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X-RAY FLUENCE AND TRANSMISSION AND
PROMPT RADIATION FLUENCE OR DOSE

THESIS

AFIT/GNE/PH/81M-5 Donald E. Jones
Captain USAF

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X-RAY FLUENCE AND TRANSMISSION AND PROMPT RADIATION FLUENCE OR DOSE

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

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Captain USAF

Graduate Nuclear Engineering

March 1981

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Preface

Under the impression that the transmission of x-rays through the atmosphere had been exhaustively studied, I was suprised to find that there is very little written in the literature which deals with the subject. This paper deals with the fluence and transmission of x-rays and the fluence or dose of prompt radiation (neutroms and secondary gamma rays) and compares the results of the former with those results predicted by use of the Horizons Technology, Inc. (HTI) x-ray fluence and transmission program.

This thesis topic was one presented by Dr. Charles Bridgman of the faculty of the School of Engineering, Air Force Institute of Technology with the expressed intent of validating the results obtained using the HTI program by obtaining similar results using mass integral scaling and the build-up factor method.

I wish to thank Dr. Bridgman for his patience and help in getting me through the rough spots in this research. I also wish to express my thanks to my wife, Linda, and my children for the patience they showed me even when I had none for them.

Donald E. Jones

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Abstract

This report is to validate and evaluate a Horizons Technology, Inc. (HTI) TI-59 program written to calculate the free field x-ray fluence from a nuclear burst. In addition to this validation of an existing program, programs were written to compute mass integral and prompt radiation effects. X-ray transmission is calculated using a build-up factor method and is compared to results from the HTI program. Results are compared for black-body temperatures of 0.1, 1.0, and 10.0 keV and mass integrals from 10^{-6} to 50.0 gm/cm^2. The results compare well with a maximum error of approximately 21%. HTI's program has a minor problem as the transmission factor approaches zero so a TI-59 program is provided for use in that regime. A quick FORTRAN program is provided to calculate the fluence reaching a receiver. TI-59 and FORTRAN programs are given to calculate the mass penetrated and prompt radiation fluence or dose.

X-RAY FLUENCE AND TRANSMISSION AND

PROMPT RADIATION FLUENCE OR DOSE

I. Introduction

Background

The work reported here was motivated by a program written by Horizons Technology, Inc. (HTI) under contract to the Defense Nuclear Agency (contract number DNA 001-78-C-0247). This program, x-ray fluence and transmission (Ref.1), is one of a number of nuclear weapons effects programs developed by HTI. All of these programs use the Texas Instruments TI-59 hand-held programable calculator (Ref.2). The TI-59 stores and retrieves these programs on/from small magnetic cards.

The original purpose of the project was to evaluate the HTI x-ray fluence and transmission program. The evaluation was to be accomplished by comparing the HTI results to x-ray transmission factors computed using a build-up factor method. The build-up factors were calculated for infinite, homogeneous air using coefficients provided by G. Kalansky (Ref.3). As will be shown, the use of build-up factors amounts to applying the mass integral scaling approximation first described by Zerby (Ref.4) and recently studied by Shulstad (Ref.5). The mass integral scaling approximation has also been used by Murphy (Ref.6) and Eamon (Ref.7) to calculate free field neutron and secondary gamma fluences and/or doses from a nuclear burst. So, an extension of the project and the mass integral scaling technique led to a new program, not published by HTI, to calculate prompt radiation effects. Since both the existing HTI program and the build-up x-ray and prompt radiation programs require the mass integral as an input, a second new program was written to calculate the mass integral.

Purpose

The purpose of this work became threefold. The first part was to validate the HTI TI-59 x-ray flux and transmission program (Ref.1:9-1,13).

The second part of the purpose was to write a new program to calculate prompt radiation effects. Finally, a second new program was to be written to calculate the mass integral.

Method

The use of build-up factors to compute x-ray fluence and the transmission factor is developed in Chapter II. The build-up factor method (BU) is contrasted to HTI's method of calculation. The programs written for this project are described in Chapter III. Results of both methods are compared in Chapter IV. Chapter V discusses the work of Murphy and Eamon, with respect to neutrons and secondary gammas, and the new program which is provided. Chapter VI states the conclusions and recommendations of this work.

Assumptions

Two explicit assumptions are made in this work. They are

1. Kalansky's build-up factor coefficients are applicable (Ref.3).

2. The concept of mass integral scaling applies to x-rays and prompt radiation.

The assumptions are discussed later in the text.

II. Basic Principles

Theory

In this work, the HTI program is evaluated by comparing its predictions to results from an alternate prediction, the build-up factor (BU) method. Both methods use the same equation for fluence:

$$F = \frac{SfT}{4\pi r^2} \qquad (1)$$

where

F = fluence in calories per square centimeter

S = source yield in calories

T = transmission factor

r = distance from source to receiver in centimeters

f = x-ray fraction of the source yield

The only real difference between the BU method and the HTI model is in the calculation of the transmission factor, T. For this reason, a large portion of this work is devoted to the calculation of the transmission ceofficient by each model.

Transmission Factor for the BU Method

The BU method for calculation of the transmission factor, T , is based on mass integral scaling of x-ray transmission in a homogeneous atmosphere. Mass integral scaling, first suggested by Zerby (Ref.4) in 1956, is currently used for neutron and gamma ray transport in the Air Force Weapons Laboratory computer code SMAUG (Ref.6) and has recently been described by Shulstad (Ref.5). An explanation of mass integral scaling is given in Appendix A.

This work made use of build-up factor coefficients determined by Kalansky (Ref.3) to account for the increased number of x-rays reaching a receiver due to scattering. Kalansky did his x-ray transmission calculations using a moments method solution of the Boltzmann transport equation in an infinite, homogeneous atmosphere. His results are reported in the form of BUF as a function of mean-free-path with x-ray energy as a parameter.

If the build-up factors are known for all energies, they can be used to compute the transmission factor for a spectrum of x-ray energies by

$$T = \int_0^\infty P(h\nu) BUF(h\nu) \exp\{-[\mu/\rho]_{air}(h\nu) M.I.\} d(h\nu) \qquad (2)$$

where

$P(h\nu)$ = probability of an x-ray with energy between $h\nu$ and $h\nu + d(h\nu)$

$[\frac{\mu}{\rho}]_{air}(h\nu)$ = total mass attenuation coefficient for air for an x-ray with energy between $h\nu$ and $h\nu + d(h\nu)$

M.I. = mass integral = $\int_0^r \rho(r)\, dr$ which is the mass contained in a unit area tunnel of length, r, from source to receiver

BUF($h\nu$) = build-up factor for an x-ray with energy between $h\nu$ and $h\nu + d(h\nu)$

Since the integration of Eq.(2) would be difficult, if not impossible, to do analytically, it is usually solved by numerical integration. Eq.(2) can be rewritten in discrete energy space as

$$T = \sum_{g=1}^{G} P_g \, BUF_g \exp[-(\mu/\rho)^g_{air} \; M.I.] \tag{3}$$

where

G = total number of energy groups

P_g = probability of an x-ray energy within the limits of the group, g

$(\mu/\rho)^g_{air}$ = total mass attenuation coefficient for air for an x-ray energy within the limits of the group, g

BUF_g = BUF for an x-ray of energy within the limits of the group, g

If the groups are sufficiently narrow, one does not have to worry about what value of μ/ρ and BUF are appropriate for each group. Eq.(3) is used by the BU method.

<u>Group Probability</u>. The BU method assumes the source to be a perfect black-body radiator and that the source x-rays can be represented by a single normalized Planckian black-body spectrum. These normalized Planckian functions

are (Ref.8)

$$P(h\nu;T) = \frac{15}{(\pi kT)^4}\left[\frac{(h\nu)^3}{e^{h\nu/kT}-1}\right] \qquad (4)$$

where $P(h\nu;T)$ is the probability of an x-ray of energy $h\nu$ with a black-body temperature of kT keV . Determination of P_g in Eq.(3) can be made by integrating Eq.(4) over the energy range of each group (Ref.8)

$$P_g = \int_{h\nu_{g-1}}^{h\nu_g} \left[\frac{15}{(\pi kT)^4}\,\frac{(h\nu)^3}{e^{h\ /kT}-1}\right] d(h\nu) \qquad (5)$$

This integration allows the computation of a probability for each energy group being used. Equation (5) can be put in normalized form by first defining the dimensionless quantity, u , to be $u=h\nu/kT$. Then Eq.(5) can be rewritten as

$$P_g = \int_{u_{g-1}}^{u_g} \frac{15}{\pi^4}\left(\frac{u^3}{e^u-1}\right) du \qquad (6)$$

Evaluation of Eq.(6) can be accomplished by integration. reading values from a graph such as Figure 1 (Ref.8), or reading tables of the Planck function and its integral (Ref.9). In this work, the probability for each group is found by numerical integration over u using a box approximation to numerically calculate the integral. Note that due to the nature

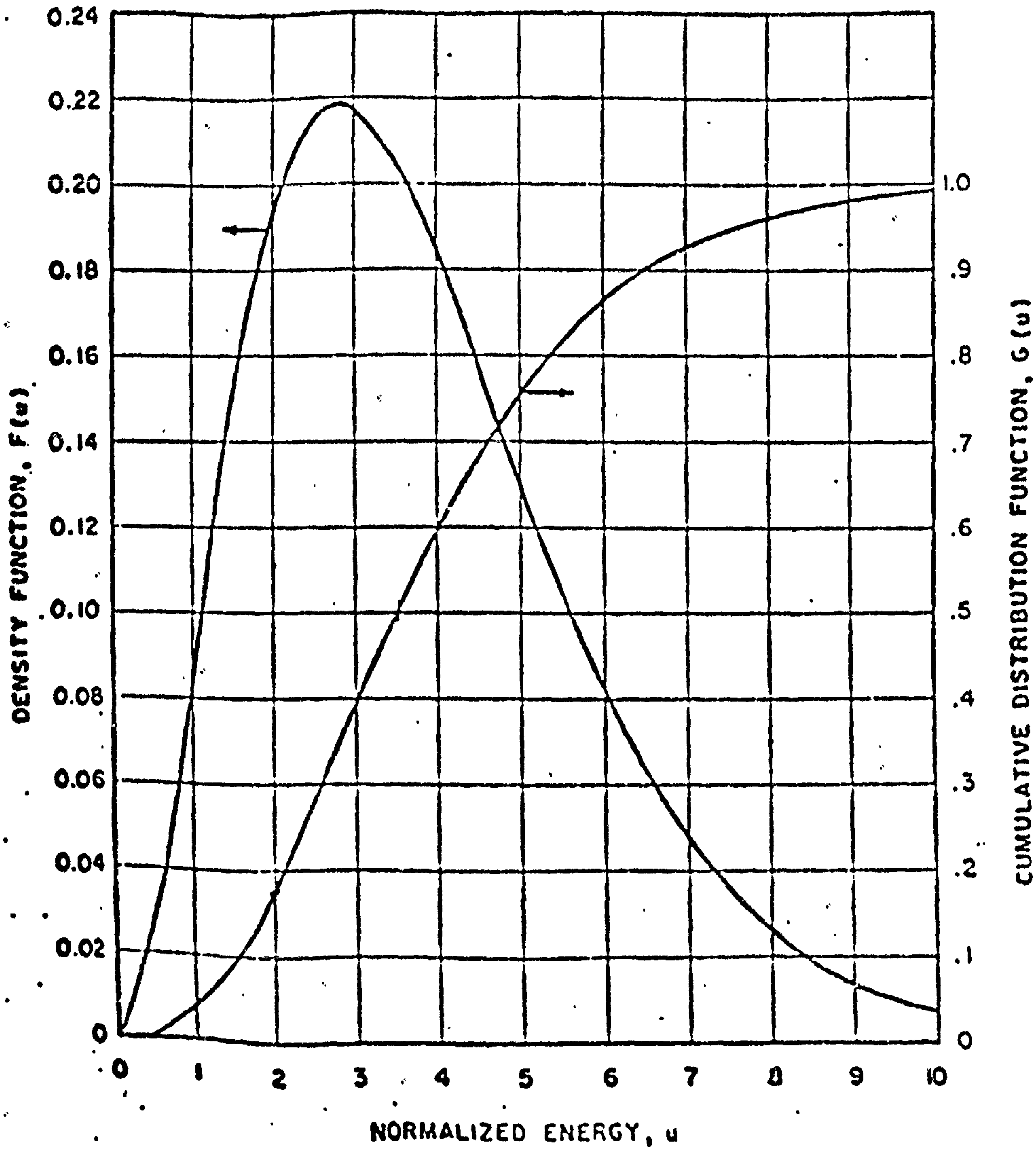

Figure 1. The Planck Function and Its Integral.(Ref.8)

of the Planckian function and u , one computation of the probability for each group is all that is required since the probability of energy group u_i is the same regardless of the temperature of the radiating body.

The computation of the probabilities for each group for the baseline program is accomplished in Subroutine PLANCK (Appendix C) using equal Δu .

Mass Attenuation Coefficient. The mass attenuation coefficients for air can be obtained from several sources (Refs8;10;11). The primary source used in this work is UCRL 50174, Compilation of X-ray Cross Sections (Ref.10). The data points which were used to generate the polynomial fit to the mass attenuation ceofficients are plotted as circles on Figure 2. The line in Figure 2 was generated using the fit coefficients given in Table I.

The mass attenuation coefficients were fit using a Laurent series polynomial fit in powers of $1/E$, where E is the x-ray energy. Fit coefficients, root-mean-square errors and plots of the fits were generated for powers of $1/E$ from two through six. The best fit is of fifth degree. The coefficients for the fifth degree fit are shown in Table I. This polynomial fit is plotted in Figure 2 along with the data points used to generate the fit.

The results of the mass attenuation coefficient fit are written into Subroutine MURHO for the baseline program (Appendix C).

