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A Simple Design Code for Duct-Streaming Radiations

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DUCT-III: A Simple Design Code for Duct-Streaming Radiations

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Abstract

The DUCT-III code is a simple design code to calculate duct-streaming radiations in nuclear facilities by using a semi-empirical formula based on an albedo analytical method. This code is applicable to designs of penetrations in nuclear power plants, fusion reactor facilities, accelerator facilities, and so on, because albedo data for γ-rays up to 10 MeV and neutrons up to 3 GeV are implemented in it. There are two versions of this code, the UNIX version runs on workstations and the Visual Basic version runs on Microsoft Excel 97*. The code package contains the Fortran source (or PC executable), data libraries, sample input and output data.

In this report, an outline, additional functions of the DUCT-III code, and how to install and use it are described.

Contents

1. Introduction

Penetrations such as an entrance, supply / exhaust ducts and pipes go through walls in nuclear facilities. They are generally made as bent structures in order to decrease leakage radiations (streaming) through them. However it is very difficult to evaluate the streaming radiations because the structures are complex. The DUCT code[1-1, -2, -3], which is a program to calculate duct-streaming radiations of neutrons and photons with a semi-empirical formula, was developed in 1988 for the purpose of penetration designs. This code can treat the main types of penetrations i.e., cylindrical duct, rectangular duct, annulus and slit. Since then, this code has been updated by simplification of input data, addition of functions to deal with bent ducts, and so on, and the DUCT-II code[1-4] was developed. In 1998 –2001, the DUCT-III code was developed by adding the following functions to the DUCT-II code to allow application to high energy accelerator facilities, further simplification of input data, and so on.

(1) Addition of high-energy neutron albedo data (maximum energy 3GeV)
(2) Addition of a function to calculate wall scattered radiation
(3) Addition of typical source spectra
(4) Addition of a point kernel program PKN-H
(5) Optional setup of source position
(6) Development of a Visual Basic version

This report is a program manual for the DUCT-III code, in which the outline, functions, and how to install and use it are described.

The outline of the DUCT-III code is given in the second chapter. The additional functions of the code are described in the third chapter. In the fourth chapter, installation and use are explained.

2.Outline of the DUCT-III code

The DUCT code is a program to calculate duct-streaming radiations of neutrons and photons through penetrations such as a cylindrical duct, rectangular duct, annulus and slit with a semi-empirical formula. The code outline is explained below.

2.1 Types of radiation sources and energy structures

(1) Types of energy structures

Neutrons or/and photons with the following four types of energy structures are dealt with in the DUCT-III code.

1) Neutrons in the energy range below 15 MeV (12 groups)
2) Photons in the energy range below 10 MeV (5 groups)
3) Both 1) and 2) (17 groups)
4) Neutrons in the energy range below 3 GeV (12 groups)

Table 2-1 shows each energy group structure.

(2) Types of radiation sources

An isotropic point source or a line source may be used. Each radiation source is set at any position related to the origin, which corresponds to the duct inlet center of the first leg as shown in Fig. A-1. The line source is divided into some isotropic point sources specified by input data, and the sources are assumed at each center of the subdivisions.

2.2 Formula for straight duct, and parameters

(1) Formula for straight duct

A representative length of each duct is expressed as δ which is described below, and the length and depth of each duct are divided by δ. Multi-group approximation is used below to represent the energy dependence of the quantities, then the albedo and the source intensity are expressed by a matrix A and a vector S, respectively. The flux ϕ is considered as a vector.

Angular distributions of reflected radiations are assumed to be cosine distributions. It is not expected that this assumption causes any big problem because slowdown scattered contributions are actually dominant, though it is not suitable for the self-scattering contributions within the inlet neutron energy group.

The energy dependent flux of the streaming radiations at depth x is expressed as follows.

$$\Phi(x) = \Phi_0(x) + \gamma^2 A_2 \sum_{j=1}^{N} Sj\phi_j^{(i)}(x) + \gamma^8 A_8 \sum_{j=1}^{N} S_j \phi_j^{(8)}(x) \qquad (2\text{-}1)$$

where

$A_2=A\ (I+A+A^2)$ (2-2)

I: unit matrix

A: albedo matrix

$A_8=A^4/(I-A)$ (2-3)

γ: empirical factor (=0.87)

$\Phi_0(x)$: flux due to direct component

i=1: photons

i=2: neutrons

S_j: source intensity vector

$\phi_j^{(n)}(x)$: function described below

A_8 is originally expressed by the next equation.

$$A_8 = A^4\left(I + A + A^2 + ...\right) \quad (2\text{-}4)$$

A_8 cannot be solved, if the albedo of neutrons for some energy group is over 1. The multiplicity of evaporation neutrons emitted by nuclear reactions is much greater than 1 for high-energy neutrons. This phenomenon becomes remarkable, as the mass number of the target atomic nucleus gets bigger. The majority of these neutrons are emitted from the reflected wall and they contribute to the albedo value. The value of the high-energy group is, therefore, bigger than 1, especially the albedo for iron in which the first energy group reaches 20 as shown below. Because of this difficulty, the following equation (2-5) is adapted only for high-energy neutrons using a real number of scattering; M.

$$A_8 = A^4 + A^5 + ... + A^M \quad (2\text{-}5)$$

M=20 is used for high-energy neutrons. This value is an empirical parameter to be tested with benchmark experiments using high-energy neutrons.

(2) $\Phi_0(x)$: flux due to direct component

$\Phi_0(x)$ is given by the next equation, corrected by the ratio of the effective cross section directly seen from the source point to the actual cross section of the duct, where an isotropic point source is assumed.

$$\Phi_0(x) = \frac{S_0}{S_d}\sum_m \frac{dS_m(x)}{4\pi r_m^2} \quad (2\text{-}6)$$

where

$\Phi_0(x)$: flux due to direct component at depth x(cm^{-2} s^{-1})
S_0: source intensity (s^{-1})
r_m: distance from source point to the center of subdivision m at depth x
$dS_m(x)$: cross section of the subdivision m (cm^2)
S_d: cross section of duct (cm^2)

The cross section of the duct is subdivided and the total cross section directly seen from the source point is approximated by the sum of the cross sections for each subdivision; $dS_m(x)$, for which the center is directly seen from the source point.

(3) Definition of S_j

Behaviors of streaming radiations are different, if types of radiation sources are different. The angular distribution of the radiation sources at a duct inlet is expressed by N angular bins and is constant in each bin. The symbol μ is the cosine of the incident angle with respect to the duct axis. The angular bins are given as follows.

$$\mu_0 = 1 \geq \mu \geq \mu_{1_1}, \mu_1 \geq \mu \geq \mu_2, ..., \mu_{N-1} \geq \mu \geq \mu_N = 0 \quad (2\text{-}7)$$

For an isotropic point source, N equals 1 and μ is given as follows.

$$-1 \leq \mu \leq 1 \quad (2\text{-}8)$$

The isotropic point source is automatically assumed in DUCT-III, when the radiation source is set on the duct inlet of the first leg. S_j is defined by the following,

$$S_j = S_0 / \delta^2 \quad (2\text{-}9)$$

where S_0 is the source intensity vector in the 4π direction from the source and δ is the representative length of the duct described in subsection (4).

