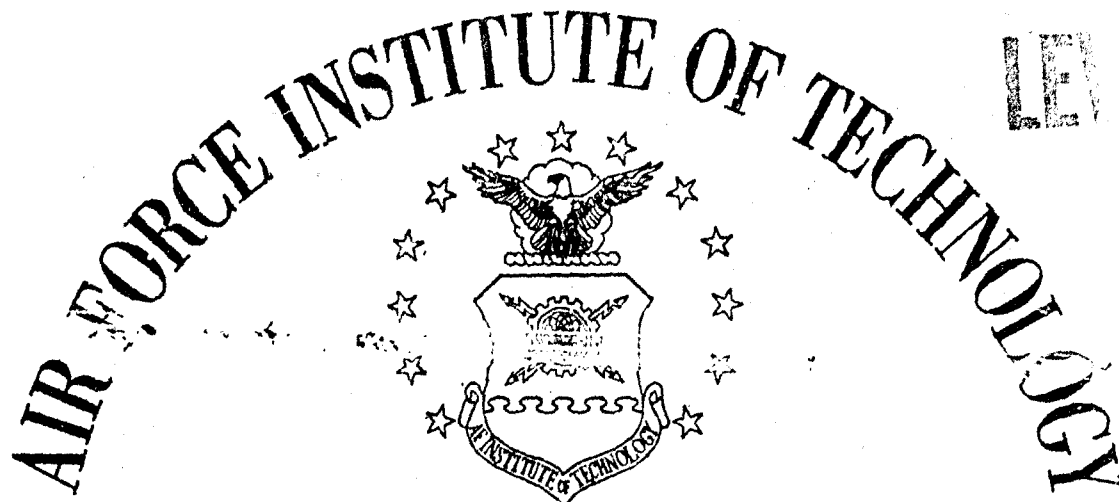
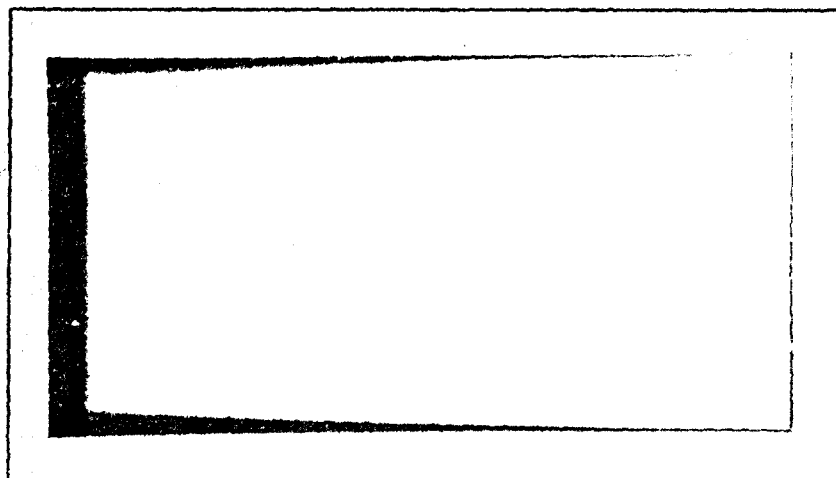


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X-RAY FLUENCE AND TRANSMISSION AND
PROMPT RADIATION FLUENCE OR DOSE.

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

Donald E. Jones, B.S., M.S.
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 surprised 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 (neutrons 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

Contents

Preface	ii
List of Figures	v
List of Tables.	vi
Abstract.	vii
I. Introduction.	1
Background.	1
Purpose	2
Method.	2
Assumptions	3
II. Basic Principles.	4
Theory.	4
Transmission Factor for the BU Method	4
Group Probability	6
Mass Attenuation Coefficient.	9
Mass Integral	11
Build-up Factors.	14
Final Form.	15
Baseline Program.	15
Limitations of BU Method.	15
Transmission Factor for the HTI Model	16
III. Solution by BU Method	18
Baseline Program.	18
Program QUICK	19
TI-59 Program	19
IV. Results	21
Comparison of Results	21
Baseline with HTI	21
QUICK and the TI-59 Program with Baseline	26
Area of Concern	26
V. Prompt Effects.	28
Background.	28
Mass Integral Scaling	30
Results	33

Contents

VI. Conclusions and Recommendations.	35
Conclusions.	35
Recommendations.	35
Bibliography	36
Appendix A: Mass Integral Scaling	38
Appendix B: Kalansky's Coefficients	39
Appendix C: Baseline Program Listing and Use.	40
Appendix D: Algorithm	47
Appendix E: Program QUICK Listing	51
Appendix F: TI-59 Programs.	54
Appendix G: Program PROMPT.	68
Vita	74

List of Figures

Figure	Page
1 The Planck Function and Its Integral.	8
2 Mass Attenuation Coefficient for Air.	10
3 Definition of Mass Integral Variables	12
4 Angle Definition.	13
5 Comparison of Baseline Results with HTI Results	22
6 Comparison of Program QUICK Results with Base- line Results.	23
7 Comparison of TI-59 QUICK Results with Base- line Results.	24
8 Sample Graph of Neutron $4\pi R^2$ Fluence	29
9 Comparison of TI-59 Prompt Radiation Program with Results from Kaman Sciences.	34

List of Tables

Table	Page
I. Fit Coefficients for Polynomial Fit of Mass Attenuation Coefficients.	11
II. Comparison of Baseline Results for Various Mass Integral Values and Black-body Temperatures.	25
III. HTI Problem Area.	27
IV. ANISN Homogeneous Air Data.	31
V. Baseline Variables.	40
VI. Data Registers.	66
VII. Data Register Entries	67
VIII. Prompt Data Registers	69

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/cm². 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:

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

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 coefficient 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

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

where

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

$[\frac{\mu}{\rho}]_{\text{air}}(h\nu)$ = 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(hv) = build-up factor for an x-ray with energy between hv and hv + d(hv)

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

$$T = \sum_{g=1}^G P_g \text{ BUF}_g \exp[-(\mu/\rho)_{\text{air}}^g \text{ M.I.}] \quad (3)$$

where

G = total number of energy groups

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

$(\mu/\rho)_{\text{air}}^g$ = 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.

