is indicated by assigning to the variable KEY the value of unity, KEY = 1. For this case, the computations are carried out for a single value of the radius of the scatterer, a single value of the scattering angle, and a single value of the wavelength of the incident radiation. The answer "NO" to the decision question "Is this case only a single point calculation?" is indicated by assigning to the variable KEY the value of zero, KEY = 0. For this case, computations are made for all combinations of all radii of the spherical scatterer, of all scattering angles, and of all wavelengths of the incident radiation.

The YES Case

For the case where the answer is YES, KEY = 1, all of the input data are contained on the first card, Card Number 1, and the arrangement shown in Figure 2 is used. The variables RER, RERP, ALMBT, RDD, and THETT are all floating point variables written in an E10.3 format. The variable KEY is an integer variable written in an I5 format. These format selections are, of course, quite arbitrary, and selections considered more appropriate by the individual users may be readily substituted.

The NO Case

For the case where the answer is NO, KEY = 0, all three data cards are needed and the arrangements shown in Figures 3 and 4 are used. The variables RER, RERP, ALMBT, RDD, and THETT are all floating point variables written in an E10.3 format. The variables NR, NT, and KEY are integer variables written in an I5 format. As before, the choice of format was arbitrary, and appropriate substitutions may be made.

Columns 1 through 10 – the variable named RER. This is the real part of the index of refraction.

Columns 11 through 20 – the variable named RERP. This is the imaginary part of the index of refraction.

Columns 21 through 30 – the variable named ALMBT. This is the wavelength of the incident radiation.

Columns 31 through 40 – the variable named RDD. This is the radius of the spherical scatterer in microns.

Columns 41 through 50 – the variable named THETT. This is the scattering angle, expressed in degrees, and measured from the direction of the incident ray.

Columns 51 through 60 not used.

Columns 61 through 65 – the variable named KEY. For this case this variable is assigned the value of unity, KEY = 1.

Columns 66 through 80 – not used.

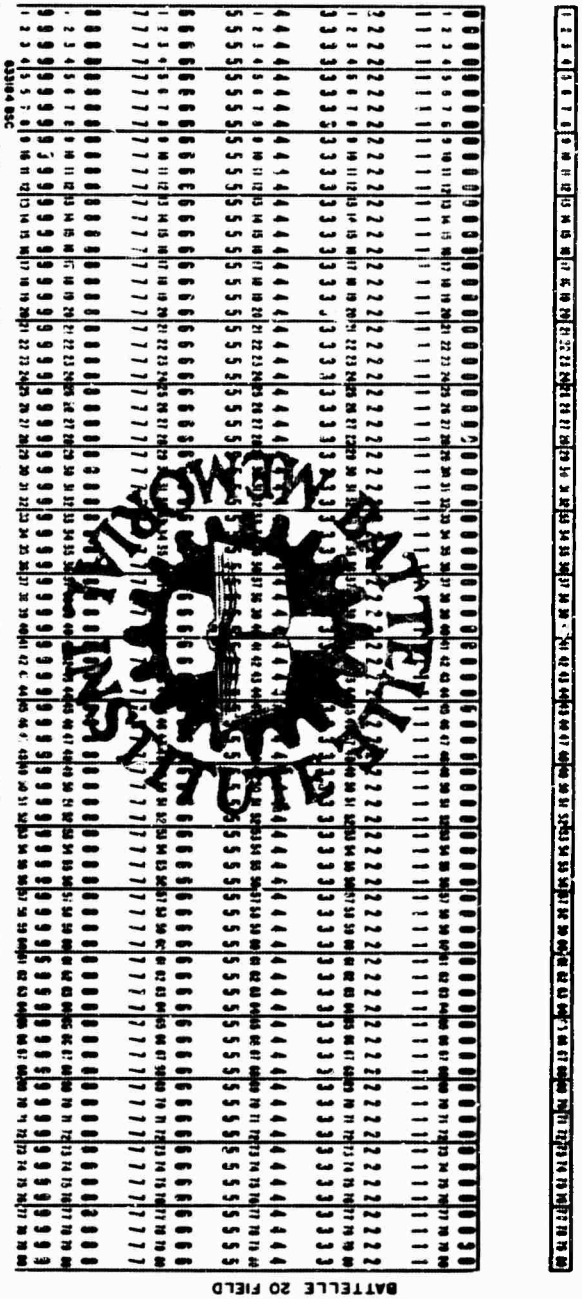

FIGURE 2. DATA CARD ARRANGEMENT FOR "YES" CASE

Columns 1 through 10 – the variable named RER. This is the real part of the index of refraction.