An angular source at the duct inlet is assumed in DUCT-III, when the radiation source is set at any position except for the duct inlet. For an angular source, S_j is the incident current in the j-th angular bin at the duct inlet and it is given in the unit of cm^{-2} as follows.

$$S_j = S_0 \sum_m \frac{dS_m \mu_m}{4\pi r_m^2 S_d} \quad (2\text{-}10)$$

where

dS_m: cross section of subdivision m (cm^2)

μ_m: cosine of incident angle with respect to duct axis

r_m: distance from source point to the center of subdivision m (cm)

S_d: total cross section of duct (cm^2)

When μ_m is not in the angular bin defined by the DUCT-III code, $\frac{dS_m \mu_m}{4\pi r_m^2 S_d}$ is zero.

(4) Definition of $\phi_j^{(n)}(x)$

The function $\phi_j^{(n)}(x)$ is a flux of radiations which are emitted in the j-th angular bin direction and reach to the depth x after scattering n times on the duct wall. This function is defined when the albedo and the source intensity are both 1. The function $\phi_j^{(n)}(x)$ has been obtained for some typical duct geometries analytically or with Monte Carlo calculations. The following empirical formula has been fitted to the calculated values,

$$\phi^{(n)}(x) = \frac{C_n}{1+(x/a_n)^{b_n}} \left\{1 - \xi_n \mathrm{Exp}(-\theta_n x)\right\} \qquad (2\text{-}11)$$

where a_n, b_n, c_n, ξ_n and θ_n are fitting parameters, which depend on the angular bin, the duct geometries and the type of the duct as shown in Tables 2-2 to 2-5. The parameters have been stored in the DUCT-III code and are explained next.

a) Cylindrical duct

For a cylindrical duct, the parameters for an isotropic point source and an angular source with two angular bins (N=2) have been prepared. The representative length δ is the radius of the cylindrical duct.

b) Rectangular duct

For a rectangular duct, the parameters for an isotropic point source and an angular source with two angular bins (N=2) have been prepared, the same as for the cylindrical duct. The representative length δ is the width of the rectangular duct, where the width a must be equal to or smaller than the height b. The parameters are given for a/b values, 1.0, 1.5, 2.0 and 4.0. A cylindrical duct may also be selected when a is equal to b.

c) Annulus

For an annulus, the parameters for an angular source with two angular bins (N=2) have been prepared.

The representative length δ is the outer radius *r1* of the annulus. The parameters are given for *r2/r1* values, 0.5, 0.75, 0.87 and 0.95, where *r2* is the inner radius of the annulus. The parameters for an isotropic point source have not been prepared for the annulus.

d) Slit

For a slit, the parameters for an angular source with three angular bins (*N*=3) have been prepared. The representative length δ is the width (1 cm only) of the slit. The parameters are given for *h* values, 8.0, 20.0, 60.0 and 200.0, where *h* is the height of the slit. The parameters for an isotropic point source have not been prepared for the slit.

(5) Albedo matrices

Albedo matrices, implemented in the DUCT-III code, are shown in Tables 2-6 to 2-9. The albedo matrices [1-1) – 1-3)] of neutrons in the energy range below 15 MeV have been calculated by ANISN [2-1)]. The albedo matrices[1-1) – 1-3)] of photons, on the other hand, have been approximated with the total dose albedo data published by Selph [2-2)]. These matrices have been prepared for polyethylene, iron, concrete and so on. The albedo matrices for neutrons and secondary gamma rays have been prepared for the above materials, too. The albedo matrices of high-energy neutrons up to 3 GeV are also prepared for concrete and iron as shown in Table 2-9. These data have been calculated by NMTC [2-3)] and MCNP [2-4)]. Details of the albedo calculation for high-energy neutrons are described in Appendix D.

The matrix used in calculations can be specified by input data, i.e., radiation energy structure (INP) and material of duct (MDUCT).

(6) Source intensity at inlet of next leg for bent duct

The incident currents to the side wall and the front wall of the first leg are given with equation (2-1) by multiplying the averaged cosine value of the incident angle to each wall. The averaged cosine values for each wall have been calculated by Monte Carlo calculations[1-1) – 1-3)], and stored in the DUCT-III code. The values are listed in Table 2-10. The source intensity at the inlet of the next leg is denoted as the sum of the incident current to the front wall and the multiplied incident currents to the front wall by the albedo matrix. The above two incident currents are dominant to the source intensity of the next leg. The source intensity is corrected by empirical correction factors, because incident currents to other walls contribute only a little to the source intensity.

When the bent duct to be investigated crosses obliquely, albedo data dependent on incident angle and differential albedo data are needed. Only the albedo data of iron and stainless steel for a low neutron energy structure have been stored in the DUCT-III code.

2.3 Formula for wall scattered radiation current

Ducts are generally positioned far away from radiation sources in order to decrease leakage radiations (streaming) through them. If there are radiation sources surrounded by walls, the wall scattered radiations are not negligible compared to the directly reached radiations to the ducts. For this reason, an option is prepared to calculate the wall scattered radiations and their steaming through the duct. A formula for multi-scattered radiation flux in a spherical cavity based on an albedo analytical method developed by Shin et al.[2-5] is employed to calculate the wall scattered radiations. The radiation current incident to the duct is given by

$$S = \frac{J}{2\pi} \tag{2–12}$$

$$J = \frac{A}{(I-A)}\frac{S_0}{S_a} \tag{2–13}$$

where S is the isotropic radiation current in $cm^2sr^{-1}s^{-1}$, J is the accumulated radiation current in cm^2s^{-1}, A is the albedo matrix, I is the unit matrix, S_0 is the isotropic radiation source intensity in s^{-1}, and S_a is the inner surface area of the cavity wall in cm^2. Equation (2-13) was corrected from the original equation, $J=I/(I-A)\ S_0/S_a$ in which the radiation current directly incident to the duct was included. The radiation current S is expressed in DUCT-III as a function of the incident angle. Equation (2-12) is rewritten by

$$S_j = (\cos(\theta_j) - \cos(\theta_{j+1}))\frac{A}{(I-A)}\frac{S_0}{S_a} \tag{2–14}$$

where S_j is the incident current in the j-th angular bin at duct inlet (cm^2s^{-1}), and θ_j is the angular mesh boundary of radiation incident into the duct in deg. Because of the difficulty described earlier, $A/(I-A)$ in equation (2-14) is, for high-energy neutrons, changed to the following,

$$\frac{A}{(I-A)} \cong A^1 + A^2 + ... + A^M \tag{2-15}$$

where M=20 is used.

3. Additional functions of the DUCT-III code

The following functions are implemented in the DUCT-III code.

3.1 Radiation source data library

Users are able not only to input radiation source data with an input card, but also to select a spectrum from the neutron source data library implemented in the DUCT-III code or the database file given with the logical unit 4 (file name is "bdt") as follows.

(1) Typical neutron source data library

The following representative neutron spectra, the total intensity of which was normalized to unity, have been implemented in the DUCT-III code.

(a) 1/E spectrum

(b) U-235 fission spectrum

(c) Neutron spectrum emitted at 90 deg from thick iron target for 3 GeV protons

(d) Neutron spectrum, reflected by surrounded concrete after emitted from thick iron target for 3 GeV protons

These spectra are shown in Table 3-1 to Table 3-3. For (a), the maximum neutron energy group from which source data starts can be specified and the source spectrum is automatically renormalized to unity in the code. An option to normalize the calculated response distributions with response data at the duct inlet of the first leg given by input is also added only for (a).