Group Probability. 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)

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

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)

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

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

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

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

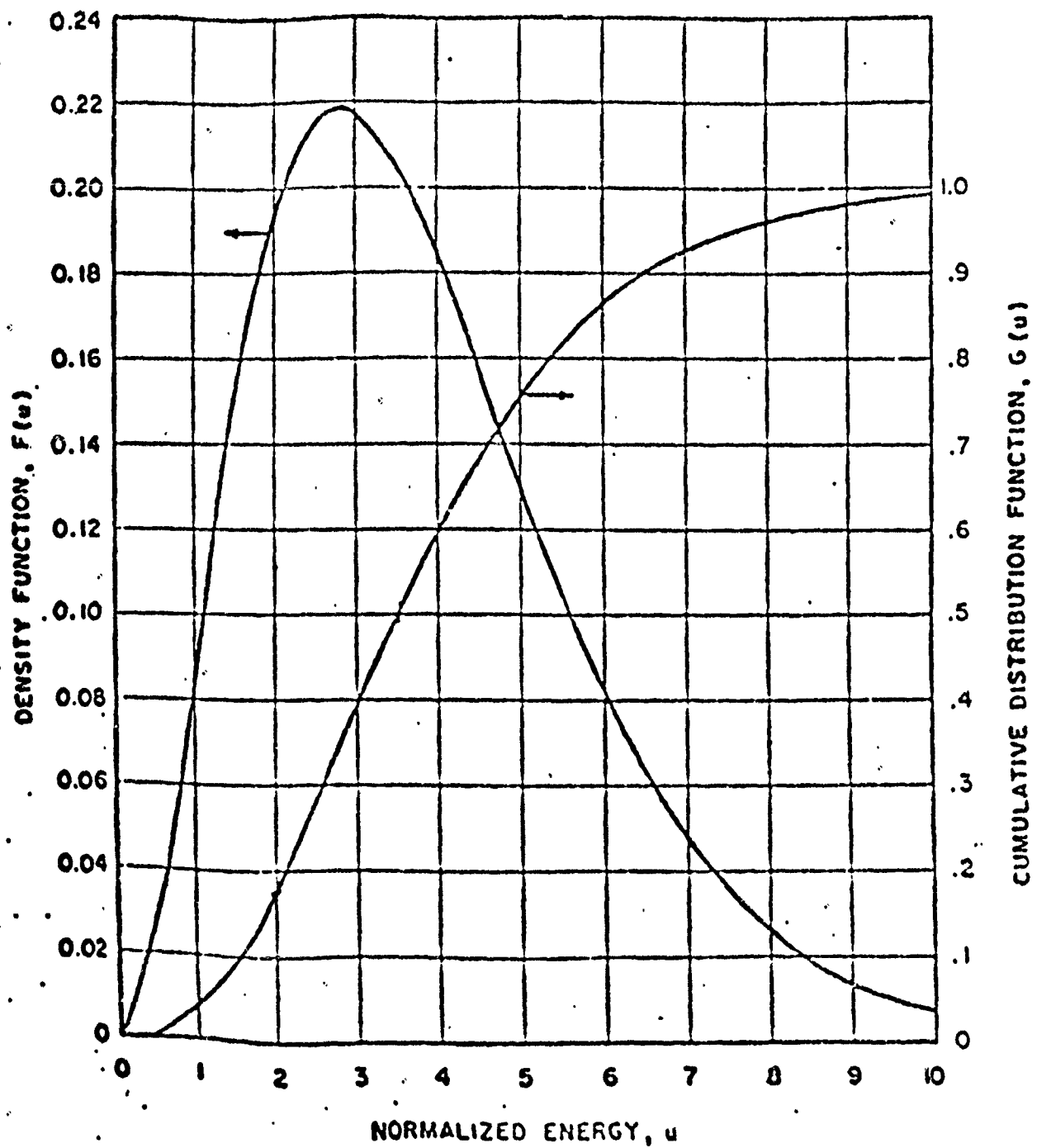


Figure 1. The Planck Function and Its Integral. (Ref. 8)

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_1 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 coefficients 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).

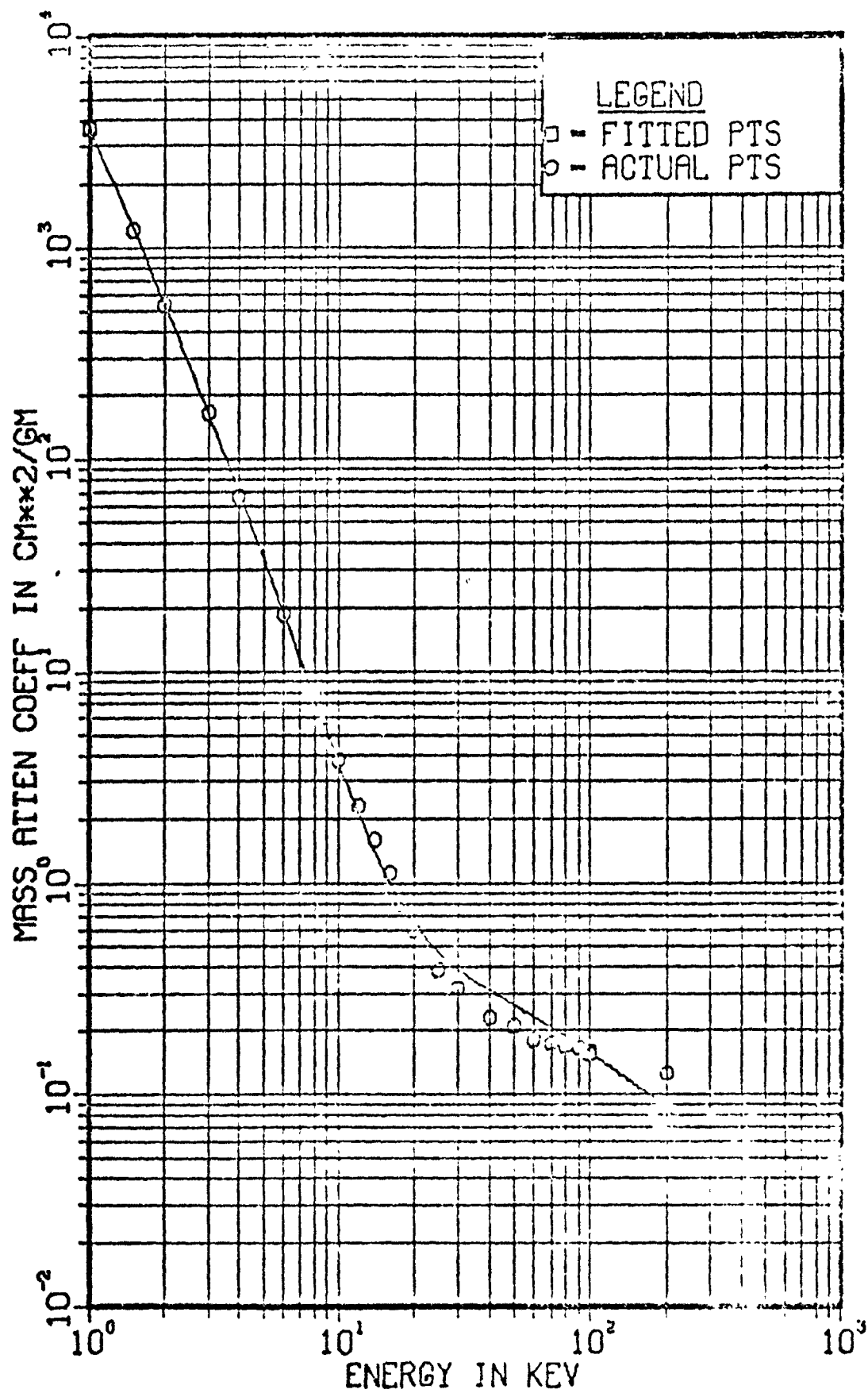


Figure 2. Mass attenuation coefficient for air.