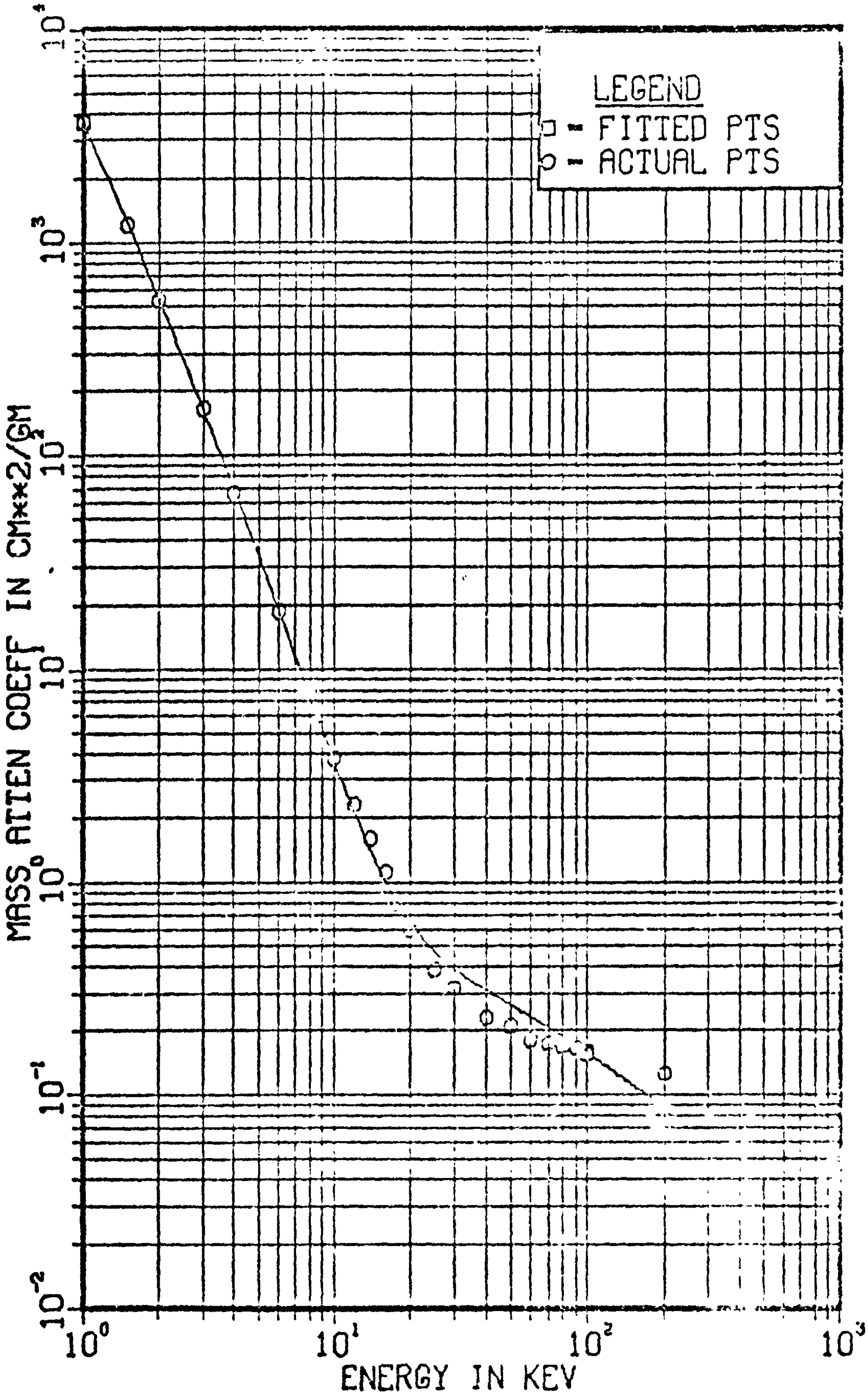

Figure 2. Mass attenuation coefficient for air.

TABLE I

Fit Coefficients for Polynomial Fit of Mass Attenuation Coefficients

Degree	Coefficient
constant	-.001354
$1/E$	19.7541
$1/E^2$	-461.7632
$1/E^3$	6680.0229
$1/E^4$	-3497.3643
$1/E^5$	907.3575

Mass Integral. The mass integral is the mass of air contained in a unit area tunnel between the source and the receiver. Mathematically, this is stated as

$$M.I. = \int_0^r \rho(r') \, dr' \tag{7}$$

where r is the slant range as defined in Figure 3. If the air is assumed to be exponentially varying in density according to the local pressure scale height, then

$$M.I. = \frac{1}{\sin\theta} \int_0^{z'} \rho(z_B) \exp\left[-z/H_B\right] \, dz' \tag{8}$$

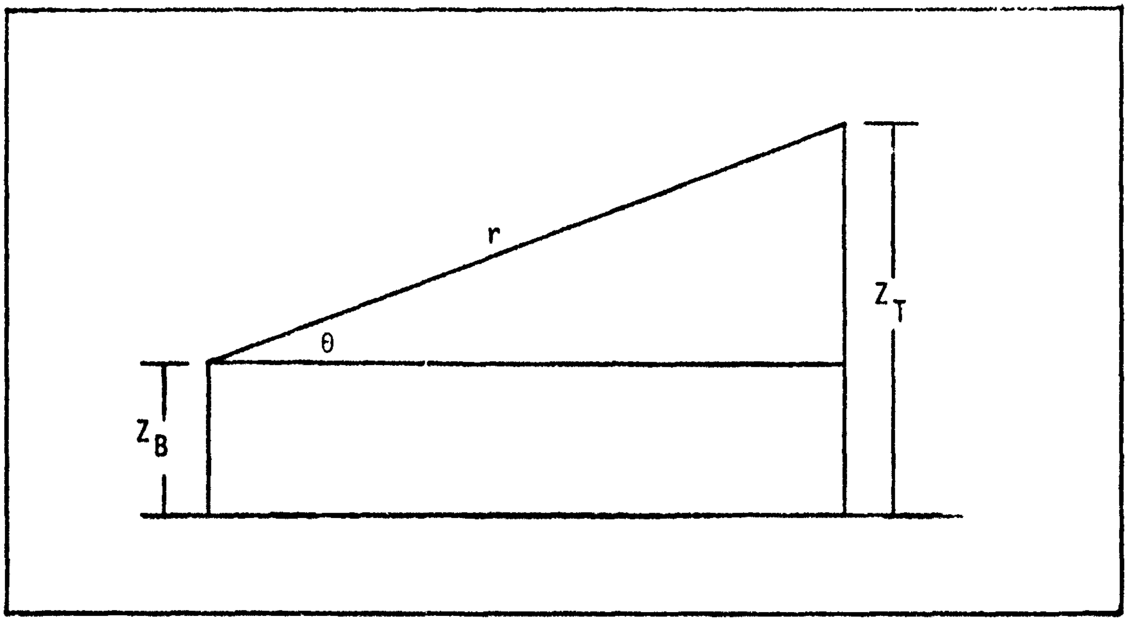

Figure 3. Definition of Mass Integral Variables. Z_B is the source height. Z_T is the receiver height, θ is the inclination of the receiver with respect to the source, and r is the slant range.

where

M.I. = mass integral

θ = as defined in Figure 4

$z = z_B - z_T$

$\rho(z_B)$ = density of air at the source height

H_B = scale height of atmosphere

z_B = source height

z_T = receiver height

The density and scale height can be obtained from U.S. Standard Atmosphere 1976 (Ref.12). Since z_B , z_T , and H_B are all in units of kilometers and ρ is usually in units of

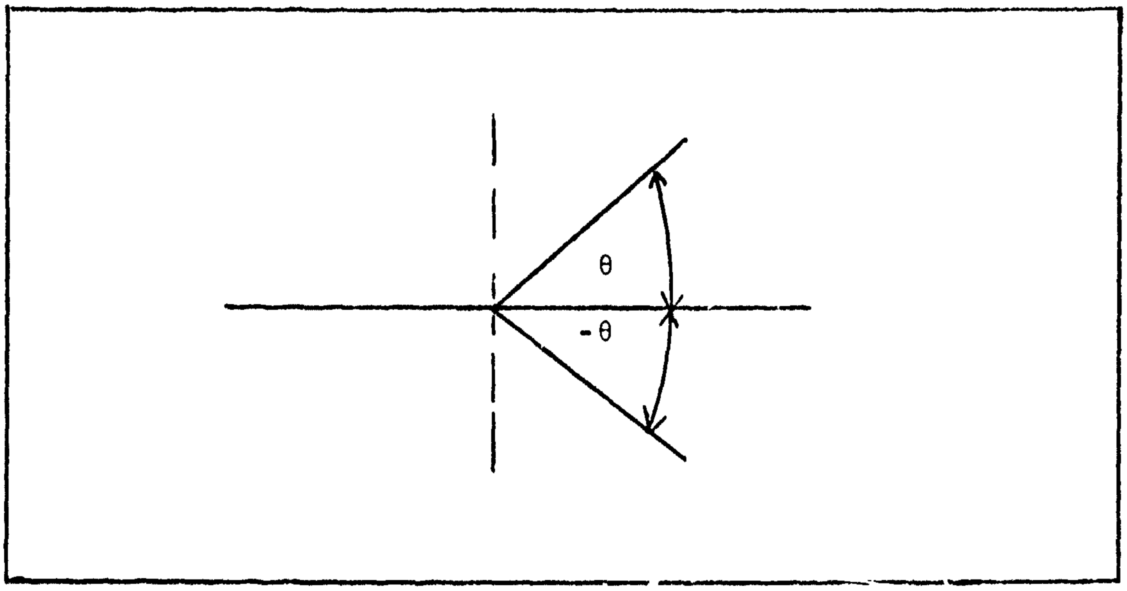

Figure 4. Angle Definition.

gm/m^3, a conversion factor must be used to get the mass integral in units of gm/cm^2.

Eq.(8) is directly integrable,

$$M.I. = \frac{-H_B}{\sin\theta}\,\rho(z_B)\left[\exp(-z'/H_B)-1\right] \tag{9}$$

Examination of Eq.(9) shows that the mass integral will always be positive since z' is negative whenever $\sin\theta$ is negative and positive when $\sin\theta$ is positive.

There is one area where Eqs.(8) and (9) cannot be applied. That is when the source and receiver are co-altitude which implies that $\sin\theta$ is zero and $1/\sin\theta$ is infinite. For the co-altitude case, another form of the mass integral must be used (Ref.8).

$$M.I. = \rho(Z_B)r \tag{10}$$

where r is the range from the source to the receiver.

Equations (9) and (10), with conversion factors to obtain the correct units for the mass integral, are written into Subroutine MASSI for the baseline program (Appendix C).

Build-up Factors. As previously stated, the BUF used in this paper are obtained from Kalansky (Ref.3). As Kalansky points out, Taylor (Ref.13) suggested the following equation for describing build-up factors:

$$B = A_1 \exp(C_1 y) + A_2 \exp(C_2 y) \tag{11}$$

where

B = build-up factor to account for the arrival of scattered x-rays at the receiver

y = number of mean-free-paths of source energy

$A_2 = 1 - A_1$

A_1, C_1, C_2 = constants determined from calculated BUF

Kalansky determined the constants A_1, C_1, and C_2 by fitting his moments calculated results (Ref.3). The coefficients Kalansky derived are tabulated in Appendix B which is a table extracted from Kalansky's work. When using this data to calculate BUF, interpolation of BUF, not Kalansky's coefficients, should be made when coefficients are not given for the exact energy of interest.

Final Form. With the previous factors in mind, Eq.(3) can be written in the final form used in the baseline program

$$T = \sum_{g=1}^{150} P_g \ BUF_g \ \exp\left[-(\mu/\rho)^g_{air} \ M.I.\right] \tag{12}$$

Baseline Program. All of the pieces described to this point are consolidated into the baseline program described and listed in Appendix C. Additionally, the baseline program is set-up to calculate the $4\pi R^2$ fluence. The program can be modified to calculate the fluence at a particular spatial position.

Limitations of BU Method. There are two factors which must be considered before applying the BU method to a particular problem. They are:

1. Kalansky's BUF consider mean-free-paths of up to 15. His fitted results did not converge to his calculated moments results beyond 15 mfp.
2. The BUF are based on infinite homogenous air and are then assumed valid in exponentially varying air by use of mass integral scaling. This assumption is only valid as long as the assumption of mass integral

scaling is valid. A literature search did not reveal that any research has been done to determine the applicability of mass integral scaling to the x-ray transmission problem. Therefore, at this point, little can be said about the applicability of the BU method.

Transmission Factor for the HTI Model

The HTI model used in its TI-59 program is an empirical fit to data extracted from another source (Ref.1). The HTI transmission factor equation is

$$T = f(x)\ B(x,\theta) \tag{13}$$

and

$$f(x) = \left[1 + 81.4\ \exp(1.86x)\right]^{-1} \tag{14}$$

$$B(x,\theta) = \left[A(x_0-x)-1\right]\exp\left[-\alpha(x_0-x)^2\right]+1 \tag{15}$$

$$x = \log_{10} \frac{M}{\theta^3} \tag{16}$$

where

M = mass integral

θ = black-body temperature

A, x_0, α = constants determined from the empirical fit (Ref.1: 9-5)

The exact origin of the above equations is not clear. The functions f and B are not defined other than by Eqs.(14) through (16). It appears that f(x) is the result of a fit applied to a family of curves in Ref.1 which were the transmission factor excluding build-up. Then B(x,θ) is the fit to the difference between f(x) and another family of curves in Ref.1 which do include build-up. Ref.1 is not completely clear on this either. If this surmise is correct, HTI is also using a form of build-up factor from an undefined original source. Thus, we may be merely comparing build-up factors in this validation, but there is no way of knowing that.

HTI's method allows a complicated program to be put into 479 program steps for the TI-59. That was no small feat as can be seen by comparing their program with the TI-59 program written for this report and covered later. However, there is a problem with the HTI program as the transmission coefficient approaches zero, say less than (0.01). The problem is that the empirical fit generated does not smoothly approach zero as would be expected but, instead, reaches zero earlier than predicted by the BU method and then returns to significant values which are higher than the values predicted by the BU method. This problem area will be discussed further in Chapter IV.

III. Solution by BU Method

Baseline Program

The baseline program developed in this work uses 150 normalized energy groups based on .1 increments of u . As previously pointed out, the Planckian probability need only be calculated once in the program since u does not change with changing black-body temperature. However, the average energy per group does change. For the baseline program, the average energy for each group is taken as the endpoint energy of each .1 increment of u . This usage would not be appropriate for a coarser grouping, but is suitable for the fine grouping.