The spectra (c) and (d) have been calculated by NMTC [2-3)] and MCNP[2-4)].

(2) Neutron energy spectra emitted from thick targets for protons

Neutron energy spectra dependent on proton energy, material of thick target and emission angle as follows are prepared as a database, too. Details of this calculation are described in Appendix E.

1) Proton energy: 0.2, 0.4, 0.6, 1.0, 3.0, 15.0 and 50.0GeV

2) Material of thick target: iron, copper and aluminum

3) Emission angle: 7.1, 14.0, 26.6, 45.0, 56.3, 71.6, 90.0, 108, 124, 135, 153, 166 and 173 deg

These spectra are listed in Table 3-4 to Table 3-6. Calculated neutron fluences have been corrected with $4\pi r^2$, where r is the distance from the target to the estimator point. Fluences are expressed as neutrons per unit proton. Neutrons in the energy range above 3 GeV, which is the upper limit of neutron energy for the high-energy structure (see Table 2-1), are added in the first group.

The proton energy is given as input. The code selects a higher energy than the input to be on the safe side, when the input is not equal to the above proton energy data (for example, if inputted proton energy

is 2 GeV, the spectrum for 3 GeV protons is selected).

The incident angle relative to the duct axis of the first leg is automatically calculated with the source position and the proton emission direction (for line source, the start and the end points of the source) given by the input. The code selects a lower angle than the calculated angle to be on the safe side, when the calculated angle is not equal to the above angle data (for example, if the calculated angle is 80 deg, the spectrum at 71.6 deg is selected).

This library is available for dealing with the line source with angular distribution in accelerator facilities. The library can be changed or expanded by users.

3.2 A function for the bulk shielding calculation

The DUCT-III code has been linked with a point kernel program PKN-H [4-1)], in order to do the bulk shielding calculation together. The PKN-H code is a program to calculate neutron and secondary gamma-ray dose equivalents in water, ordinary concrete and iron shields for neutron sources up to 400 MeV in a 3-dimensional geometry. It has been developed by JAERI. It will be necessary to improve the PKN-H code, such as by expanding the applicable neutron energies, sharing input data with the DUCT-III code, and so on.

4. Installing and using the DUCT-III code

4.1 Installing and running the DUCT-III code

There are two versions of the DUCT-III code, i.e., the UNIX version and the Visual Basic version (BS) which runs on Microsoft Excel 97*.

*: Copyright (C) Microsoft Corporation.

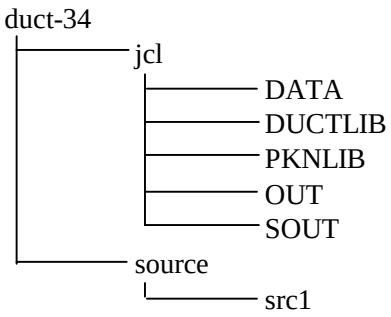
4.1.1 For UNIX version

(1) Extraction of the package

The code package is a compressed tar file, and it is uncompressed and extracted with the following command.

```
#uncompress duct-34.tar.z
#tar xvf - < duct-34.tar
```

The directory structure after the extraction is shown in the following.



(2) Installation

Source programs (*.f) of the DUCT-III code containing the PKN-H code[3-1)] and a make file (MM) for making an executable are stored in a directory src1. The MM list is shown in the following.

```
#
set CHOME0=/xx/duct-34/jcl
set CHOME1=/xx/duct-34/source/src1
#
f77 -o joint.n *.f    +autodblpad
```

```
rm *.o
cp $CHOME1/joint.n $CHOME0
#
exit
```

The file MM is run with the next command after the extracted directory is set in xx of the above list. There are a few influences on the DUCT-III results, even if the command “+autodblpad”, which gives a program double precision, is not used.

```
#./MM
```

The executable “joint.n” is made in a directory “jcl”, after the file MM is finished.

(3) Running the DUCT-III code

A sample shell script “jcl” for running the DUCT-III code is stored in the directory “jcl”. The extracted directory is inputted in xx of the following script.

```
#       HDUCT-2    PKN_H joint program
#       2000.2.17        ...by      H.Nakano
#########################################################
set CHOME0=/xx/duct-34/jcl
set CHOME1=/xx/duct-34/jcl/DATA
set CHOME2=/xx/duct-34/jcl/OUT
set CHOME3=/xx/duct-34/jcl/DUCTLIB
set CHOME4=/xx/duct-34/jcl/PKNLIB
#########################################################
#
#########################################################
cd $CHOME3
cp alb1 $CHOME0/UNI01
cp alb2 $CHOME0/UNI02
cp alb3 $CHOME0/UNI03
cp bdt    $CHOME0/UNI04
cd $CHOME4
```

```
cp pknhngrp.lib $CHOME0/UNI11
cp pknhwate.lib $CHOME0/UNI13
cp pknhconc.lib $CHOME0/UNI14
cp pknhiron.lib $CHOME0/UNI15
#########################################################
cd $CHOME0
cp $CHOME1/$2 $CHOME 0/wrk.pkn
$CHOME0/joint.n $CHOME1/$1 $CHOME2/$1.out
cp pkn.out $CHOME2/$2 .out
# - - - - - collect input and output
echo     " $1 'written'
#
echo     '------> all done, master <------------------------'
rm UNI*
rm *.list
rm *.fgx
rm pkn.out
rm wrk.pkn
exit
```

Input and library data are necessary for running the DUCT-III code. The library data for the DUCT-III code and the PKN-H code are stored in directories “DUCTLIB” and “PKNLIB”, respectively. The input data are stored in a directory “DATA”. The following sample data[4-1)] have already been stored in the directory “DATA”. The calculational models and radiation sources of the sample data have been described in reference 4-1).

nim1: DUCT-III input data for NIMROD straight tunnel
nim2: DUCT-III input data for NIMROD bent tunnel
pri1: DUCT-III input data for PRINCETON bent labyrinth (T1 source)
pri2: DUCT-III input data for PRINCETON bent labyrinth (T2 source)
pri3: DUCT-III input data for PRINCETON bent labyrinth (T3 source)
tia: DUCT-III input data for TIARA bent labyrinth
pkn-tia: PKN-H input data for TIARA bent labyrinth

The DUCT-III code is run with the above data by the next command on the directory “jcl”.

#./jcl tia

The command is the following, when the PKN-H code is run together.

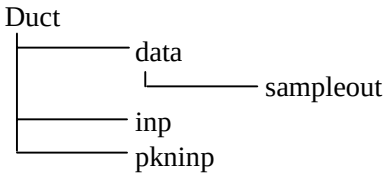
#./jcl tia pkn-tia

The result is outputted as an input file name .out in a directory “OUT”, after the run is finished. It must be confirmed that the calculated results are consistent with the corresponding sample output stored in a directory “SOUT”.

4.1.2 For Visual Basic version

(1) Extraction of the package

The code package is a compressed lha file, and it is uncompressed and extracted by applications such as LHUT. The directory structure after the extraction is shown in the following.



(2) Setup of directory

An Excel file INP_2.xls stored in a directory “Duct” is opened, and the extracted directory (Default: c:¥duct) is inputted in “Executive directory”, and the “End” button must be clicked.