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

$$M.I. = \int_0^r \rho(r') dr' \quad (7)$$

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

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

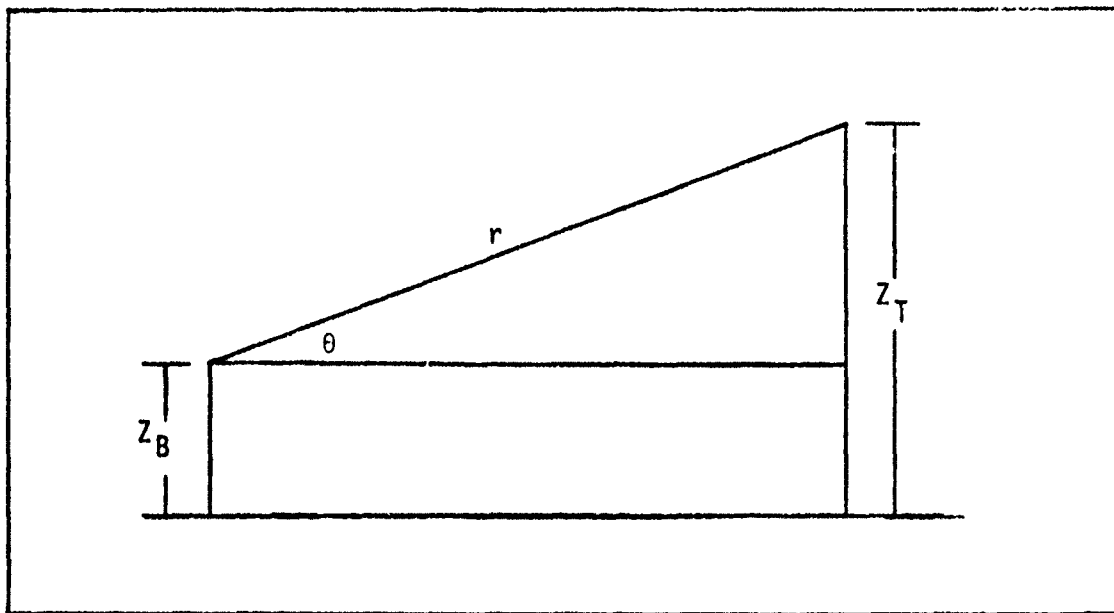


Figure 3. Definition of Mass Integral Variables. z_B is the source height. z_T is the receiver height, θ is the inclination of the receiver with respect to the source, and r is the slant range.

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

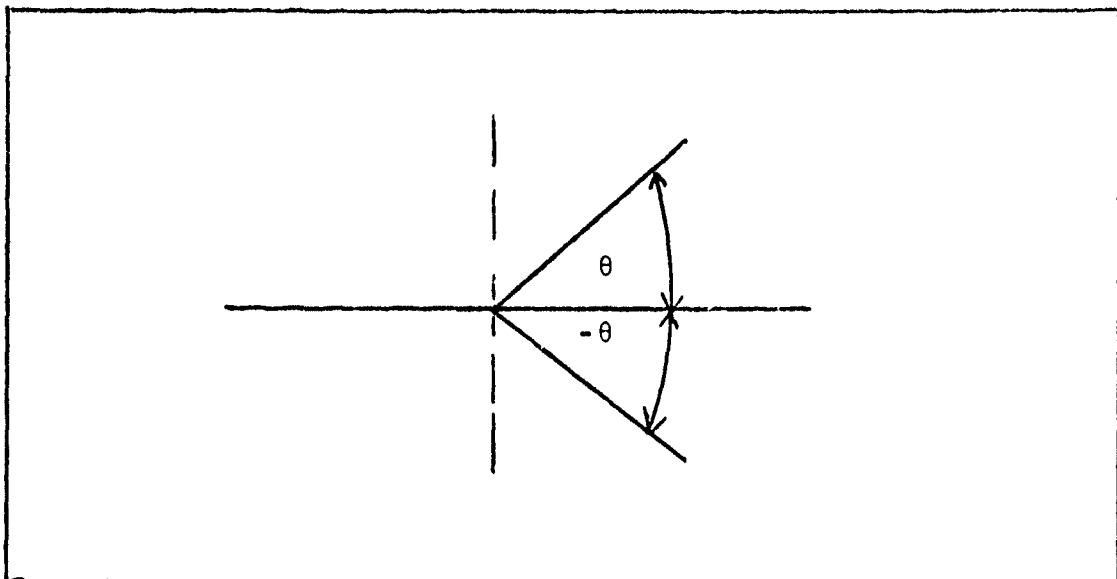


Figure 4. Angle Definition.

gm/m³, a conversion factor must be used to get the mass integral in units of gm/cm².

Eq.(8) is directly integrable,

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

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).

$$M.I. = \rho(Z_B)r \quad (10)$$

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:

$$B = A_1 \exp(C_1 y) + A_2 \exp(C_2 y) \quad (11)$$

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

$$T = \sum_{g=1}^{150} P_g \text{ BUF}_g \exp \left[-(\mu/\rho)_{\text{air}}^g \text{ M.I.} \right] \quad (12)$$

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

$$T = f(x) B(x, \theta) \quad (13)$$

and

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

$$B(x, \theta) = [A(x_0 - x) - 1] \exp[-\alpha(x_0 - x)^2] + 1 \quad (15)$$

$$x = \log_{10} \frac{M}{\theta^3} \quad (16)$$

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 $B(x,0)$ 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.