The baseline program is written in the FORTRAN 5 computer programming language (Ref.14). The algorithms of Appendix D can be used to program into another computer language if desired.

The baseline program was written in a modular style to facilitate changing subroutines (Ref.15). For instance, if it is decided that the assumption of a Planckian spectrum for the source is inaccurate and another function better describes what is happening, then a subroutine employing the new function can be written to replace the subroutine, PLANCK, currently in use (Appendix C).

Program QUICK

In addition to the 150 group baseline program a program using ten energy groups rather than 150 groups was also written. This program was written to provide a fast, easy-to-use program for future users and to determine if the 150 group fine structure of the baseline program was really necessary. Each group is constructed to be of equal number density. A program listing for program QUICK is provided in Appendix E. The average energy for each group is taken as the energy at the mid-point probability for each group rather than the mid-point energy of each group. In reality, this is of importance only in the first and last energy groups. In those cases, using the mid-point of the probability group tends to weight the group towards those events of higher probability.

The program is set up so that both the mass integral and the black-body temperature are read in as data. The program can be modified to make use of the mass integral subroutine (MASSI) used in the baseline program (Appendix C). Appendix E describes how the data is to be input.

The results of program QUICK are compared to those of the baseline program and the HTI program in Chapter IV.

TI-59 Program

The TI-59 program written to calculate the x-ray fluence and transmission is similar to the FORTRAN QUICK program.

It is considerably longer and more difficult to use than the HTI TI-59 program. A program listing is given in Appendix F as well as instructions for its use. The program is actually two subprograms. The first is to calculate the mass integral. The second sub-program takes the output of the first and

1. computes the transmission coefficient for various groups excluding build-up,
2. then includes build-up in each group,
3. then computes the total transmission coefficient,
4. then calculates the $4\pi r^2$ fluence,
5. and, finally, calculates the fluence at a particular spatial distance.

Steps four and five are optional depending on what results the user desires.

One problem with the sub-programs is their length. To execute through step three requires 826 program steps. With a required partitioning of 639.39 (Ref.2), the length necessitates reading in four card sides and executing through step two, then reading in another card side and executing step three. To execute the entire program, excluding the mass integral calculation, requires 978 program steps and six sides of magnetic cards to be read in. This makes the program somewhat unwieldy, but the results compare well. See Chapter IV for the comparison.

IV. Results

Comparison of Results

The results to be compared are those obtained from

1. HTI TI-59 program
2. Baseline FORTRAN program
3. FORTRAN program QUICK
4. TI-59 QUICK program.

The results are best described by referring to the graphs in Figures 5, 6, and 7. The plots were generated using DISSPLA (Ref.16), which is a computer graphics package. For each plot, nine points were used for the 0.1 and 1.0 keV curves and 16 points were used for the 10.0 keV curve. Subroutine SPLINE (Ref.16) was used to smooth the curve. The curves all were generated with the mass integral on the x-axis, the transmission coefficient on the y-axis, and three black-body temperatures: 0.1, 1.0, and 10.0 keV. Other black-body temperatures were examined but not included to avoid cluttering the plots. The other temperatures examined followed the pattern shown in Figure 5.

The data used for comparison can be found in Table II.

Baseline with HTI. Figure 5 compares the results obtained using the BU method with those obtained from the HTI model. As can be seen, the results are comparable. The largest difference between the two is approximately 21% which occurs at a mass integral value of $10.0 gm/cm^2$ and a black-body temperature of 10.0 keV.

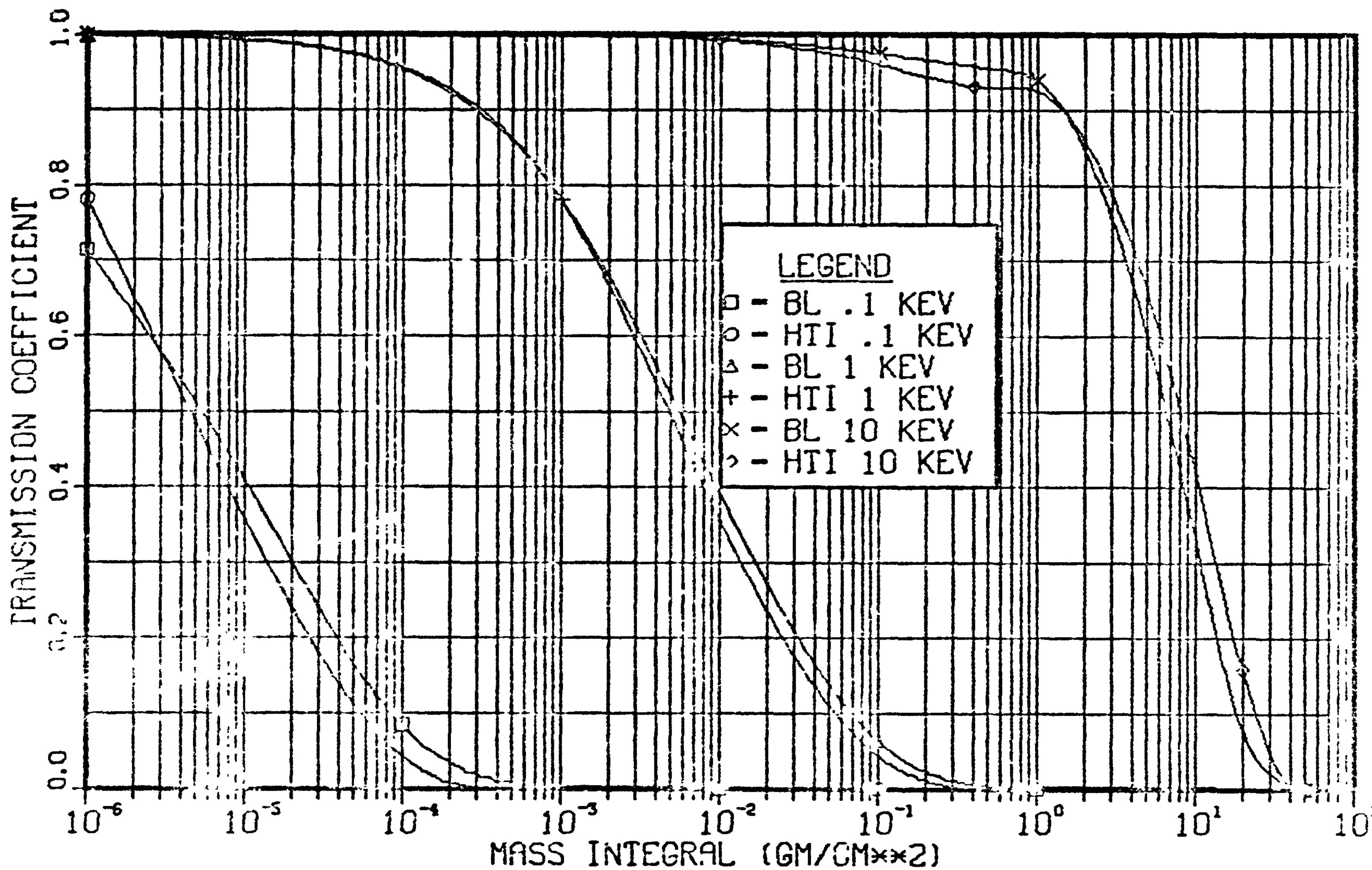

Figure 5. Comparison of baseline results with HTI results.

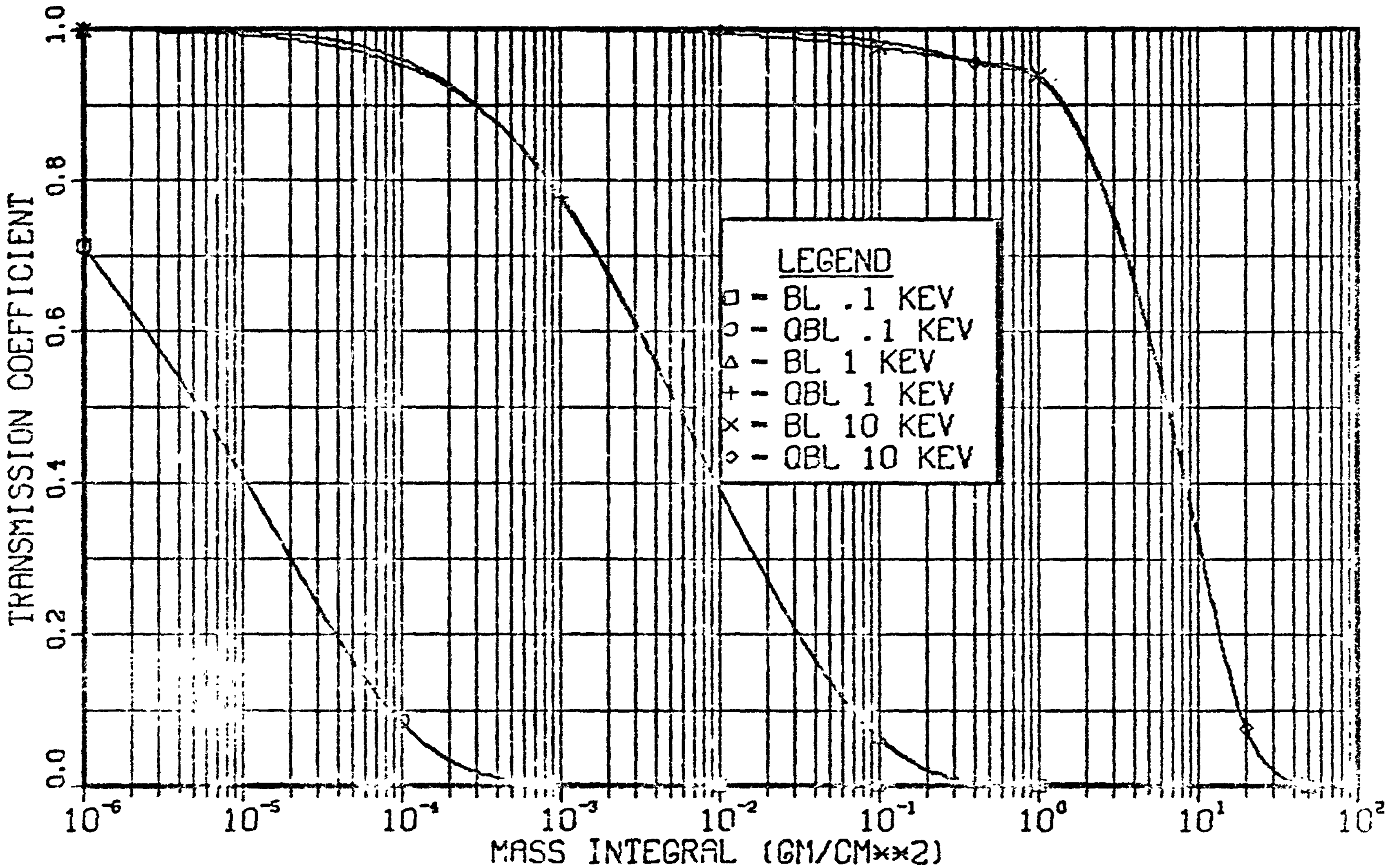

Figure 6. Comparison of program QUICK results with baseline results.

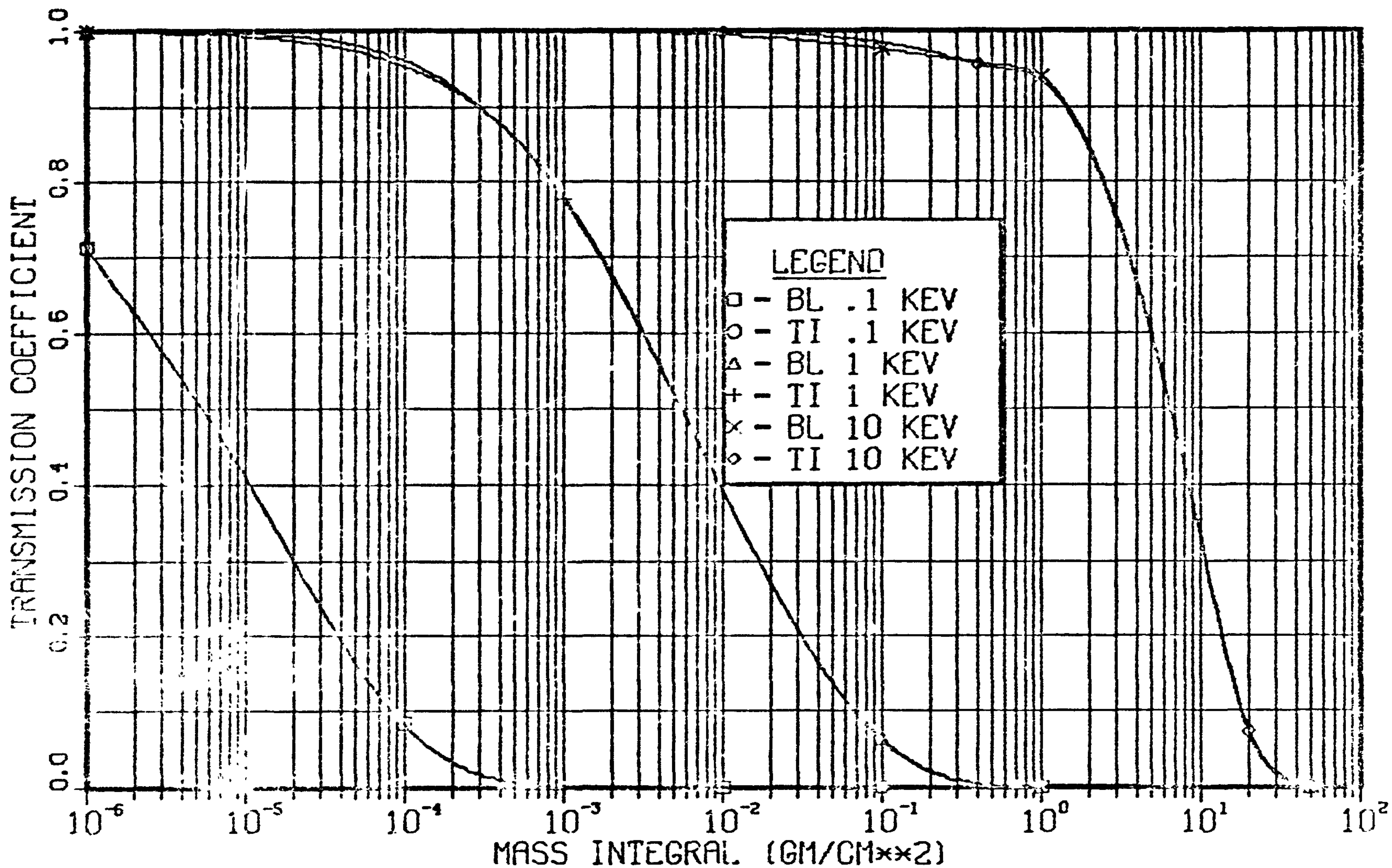

Figure 7. Comparison of TI-59 QUICK results with baseline results.