(3) Running the DUCT-III code

Input and library data are necessary for running the DUCT-III code. The library data for the DUCT-III and the PKN-H codes are stored in the directory “Duct”. The input data for the DUCT-III and the PKN-H codes are stored in directories “inp” and “pkninp”, respectively. The following sample data [4-1)] have already been stored in these directories. The calculational models and radiation sources of the sample data have been described in reference 4-1).

nim1: DUCT-III input data for NIMROD straight tunnel
nim2: DUCT-III input data for NIMROD bent tunnel
pri1: DUCT-III input data for PRINCETON bent labyrinth (T1 source)
pri2: DUCT-III input data for PRINCETON bent labyrinth (T2 source)
pri3: DUCT-III input data for PRINCETON bent labyrinth (T3 source)
tia: DUCT-III input data for TIARA bent labyrinth
pkn-tia: PKN-H input data for TIARA bent labyrinth

The DUCT-III code is run on the file INP_.2.xls, after setting "Executive directory". The file INP_.2.xls (see Fig. 4-1) is opened, and one of the input data files in "Select input data file" box is selected. Edits of the input data are available on the file INP_.2.xls and inputs using some equation are also available. A file name to be saved is inputted in "File name" box. The DUCT-III code starts running when the "Run" button is clicked.

An option (IPKN) as one of the inputs for the DUCT-III code is set to 1, when the PKN-H code is run together with it. After the file name to be saved is inputted, the "To PKN data" button must be clicked. An input data sheet (see Fig. 4-2) for the PKN-H code is displayed. After one of the input data files in "Select input data file" box is selected and edited, the "To DUCT data" button must be clicked. Both codes start running when the "Run" button is clicked on the sheet for the DUCT-III code.

The application name "Ductmain" is displayed on the taskbar, while the code is running. The result is outputted, when the "Indicate result" button is clicked after the run is finished. Output files for the DUCT-III code are as follows.

1) file name.inp: Input data are stored in the directory "inp".
2) file name.all: All results are stored in the directory "data".
3) file name.dip: Calculated radiation flux and response are stored in the directory "data".
4) file name.txt: Input data and calculated response are stored in the directory "data".

The calculated radiation flux and response are also stored on newly created Excel sheets, with the names "LEG_FL_x" and "LEG_CT_x" for each leg in the file "INP_2.xls", respectively.

Output files for the PKN-H code are as follows.

5) file name.pkn: Input data are stored in the directory "pkninp".
6) file name.pkn: All results are stored in the directory "data".

Radiation dose rates at calculation points are also stored on a newly created sheet "PKN_OUT" in the file "INP_2.xls".

It must be confirmed that the calculated result is consistent with the corresponding sample output stored in a directory “sampleout”.

4.2 Input/output of the DUCT-III code

(1) Input data

How to make input data and additional functions for the DUCT-III code are described next using several sample problems. The explanation of the input data for the DUCT-III code is shown in Appendix A. Please refer also sample input data for benchmark calculations described in section 4.1, which have been stored in the code package.

1) Sample problem 1

Figure 4-3 shows the calculational model of sample problem 1. This sample problem is to calculate neutron effective dose rate distribution along a bent cylindrical duct passing through a concrete wall. The radius of the duct is 15 cm. The lengths of the first, second and third legs are 100 cm, 50 cm and 100 cm, respectively, and each bent angle is 90 degree. An isotropic point source of 14 MeV neutrons is positioned at the coordinate (0 cm, 0 cm, -100 cm) relative to the center of the duct inlet, and its intensity is 10^{10} s^{-1}. The option to calculate a wall scattered neutron source is not used (IFWS=0), because neutrons directly reaching the calculation points are dominant in this neutron-streaming calculation.

```
Duct-streaming calculations for 100 MeV neutrons
     4       1       0                                                  /INP, NSI, IFWS
     1       1                                                          /MDUCT, KDUCT
   100.000       15.000        0.000        0.000                      /ZMX, RDUCT, RINN, RSORC
     1       1                                                          /NSN, NSR
     0.000         0.000    -100.000                                    /XS, YS, ZS
 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.000E+10 0.000E+00   /SS0(I)
 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
     1                                                                   /NRES
 0.000E-00 0.000E-00 0.000E-00 0.000E-00 1.700E-06 1.550E-06       /RES(I, J)
 6.260E-07 9.490E-08 5.170E-08 5.380E-08 5.060E-08 2.260E-08
     90.000       50.000                                                /ANGLE, ZMX (2nd leg)
     90.000      100.000                                                /ANGLE, ZMX (3rd leg)
```

```
  0.000        0.000                                          /ANGLE, ZMX
0                                                             /IPKN
```

2) Sample problem 2

When a line radiation source is investigated for the same geometry as sample problem 1 as shown in Fig. 4-4, the fifth and sixth lines of the above sample input data are changed to the following. The one meter long line source is set between the start coordinate (-50 cm, 0 cm, -100 cm) and end coordinate (50 cm, 0 cm, -100 cm). The line source is divided by NSR (=50), and the point sources are assumed at the center of the subdivisions by the DUCT-III code.

```
  2    50                                                     /NSN, NSR
-50.000       0.000   -100.000      50.000       0.000   -100.000   /XS, YS, ZS, XE, YE, ZE
```

3) Sample problem 3

Figure 4-5 shows the calculational model of sample problem 3. This sample problem is to calculate neutron effective dose rate distribution along a rectangular duct passing through a concrete wall. The width and height of the duct are 50 cm and 100 cm, respectively, where the width must be equal to or larger than the height. The length of the duct is 10 m. An isotropic point source of ^{235}U fission neutrons is positioned at the coordinate (10 m, -3 m, -1 m) relative to the center of the duct inlet as the origin, and its intensity is 10^{14} s^{-1}. The fission neutron spectra normalized by one is selected from the block data implemented in the DUCT-III code with parameters NSI=2 and NNS=4. The IFWS option is used in this case, because wall scattered neutrons are dominant. The wall surface area (WSA) is calculated with $4\pi r^2$, where r is the distance from the radiation source to the center of the duct inlet. It has been confirmed that radiation flux at the duct inlet using the above wall surface area reproduces with Monte Carlo code[4-1)].

```
Straight duct for U-235 fission spectra
    1      2      1   1.38E+07                          /INP, NSI, IFWS, WSA
    1      2                                            /MDUCT, KDUCT
 1000.000      50.000     100.000       0.000           /ZMX, RDUCT, RINN, RSORC
    1      1                                            /NSN, NSR
-1000.000   -300.000   -100.000                        /XS, YS, ZS
    4 1.000E+14                                              /NNS, SN0
    1                                                        /NRES
```

```
1.790E-06 1.760E-06 1.540E-06 1.230E-06 7.640E-07 3.980E-07      /RES(I, J)
1.380E-07 5.300E-08 5.260E-08 5.440E-08 5.050E-08 2.260E-08
    0.000       0.000                                            /ANGLE, ZMX
    0                                                            /IPKN
```