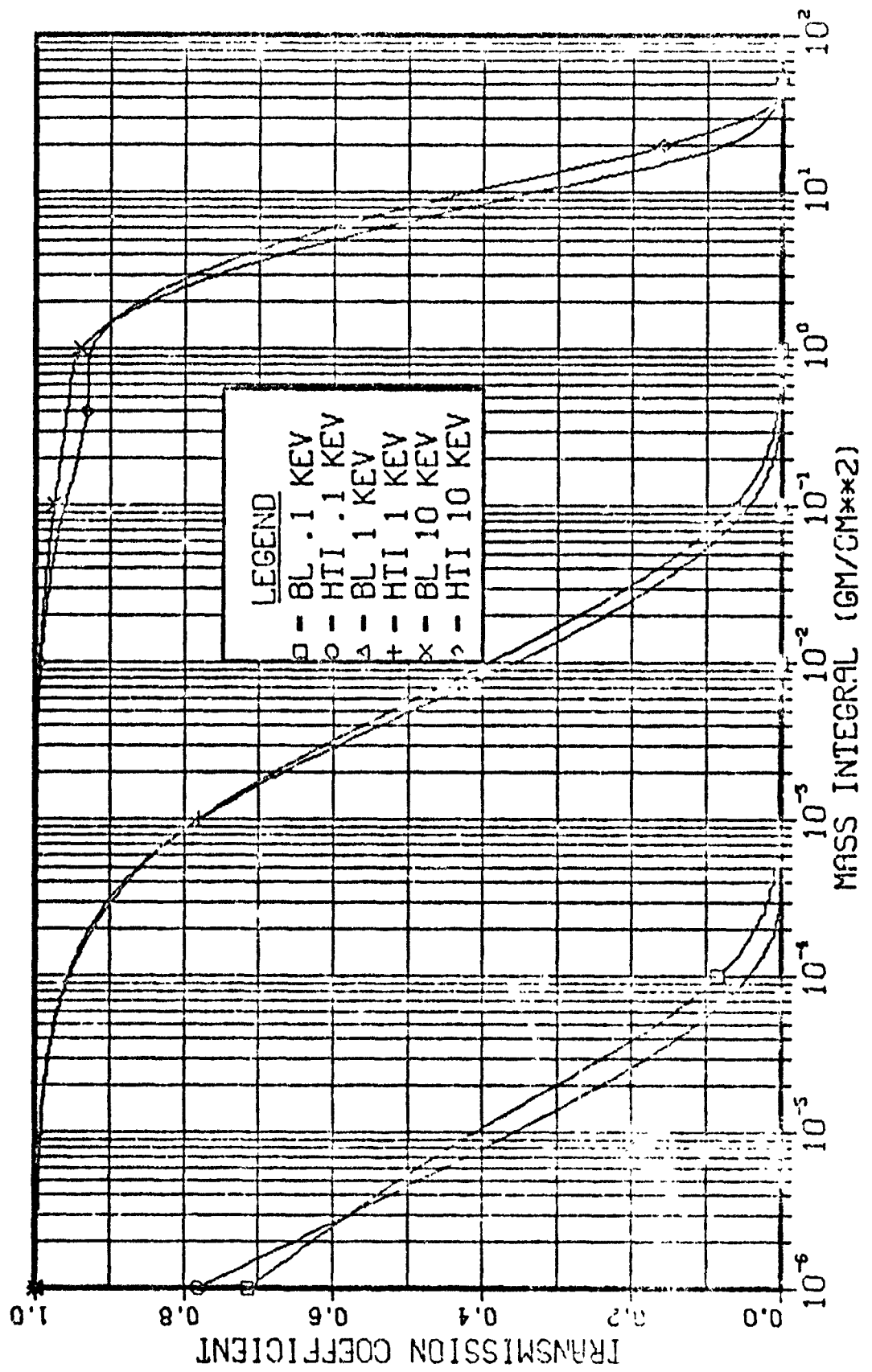


Figure 5. Comparison of baseline results with HTI results.

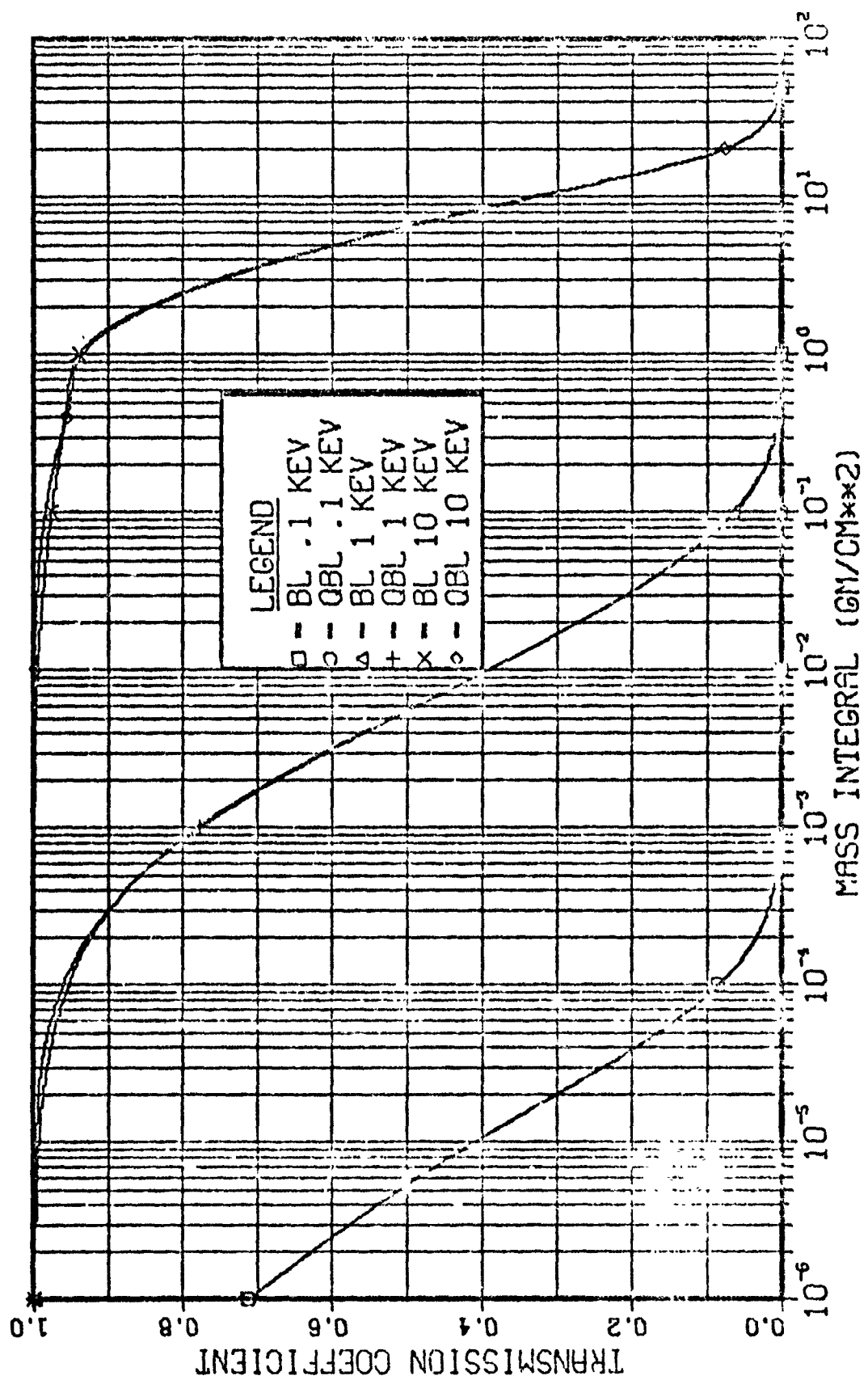


Figure 6. Comparison of program QUICK results with baseline results.