TABLE II

Comparison of Results for Various Mass Integral Values and Black-body Temperatures

Mass Integral (gm/cm^2)	Black-body Temperature (keV)	Transmission Factor			
		Baseline	HTI	QUICK	TI-59
1E-6 a	.1	.7127	.7824	.7110	.7110
1E-5	.1	.4101	.3585	.4096	.4096
1E-4	.1	.0825	.0483	.0807	.0807
1E-3	.1	9E-4	0.	7E-5	7E-5
1E-2	.1	9E-10	.0006	0.	0.
.1	.1	0.	.0003	0.	0.
1.	.1	0.	5E-5	0.	0.
10.	.1	0.	7E-6	0.	0.
50	.1	0.	2E-7	0.	0.
1E-6	1.	.9984	.9988	.9996	.9996
1E-5	1.	.9918	.9926	.9956	.9956
1E-4	1.	.9522	.9552	.9598	.9598
1E-3	1.	.7809	.7796	.7760	.7760
1E-2	1.	.3921	.3573	.3920	.3920
.1	1.	.0633	.0436	.0606	.0606
1.	1.	1E-4	0.	2E-5	2E-5
10.	1.	1E-9	.0006	0.	0.
50.	1.	0.	.0004	0.	0.
1E-6	10.	.9998	1.	1.	1.
1E-5	10.	.9998	1.	1.	1.
1E-4	10.	.9997	.9998	1.	1.
1E-3	10.	.9988	.9988	.9998	.9998
1E-2	10.	.9937	.9926	.9981	.9981
.1	10.	.9750	.9600	.9833	.9833
.2	10.	.9662	.9431	.9712	.9712
.3	10.	.9610	.9348	.9621	.9621
.4	10.	.9572	.9308	.9556	.9556
.5	10.	.9541	.9288	.9505	.9505
1.	10.	.9390	.9245	.9333	.9334
10.	10.	.3346	.4220	.3336	.3293
20.	10.	.0774	.1572	.0748	.0727
30.	10.	.0188	.0484	.0168	.0160
40.	10.	.0049	0.	.0038	.0036
50.	10.	.0014	0.	.0009	.0008

a 1E-6 = 1×10^{-6}

QUICK and the TI-59 Program with Baseline. Figures 6 and 7 compare the results of program QUICK FORTRAN and the TI-59 program written for this work, respectively, with the baseline FORTRAN program. The results are very close with a maximum error of less than 1%. The comparison shows that little is gained by using 150 energy groups rather than 10 energy groups as long as the groups are carefully chosen. This agreement was the reason QUICK was programmed for the TI-59 to see if it would be a better method than the existing algorithm.

Area of Concern

As mentioned in Chapter II, there is one potential problem with the original HTI program. The problem occurs as the transmission coefficient approaches zero and cannot be seen by reference to Figure 5. The data given in Table II shows the problem, namely that HTI's transmission factor reaches zero prematurely and then jumps back up to a value believed to be a little too high. The result of this is that the HTI program can show the fluence at a point to be zero when it actually may be a significant value. Also, just beyond this mass integral value, the program may give too high a value for the fluence. Table III shows one such sequence compared with the TI-59 results of this work.

Considering a x-ray source strength of 10^{12} calories (1 kiloton) and a black-body temperature of .1 keV, the HTI

TABLE III		
HTI Problem Area (kT = .1)		
Mass Integral	Transmission Factor	
	HTI	TI-59
1E-4 a	.0483	.0807
1E-3	0.	7E-5
1E-2	.0006	0.
.1	.0003	0.

a 1E-4 = 1×10^{-4}

program would predict a $4\pi r^2$ fluence of zero for a mass integral of 10^{-3}gm/cm^2 (receiver roughly 0.01 kilometers from the source at 50.0 kilometers altitude) while the BU method would predict a $4\pi r^2$ fluence of 6.9×10^7 calories. Roughly the opposite is true for a mass integral of 10^{-2}gm/cm^2. This example was for illustrative purposes only since, in this case, the receiver would be inside the fireball; however, it does demonstrate the problem area.

The problem is almost certainly the result of the empirical fit used by HTI to fit its curves. Again, there is no problem as long as the transmission coefficient is not close to zero, say not less than (0.01).

V. Prompt Effects

Background

Because of the greater number of interactions between source and receiver when neutrons and secondary gamma rays are considered, the method of build-up factors cannot be used for these radiations. However, the method of mass integral scaling has been used for prompt radiation using a one dimensional numerical solution of the Boltzmann transport equation in a homogeneous atmosphere as a starting point. That is, equation (2) is replaced by this solution. The method used was an anisotropic S-N calculation of the transport of a single source neutron with the energy distribution of a fission or fusion source. The calculation was done by Straker and Gritzner and first reported in ORNL 4464 (Ref.17). The results are presented as $4\pi r^2$ fluence or $4\pi r^2$ dose as a function of mass integral. A graphical example of these results is shown as Figure 8. This figure was extracted from Eamon's work (Ref.7).

Thus, in parallel with the x-ray treatment we have

$$4\pi r^2 F = ST \tag{17}$$

except that the $4\pi r^2$ fluence is given by a result like Figure 8 instead of by equation (1) through use of equation (2).

Murphy has provided a fit of the ANISN results of the form (Ref.6):

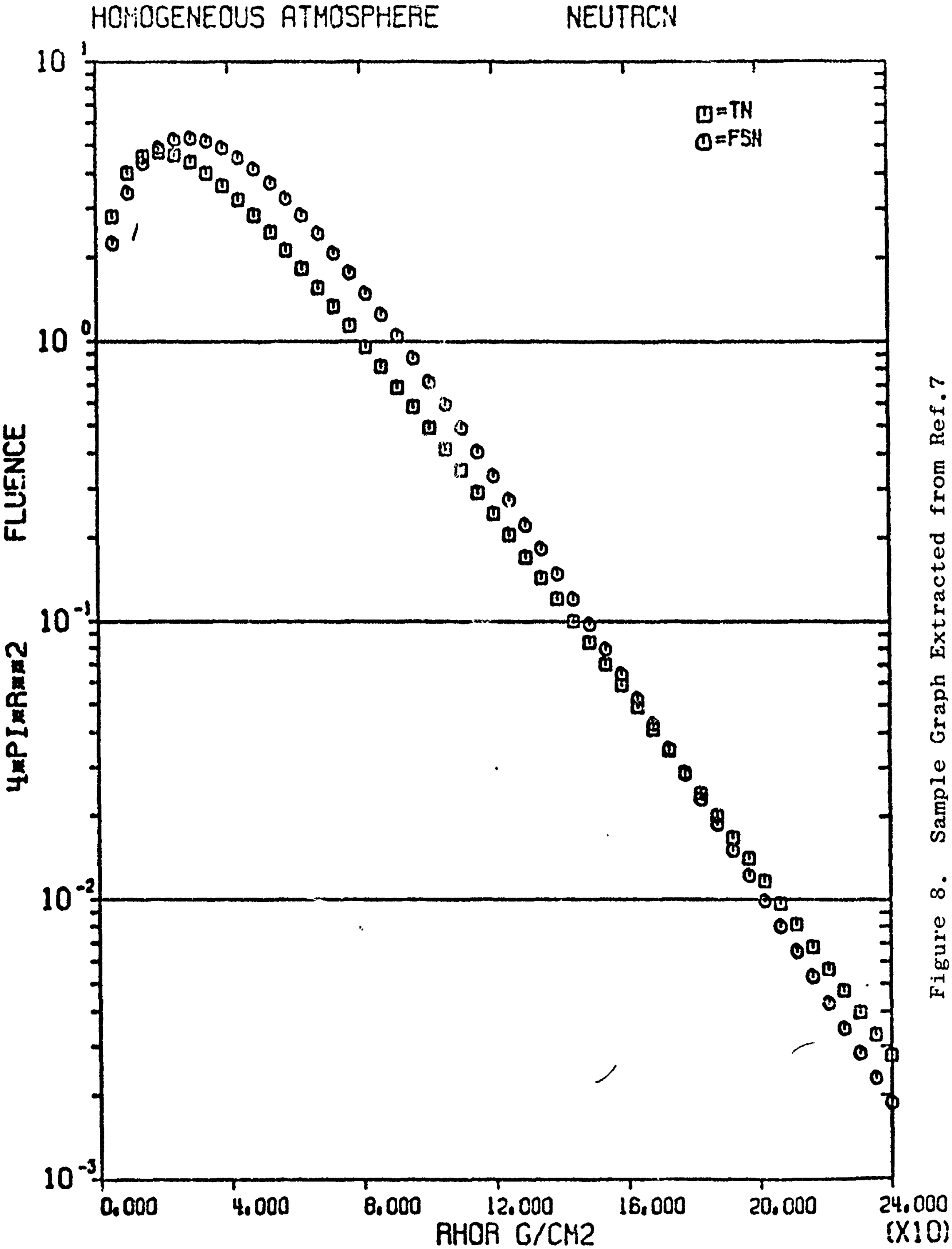

Figure 8. Sample Graph Extracted from Ref.7
TN is thermonuclear; FSN is fission.

$$F(x) = \exp(C_1+C_2X+C_3X^2+C_4X^{3/2}+C_5X^{1/2}+C_6X^{1/3}) \qquad (18)$$

where

$F(x) = 4\pi r^2$ dose or fluence

X = mass integral

C_i = empiric constants obtained through least squares fitting techniques

Eamon added one further coefficient of the form $C_7 \ln X$ inside the brackets (Ref.7) and provided the coefficients of fit to the neutron and secondary gamma transport ANISN code results (Ref.7). The coefficients of fit for differing doses and sources are in Table IV.

This method was programmed in both TI-59 logic and in FORTRAN 5. The TI-59 program and the FORTRAN 5 program appear in Appendix G.

Mass Integral Scaling

The applicability of mass integral scaling to the prompt radiation problem has been investigated by Shulstad (Ref.5). It was found that mass integral scaling was good for source altitudes between 1 and 10 kilometers (Ref.5); however, at higher altitudes, the results obtained could be as much as twice what is obtained using Shulstad's two-dimensional calculation. In a later study for the Air Force Weapons Laboratory, Kaman Sciences calculated the errors generated from 5 to 80 kilometers (Ref.7).

TABLE IV

ANISN HOMOGENEOUS AIR DATA

NEUTRONS

DOSE	SOURCE	A	B	C
Silicon	Thermonuclear	-.20795E+02	-.97296E-01	-.17913E-04
Tissue	Thermonuclear	-.19711E+02	-.98348E-01	-.22342E-04
Fluence	Thermonuclear	-.67751E+01	.52690E-02	-.54364E-05

DOSE	D	E	F	G
Silicon	.15771E-02	.17924E+01	-.32101E+01	.23746F+00
Tissue	.18226E-02	.13159E+01	-.15135E+01	-.84022E-02
Fluence	-.21468E-03	-.39214E+01	.10875E+02	-.13975E+01

SECONDARY GAMMAS

DOSE	SOURCE	A	B	C
Silicon	Thermonuclear	-.25281E+02	-.90163E-01	-.27961E-04
Tissue	Thermonuclear	-.25566E+02	-.79950E-01	-.24566E-04
Fluence	Thermonuclear	-.48600E+01	-.11511E+00	-.372675-04

DOSE	D	E	F	G
Silicon	.23939E-02	.95659E+00	-.11394E+01	.98116E+00
Tissue	.21001E-02	.65711E+00	-.57599E+00	.93271E+00
Fluence	.31732E-02	.13350E+01	-.13011E+01	.95495E+00

TABLE IV Continued

ANISN HOMOGENEOUS AIR DATA

NEUTRONS

DOSE	SOURCE	A	B	C
Silicon	Fission	-.21780E+02	-.16126E+00	-.46917E-04
Tissue	Fission	-.18463E+02	-.17636E+00	-.53973E-04
Fluence	Fission	.79627E+00	-.22572E+00	-.73701E-04

D	E	F	G
.38861E-02	.27024E+01	-.41190E+01	.21249E+00
.44464E-02	.28502E+01	-.40883E+01	.17644E+00
.61127E-02	.33426E+01	-.37018E+01	-.30794E-01

SECONDARY GAMMAS

DOSE		A	B	C
Silicon	Fission	-.26416E+02	-.16697E+00	-.56993E-04
Tissue	Fission	-.26313E+02	-.16462E+00	-.55756E-04
Fluence	Fission	-.57438E+01	-.16896E+00	-.55243E-04

D	E	F	G
.48224E-02	.26366E+01	-.35154E+01	.10916E+01
.47309E-02	.26300E+01	-.36007E+01	.11093E+01
.47643E-02	.25725E+01	-.33967E+01	.11089E+01

Results

Results of the TI-59 program written for this project are compared with results from Kaman Sciences (Ref.7) in Fig. 9. Plotted on Figure 9 is the $4\pi R^2$ fluence per source neutron as a function of mass integral. The circles are the points obtained from Kaman Sciences work (Ref.7) and, in this case, can also be read from the TN curve of Figure 8. The line is the fit to the points calculated using the TI-59 program. The differences are negligible.