4) Sample problem 4

Figure 4-6 shows the calculational model of sample problem 4. This sample problem is to calculate total neutron flux distribution along a rectangular duct passing through a concrete wall. The width and height of the duct are 2 m and 2.5 m, respectively. The length of the duct is 10 m. A point source of secondary neutrons emitted from a thick iron target for 1GeV protons is positioned at the coordinate (-300cm, 0cm, -250cm) relative to the center of the duct inlet as the origin, and its intensity is 10^{10} s^{-1}. The secondary neutron spectra per unit proton is selected from the database stored in the logical number 4 (file name "bdt") with parameter NSI=3. The direction vector of the proton source must be inputted with XE, YE and ZE, when NSI=3 is used. The vector (1, 0, 0) is inputted in this sample problem.

```
Straight duct for secondary neutrons emitted from a thick iron target for 1GeV protons
    4     3     1   1.92E+06                                     /INP, NSI, IFWS, WSA
    1     2                                                      /MDUCT, KDUCT
 1000.000   200.000   250.000     0.000                         /ZMX, RDUCT, RINN, RSORC
    1     1                                                      /NSN, NSR
 -300.000     0.000  -250.000     1.000     0.000     0.000     /XS, YS, ZS, XE, YE, ZE
    1 1.000E+00 1.000E+10                                       /MTGT, PENG, SN0
    1                                                           /NRES
1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00     /RES(I, J)
1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00
    0.000       0.000                                           /ANGLE, ZMX
    0                                                           /IPKN
```

(2) Output results

The DUCT-III code outputs the following.

1) Input data
2) Maximum and minimum values of cosθ, where θ is an incident angle relative to the duct axis
3) Source currents for the direct contribution calculation (the values, which are divided by the square of the representative length δ)
4) Source currents for the scattered contribution calculation
5) Fitting parameters for angular distributions used in the calculation
6) Albedo data A, A2, A4 and A8 used in the calculation
7) Direct flux for each energy group (PH0)
8) Scatted flux for each energy group (PH)
9) Sum of direct and scattered fluxes for each energy group (PHT)
10) Bottom currents for each energy group (CBOT)
11) Side currents for each energy group (CSIDE)
12) Values of 7)-11) at duct outlet (ZX)
13) Scattered contribution of calculated responses for each calculation point (COUNT)
14) Direct contribution of calculated response for each calculation point (COUNT0)
15) Sum of direct and scatted response for each calculation point (COUNTT)

For 7) – 11) and 13) – 15), the duct length is divided by 40 and the values at the boundaries of the subdivisions are printed.

The sample output data are stored in the code package as described above. Details of input and output of the PKN-H code are described in another report [3-1)]. The input data of the PKN-H code are explained in Appendix C.

References

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1-2) K. Shin, An Approximate Formula for Neutron and Gamma-Ray Streaming through Ducts and Slits, 7th International Conference on Radiation Shielding, Bournemouth, UK, Sep. 12 - 16 (1988).

1-3) K. Shin and A. Itoh, A Simple Calculation Method for 14 MeV Gap Streaming, International Symposium on Fusion Nuclear Technology, Tokyo, April 11-14 (1988).

1-4) K. Hayashi et al., DUCT-II and SHINE-II: Simple Design Code for Duct-streaming and Skyshine, JAERI-M 91-013 (1991).

2-1) W .W. Engle Jr., "A Users Manual for ANISN, A One Dimensional Discrete Ordinates Transport Code with Anisotropic Scatterring", K-1613, Oak Rige Gaseous Diffusion Plant(1973).....also available as CCC-8 2/ANISN from Radiation Shielding Information Center, Oak Ridge National Laboratory.

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2-3) H. Takada, et al., An Upgraded Version of the Nucleon Meson Transport Code: NMTC/JAERI97, JAERI-DATA/CODE 98-005 1998.

2-4) RSICC Computer Code Collection, MCNP-4B: Monte Carlo N-Particle Transport Code System, CCC-660 (1997).

2-5） K. Shin et al., Albedo Analytical Method for Multi-Scattered Neutron Flux Calculation in Cavity, J. Nucl. Sci. Technol., 23, 949 (1995).

3-1) H. Kotegawa, Y. Sakamoto and S. Tanaka, PKN-H: A Point Kernel Shielding Code for Neutron Source up to 400 MeV, JAERI-Data/Code 95-004.

4-1) F. Masukawa et al., Verification of the DUCT-III for Calculation of High Energy Neutron Streaming, JAERI-Report (to be published).

Appendix A DUCT-III input data manual

Appendix A DUCT-III input data manual

1. Input from card

(1) (TITLE(I),I=1,20): 20A4

Title of a calculation

(2) INP, NSI, IFWS, WSA: 3I5, E10.3

INP: Type of radiation energy structures

=1; neutrons in an energy range below 15 MeV (12 groups)

=2; photons in an energy range below 10 MeV (5 groups)

=3; both 1 and 2 (17 groups)

=4; neutrons in an energy range below 3 GeV (12 groups)

NSI: Input method of radiation source

=1; input from card

=2; select from block data (only if INP is 1 or 4)

=3; select from file 4 (only if INP is 4)

IFWS: An option to calculate wall scattered radiation sources

=0; not calculate

=1; calculate

WSA: wall surface area (cm^2), WSA is suitable, only if IFWS is 1.

(3) MDUCT, KDUCT: 2I5

MDUCT: Material number of duct

=1; concrete (only if INP is 1 – 4)

=2; iron (only if INP is 1 – 4)

=3; polyethylene (only if INP is 1 – 3)

=4; stainless steel (INP=1), iron+ water (INP=3)

KDUCT: Type of ducts

=1; cylindrical duct

=2; rectangular duct

=3; annulus

=4; slit

(4) ZMX, RDUCT, RINN, RSORC: 4F10.3

ZMX: Length of duct (cm)

RDUCT: radius of cylindrical duct (cm)

width a of rectangular duct or slit (cm)

outer radius r1 of annulus (cm)

RINN: zero for cylindrical duct

height b of rectangular duct or slit (cm)

inner radius r2 of annulus (cm)

RSORC: dummy

(5) NSN, NSR: 2I5

NSN: Type of radiation sources

=1; point source

=2; line source

NSR: Subdivided number of line source (max= 50)

NSR is used only if line source is selected.

(6) XS, YS, ZS, XE, YE, ZE: 6E10.3

XS, YX, ZS: Radiation source position relative to the origin at an inlet of the first leg (cm, for line source, input the start point)

XE, YE, ZE: Direction vector of radiation source relative to the source position (cm, for line source, input the end point)

The geometry defined in DUCT-III is shown in Fig. A-1. ZS and ZE must be zero or negative. If not, the calculation is abnormally ended. For a point source, XE, YE and ZE are used only if NSI is 3.

(7) Input radiation source spectrum

1) If NSI=1 is selected, (SS0(I),I=1,NM): 6E10.3

SS0: Energy dependent radiation source intensity (s^{-1})

2) If NSI=2 is selected, NNS, SN0, MEG: I5, E10.3, I5

NNS: Neutron spectrum number in block data

=1; 1/E spectrum for high neutron energy structure (only if INP is 4)

=2; 1/E spectrum for low neutron energy structure (only if INP is 1)

=3; U-235 fission spectrum for high neutron energy structure (only if INP is 4)

=4; U-235 fission spectrum for low neutron energy structure (only if INP is 1)

=5; neutron spectrum emitted from iron target for 3 GeV protons at 90 deg (only if INP is 4)

=6; reflected neutron spectrum by surrounded concrete after emitted from iron target for 3 GeV protons at 90 deg (only if INP is 4)

If NNS is –1 or –2, the calculated response distribution is normalized with the next SN0 at the duct inlet of the first leg.