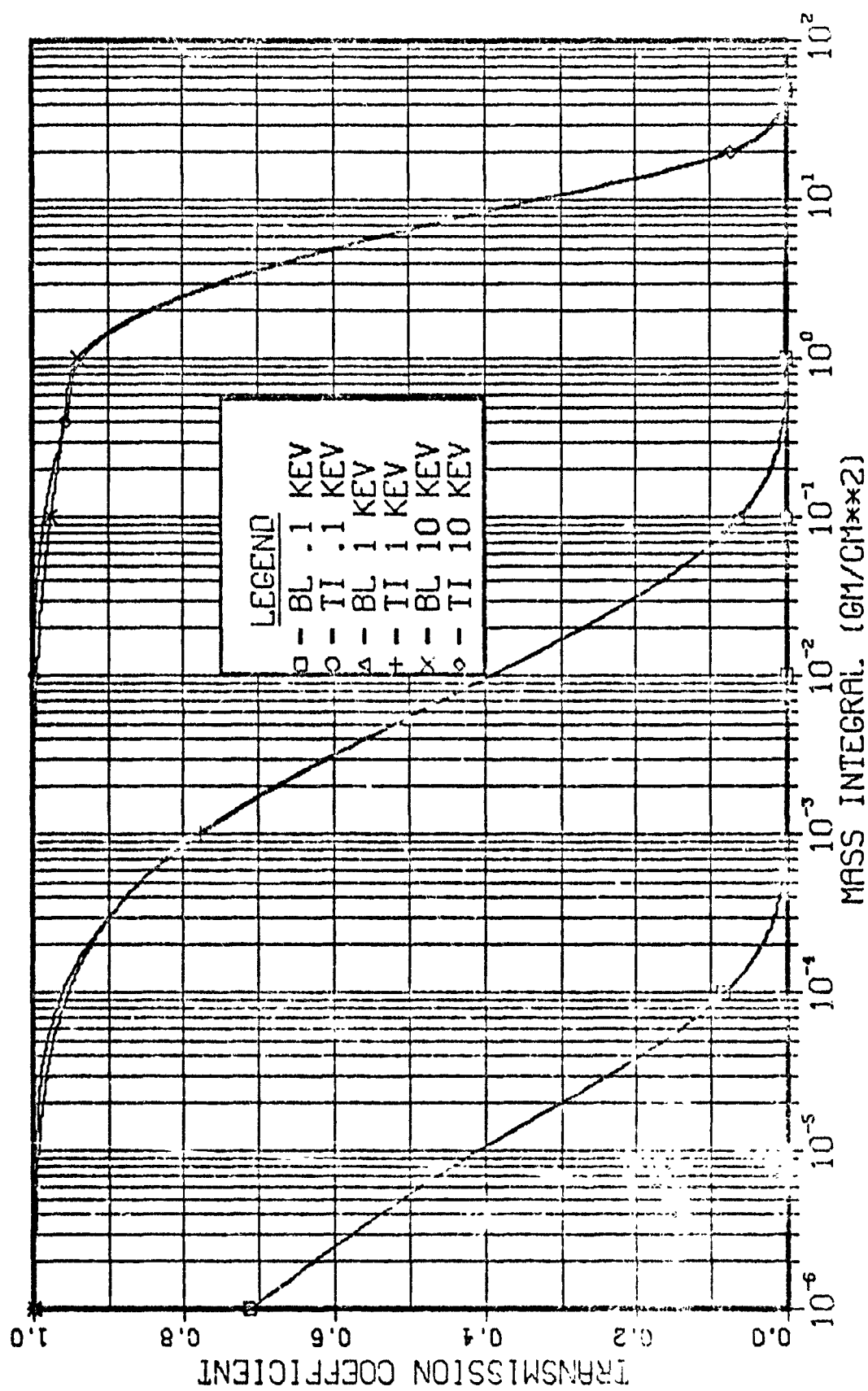


Figure 7. Comparison of TI-59 QUICK results with baseline results.

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

$$4\pi r^2 F = ST \quad (17)$$

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):