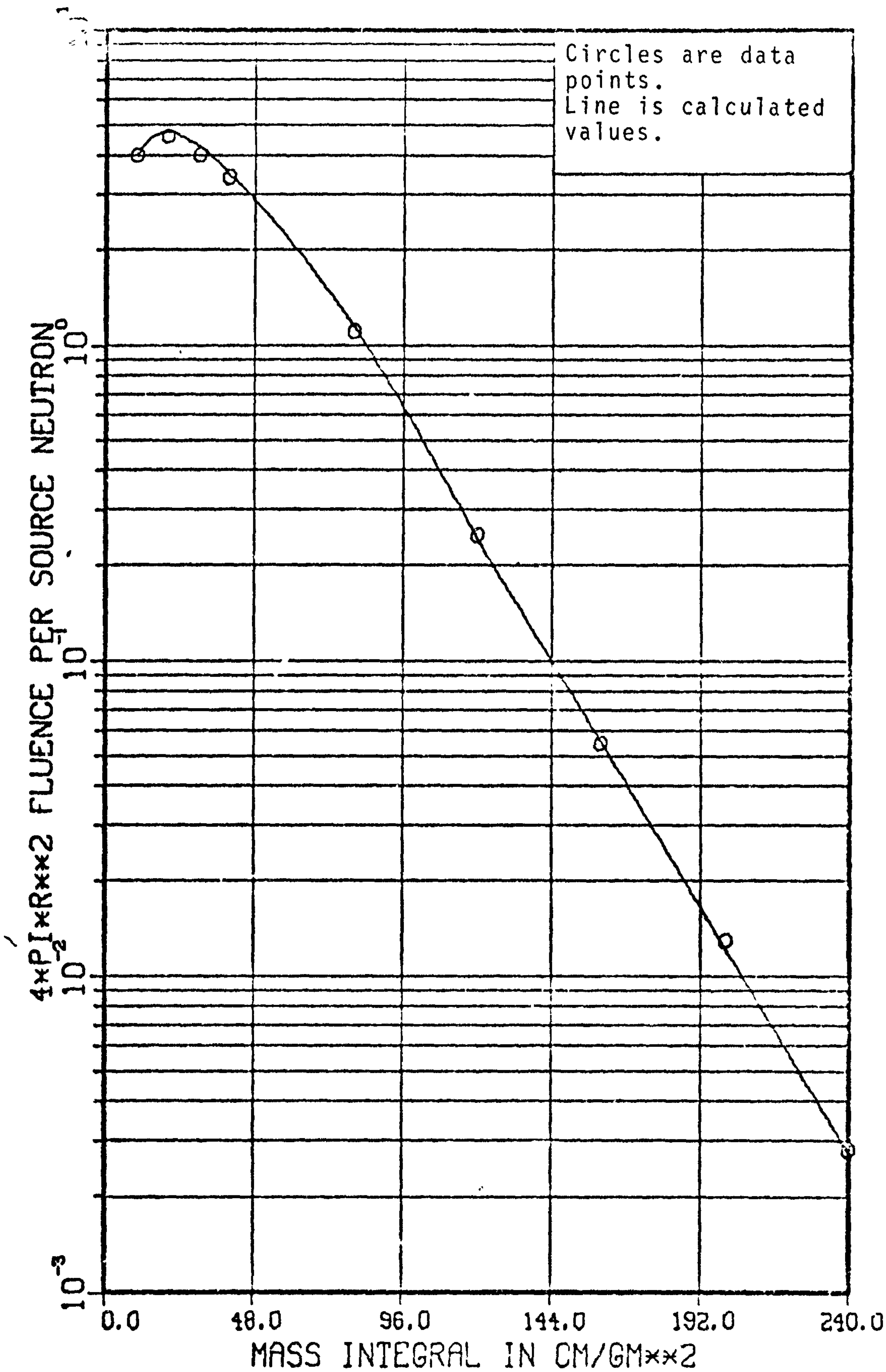

Figure 9. Comparison of TI-59 prompt radiation program results with those of Kaman Science (Ref.7).

VI. Conclusions and Recommendations

Conclusions

The HTI program compares well with the BU method as shown by Figure 5 with the exception of the problem area mentioned in Chapter IV.

Additional contributions of this project were programs to calculate prompt radiation and the mass integral. Such programs are not included by HTI (Ref.1); instead, the mass integral is left as an input variable with no direction as to how it is to be determined and prompt radiation is not examined.

Recommendations

There are two recommendations to be made. The first applies to future work. It is suggested that a study be undertaken to determine the validity of using mass integral scaling in the x-ray problem.

The second recommendation applies to the use of the HTI TI-59 program versus the use of the program written for this work. Due to the HTI program's ease of use, combined with results which are comparable, it is recommended that the HTI program be used to calculate the transmission coefficient and fluence as long as the transmission coefficient is not less than approximately (0.01). If the transmission coefficient is less than 0.01, then it is felt that the TI-59 program written for this work should be used to avoid the curve fitting problem.

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Appendix A: Mass Integral Scaling

The mass scaling law can be stated in the following manner (Ref.5): In an infinite homogeneous medium with an isotropic point source, the $4\pi r^2$ fluence is a function only of the density and range from source to receiver: $MI = \rho R$. An assumption must be made to allow the application of the mass scaling law to the actual case. The assumption made is that if the mass range between a source and a receiver in infinite homogeneous air is equal to the mass range in variable density air, then the $4\pi r^2$ fluences will be equal. That is, points from the infinite homogeneous air case will map directly to points in the variable density air case at identical mass integral values. For a derivation of the mass scaling law, see Shulstad (Ref.5:86-89).

While Shulstad (Ref.5) has examined mass integral scaling as it applies to neutrons and gamma rays, no references were found in the literature to the same type work being accomplished for x-rays.

Appendix B: Kalansky's Coefficients (Ref.3)

Energy in keV	A_1	A_2	c_1	c_2
12	-0.227	1.227	-0.400	0.000
14	-0.370	1.370	-0.400	0.000
16	-0.323	1.323	-0.680	0.020
18	-0.634	1.634	-0.460	0.020
20	-1.072	2.072	-0.360	0.020
22	-1.048	2.048	-0.480	0.040
24	-1.740	2.748	-0.340	0.040
26	-2.673	3.673	-0.260	0.040
28	-2.664	3.664	-0.300	0.060
30	-6.038	7.038	-0.140	0.040
32	-8.805	9.805	-0.100	0.040
34	-8.504	9.504	-0.100	0.060
36	-75.83	76.83	0.000	0.020
38	-20.03	21.03	-0.020	0.060
40	-16.94	17.94	-0.020	0.080
45	14.59	-13.59	0.120	-0.020
50	11.31	-10.31	0.160	-0.040
55	109.2	-108.2	0.120	0.100
60	-11.05	12.05	0.000	0.200
70	-114.1	115.1	0.140	0.160
80	-113.1	114.1	0.160	0.180
100	-10.93	11.93	0.060	0.260
120	-8.153	9.153	0.020	0.280
150	13.14	-12.14	0.260	0.100
200	-88.92	89.92	0.180	0.200
250	-6.308	7.308	0.000	0.260
300	19.89	-18.89	0.200	0.120
350	72.37	-71.37	0.160	0.140
400	-6.063	7.063	0.000	0.220
500	16.29	-15.29	0.120	0.080
600	-57.58	57.58	0.100	0.120
750	-17.20	18.20	0.060	0.120

Appendix C: Baseline Program Listing and Use

The baseline program, with all its subroutines, is listed on the next few pages. The program was written with future users in mind; that is, comments are provided as documentation to make the program easier to use. Additionally, Table V provides a list of the input variables and their units.

TABLE V

Variable	Representing	Units
K, A_1, A_2, C_1, C_2	Read in of Kalansky's data (Appendix B)	K in keV
N, NN, L	Dummy variables (see comments in program)	--
YLD	Yield of source	Kilotons
XF	X-ray fraction of source	--
XKT	Black-body Temperature	keV
RHO	Density of air at source altitude	gm/m
R	Distance from source to receiver	kilometers
ZB	Source height	kilometers
ZT	Receiver height	kilometers
HB	Scale height of atmosphere	kilometers
ANGLE	As defined in Figure 4	degrees
CM	Slant range from source to receiver	centimeters

```
      PROGRAM TRANS
      DIMENSION PG(0:150), PC(0:150)
      DIMENSION HNU(150),Z(0:150),Y(150),X(150),XMU(150)
      DIMENSION TG(0:150),BBB(150)
      DIMENSION B(150),TY(0:150),YY(0:150),YYY(150),BB(0:150)
      DIMENSION V(0:150),A(0:150),AAA(150)
      DIMENSION K(32),A1(32),A2(32),C1(32),C2(32)
C
C   READ IN BUILD-UP FACTORS FOR LATER USE.
C   SOURCE USED IN THIS WORK:  UNPUBLISHED
C   MASTERS THESIS, 'X-RAY BUILD-UP FACTORS',
C   KALANSKY, G.M.  AFIT, SCHOOL OF ENG,
C   DEC 1978.
C
      DO 2 I=1,32
         READ(*,*,END=999) K(I),A1(I),A2(I),C1(I),C2(I)
 2    CONTINUE
      CALL PLANCK(PG,PC)
      KK = 0
 10   CONTINUE
      KK = KK + 1
C
C   N IS USED TO TELL THE PROGRAM HOW THE
C   MASS INTEGRAL IS TO BE HANDLED.  N=1
C   IMPLIES THAT THE TARGET AND BURST ARE
C   CO-ALTITUDE.  N=2 IMPLIES THE MASS INT-
C   EGRAL VALUES ARE TO BE READ IN.  ANY
C   OTHER VALUE FOR N IMPLIES THE M.I. IS TO
C   BE COMPUTED AND THE TARGET AND BURST ARE
C   NOT CO-ALTITUDE.
C
C   NN IS USED TO TELL THE PROGRAM WHETHER
C   OR NOT TO CALCULATE THE 4 PI R**2 FLUENCE
C   (NN=1 IMPLIES CALCULATE).
C
C   IF L=0, THEN THE PROGRAM WILL NOT IN-
C   CLUDE BUILD-UP IN THE TRANSMISSION CO-
C   EFFICIENT CALCULATION.
C
      READ(*,*,END=999)N
      READ(*,*,END=999) NN
      READ(*,*,END=999) L
      CALL MASSI(N,XMI)
      IF(NN.EQ.1) THEN
         READ(*,*,END=999) YLD,XF
      ENDIF
C
C  THIS PORTION COMPUTES A MASS ATTENUATION COEFF FOR
C  EVERY ENERGY GROUP.  U=HNU/KT.
C  THIS PROGRAM IS SET UP TO USE
C  SEVERAL VALUES FOR BLACK BODY TEMP.
C  THE PROGRAM CAN BE MODIFIED TO READ
C  IN BLACK BODY TEMPS OF INTEREST.
C
```

```
      DO 300 LL=1,13
      IF(LL.EQ.1) THEN
         XKT = .1
      ELSE IF(LL.GT.1.AND.LL.LE.10) THEN
         XKT = XKT + .1
      ELSE IF(LL.GT.10) THEN
         XKT = LL - 9.
      ENDIF
      PRINT*,'BLACK BODY TEMP= ',XKT
      PRINT*, ' '
      U=.1
      DO 3 I=1,150
         HNU(I)=U*XKT
         U=U+.1
3     CONTINUE
      CALL MURHO(HNU,XMU)
      CALL MFP(XMI,XMU,X)
      IF(L.NE.0) THEN
      CALL BUF(HNU,B,IEOF,X,K,A1,A2,C1,C2,KK,BB,BBB,PG)
      IF(IEOF.EQ.0) GO TO 998
      ENDIF
      CALL TRNS(TY,YY,TG,Z,V,X,Y,PG,B,YYY,L)
      IF(NN.EQ.1) THEN
         CALL FLUENCE(TG(150),YLD,XF)
      ENDIF
      PRINT*,' '
      PRINT*,' '
300   CONTINUE
      GO TO 10
998   PRINT*,'ERROR:  END OF DATA AT IMPROPER TIME'
999   STOP
      END


      SUBROUTINE PLANCK(PG,PC)
      DIMENSION PG(0:150), PC(0:150)
      PG(0)=0.
      A=15./((ACOS(-1.))**4)
      PC(0)=0.
      U=.1
      DO 1 I=1,150
         PG(I)=A*(U**3)/(EXP(U)-1)
         PC(I)= ((PG(I)+PG(I-1))/2.)*.1
         U=U+.1
1     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MASSI(N,XMI)
C
C   IF N=1, READ IN THE DENSITY OF AIR AT
C   BURST HEIGHT IN GM/M**3 AND THE DISTANCE
C   FROM BURST TO TARGET IN KILOMETERS.
C
C   IF N=2, READ IN THE MASS INTEGRAL VALUES
C   IN GM/CM**2.
C
C   IF N NOT EQUAL TO 1 OR 2, THEN VALUES
C   MUST BE READ IN (IN ORDER) FOR:
C ----------------------------------------------------------------
C     ZB=HGT OF BURST (KM)
C     ZT=HGT OF TARGET (KM)
C     RHO=DENSITY AT ZB (GM/M**3)
C     HB=SCALE HGT OF ATMOSPHERE (KM)
C        (SOURCE:U.S. STANDARD ATMOSPHERE)
C     ANGLE=ANGLE BETWEEN HORIZONTAL AND
C              STRAIGHT LINE FROM BURST TO TGT
C              (DEGREES).  ANGLE IS MINUS IF
C              THE TGT IS LOWER IN ALTITUDE
C              THAN THE BURST.
C
      IF(N.EQ.2) THEN
         READ(*,*,END=998) XMII
         XMI = XMII
         PRINT*,'THE MASS INTEGRAL WAS AN INPUT VALUE'
         GO TO 50
      ENDIF
      IF(N.EQ.1) GO TO 40
      READ(*,*,END=998) ZB ,ZT ,RHO ,HB ,ANGLE
      PRINT*,'BURST ALT= ',ZB,'  TGT ALT= ',ZT,
     *'  DENSITY= ',RHO,'  SCALE HGT AT BURST= ',HB
      PRINT*,'ANGLE OF TGT FROM BURST= ',ANGLE
      ANGLE = ANGLE * .01745
      GO TO 41
 40   READ(*,*,END=998) RHO,R
      XMI=RHO*R/10.
      GO TO 50
 41   CONTINUE
      Z1=0.
      Z2=ZT-ZB
      XMI=(-HB)*(RHO)*(1000.)*(1.E-4)*(EXP(-Z2/HB)-1.)/
     *SIN(ANGLE)
 50   PRINT*,'THE MASS INTEGRAL IS ',XMI,' GM/CM**2'
      GO TO 51
 998  STOP 'END OF DATA IN MASSI AT WRONG TIME'
 51   RETURN
      END
```

```
      SUBROUTINE BUF(HNU,B,IEOF,X,K,A1,A2,C1,C2,N,
     *BB,BBB,PG)
      DIMENSION B(150),HNU(150),BB(0:150),BBB(150)
      DIMENSION K(32),A1(32),A2(32),C1(32),C2(32)
      DIMENSION X(150),PG(0:150)
      IF(HNU(150).LT.12) THEN
         DO 31 I=1,150
31       B(I) = 1.
         GO TO 35
      ENDIF
      N = 12
      DO 1 I=1,150
         IF(HNU(I).LT.12) GO TO 12
      IF(HNU(I).GT.750) GO TO 48
         DO 5 J=1,32
            IF(K(J).GE.HNU(I)) GO TO 3
            IF(K(J).LT.N) GO TO 5
            A11 = A1(J)
            A22 = A2(J)
            C11 = C1(J)
            C22 = C2(J)
            N = K(J)
5        CONTINUE
3        A = K(J) - N
         DD = HNU(I) - N
         D = DD / A
      BH = (A1(J)*EXP(X(I)*C1(J)))+ (A2(J)*
     *    EXP(X(I)*C2(J)))
      BL = (A11*EXP(X(I)*C11)) + (A22*EXP(X(I)*C22))
      B(I) = (BH - BL)*D + BL
         GO TO 10
12       B(I) = 1.
10       CONTINUE
1     CONTINUE
35    CONTINUE
      BUFF = 0.
      BB(0) = 0.
      DO 600 I=1,150
      BB(I) = B(I) + PG(I)
      BBB(I) = ((BB(I)+BB(I-1))/2.)*.1
      BUFF = BBB(I) + BUFF
600   CONTINUE
      PRINT*,'TOTAL BUF =  ',BUFF
      GO TO 50
49    IEOF = 0
      PRINT*,'ERROR:  END OF DATA AT IMPROPER
     *TIME IN BUF '
      GO TO 50
48     PRINT*,'HNU IS TOO LARGE FOR KALANSKYS
     *   BUILD-UP > 750'
 50   RETURN
      END
```

```
 SUBROUTINE TRANS(TY,YY,TG,Z,V,X,Y,
*PG,B,YYY,L)
 DIMENSION TY(0:150),YY(0:150),TG(0:150),
*Z(0:150),V(0:150),X(150),Y(150)
*,PG(0:150),B(150),YYY(150)
 TY(0) = 0.
 YY(0) = 0.
 TG(0)=0.
 Z(0)=0.
 V(0) = 0.
 DO 5 I=1,150
    Y(I)=EXP(-X(I))
    IF(Y(I).LT.1.E-20) Y(I)=0.
 YY(I) = PG(I) * Y(I)
 YYY(I) = ((YY(I) + YY(I-1))/2.)*.1
 TY(I) = YYY(I) + TY(I-1)
 IF(L.EQ.0) THEN
    Z(I) = Y(I) * PG(I)
 ELSE
 Z(I) = Y(I)*B(I)*PG(I)
 ENDIF
 V(I) = ((Z(I)+Z(I-1))/2.)*.1
 TG(I) = V(I) + TG(I-1)
5 CONTINUE
 IF(L.EQ.0) THEN
    PRINT*,'DIRECT TRANSMISSION COEFFICIENT= ',
*   TG(150)
 ELSE
    PRINT*,'TRANSMISSION COEFFICIENT= ',TG(150)
 ENDIF
 PRINT*,'INTEGRATED EXP ATTEN= ',TY(150)
 RETURN
 END
```

```
 SUBROUTINE MURHO(HNU,XMU)
 DIMENSION HNU(150),XMU(150)
 DO 1 I=1,150
 E = 1. / HNU(I)
 XMU(I) = -.0014+(19.7541*E)-(461.7332*E**2)+
*(6680.0228*E**3)-(3497.3343*E**4)
*   +(907.3575*E**5)
1 CONTINUE
 RETURN
 END
```

```
      SUBROUTINE MFP(X,XMU,XMI)
      DIMENSION X(150),XMU(150)
C
C    COMPUTES MEAN FREE PATH FOR VARYING
C    X-RAY ENERGIES.
C
C    IF X IS > 100, THE NEGATIVE EXPONENTIAL
C    OF X RESULTS IN AN UNDERFLOW.  THEREFORE,
C    X IS JUST SET TO 100 IF IT EXCEEDS 100.
C
      DO 6 I=1,150
         X(I)=XMU(I)*XMI
         IF(X(I).GT.100) X(I)=100.
  6   CONTINUE
      RETURN
      END



      SUBROUTINE FLUENCE(TRANS,YLD,XF)
      XYLD = YLD * XF
      PRINT*,'X-RAY YIELD IN KILOTONS= ',XYLD
      YLDD = XYLD * 1.E12
      FL = YLDD * TRANS
      PRINT*,'4 PI R**2 FLUENCE= ',FL
      RETURN
      END
```