SN0: neutron source intensity (s^{-1})

If NNS is –1 or –2, SN0 can be used as response.

MEG: maximum neutron energy group for 1/E spectrum (only if NNS is 1 or 2)

The code renormalizes the 1/E spectrum with MEG.

3) If NSI=3 is selected, MTGT, PENG, SN0: I5, 2E10.3

MTGT: Material number of thick target

=1; iron

=2; cupper

=3; aluminum

PENG: Proton energy (GeV)

SN0: Proton source intensity (s^{-1})

(8) NRES: I5

NRES: Number of response functions to be inputted below (max=5)

If NRES=0 is inputted, only flux is calculated.

(9) (RES(I,J),I=1,NM): 6E10.3

RES: energy dependent response function

Card (9) is inputted NRES times.

(10) ANGL, ZMX: 2F10.3

ANGL: Bent angle of the next leg relative to the duct axis

ZMX: Length of the next leg (cm)

Card (10) is inputted number of legs times. Finally a blank card or zero must be inputted. Only the albedo data below 70 deg for stainless steel and iron for low neutron energy structure have been prepared.

(11) IPKN: I5

IPKN: Option to run the PKN-H code

=0; not run the PKN-H code

=1; run the PKN-H code

2. Input from logical number 1

Twelve types of albedo data are stored with the following format.

(1) ((TIT(I),I=1,18),M1,M2): 18A4, 2I2

TIT: Title

M1: Material number (=MDUCT)

M2: Type of radiation sources (=INP)

(2) (AX(I,J),I=1,NM): 6E12.5

3. Input from logical number 2

Eight types of albedo data which depend on incident angles are stored with the following format.

(1) ((TIT(I),I=1,18),M1,M2,M3): 18A4, 3I2

TIT: Title

M1: Material number (MDUCT=2 and 4)

M2: Type of radiation sources (INP=1)

M3: Cosine of incident angles (=.218, .577, .787 and .951)

(2) (AA(I,J),I=1,NM): 6E12.5

AA: Incident angle dependent albedo data for iron and stainless steel

4. Input from logical number 3

Eight types of differential albedo data which depend on incident angles are stored with the following format.

(1) ((TIT(I),I=1,18),M1,M2,M3): 18A4, 3I2

TIT: Title

M1: Material number (MDUCT=2 and 4)

M2: Type of radiation sources (INP=1)

M3: Cosine of incident angles (=.218, .577, .787 and .951)

(2) (AM(I,J),I=1,NM): 6E12.5

AM: Differential albedo data for iron and stainless steel

5. Input from logical number 4

Neutron spectra which depend on proton energy, material of the thick target and emission angle are stored in this file with the following format.

(1) NEN, NTHE, NMAT: 3I5

NEN: Number of proton energies (max=7)

NTHE: Number of emission angles (max=13)

NMAT: Number of materials (max=3)

(2) (PENG(I),I=1,NEN): 13E9.3

PENG: Proton energies (GeV)

(3) (PTHE(I),I=1,NTHE): 13E9.3

PTHE: Emission angles (deg)

(4) (PNSP(I,J,K,L),I=1,NM,J=1,NTHE,K=1,NEN,L=1,NMAT): 13E9.3

PNSP: Neutron spectra per source protons

Appendix B Program document of the DUCT-III code

Appendix B Program document of the DUCT-III code

1. Name of program

DUCT-III

2. Programming language

FORTRAN-77

3. Memory of program package

1) For UNIX version

1.8 MB (uncompressed file)

2) For Visual Basic version (on Microsoft Excel version 97*)

2.3 MB (uncompressed file)

4. Structure of program

Fig. B-1 shows the tree structure of the DUCT-III code.

5. Description of subroutines

The description of the subroutines, which make up the DUCT-III code are shown in Table B-1.

6. Description of symbols in common blocks

Symbols in main common blocks are described in Table B-2.

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Appendix C PKN-H input data manual

Appendix C PKN-H input data manual

1. Card input

(1) TITLE(Ⅰ),I=1,20) : 20A4
The title of the calculation

(2) (LSO,MSO,NSO,dummy,dummy,NPOINT,dummy,IPSEUD,NSOPT,dummy,ISRC) : 11I5
LSO : Total number of input location of X1 coordinate of source
MSO : Total number of input location of X2 coordinate of source
NSO : Total number of input location of X3 coordinate of source
NPOINT : Total number of regions(or zones) defined in CARD-CGC
IPSEUD : Total number of bodies defined in CARD-CGB
NSOPT : Coordinates system describing the form of the source
(0/1/2)= (cylindrical/cartesian/spherical coordinates)
ISRC : Type of source
(0/1/2)= (source of the previous case is used/cosine distributed source is used/source is computed using the weighting values input along each coordinate axis)

(3) ASO,((XISO(I,J),I=1,2),J=1,3) : E10.3,6I5
ASO : The total source strength in fissions/s,captures/s, or decays/s. (default = 1)
XISO : Constants for cosine source distribution.
(CID is ignored, if ISRC does not equal 1.)
Is ISRC equals 1, source strength distribution is calculated as the following equation,
Source strength(X1,X2,X3) = ASO*COS(XISO(1,1)*(X1-XISO(2,1))
ASO*COS(XISO(1,2)*(X2-XISO(2,2))
ASO*COS(XISO(1,3)*(X3-XISO(2,3))

(4) (RSO(I),I=1,LSO+1) : 8F9.2
RSO : Coordinate of source volume divisions along X1-axis.

(5) (ZSO(I),I=1,MSO+1) : 8F9.2
ZSO : Coordinate of source volume divisions along X2-axis.

(6) (RHISO(I),I=1,NSO+1) : 8F9.4
RHISO : Coordinate of source volume divisions along X3-axis.

Note : Source intensity is normalized to 1.

(7) (xs,ys,zs,weight),I=1,NPOINT : 4F9.2
xs : Center coordinate of I-th source volume along X1-axis.
ys : Center coordinate of I-th source volume along X1-axis.
zs : Center coordinate of I-th source volume along X1-axis.
weight : Weight(ratio) of I-th source volume

Note : This input iterates numbers of source blocks, if source separates into more than two blocks.
Note : I-th source coordinate is calculated, as follows,
(RSO+xs(I),ZSO+ys(I),RHISO+zs(I))

If ISRC does not equal 2, No.（8） to No.（10） are not necessary.

(8) （FL(I),I=1,LSO+1）：8F9.2

FL ： Weight of source strength for source location RSO.

(9) （FM(I),I=1,MSO+1）：8F9.2

FM ： Weight of source strength for source location ZSO.

(10) （FN(I),I=1,RHISO+1）：8F9.2

FN ： Weight of source strength for source location RHISO.

(11) （IVOPT,IDBG,(JTYX（Ｉ）,I=1,10)）：2I5,10X,10A6

IVOPT ： Set to zero for PKN-H input.

IDBG ： Set to zero for PKN-H input.

JTYX ： Alphanumeric title for geometry input(columns 21-80)

(12) （ITYPEX,IALP,FPD）：2X,A3,1X,I4,6E10.3/10X,6E10.3

One set of CGB cards is required for each and for the END card.
Leave columns 1-6 blank on all continuation cards.