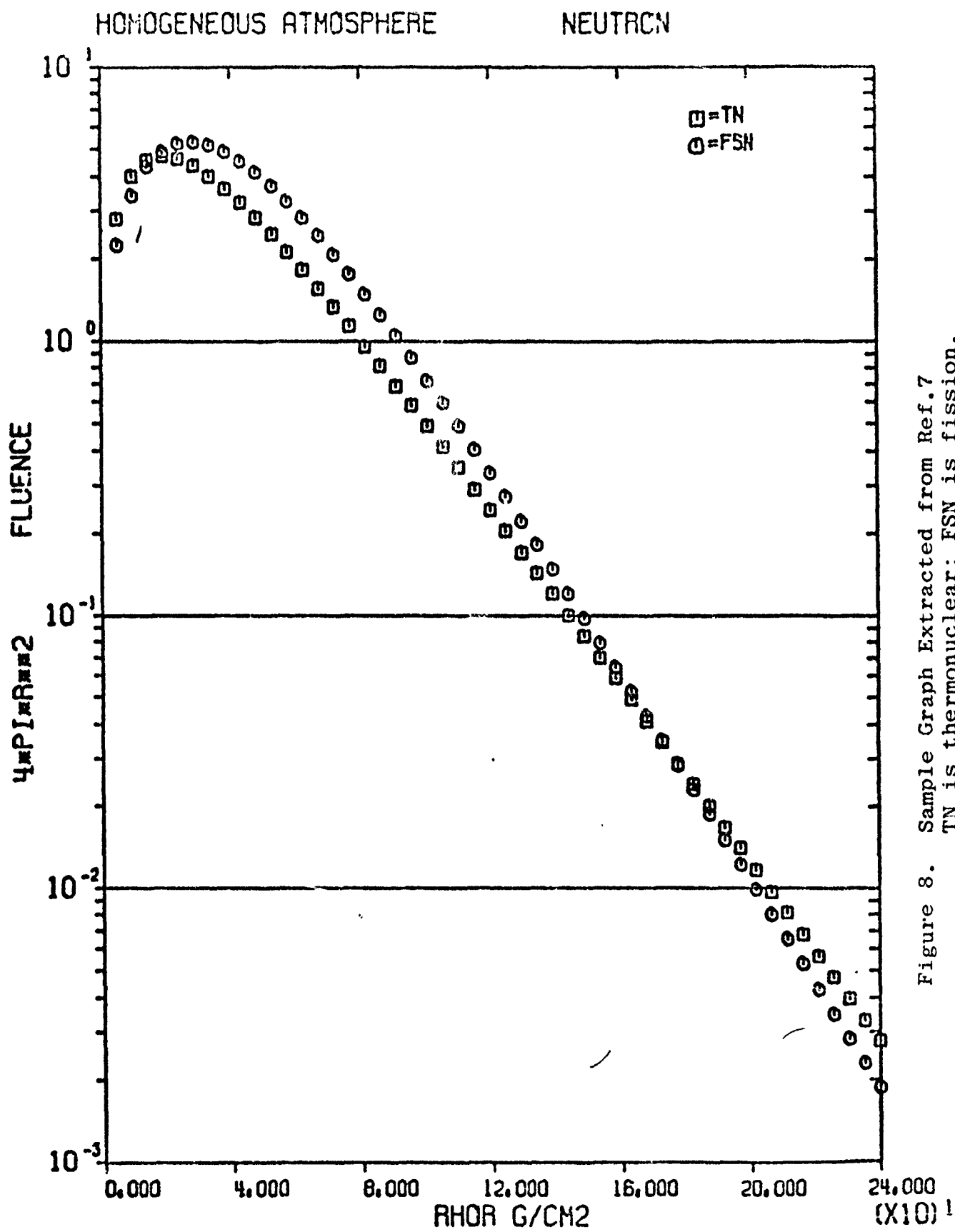


Figure 8. Sample Graph Extracted from Ref.7
TN is thermonuclear; FSN is fission.

$$F(x) = \exp(C_1 + C_2 X + C_3 X^2 + C_4 X^{3/2} + C_5 X^{1/2} + C_6 X^{1/3}) \quad (18)$$

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
		D	E	F
		.15771E-02	.17924E+01	-.32101E+01
		.18226E-02	.13159E+01	-.15135E+01
		-.21468E-03	-.39214E+01	.10875E+02
		G		
		.23746E+00		
		-.84022E-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	-.372675E-04
		D	E	F
		.23939E-02	.95659E+00	-.11394E+01
		.21001E-02	.65711E+00	-.57599E+00
		.31732E-02	.13350E+01	-.13011E+01
		G		
		.98116E+00		
		.93271E+00		
		.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
		.38861E-02	.27024E+01	-.41190E+01
		.44464E-02	.28502E+01	-.40883E+01
		.61127E-02	.33426E+01	-.37018E+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
		.48224E-02	.26366E+01	-.35154E+01
		.47309E-02	.26300E+01	-.36007E+01
		.47643E-02	.25725E+01	-.33967E+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.

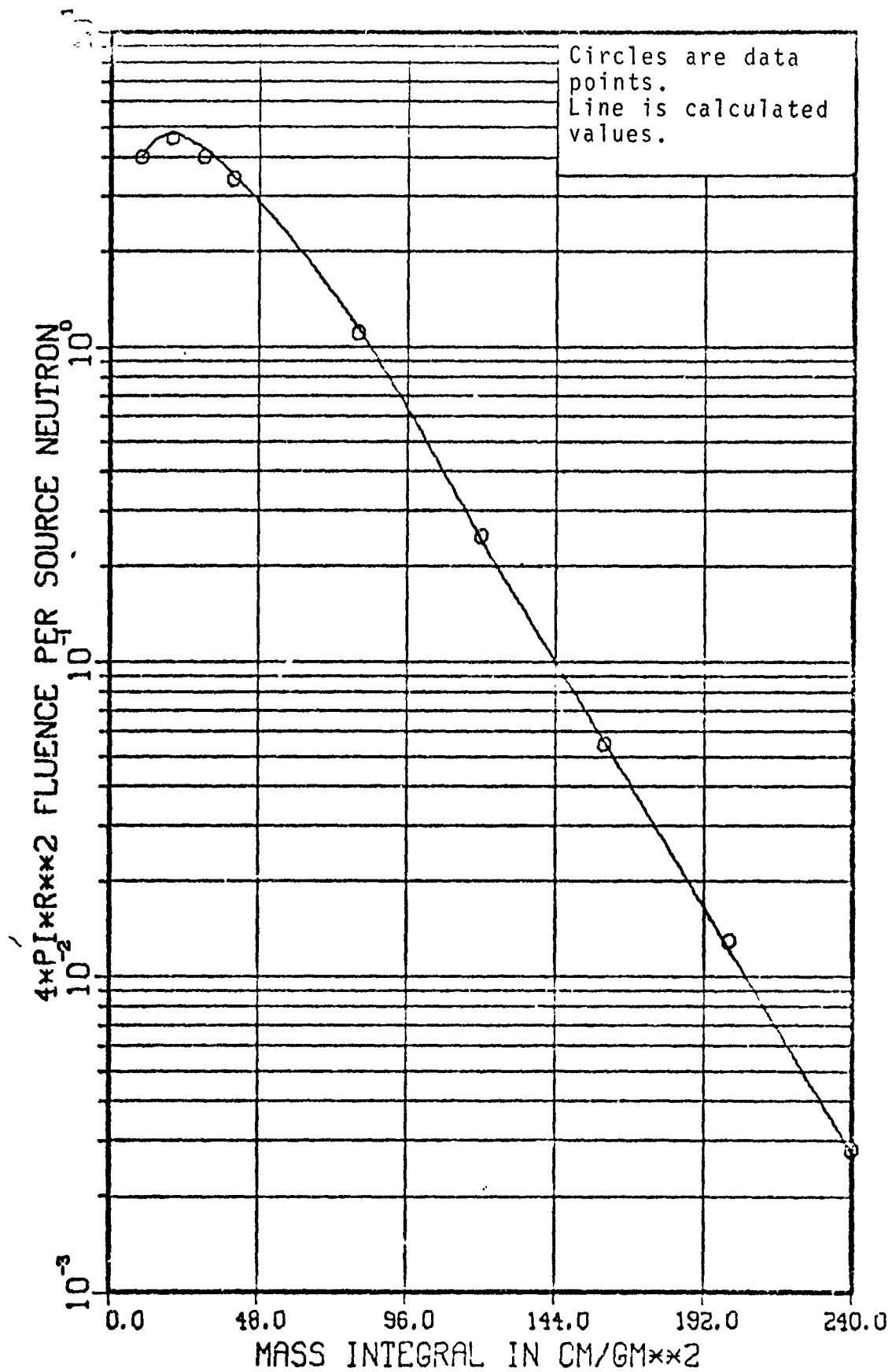


Figure 9. Comparison of TI-59 prompt radiation program results with those of Kaman Science (Ref.7).