Appendix D: Algorithm

The intent of this appendix is to provide the user with an algorithm which can be programmed into any suitable computer language. The algorithm is based on the numerical integration of Eq.(12) with the involved factors properly calculated. Proceed as follows:

1. Decide whether mass integral values are to be input or calculated. If input, proceed to step two. If calculated, use either Eq.(9) or (10) as the case dictates. Density and scale height can be found in Ref.12 and source height, receiver height, and theta or range should be provided by the problem definition.

2. Determine the probability of each group using

$$P_g = (15/\pi^4)\left[\frac{u^3}{e^u-1}\right] \tag{19}$$

   Store the results. For the baseline program, u was between 0 and 15, inclusive, and was incremented by 0.1 for each group.

3. Input the Planckian black-body temperature. Determine the energy of each group by

$$(h\nu)_g = u_g * kT \tag{20}$$

   Store for future use.

4. Calculate the mass attenuation coefficient for each

group using

$$E_g = 1/(h\nu)_g \tag{21}$$

$$(\mu/\rho)_g = -.0014+(19.7541*E_g)-(461.7632*E_g^2) +(6680.0229*E_g^3)-(3497.3643*E_g^4) +(907.3575*E_g^5) \tag{22}$$

Store each as it is calculated.

5. Calculate the mean-free-path for each group.

$$(MFP)_g = (\mu/\rho)_g*M.I. \tag{23}$$

Store the results.

6. Input Kalansky's build-up coefficients. Calculate the build-up factor for each group.

   a. If $(h\nu)_g$ is less than 12 keV, then set $(BUF)_g$ equal to 1.0 .

   b. If $(h\nu)_g$ is greater than 750 keV, stop. Kalansky's coefficients are not valid above 750 keV.

   c. If $(h\nu)_g$ is greater than 12 keV and less than 750 keV, interpolate for $(BUF)_g$ between given energies for which Kalansky provides coefficients. Note: Interpolate between BUF not coefficients. As used below, h = high and l = low .

$$(BUF)_h = (A_1)_h \exp\left[(C_1)_h (MFP)_g\right] + (A_2)_h \exp\left[(C_2)_h (MFP)_g\right] \tag{24}$$

and

$$(BUF)_l = (A_1)_l \exp\left[(C_1)_l (MFP)_g\right] + (A_2)_l \exp\left[(C_2)_l (MFP)_g\right] \tag{25}$$

$$(h\nu)_T = (h\nu)_h - (h\nu)_\ell \tag{26}$$

$$(h\nu)_P = (h\nu)_g - (h\nu)_\ell \tag{27}$$

$$(BUF)_g = \left[(BUF)_h - (BUF)_\ell\right] * \left[(h\nu)_P / (h\nu)_T\right] + (BUF)_\ell \tag{28}$$

Store the results.

7. Calculate the transmission factor, first for each group, then sum. This step makes use of the previous six steps.

$$Y_g = \exp\left[-MFP_g\right] \tag{29}$$

$$(Trans)_g = P_g * Y_g * (BUF)_g \tag{30}$$

Finally, integrate and sum. The baseline program uses a box approximation to evaluate the integral.

$$\text{Trans} = \sum_{g=1}^{G} \left\{ \left\{ \left[(\text{Trans})_g + (\text{Trans})_{g-1} \right] / 2 \right\} * .1 \right\} \tag{31}$$

8. The $4\pi r^2$ fluence is found by multiplying Eq.(31) by the x-ray fource strength in calories, XS.

$$4\pi r^2 \text{ fluence} = \text{XS*Trans} \tag{32}$$

9. Finally, the fluence is found by

$$\text{Fluence} = \frac{\text{XS*Trans}}{4\pi r^2} \tag{33}$$

where r is the distance from the source to the receiver of interest in centimeters.

Appendix E: Program QUICK Listing

As previously explained, program QUICK is a FORTRAN program which uses 10 equi-probability groups rather than 150 equal energy spacing groups. Program QUICK is designed to be quick running and simple. A program listing is provided on the next two pages. For convenience, Kalansky's coefficients are read in as the first piece of data in the program since an interactive computer system was used to facilitate program modification. The coefficients could be put in DATA (Ref.14) statements if so desired.

All factors should be easily identifiable with the possible exceptions of A, XMI, XKT, YLD, XF, and CM. They are

A - the mid-probability value of u for each group

XMI - the mass integral

XKT - the Planckian black-body temperature

YLD - yield in kilotons

XF - x-ray fraction of YLD

CM - range from source to receiver in centimeters

Program QUICK is written with the mass integral as an input; however, it could be modified to compute the mass integral using subroutine MASSI (Appendix C).

```
      PROGRAM QUICK
      DIMENSION A(10),K(32),A1(32),A2(32),C1(32)
      DIMENSION C2(32),HNU(10),XMU(10),X(10),B(10)
      DIMENSION Y(0:10),TG(0:10)
      DO 1 I=1,32
         READ(*,*,END=999)K(I),A1(I),A2(I),C1(I),C2(I)
  1   CONTINUE
      DATA A/1.1,1.8,2.35,2.8,3.25,3.75,4.3,5.,5.9,7.7/
      READ(*,*,END=999)XMI,XKT,YLD,XF,CM
      DO 2 I=1,10
         HNU(I) = A(I) * XKT
         E = 1. / HNU(I)
         XMU(I) = -.0014 + (19.7541*E) - (461.7632*
     *         E*E) + (6680.0229*E**3) - (3497.3643
     *         *E**4) + (907.3575*E**5)
         X(I) = XMU(I) * XMI
         IF(X(I).GT.100) X(I) = 100.
         Y(I) = EXP(-X(I))
  2   CONTINUE
      IF(HNU(10).LT.12) THEN
         DO 3 I=1,10
  3         B(I) = 1.
         GO TO 10
      ENDIF
      N = 12
      DO 4 I=1,10
         IF(HNU(I).LT.12) GO TO 11
         IF(HNU(I).GT.750) GO TO 99
         DO 5 J=1,32
            IF(K(J).GE.HNU(I)) GO TO 6
            IF(K(J).LT.N) GO TO 5
            A11 = A1(J)
            A22 = A2(J)
            C11 = C1(J)
            C22 = C2(J)
            N = K(J)
  5      CONTINUE
  6      AA = K(J) - N
         DD = HNU(I) - N
         D = DD / AA
         BH = (A1(J)*EXP(X(I)*C1(J))) + (A2(J)
     *       *EXP(X(I)*C2(J)))
         BL = (A11*EXP(X(I)*C11)) + (A22*EXP(X(I)
     *       *C22))
         B(I) = (BH - BL)*D + BL
         GO TO 9
  11     B(I) = 1.
  9      CONTINUE
  4   CONTINUE
  10  CONTINUE
```

```
      Y(0) = 0.
      TG(0) = 0.
      DO 7 I=1,10
         IF(Y(I).LT.1.E-20) Y(I) = 0.
         Y(I) = Y(I) *  .1 * B(I)
         TG(I) = Y(I) + TG(I-1)
 7    CONTINUE

      XYLD = YLD * XF
      YYLD = XYLD * 1.E12
      FL = YYLD * TG(10) /(4.*ACOS(-1.)*(CM*CM))
      PRINT*,'FOR A BLACK BODY TEMPERATURE OF ',XKT,' KEV,
     * A MASS PENETRATED OF ',XMI,' GM/CM**2, A WEAPON
     * YIELD OF ',YLD,' KILOTONS, A X-RAY FRACTION OF '
     *,XF,' AND A DISTANCE FROM BURST TO TARGET OF ',
     *CM,' CM, THE TRANSMISSION COEFFICIENT IS ',TG(10)
     *,' AND THE FLUENCE IS ',FL
      GO TO 1
 99   PRINT*,'HNU IS TOO LARGE FOR KALANSKYS BUF- > 750'
 999  STOP
      END
```

Appendix F: TI-59 Programs

Comments

The program listings provided on the next nine pages are those written during this research to calculate the transmission factor, $4\pi r^2$ fluence, and fluence at a particular point using the TI-59. For a recommendation on when to use this group of programs, see Chapter VI.

The program listed on page 55 is to calculate the mass integral. Such a program is not provided in HTI's work. The program on pages 56 through 60 is to calculate the transmission factor for each group. The program is not complete by itself. It needs at least a portion of the program (the first 186 steps) on pages 61 through 63 to determine the transmission factor for the situation being investigated. The other portions of the program listed on pages 61 through 63 are to compute the $4\pi r^2$ fluence and the fluence at a particular point.

Because the use of the TI-59 programs provided in this work is somewhat cumbersome, instructions for their use are provided.

Instructions for Use

Note: Partitioning is 639.39 for all TI-59 programs written for this work (Ref.2).