ITYPEX ： Specifies body type or END to terminate reading of body (for example BOX, RPP, ARB, etc.). Leave blank for continuation cards.

IALP ： Body number assigned by user (all input body numbers must form a sequence set beginning at 1). If left blank, numbers are assigned sequentially.
Either assign all or none of the numbers. Leave blank for continuation cards.

FPD ： Real data required for the given body.
These data must be in cm.

Note ： Must add an 'END' line at the end of the data.

(13) （IALPX,NAZ,(IIBIAS(I),JTY(I),I=1,9）：2X,A3,I5,9(A2,I5)

Input zone specification cards. One set of card required for each input zone, with input zone numbers being assigned sequentially.

IALPX ： IALPX must be a nonblank for the first card of each set of cards defining an input zone. If IALPX is blank, this card is treated as a continuation of the previous zone card.
IALPX = END denotes the end zone description.

NAZ ： Total number of zones that can be entered upon leaving any of the bodies defined for this input region (some zones may be counted more than once). Leave blank for continuation cards for a given zone. (If NAX < 0 on the first card of the zone card set, then it is set to 5).
This is used to allocate blank common.

IIBIAS(I) ： Specify the "OR" operator if required for the JTY(I) body.

JTY(I) ： Body number with the (+) or (-) sign as required for the zone description.

Note ： Must add an 'END' line at the end of the data.

(14) （NSTOR）NSTOR(I),I=1,IALPX ：14I5

NSTOR ： NSTOR(I) is the region number in which the "Ith" input zone is contained(I = 1, to the number of input zone).
Region numbers must be sequentially defined from 1.
Number 1 region should be a region including the source.

(15) （NSTOR）NSTOR(I),I=1,IALPX ： 14I5

NSTOR ： NSTOR(I) is the medium number in which the "Ith" input zone is contained(I = 1, to the number of input zone).
Medium numbers must be sequentially defined from 1 to 3, else 0 for external void, or 1000 for internal void.

(16) （IPP,IPD(1),IPD(2)） ： I5,I6,I5

IPP ： ID number of energy dependence of source.
= (1:mono energy/2:spread energy3:235U/4:252CF/5:241Am-Be /6:Watt formula)

IPD(1) ： First group of input of source group information (-1 to 59)

IPD(2) ： Last group of input of source group information (-1 to 59)

If IPP = 6, source strength is calculated according to the following equation.

$S(E) \sim \exp(-PD6A * E) * \sinh(\sqrt{2} * PD6B * E)$

E ： source neutron energy(MeV)

(17) （QID）QID(I),I=1,IPD(2)-IPD(1)+1 ： I3,E8.2

QID ： The IPD(2) - IPD(1) + 1 relative source strengths from IPD(1) to IPD(2) is necessary, if IPP=2.
This card is not necessary when IPD(2) is larger then IPD(1).
This card is ignored when IPP=6.

(18) （IKENN,IW6） ： I4,I5

IKENN ： Definition of Detector Point

Note ： （１９）、（２０） should be necessary at the time of IKENN < 3
（２１） should be necessary at the time of IKENN = 3

(19) （XMIN,XMAX,XBUN,JIKU） ： 4F9.2

XMIN ： Calculational coordinate along X1-axis.

XMAX ： Calculational coordinate along X2-axis.

XBUN ： Calculational coordinate along X3-axis.

JIKU ： Coordinate system describing detector point
(0/1/2) = (cylindrical/cartesian/spherical coordinates)

Note ： It is necessary in the case of IKENN < 3.

(20) （YMIN,YMAX,YBUN,AJIKU） ： 4F9.2

YMIN ： Calculational coordinate along Y1-axis.

YMAX ： Calculational coordinate along Y2-axis.

YBUN ： Calculational coordinate along Y3-axis.

AJIKU ： Coordinate system describing detector point
(0/1/2) = (cylindrical/cartesian/spherical coordinates)

Note ： It is necessary in the case of IKENN < 3.

(21) （RRC,ZEC,PHIRC,NRCOCT,NGRE,NGPL,NGPI） ： 2F9.2,9.1,7X,4I2

Appendix D Albedo data for high-energy neutrons

Appendix D Albedo data for high-energy neutrons

Scattering calculations were carried out to get the albedo data for high-energy neutrons.

1. Method

(1) Calculation code and cross section library

Calculations were carried out by using NMTC/JAERI[2-3] and MCNP[2-4]. Neutrons in the energy range above and below 20 MeV were calculated with NMTC and MCNP, respectively. The JENDL3.2 [D-1] was used for MCNP,and the intra-nuclear cascade model Bertini, for NMTC.

(2) Neutron energy structure of albedo data

The energy structure of albedo data for high-energy neutrons is shown in Table 2-1. The number of energy groups of the albedo data is 12, which is the same as that of the old library of the DUCT-III code. This structure covers energies from thermal to 3 GeV neutrons. The upper energies from group 1 to group 5 are set based on representative proton energies used in accelerator facilities. The upper energies from group 6 to group 12 are set so as to have a constant lethargy width of each energy bin based on HILO86[D-2] neutron energy structure.

(3) Calculational models

Calculational models of albedo data for concrete and iron are shown in Figs. D-1 and D-2, respectively. Line beam neutrons go into a slab with a direction, which has been used in the calculations of other albedo data and corresponds to the minimum angle in the symmetric S8 quadrature set. The slab has the thickness, such that the dose rate due to GeV neutrons attenuates one order of magnitude. The atomic number densities of the materials are listed in Table D-2.

A mono-energetic neutron source, due to NMTC calculations, was used and the median of lethargy for each energy bin was used as the representative energy. For group 12, corresponding to thermal neutron region, 0.025 MeV was used as the representative energy. Twelve calculation cases were carried out. The neutron currents crossing the upper surface of the slab were tallied for each energy group shown in Table 2-1. The incident currents were subtracted from the calculated currents by MCNP, because not only the albedo, but also the incident currents were tallied.

2. Results

The calculated currents are shown in Table D-3 and Table D-4. These data were edited and implemented into the DUCT-III code as the block data. These have been shown in Table 2-9.

References

D-1) Nakagawa T. et al., Japanese Evaluated Nuclear Data Library Version 3 Revision-2: JENDL-3.2, J. Nucl. Sci. Technol., 32, 1259 (1995).

D-2) R. G. Alsmiller Jr, J. M. Barnes and J. D. Drischler : Neutron-Photon Multigroup Cross Sections for Neutron Energies $\leqq$ 400 MeV (Revision 1), ORNL/TM-9801(1986).

Appendix E Angular dependent secondary neutron spectra for proton accelerator facilities

Appendix E Angular dependent secondary neutron spectra for proton accelerator facilities

The NMTC/JAM[2-3)] and the MCNP4A[2-4)] were used to calculate the angular depended secondary neutron energy spectra by the incident mono-energic protons which have a kinetic energy from 200 MeV to 50 GeV, to provide a source to the DUCT-III.

1. Calculations

Figure E-1 shows the model for calculating secondary neutron spectra. The searching parameters are the following.

1) Proton source

Incident particles are protons with pencil beam. Incident proton energies at 0.2, 0.4, 0.6, 1.0, 3.0, 15.0 and 50.0 GeV are searched.