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	0.160	0.080
600	-57.58	57.58	0.100	0.120
750	-17.20	13.20	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), B2B(150)
DIMENSION B(150), TY(0:150), YY(0:150), YYY(150), B2(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
C DO 2 I=1,32
C   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
C   READ(*,*,END=999) N
C   READ(*,*,END=999) NN
C   READ(*,*,END=999) L
C   CALL MASSI(N,XMI)
C   IF(NN.EQ.1) THEN
C     READ(*,*,END=999) YLD,XF
C   ENDIF

C
C THIS PORTION COMPUTES A MASS ATTENUATION COEFF FOR
C EVERY ENERGY GROUP. U=HNU/XT.
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=1,12
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 999
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

```

```

C      SUBROUTINE MASSI(XMII)
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
C      IF(N.EQ.2) THEN
C        READ(*,*,END=998) XMII
C        XMI = XMII
C        PRINT*, 'THE MASS INTEGRAL WAS AN INPUT VALUE'
C        GO TO 50
C      ENDIF
C      IF(N.EQ.1) GO TO 40
C      READ(*,*,END=998) ZB ,ZT ,RHO ,HB ,ANGLE
C      PRINT*, 'BURST ALT= ',ZB,' TGT ALT= ',ZT,
C      *' DENSITY= ',RHO,' SCALE HGT AT BURST= ',HB
C      PRINT*, 'ANGLE OF TGT FROM BURST= ',ANGLE
C      ANGLE = ANGLE * .01745
C      GO TO 41
C 40  READ(*,*,END=998) RHO,R
C      XMI=RHO*R/10.
C      GO TO 50
C 41  CONTINUE
C      Z1=0.
C      Z2=ZT-ZB
C      XMI=(-HB)*(RHO)*(1000.)*(1.E-4)*(EXP(-Z2/HB)-1.)/
C      *SIN(ANGLE)
C 50  PRINT*, 'THE MASS INTEGRAL IS ',XMI,' GM/CM**2'
C      GO TO 51
C 998 STOP 'END OF DATA IN MASSI AT WRONG TIME'
C 51  RETURN
C      END

```

```

SUBROUTINE BUF(HNU,B,IEOF,X,K,A1,A2,C1,C2,AX,
*BB,BBB,PG)
  DIMENSION B(150),HNU(150),BB(0:150),BBB(150)
  DIMENSION X(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 TR(B,T,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 MURHD(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)+
* (6680.0223*E**3)-(3497.3343*E**4)
*   +(907.3575*E**5)
1 CONTINUE
RETURN
END

```

SUBROUTINE XRAY(X,Y,XI,XF)
 DIMENSION XMI(100),X(100)

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)=XMI(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

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

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

$$(h\nu)_g = u_g * kT \quad (20)$$

Store for future use.

4. Calculate the mass attenuation coefficient for each

group using

$$E_g = 1/(h\nu)_g \quad (21)$$

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

Store each as it is calculated.

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

$$(MFP)_g = (\mu/\rho)_g * M.I. \quad (23)$$

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 .

$$(BUF)_h = (A_1)_h \exp[(C_1)_h(MFP)_g] + (A_2)_h \exp[(C_2)_h(MFP)_g] \quad (24)$$

and

$$(BUF)_l = (A_1)_l \exp[(C_1)_l(MFP)_g] + (A_2)_l \exp[(C_2)_l(MFP)_g] \quad (25)$$

$$(h\nu)_T = (h\nu)_h - (h\nu)_l \quad (26)$$

$$(h\nu)_p = (h\nu)_g - (h\nu)_l \quad (27)$$

$$(BUF)_g = [(BUF)_h - (BUF)_l] * [(h\nu)_p / (h\nu)_T] + (BUF)_l \quad (28)$$

Store the results.

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

$$Y_g = \exp[-MFP_g] \quad (29)$$

$$(Trans)_g = P_g * Y_g * (BUF)_g \quad (30)$$

Finally, integrate and sum. The baseline program

uses a box approximation to evaluate the integral.

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

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

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

9. Finally, the fluence is found by

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

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).

```

1      PROGRAM BLICK
2      DIMENSION A(10),K(32),A1(32),A2(32),C1(32)
3      DIMENSION C2(32),HNU(10),XMU(10),X(10),B(10)
4      DIMENSION Y(0:10),TG(0:10)
5      DO 1 I=1,32
6          READ(*,*,END=999)K(I),A1(I),A2(I),C1(I),C2(I)
7      1  CONTINUE
8      DATA A/1.1,1.8,2.35,2.8,3.25,3.75,4.3,5.,5.9,7.7/
9      READ(*,*,END=999)XMI,XKT,YLD,XF,CM
10     DO 2 I=1,10
11         HNU(I) = A(I) * XKT
12         E = 1. / HNU(I)
13         XMU(I) = -.0014 + (19.7541*E) - (461.7632*
14     *      E*E) + (6680.0229*E**3) - (3497.3643
15     *      *E**4) + (907.3575*E**5)
16         X(I) = XMU(I) * XMI
17         IF(X(I).GT.100) X(I) = 100.
18         Y(I) = EXP(-X(I))
19     2  CONTINUE
20     IF(HNU(10).LT.12) THEN
21         DO 3 I=1,10
22     3     B(I) = 1.
23         GO TO 10
24     ENDIF
25     N = 12
26     DO 4 I=1,10
27         IF(HNU(I).LT.12) GO TO 11
28         IF(HNU(I).GT.750) GO TO 99
29         DO 5 J=1,32
30             IF(K(J).GE.HNU(I)) GO TO 6
31             IF(K(J).LT.N) GO TO 5
32             A11 = A1(J)
33             A22 = A2(J)
34             C11 = C1(J)
35             C22 = C2(J)
36             N = K(J)
37     5     CONTINUE
38     6     AA = K(J) - N
39             DD = HNU(I) - N
40             D = DD / AA
41             BH = (A1(J)*EXP(X(I)*C1(J))) + (A2(J)
42     *      *EXP(X(I)*C2(J)))
43             BL = (A11*EXP(X(I)*C11)) + (A22*EXP(X(I)
44     *      *C22))
45             B(I) = (BH - BL)*D + BL
46             GO TO 9
47     11     B(I) = 1.
48     9     CONTINUE
49     4     CONTINUE
50     10    CONTINUE

```

```

51      Y(0) = 0.
52      TG(0) = 0.
53      DO 7 I=1,10
54          IF(Y(I).LT.1.E-20) Y(I) = 0.
55          Y(I) = Y(I) * .1 * B(I)
56          TG(I) = Y(I) + TG(I-1)
57 7     CONTINUE

      . . .