1. If mass integrals are already known, skip to step two. If not, read in the one card side

Mass Integral Program

```
000  76  LBL
001  11   A
002  91  R/S
003  42  STO
004  01   01
005  91  R/S
006  42  STO
007  02   02
008  53   (
009  53   (
010  43  RCL
011  01   01
012  65   x
013  43  RCL
014  02   02
015  54   )
016  55   ÷
017  01   1
018  00   0
019  54   )
020  42  STO
021  01   01
022  92  RTN
023  76  LBL
024  12   B
025  91  R/S
026  42  STO
027  01   01
028  91  R/S
029  42  STO
030  02   02
031  91  R/S
032  42  STO
033  03   03
034  91  R/S
035  42  STO
036  04   04
037  91  R/S
038  42  STO
039  05   05
040  91  R/S
041  00   0
042  42  STO
043  06   06
044  53   (
045  43  RCL
046  02   02
047  75   -
048  43  RCL
049  01   01
050  54   )
051  42  STO
052  01   01
053  53   (
054  43  RCL
055  05   05
056  38  SIN
057  65   x
058  01   1
059  00   0
060  54   )
061  42  STO
062  05   05
063  53   (
064  43  RCL
065  04   04
066  94  +/-
067  65   x
068  43  RCL
069  03   03
070  54   )
071  42  STO
072  03   03
073  53   (
074  53   (
075  53   (
076  43  RCL
077  01   01
078  94  +/-
079  55   ÷
080  43  RCL
081  04   04
082  54   )
083  22  INV
084  23  LNX
085  54   )
086  75   -
087  01   1
088  54   )
089  42  STO
090  01   01
091  53   (
092  53   (
093  43  RCL
094  03   03
095  65   x
096  43  RCL
097  01   01
098  54   )
099  55   ÷
100  43  RCL
101  05   05
102  54   )
103  42  STO
104  01   01
105  92  RTN
```

Transmission Factor: First Part

```
000  76  LBL
001  12  B
002  43  RCL
003  37  37
004  69  OP
005  04  04
006  43  RCL
007  01  01
008  69  OP
009  06  06
010  69  OP
011  00  00
012  43  RCL
013  38  38
014  69  OP
015  02  02
016  43  RCL
017  39  39
018  69  OP
019  03  03
020  69  OP
021  05  05
022  91  R/S
023  42  STO
024  02  02
025  53  (
026  43  RCL
027  02  02
028  65  ×
029  01  1
030  93  .
031  01  1
032  54  )
033  71  SBR
034  33  X²
035  42  STO
036  03  03
037  53  (
038  43  RCL
039  02  02
040  65  ×
041  01  1
042  93  .
043  08  8
044  54  )
045  71  SBR
046  33  X²
047  42  STO
048  04  04
049  53  (
050  43  RCL
051  02  02
052  65  ×
053  02  2
054  93  .
055  03  3
056  05  5
057  54  )
058  71  SBR
059  33  X²
060  42  STO
061  05  05
062  53  (
063  43  RCL
064  02  02
065  65  ×
066  02  2
067  93  .
068  08  8
069  54  )
070  71  SBR
071  33  X²
072  42  STO
073  06  06
074  53  (
075  43  RCL
076  02  02
077  65  ×
078  03  3
079  93  .
080  02  2
081  05  5
082  54  )
083  71  SBR
084  33  X²
085  42  STO
086  07  07
087  53  (
088  43  RCL
089  02  02
090  65  ×
091  03  3
092  93  .
093  07  7
094  05  5
095  54  )
096  71  SBR
097  33  X²
098  42  STO
099  08  08
100  53  (
101  43  RCL
102  02  02
103  65  ×
104  04  4
105  93  .
106  03  3
107  54  )
108  71  SBR
109  33  X²
110  42  STO
111  09  09
112  53  (
113  43  RCL
114  02  02
115  65  ×
116  05  5
117  54  )
118  71  SBR
119  33  X²
120  42  STO
121  10  10
122  53  (
123  43  RCL
124  02  02
125  65  ×
126  05  5
127  93  .
128  09  9
129  54  )
130  71  SBR
131  33  X²
132  42  STO
133  11  11
134  53  (
135  43  RCL
136  02  02
137  65  ×
138  07  7
```

139	93	.	174	43	RCL	209	53	(	244	54	)
140	07	7	175	06	06	210	43	RCL	245	42	STO
141	54	)	176	65	×	211	10	10	246	14	14
142	71	SBR	177	43	RCL	212	65	×	247	53	(
143	33	X^2	178	01	01	213	43	RCL	248	43	RCL
144	42	STO	179	54	)	214	01	01	249	04	04
145	12	12	180	42	STO	215	54	)	250	94	+/-
146	53	(	181	06	06	216	42	STO	251	22	INV
147	43	RCL	182	53	(	217	10	10	252	23	LNX
148	03	03	183	43	RCL	218	53	(	253	54	)
149	65	×	184	07	07	219	43	RCL	254	42	STO
150	43	RCL	185	65	×	220	11	11	255	15	15
151	01	01	186	43	RCL	221	65	×	256	53	(
152	54	)	187	01	01	222	43	RCL	257	43	RCL
153	42	STO	188	54	)	223	01	01	258	05	05
154	03	03	189	42	STO	224	54	)	259	94	+/-
155	53	(	190	07	07	225	42	STO	260	22	INV
156	43	RCL	191	53	(	226	11	11	261	23	LNX
157	04	04	192	43	RCL	227	53	(	262	54	)
158	65	×	193	08	08	228	43	RCL	263	42	STO
159	43	RCL	194	65	×	229	12	12	264	16	16
160	01	01	195	43	RCL	230	65	×	265	53	(
161	54	)	196	01	01	231	43	RCL	266	43	RCL
162	42	STO	197	54	)	232	01	01	267	06	06
163	04	04	198	42	STO	233	54	)	268	94	+/-
164	53	(	199	08	08	234	42	STO	269	22	INV
165	43	RCL	200	53	(	235	12	12	270	23	LNX
166	05	05	201	43	RCL	236	69	OP	271	54	)
167	65	×	202	09	09	237	00	00	272	42	STO
168	43	RCL	203	65	×	238	53	(	273	17	17
169	01	01	204	43	RCL	239	43	RCL	274	53	(
170	54	)	205	01	01	240	03	03	275	43	RCL
171	42	STO	206	54	)	241	94	+/-	276	07	07
172	05	05	207	42	STO	242	22	INV	277	94	+/-
173	53	(	208	09	09	243	23	LNX	278	22	INV

```
279  23  LNX
280  54  )
281  42  STO
282  18  18
283  53  (
284  43  RCL
285  08  08
286  94  +/-
287  22  INV
288  23  LNX
289  54  )
290  42  STO
291  19  19
292  53  (
293  43  RCL
294  09  09
295  94  +/-
296  22  INV
297  23  LNX
298  54  )
299  42  STO
300  20  20
301  53  (
302  43  RCL
303  10  10
304  94  +/-
305  22  INV
306  23  LNX
307  54  )
308  42  STO
309  21  21
310  53  (
311  43  RCL
312  11  11
313  94  +/-
314  22  INV
315  23  LNX
316  54  )
317  42  STO
318  22  22
319  53  (
320  43  RCL
321  12  12
322  94  +/-
323  22  INV
324  23  LNX
325  54  )
326  42  STO
327  23  23
328  98  ADV
329  69  OP
330  00  00
331  92  RTN
332  76  LBL
333  33  X²
334  99  PRT
335  35  1/X
336  95  =
337  42  STO
338  13  13
339  53  (
340  53  (
341  01  1
342  09  9
343  93  .
344  08  8
345  65  ×
346  43  RCL
347  13  13
348  54  )
349  75  -
350  53  (
351  04  4
352  06  6
353  01  1
354  93  .
355  08  8
356  65  ×
357  53  (
358  43  RCL
359  13  13
360  33  X²
361  54  )
362  54  )
363  85  +
364  53  (
365  06  6
366  06  6
367  08  8
368  00  0
369  65  ×
370  53  (
371  43  RCL
372  13  13
373  45  YX
374  03  3
375  54  )
376  54  )
377  75  -
378  53  (
379  03  3
380  04  4
381  09  9
382  07  7
383  93  .
384  04  4
385  65  ×
386  53  (
387  43  RCL
388  13  13
389  45  YX
390  04  4
391  54  )
392  54  )
393  85  +
394  53  (
395  09  9
396  00  0
397  07  7
398  93  .
399  04  4
400  65  ×
401  53  (
402  43  RCL
403  13  13
404  45  YX
405  05  5
406  54  )
407  54  )
408  54  )
409  92  RTN
410  76  LBL
411  13  C
412  43  RCL
413  03  03
414  71  SBR
415  45  YX
416  42  STO
417  03  03
418  43  RCL
```

419	04	04
420	71	SBR
421	45	Y^X
422	42	STO
423	04	04
424	43	RCL
425	05	05
426	71	SBR
427	45	Y^X
428	42	STO
429	05	05
430	43	RCL
431	06	06
432	71	SBR
433	45	Y^X
434	42	STO
435	06	06
436	43	RCL
437	07	07
438	71	SBR
439	45	Y^X
440	42	STO
441	07	07
442	43	RCL
443	08	08
444	71	SBR
445	45	Y^X
446	42	STO
447	09	08
448	43	RCL
449	09	09
450	71	SBR
451	45	Y^X
452	42	STO
453	09	09
454	43	RCL
455	10	10
456	71	SBR
457	45	Y^X
458	42	STO
459	10	10
460	43	RCL
461	11	11
462	71	SBR
463	45	Y^X
464	42	STO
465	11	11
466	43	RCL
467	12	12
468	71	SBR
469	45	Y^X
470	42	STO
471	12	12
472	92	RTN
473	76	LBL
474	45	Y^X
475	42	STO
476	13	13
477	01	1
478	02	2
479	32	X:T
480	91	R/S
481	42	STO
482	34	34
483	22	INV
484	77	GE
485	06	06
486	38	38
487	91	R/S
488	42	STO
489	24	24
490	91	R/S
491	42	STO
492	25	25
493	91	R/S
494	42	STO
495	26	26
496	91	R/S
497	42	STO
498	27	27
499	91	R/S
500	42	STO
501	28	28
502	91	R/S
503	42	STO
504	29	29
505	91	R/S
506	42	STO
507	30	30
508	91	R/S
509	42	STO
510	31	31
511	53	(
512	53	(
513	53	(
514	53	(
515	43	RCL
516	13	13
517	65	×
518	43	RCL
519	26	26
520	54	)
521	22	INV
522	23	LNX
523	54	)
524	65	×
525	43	RCL
526	24	24
527	54	)
528	85	+
529	53	(
530	53	(
531	53	(
532	43	RCL
533	13	13
534	65	×
535	43	RCL
536	27	27
537	54	)
538	22	INV
539	23	LNX
540	54	)
541	65	×
542	43	RCL
543	25	25
544	54	)
545	54	)
546	42	STO
547	32	32
548	53	(
549	53	(
550	53	(
551	53	(
552	43	RCL
553	13	13
554	65	×
555	43	RCL
556	30	30
557	54	)
558	22	INV

559	23	LNX
560	54	)
561	65	×
562	43	RCL
563	28	28
564	54	)
565	85	+
566	53	(
567	53	(
568	53	(
569	43	RCL
570	13	13
571	65	×
572	43	RCL
573	31	31
574	54	)
575	22	INV
576	23	LNX
577	54	)
578	65	×
579	43	RCL
580	29	29
581	54	)
582	54	)
583	42	STO
584	33	33
585	91	R/S
586	42	STO
587	35	35
588	91	R/S
589	42	STO
590	36	36
591	53	(
592	43	RCL
593	36	36
594	75	-
595	43	RCL
596	35	35
597	54	)
598	42	STO
599	36	36
600	53	(
601	43	RCL
602	34	34
603	75	-
604	43	RCL
605	35	35
606	54	)
607	42	STO
608	34	34
609	53	(
610	43	RCL
611	34	34
612	55	÷
613	43	RCL
614	36	36
615	54	)
616	42	STO
617	36	36
618	53	(
619	53	(
620	53	(
621	43	RCL
622	33	33
623	75	-
624	43	RCL
625	32	32
626	54	)
627	65	×
628	43	RCL
629	36	36
630	54	)
631	85	+
632	43	RCL
633	32	32
634	54	)
635	61	GTO
636	06	06
637	39	39
638	01	1
639	92	RTN

Transmission Factor: Second Part Plus

$4\pi r^2$ Fluence and Fluence

001	15	E
002	03	3
003	07	7
004	03	3
005	02	2
006	03	3
007	07	7
008	01	1
009	03	3
010	02	2
011	07	7
012	69	OP
013	02	02
014	03	3
015	07	7
016	03	3
017	05	5
018	03	3
019	01	1
020	03	3
021	06	6
022	69	OP
023	03	03
024	69	OP
025	05	05
026	00	0
027	69	OP
028	02	02
029	69	OP
030	03	03
031	53	(
032	43	RCL
033	03	03
034	65	×
035	43	RCL
036	14	14
037	65	×
038	93	.
039	01	1
040	54	)
041	42	STO
042	03	03
043	53	(
044	43	RCL
045	04	04
046	65	×
047	43	RCL
048	15	15
049	65	×
050	93	.
051	01	1
052	54	)
053	42	STO
054	04	04
055	53	(
056	43	RCL
057	05	05
058	65	×
059	43	RCL
060	16	16
061	65	×
062	93	.
063	01	1
064	54	)
065	42	STO
066	05	05
067	53	(
068	43	RCL
069	06	06
070	65	×
071	43	RCL
072	17	17
073	65	×
074	93	.
075	01	1
076	54	)
077	42	STO
078	06	06
079	53	(
080	43	RCL
081	07	07
082	65	×
083	43	RCL
084	18	18
085	65	×
086	93	.
087	01	1
088	54	)
089	42	STO
090	07	07
091	53	(
092	43	RCL
093	08	08
094	65	×
095	43	RCL
096	19	19
097	65	×
098	93	.
099	01	1
100	54	)
101	42	STO
102	08	08
103	53	(
104	43	RCL
105	09	09
...	..	..
106	65	×
107	43	RCL
108	20	20
109	65	×
110	93	.
111	01	1
112	54	)
113	42	STO
114	09	09
115	53	(
116	43	RCL
117	10	10
118	65	×
119	43	RCL
120	21	21
121	65	×
122	93	.
123	01	1
124	54	)
125	42	STO
126	10	10
127	53	(
128	43	RCL
129	11	11
130	65	×
131	43	RCL
132	22	22
133	65	×
134	93	.
135	01	1
136	54	)
137	42	STO
138	11	11
139	53	(
140	43	RCL
...	..	..