Columns 11 through 20 – the variable named RERP. This is the imaginary part of the index of refraction.

Columns 21 through 30 – the variable named ALMBT. This is the wavelength of the incident radiation and the initial value is given here. If these columns are left blank, it is assumed that the initial value is 0.2μ.

Columns 31 through 40 – the variable named RDD. This is the final value taken on by the wavelength of the incident radiation. If these columns are left blank, the final value is assumed to be 10μ.

Columns 41 through 50 – the variable named THETT. This is the increment used for stepping the wavelength of the incident radiation.

Columns 51 through 55 – the variable named NR. This term specifies the number of values of the variable named RAD, the radius of the spherical scatterer, that will be introduced.

Columns 56 through 60 – the variable named NT. This term specifies the number of values of the variable named THETA, the scattering angle, that will be introduced.

Columns 61 through 65 – the variable named KEY. For this case this variable is assigned the value of zero, KEY = 0.

Columns 66 through 70 – the variable named KTAPE. This term is given the value zero, KTAPE = 0, if no plots are desired. This term is given the value unity, KTAPE = 1, if the plot of $\$_\lambda(\theta)$ versus θ is desired.

Columns 71 through 80 – the variable named ALMBTP. If KTAPE = 0, these columns are not used. If KTAPE ± 0, the value of the wavelength is listed for which plots are to be made.