58      XYLD = YLD * XF
59      YYLD = XYLD * 1.E12
60      FL = YYLD * TG(10) / (4.*ACOS(-1.)*(CM*CM))
61      PRINT*, 'FOR A BLACK BODY TEMPERATURE OF ',XKT,' KEV,
62      * A MASS PENETRATED OF ',XMI,' GM/CM**2, A WEAPON
63      * YIELD OF ',YLD,' KILOTONS, A X-RAY FRACTION OF '
64      *,XF,' AND A DISTANCE FROM BURST TO TARGET OF ',
65      *CM,' CM, THE TRANSMISSION COEFFICIENT IS ',TG(10)
66      *, ' AND THE FLUENCE IS ',FL
67      GO TO 1
68 99     PRINT*, 'HNU IS TOO LARGE FOR KALANSKYS BUF- > 750'
69 999    STOP
70      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	035	42	STD	070	54	)
001	11	H	036	04	04	071	42	STD
002	91	R/S	037	91	R/S	072	03	03
003	42	STD	038	42	STD	073	53	)
004	01	01	039	05	05	074	53	)
005	91	R/S	040	91	R/S	075	53	)
006	42	STD	041	00	0	076	43	RCL
007	02	02	042	42	STD	077	01	01
008	53	(	043	06	06	078	94	+/-
009	53	(	044	53	(	079	55	-
010	43	RCL	045	43	RCL	080	43	RCL
011	01	01	046	02	02	081	04	04
012	65	*	047	75	-	082	54	)
013	43	RCL	048	43	RCL	083	22	11
014	02	02	049	01	01	084	23	11
015	54	)	050	54	)	085	54	)
016	55	+	051	42	STD	086	75	)
017	01	1	052	01	01	087	01	1
018	00	0	053	53	(	088	54	)
019	54	)	054	43	RCL	089	42	STD
020	42	STD	055	05	05	090	01	01
021	01	01	056	38	SIN	091	53	)
022	92	RTH	057	65	*	092	53	)
023	76	LBL	058	01	1	093	43	RCL
024	12	B	059	00	0	094	03	01
025	91	R/S	060	54	)	095	65	)
026	42	STD	061	42	STD	096	43	RCL
027	01	01	062	05	05	097	01	01
028	91	R/S	063	53	(	098	54	)
029	42	STD	064	43	RCL	099	55	+
030	02	02	065	04	04	100	43	RCL
031	91	R/S	066	94	+/-	101	05	05
032	42	STD	067	65	*	102	54	)
033	03	03	068	43	RCL	103	42	STD
034	91	R/S	069	03	03	104	01	0
						105	92	R7

Transmission Factor: First Part

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

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

279	23	LNK	314	22	INV	349	75	-	384	04	4
280	54	)	315	23	LNK	350	53	(	385	65	X
281	42	STD	316	54	)	351	04	4	386	53	(
282	18	18	317	42	STD	352	06	6	387	43	RCL
283	53	(	318	22	22	353	01	1	388	13	13
284	43	RCL	319	53	(	354	93	.	389	45	YX
285	08	08	320	43	RCL	355	08	8	390	04	4
286	94	+/-	321	12	12	356	65	X	391	54	)
287	22	INV	322	94	+/-	357	53	(	392	54	)
288	23	LNK	323	22	INV	358	43	RCL	393	85	+
289	54	)	324	23	LNK	359	13	13	394	53	(
290	42	STD	325	54	)	360	33	X ²	395	09	9
291	19	19	326	42	STD	361	54	)	396	00	0
292	53	(	327	23	23	362	54	)	397	07	7
293	43	RCL	328	98	HDV	363	85	+	398	93	.
294	09	09	329	69	DP	364	53	(	399	04	4
295	94	+/-	330	00	00	365	06	6	400	65	X
296	22	INV	331	92	RTN	366	06	6	401	53	(
297	23	LNK	332	76	LBL	367	08	8	402	43	RCL
298	54	)	333	33	X ²	368	00	0	403	13	13
299	42	STD	334	99	PRT	369	65	X	404	45	YX
300	20	20	335	35	1/X	370	53	(	405	05	5
301	53	(	336	95	=	371	43	RCL	406	54	)
302	43	RCL	337	42	STD	372	13	13	407	54	)
303	10	10	338	13	13	373	45	YX	408	54	)
304	94	+/-	339	53	(	374	03	3	409	92	RTN
305	22	INV	340	53	(	375	54	)	410	76	LBL
306	23	LNK	341	01	1	376	54	)	411	13	C
307	54	)	342	09	9	377	75	-	412	43	RCL
308	42	STD	343	93	.	378	53	(	413	03	03
309	21	21	344	08	8	379	03	3	414	71	SBR
310	53	(	345	65	X	380	04	4	415	45	YX
311	43	RCL	346	43	RCL	381	09	9	416	42	STD
312	11	11	347	13	13	382	07	7	417	03	03
313	94	+/-	348	54	)	383	93	.	418	43	RCL

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

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

Transmission Factor: Second Part Plus

$4\pi r^2$ Fluence and Fluence

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

141	12	12	176	43	RCL	211	02	2	246	02	2
142	65	X	177	11	11	212	07	7	247	65	X
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	X	180	12	12	215	01	1	250	65	X
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	STD	218	01	1	253	54	)
149	42	STD	184	13	13	219	01	1	254	42	STD
150	12	12	185	98	ADV	220	05	5	255	13	13
151	53	(	186	92	RTH	221	69	DP	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	RTH
154	85	+	189	91	R/S	224	07	7	259	76	LBL
155	43	RCL	190	42	STD	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	STD	228	00	0	263	91	R/S
159	05	05	194	21	21	229	00	0	264	42	STD
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	DP	232	00	0	267	01	1
163	85	+	198	01	01	233	69	DP	268	02	2
164	43	RCL	199	07	7	234	04	04	269	07	7
165	07	07	200	06	6	235	69	DP	270	04	4
166	85	+	201	03	3	236	05	05	271	01	1
167	43	RCL	202	05	5	237	69	DP	272	01	1
168	08	08	203	07	7	238	00	00	273	07	7
169	85	+	204	00	0	239	53	(	274	69	DP
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	X	277	01	1
173	43	RCL	208	01	1	243	01	1	278	01	1
174	10	10	209	69	DP	244	52	EE	279	05	5
175	85	+	210	02	02	245	01	1	280	01	1

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

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 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 C₂ 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

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

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140	00	00
141	53	(
142	53	(
143	53	(
144	04	4
145	65	X
146	89	n
147	65	X
148	53	(
149	43	RCL
150	09	09
151	33	X2
152	54	)
153	54	)
154	35	1/X
155	54	)
156	65	X
157	43	RCL
158	10	10
159	54	)
160	99	FRT
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 commission 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, Louisiana, 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.

Permanent address: Rte 1 Box 274

Steens, Mississippi 39766

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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 10.0 g/cm^2 . The		

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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.
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