141	12	12	176	43	RCL	211	02	2	246	02	2
142	65	×	177	11	11	212	07	7	247	65	×
143	43	RCL	178	85	+	213	04	4	248	43	RCL
144	23	23	179	43	RCL	214	01	1	249	21	21
145	65	×	180	12	12	215	01	1	250	65	×
146	93	.	181	54	)	216	07	7	251	43	RCL
147	01	1	182	99	PRT	217	03	3	252	13	13
148	54	)	183	42	STO	218	01	1	253	54	)
149	42	STO	184	13	13	219	01	1	254	42	STO
150	12	12	185	98	ADV	220	05	5	255	13	13
151	53	(	186	92	RTN	221	69	OP	256	99	PRT
152	43	RCL	187	76	LBL	222	03	03	257	98	ADV
153	03	03	188	10	E'	223	01	1	258	92	RTN
154	85	+	189	91	R/S	224	07	7	259	76	LBL
155	43	RCL	190	42	STO	225	00	0	260	19	D'
156	04	04	191	20	20	226	00	0	261	22	INV
157	85	+	192	91	R/S	227	00	0	262	52	EE
158	43	RCL	193	42	STO	228	00	0	263	91	R/S
159	05	05	194	21	21	229	00	0	264	42	STO
160	85	+	195	00	0	230	00	0	265	20	20
161	43	RCL	196	05	5	231	00	0	266	02	2
162	06	06	197	69	OP	232	00	0	267	01	1
163	85	+	198	01	01	233	69	OP	268	02	2
164	43	RCL	199	07	7	234	04	04	269	07	7
165	07	07	200	06	6	235	69	OP	270	04	4
166	85	+	201	03	3	236	05	05	271	01	1
167	43	RCL	202	05	5	237	69	OP	272	01	1
168	08	08	203	07	7	238	00	00	273	07	7
169	85	+	204	00	0	239	53	(	274	69	OP
170	43	RCL	205	00	0	240	43	RCL	275	01	01
171	09	09	206	00	0	241	20	20	276	03	3
172	85	+	207	02	2	242	65	×	277	01	1
173	43	RCL	208	01	1	243	01	1	278	01	1
174	10	10	209	69	OP	244	52	EE	279	05	5
175	85	+	210	02	02	245	01	1	280	01	1

```
281  07   7
282  00   0
283  00   0
284  02   2
285  04   4
286  69  OP
287  02   02
288  03   3
289  01   1
290  00   0
291  00   0
292  01   1
293  05   5
294  01   1
295  03   3
296  02   2
297  07   7
298  69  OP
299  03   03
300  06   6
301  03   3
302  01   1
303  05   5
304  03   3
305  00   0
306  07   7
307  00   0
308  00   0
309  00   0
310  69  OP
311  04   04
312  69  OP
313  05   05
314  53   (
315  53   (
316  53   (
317  43  RCL
318  20   20
319  33  X²
320  65   ×
321  89   π
322  65   ×
323  04   4
324  54   )
325  35  1/X
326  54   )
327  65   ×
328  43  RCL
329  13   13
330  54   )
331  42  STO
332  13   13
333  99  PRT
334  00   0
335  69  OP
336  00   00
337  98  ADV
338  98  ADV
339  92  RTN
```

for the mass integral program (page 55). Then

a. If the source and receiver are co-altitude:

Press A

Enter density in gm/m^3	Press R/S
Enter range in km	Press R/S

Read mass integral

b. If the source and receiver are not co-altitude:

Press B

Enter source in km	Press R/S
Enter receiver height in km	Press R/S
Enter density in gm/m^3	Press R/S
Enter scale height of atmosphere in km	Press R/S
Enter angle as defined in Fig.4 in degrees	Press R/S

Read mass integral

2. Read in four card sides of program on pages 56 through 60. Then

a. Store mass integral in data register 01 (Ref.2).

b. Press B

Enter black-body temperature in keV	Press R/S

Read energy of each group

c. Press C

Do, for j=1 to 10

(i) Enter energy of group j, from above (b). Press R/S

Note: If the energy of group j is less than 12 keV, then repeat this step for the next energy group. If the energy is is 12 keV or higher, then continue with (ii).

(ii) Enter Kalansky's coefficients (Appendix B) for the nearest energy BELOW the energy of the group (A_1,A_2,C_1,C_2), pressing R/S after each coefficient. Repeat the process for the nearest energy ABOVE the energy group.

(iii) Enter energy corresponding to the coefficients BELOW the group energy, press R/S. Do the same for the energy corresponding to the HIGHER energy.

(iv) Return to step(i) unless this was group 10 in which case go to three.

Note: Table VI identifies the data registers used for each coefficient in (ii) above. As long as an error in entering a coefficient is detected prior to entering C_2 high, then the correct values can replace the incorrect values by storing the correct value in the applicable storage register.

TABLE VI	
Data Registers	
Coefficient	Data Register
A_1 low	24
A_2 low	25
C_1 low	26
C_2 low	27
A_1 high	28
A_2 high	29
C_1 high	30
C_2 high	31

However, once C_2 high is entered for each group, the program is irrecoverable. If an error has been made, the program must be re-executed from 2.b. above.

3. Enter card side five. Card side six should also be read in if either the $4\pi r^2$ fluence or fluence calculations are desired. Card sides five and six are composed of the program on pages 61 through 63.

   After card read-in

   Press E

   Read Transmission Coefficient

TABLE VII	
Data Register Entries	
Quantity	Data Register
30402440	37
13422200	38
17310000	39

Optional

Press E'

Enter source yield in kilotons Press R/S

Enter x-ray fraction of source yield Press R/S

Read $4\pi r^2$ fluence in calories

Press D'

Enter range to receiver in centimeters Press R/S

Read fluence at range r in calories/cm

These instructions, while certainly complicated, are hopefully clear enough to enable the reader to use the program.

Programming and Data Registers

Prior to entering the program to be executed, the partitioning of the TI-59 must be adjusted to 639.39. Additionally, the quantities shown in Table VII should be stored in their respective data registers prior to executing the program or recording it on magnetic cards. The other 26 data registers are used as working registers.

Appendix G: Program PROMPT

Program PROMPT is used to calculate the prompt radiation fluences or doses. The applicable coefficients from Table IV must be input. The FORTRAN PROMPT listing is shown on page 71. A TI-59 program listing is shown on pages 72 and 73. The HTI group of programs does not contain a similar program.

FORTRAN PROMPT

The input variables for the FORTRAN version are

I = 1 implies a thermonuclear calculation

  2 implies a fission calculation

K = 1 implies a neutron calculation

  2 implies a secondary gamma ray calculation

A,B,C,D,E,F,G are taken from Table IV

XMI is the mass integral. The program can be modified to calculate the mass integral.

Note that the output statement says '$4\pi R^2$ FLUENCE' ; however, the result may be $4\pi R^2$ Dose depending on the particular problem being worked.

TI-59 PROMPT

To use the TI-59 program listed on pages 72 and 73, 15 quantities must be stored prior to execution. The quantities and their storage locations are shown in Table VIII.

TABLE VIII	
Prompt Data Registers	
Quantity	Data Register
M.I.	1
A	2
B	3
C	4
D	5
E	6
F	7
G	8
Slant Range (cm)	9
576357000	11
2127411731	12
1517003235	13
16323617	14
212741	15
1731151700	16
3235001632	17
3617000000	18

Once these quantities are input, pressing B will cause the program to execute. As in the FORTRAN prompt program, the output will always be titled $4\pi R^2$ FLUENCE; however, the answer may be $4\pi R^2$ DOSE depending on the input coefficients.

Output

The output from both PROMPT programs is in the form of $4\pi r^2$ fluence or dose per source neutron. Therefore, to find the fluence or dose at some point, the number of source neutrons must be known.

```
      PROGRAM PROMPT
10    CONTINUE
      READ(*,*,END=999) I,K,A,B,C,D,E,F,G,XMI
      PRINT*,' '
      PRINT*,'THE MASS INTEGRAL IS: ',XMI
      IF(I.EQ.1)THEN
         PRINT*,'THERMONUCLEAR'
      ELSE IF(I.EQ.2) THEN
         PRINT*,'FISSION'
      ENDIF
      IF(K.EQ.1) THEN
         PRINT*,'NEUTRON CALCULATION'
      ELSE IF(K.EQ.2) THEN
         PRINT*,'SECONDARY GAMMA CALCULATION'
      ENDIF
      H = A + (B*XMI) + (C*XMI*XMI) + (D*(XMI**1.5)) +
     *(E*SQRT(XMI)) + (F*(XMI**(1./3.))) + (G*ALOG(XMI))
      HH = EXP(H)
      PRINT*,'THE 4 PI R**2 FLUENCE IS: ',HH
      GO TO 10
999   STOP
      END
```

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Program PROMPT

```
000  76  LBL
001  12   B
002  00   0
003  00   0
004  03   3
005  00   0
006  04   4
007  00   0
008  02   2
009  04   4
010  04   4
011  00   0
012  69  OP
013  04   04
014  43  RCL
015  01   01
016  69  OP
017  06   06
018  69  OP
019  00   00
020  43  RCL
021  11   11
022  69  OP
023  01   01
024  43  RCL
025  12   12
026  69  OP
027  02   02
028  43  RCL
029  13   13
030  69  OP
031  03   03
032  43  RCL
033  14   14
034  69  OP
035  04   04
036  69  OP
037  05   05
038  69  OP
039  00   00
040  53   (
041  53   (
042  43  RCL
043  02   02
044  85   +
045  53   (
046  43  RCL
047  03   03
048  65   ×
049  43  RCL
050  01   01
051  54   )
052  85   +
053  53   (
054  43  RCL
055  01   01
056  33  X²
057  65   ×
058  43  RCL
059  04   04
060  54   )
061  85   +
062  53   (
063  53   (
064  43  RCL
065  01   01
066  45  YX
067  01   1
068  93   .
069  05   5
070  54   )
071  65   ×
072  43  RCL
073  05   05
074  54   )
075  85   +
076  53   (
077  43  RCL
078  01   01
079  34  ΓX
080  65   ×
081  43  RCL
082  06   06
083  54   )
084  85   +
085  53   (
086  53   (
087  43  RCL
088  01   01
089  45  YX
090  93   .
091  03   3
092  03   3
093  03   3
094  03   3
095  03   3
096  03   3
097  54   )
098  65   ×
099  43  RCL
100  07   07
101  54   )
102  85   +
103  53   (
104  43  RCL
105  01   01
106  23  LNX
107  65   ×
108  43  RCL
109  08   08
110  54   )
111  54   )
112  22  INV
113  23  LNX
114  54   )
115  42  STO
116  10   10
117  99  PRT
118  98  ADV
119  22  INV
120  52  EE
121  43  RCL
122  15   15
123  69  OP
124  01   01
125  43  RCL
126  16   16
127  69  OP
128  02   02
129  43  RCL
130  17   17
131  69  OP
132  03   03
133  43  RCL
134  18   18
135  69  OP
136  04   04
137  69  OP
138  05   05
139  69  OP
```

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140	00	00
141	53	(
142	53	(
143	53	(
144	04	4
145	65	×
146	89	π
147	65	×
148	53	(
149	43	RCL
150	09	09
151	33	X²
152	54	)
153	54	)
154	35	1/X
155	54	)
156	65	×
157	43	RCL
158	10	10
159	54	)
160	99	PRT
161	92	RTN
162	00	0

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VITA

Donald Edwin Jones was born 12 January 1950 in Montgomery, Alabama, the son of William Arthur Jones and Jane Dyer Jones. He graduated from Caledonia High School, Caledonia, Mississippi in May 1968 and entered Mississippi State University. He was awarded a Bachelor of Science degree in nuclear engineering in May 1972 and was awarded a commision as a second lieutenant in the United States Air Force the same day. His first assignment was to undergraduate pilot training. Upon graduation, he was transferred to England AFB, Lousiana, where he flew A-7s from October 1973 until January 1976. He was then transferred to Sembach AB, Federal Republic of Germany, where he flew OV-10s from May 1976 until July 1979. In August 1979, he arrived at AFIT and entered the Nuclear Weapons Effects program with a projected graduation date in March 1981.

Captain Jones married his wife, Linda Hollis Jones, on July 4, 1969. They have two children, Tracy Lynn and Tricia Kaye.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/GNE/PH/81M-5	2. GOVT ACCESSION NO. AD-A100 804	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) X-RAY FLUENCE AND TRANSMISSION AND PROMPT RADIATION FLUENCE OR DOSE		5. TYPE OF REPORT & PERIOD COVERED MS Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Donald E. Jones, Capt., USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Institute of Technology(AFIT/EN) Wright-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE March 1981
		13. NUMBER OF PAGES 83
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Approved for public release; IAW AFR 190-17 21 MAY 1981

FREDRIC C. LYNCH, Major, USAF

Director of Public Affairs

Fredric C. Lynch

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Photon Fluence; Photon Transport; Photon Transmission; X-ray Fluence; X-ray Transport; X-ray Transmission; Neutron Fluence; Neutron Dose; Gamma-Ray Fluence; Gamma-Ray Dose; Prompt Radiation Transport; Atmospheric Radiation Transport.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is to validate and evaluate a Horizons Technology Inc (HTI) TI-59 program written to calculate the free field x-ray fluence from a nuclear burst. In addition to this validation of an existing program, programs were written to compute mass integral and prompt radiation effects. X-ray transmission is calculated using a build-up factor method and is compared to results from the HTI program. Results are compared for black-body temperatures of 0.1, 1.0, and 10.0 keV and mass integrals from 10^{-6} to 10.0gm/cm^2. The

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gm/cm

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) results compare well with a maximum error of approximately 21%. HTI's program has a minor problem as the transmission factor approaches zero so a TI-59 program is provided for use in that regime. A quick FORTRAN program is provided to calculate the fluence reaching a receiver. TI-59 and FORTRAN programs are given to calculate the mass penetrated and prompt radiation fluence or dose.