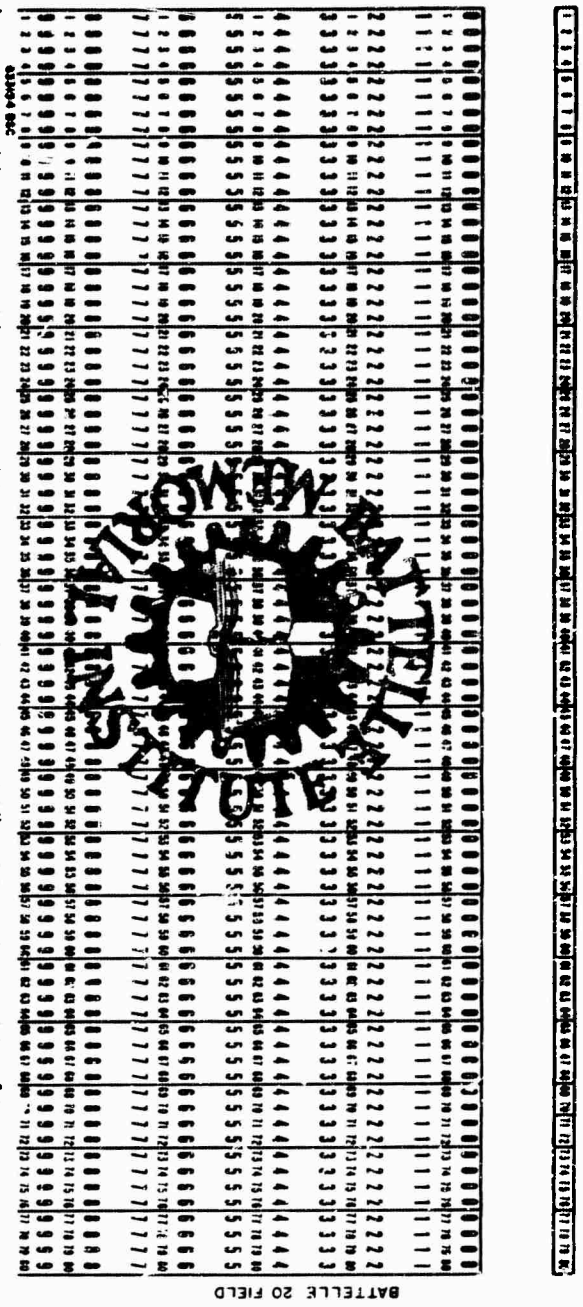

FIGURE 3. DATA CARD ARRANGEMENT – FIRST CARD – THE "NO" CASE

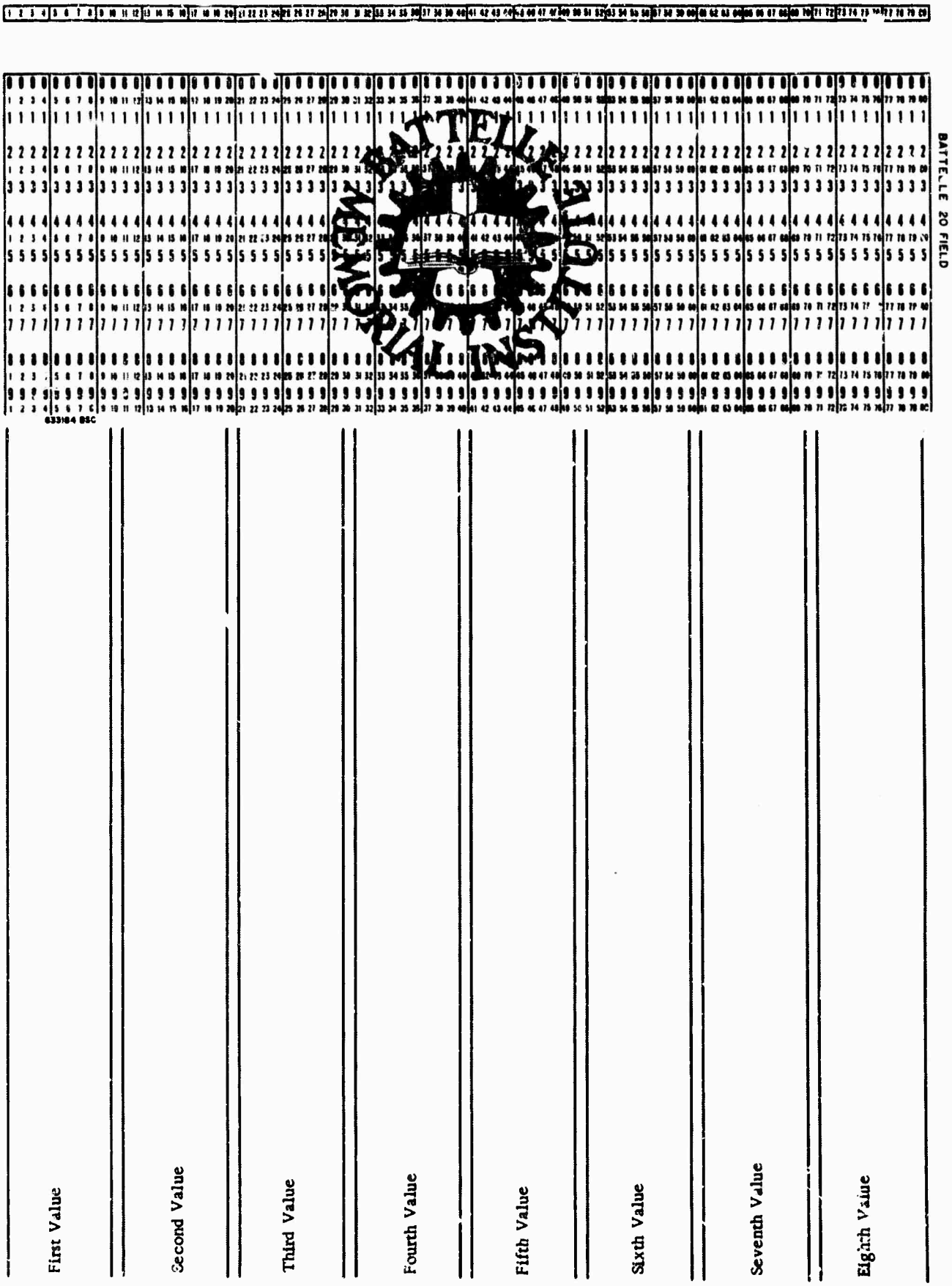

FIGURE 4. DATA CARD ARRANGEMENT - SECOND CARD - THE "NO" CASE. VALUES FOR THE RADIUS OF THE SPHERICAL SCATTERER.

The second card, Card Number 2, is used to introduce the values of the variable named RAD, the radius of the spherical scatterer, and the arrangement is shown in Figure 4. These are floating point variables so either an E10.x or an F10.x format may be used. The number of values introduced should be equal to the value assigned to the variable named NR, up to a maximum of twenty-one values. A maximum of three cards may be used to introduce these values, and the values may be distributed among these three cards in any convenient manner.

The third card, Card Number 3, is used to introduce the values of the variable named THETA, the scattering angle. The arrangement is the same as for the previous case as illustrated by Figure 4.

The Output Parameters

In deciding the printed output for this program, consideration was given particularly to the parameters that a user would need in making a physical application of the data. Obviously the input to each computation would be needed. Although, in principle, the user should have these parameters readily available since he specified the input data, experience demonstrated that having these parameters printed out on the data sheet by the computer was a great convenience. Hence, for each pair of a radius and an angle of scattering, the following are printed: Radius of Scatterer, Angle of Scattering, Complex Refractive Index, Initial Value of Wavelength, Final Value of Wavelength, and the Increment for the Wavelength.

Within the program, specific computation is made of the following parameters: Mie Number, First Electric Vector, Second Electric Vector, Scattering Efficiency, Phase Function, and Scattered Intensity. After considerable deliberation it was decided that for the pragmatic user, the investigator who needs only a working answer, only two of these, the Mie Number and the Scattered Intensity, are actually needed. Accordingly, the printout of results computed by this program was limited to these two parameters.

Plotting Option

Examining many data output tabulations and comparing these tabulations are rather burdensome, and often the comparisons must be plotted and studied further to bring a true understanding. In an effort to make such comparisons easier and more understandable, a plotting option was built into the program. Figure 5 shows the form of the output data as they were plotted directly by the computer.

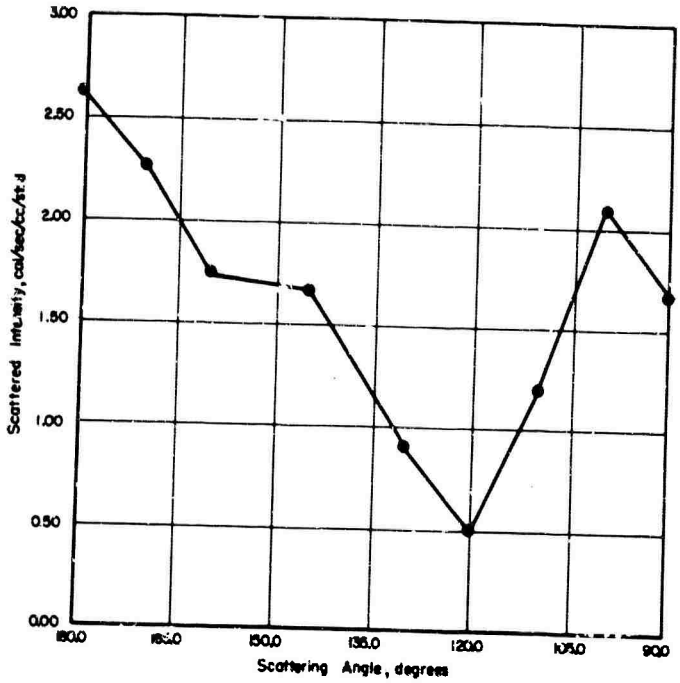

FIGURE 5. SCATTERED INTENSITY VERSUS SCATTERING ANGLE

BIBLIOGRAPHY

(1) van de Hulst, H. C., Light Scattering by Small Particles, John Wiley and Sons, Inc., New York, 1957.

(2) Stratton, Julius A., Electromagnetic Theory, McGraw-Hill Book Company, Inc., New York, 1941.

(3) Deirmendjian, D., and Clasen, R. J., "Light Scattering on Partially Absorbing Homogeneous Spheres of Finite Size", RAND Report No. R-393-PR, February 1962.

(4) Deirmendjian, D., "Tables of Mie Scattering Cross Sections and Amplitudes", RAND Report No. R-407-PR, January 1963.

(5) Stull, V. R., and Plass, G. N., "Emissivity of Dispersed Carbon Particles", Aeronutronic Division of Ford Motor Company, Journal of the Optical Society of America, 50 (2), February 1960.

(6) Hawksley, P. C. W., "The Physics of Particle Size Measurement, Part II – Optical Methods and Light Scattering", Review Series No. 114, The British Coal Utilization Research Association, Monthly Bulletin, XVI (4), April 1952.

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13. ABSTRACT

This report describes a study undertaken to provide quantitative data from which first-order estimates of the reflective power of chemically induced clouds could be made and to provide the means of making first-order estimates related to weapons effects in general. A computer program was developed that uses data consisting of the spectral distribution of the incident energy, the composition of the scatterer, and the size distribution of the scatterer to compute volumetric scattering intensity. Incorporated within the program is a plotting option by which the data may be portrayed graphically. This program is described, as is the application of radiant energy to fire spread, history of this study, and the history of the Mie problem.

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	ROLE	WT	ROLE	WT	ROLE	WT
programs (computers)	8,10					
spectral distribution	1					
incident energy	9					
compositions	1					
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distribution	1					
dimensions	9					
spectra	9					
computation	4,8					
intensity	2					
scattering	9					
volume	9					
volumetric scattering intensity	2					
applications	8					
radiation	9					
fire spread	4					
Mie problem	8,4					
estimation	4					
reflectivity	9					
clouds	2					
chemicals	1					