2) Target

Target materials to be investigated are Al, Fe, and Cu. The target geometries are cylinders for which diameter and height are in the effective range for the incident energies (for Fe and Cu), except for Al, for which diameter and height are in the effective range for 0.2GeV proton for any incident proton, and are located in vacuum. The effective range and density for each material are listed in Table E-1.

3) Emission angles

Annulus cell tallies whose radius is 1.5 m from the target axis, and are located at –12, -6, -3, -1.5, -1, -0.5, 0 (target center), 0.5, 1, 1.5, 3, 6, 12 m on the target axis, which correspond to 173, 166, 153, 135, 124, 108, 90, 71.6, 56.3, 45, 26.6, 14, and 7.1 deg, respectively. Each tally height is 0.5 m, and thickness is 0.01 m. Tally score is divided into 14 energy groups as shown in Fig. 2-1.

4) Monte Calro codes

The 13th version of NMTC/JAM was used for neutron and proton calculations above 20 MeV. The neutron spectra calculated by this version are reported to be underestimated by 20 % (private comm. from Niita). Neutrons in the energy range below 20 MeV were calculated with MCNP4A. No variance reduction technique was used, because there were many tallies and their positions were extensively dispersed. The JENDL3.2 was used for MCNP and the intra-nuclear cascade model Bertini, for NMTC.

2. Results

Secondary neutron spectra at representative emission angles, 7.1, 45, 90, 135 and 173 deg for iron, aluminum and copper targets are shown from Fig. E-2 to Fig. E-22. These spectra are multiplied by each distance from the target center to estimator center. As only an isotropic radiation source is assumed in the DUCT-III code, neutron spectra multiplied by 4π have been implemented into the DUCT-III code. The implemented data are listed in Table 3-4 to Table 3-6.

Tables

Table 2-1 Neutron and Photon Energy Structures for DUCT-III

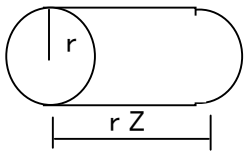
Neutron energy structure

Energy Group	Upper Energy (MeV)	
	High Energy Set	Low Energy Set
1	3.00E+03	1.50E+01
2	1.50E+03	1.30E+01
3	8.00E+02	5.49E+00
4	4.00E+02	2.47E+00
5	1.00E+02	9.07E-01
6	2.00E+01	3.34E-01
7	1.35E+00	1.11E-01
8	8.65E-02	9.12E-03
9	3.35E-03	7.49E-04
10	1.01E-04	6.14E-05
11	5.04E-06	5.04E-06
12	4.14E-07	4.14E-07
	1.00E-10	1.00E-09

Photon energy structure

Energy Group		Upper Energy (MeV)
n+γ	γ	
13	1	1.00E+01
14	2	4.00E+00
15	3	1.50E+00
16	4	5.00E-01
17	5	2.00E-01
		0.00E+00

Table 2-2 Fitting Parameters for Cylindrical Duct

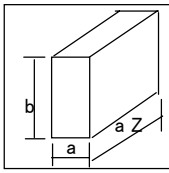


$$\phi^{(n)}(Z) = \frac{C_n}{1+\left(\frac{Z}{a_n}\right)^{b_n}}\left\{1-\xi\exp(-\theta_n Z)\right\}$$

Ωj	$\phi^{(n)}$	an	bn	cn	ξn	θn
Ω1	$\phi^{(1)}$	4.09E+00	3.16E+00	2.45E-01	6.00E-01	1.00E+00
	$\phi^{(2)}$	4.71E+00	3.27E+00	3.05E-01	6.00E-01	1.00E+00
	$\phi^{(8)}$	7.72E+00	3.85E+00	1.60E-01	7.30E-01	5.00E-01
Ω2	$\phi^{(1)}$	1.44E+00	3.28E+00	1.00E+00	8.00E-02	1.90E+00
	$\phi^{(2)}$	2.30E+00	3.68E+00	6.20E-01	4.20E-01	1.00E+00
	$\phi^{(8)}$	6.59E+00	4.78E+00	1.20E-01	6.60E-01	9.00E-01
iso	$\phi^{(1)}$	1.80E+00	3.08E+00	1.10E-01	2.18E-01	1.80E+00
	$\phi^{(2)}$	2.71E+00	3.38E+00	6.40E-02	4.00E-01	2.00E+00
	$\phi^{(8)}$	6.60E+00	4.34E+00	1.80E-02	6.89E-01	6.46E-01

Ω1：$0.879 < \mu \leqq 1$
Ω2：$0 \leqq \mu < 0.879$
iso：isotropic source

Table 2-3 Fitting Parameters for Rectangular Duct

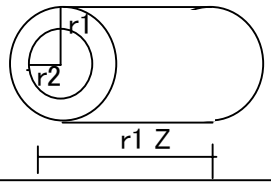


$$\phi^{(n)}(Z) = \frac{C_n}{1+\left(\frac{Z}{a_n}\right)^{b_n}}\left\{1-\xi\exp(-\theta_n Z)\right\}$$

b/a	Ωj	$\phi^{(n)}$	an	bn	cn	ξn	θn
1	Ω1	$\phi^{(1)}$	1.67E+00	3.06E+00	7.00E-01	7.14E-01	7.87E-01
		$\phi^{(2)}$	2.46E+00	3.21E+00	3.00E-01	5.74E-01	2.39E+00
		$\phi^{(8)}$	3.92E+00	3.72E+00	1.70E-01	7.53E-01	9.63E-01
	Ω2	$\phi^{(1)}$	5.96E-01	3.16E+00	1.50E+00	3.47E-01	9.72E-01
		$\phi^{(2)}$	1.28E+00	3.75E+00	4.80E-01	3.54E-01	2.55E-01
		$\phi^{(8)}$	3.05E+00	4.54E+00	1.20E-01	7.00E-01	6.03E-01
	iso	$\phi^{(1)}$	9.19E-01	3.11E+00	4.22E-01	2.86E-01	4.82E-01
		$\phi^{(2)}$	1.30E+00	3.40E+00	2.84E-01	5.36E-01	6.67E-01
		$\phi^{(8)}$	3.24E+00	4.26E+00	7.41E-02	7.33E-01	5.78E-01
1.5	Ω1	$\phi^{(1)}$	2.23E+00	3.02E+00	5.20E-01	6.15E-01	7.22E-01
		$\phi^{(2)}$	3.08E+00	3.32E+00	3.00E-01	5.67E-01	2.11E+00
		$\phi^{(8)}$	4.71E+00	3.64E+00	1.55E-01	7.29E-01	1.10E+00
	Ω2	$\phi^{(1)}$	7.74E-01	3.31E+00	1.50E+00	3.33E-01	8.47E-01
		$\phi^{(2)}$	1.49E+00	3.77E+00	4.80E-01	4.00E-01	6.42E-01
		$\phi^{(8)}$	3.53E+00	4.37E+00	1.20E-01	7.00E-01	7.09E-01
	iso	$\phi^{(1)}$	1.09E+00	3.13E+00	3.05E-01	3.39E-01	5.27E-01
		$\phi^{(2)}$	1.51E+00	3.28E+00	1.92E-01	5.37E-01	7.99E-01
		$\phi^{(8)}$	3.76E+00	4.14E+00	5.00E-02	7.30E-01	6.06E-01
2	Ω1	$\phi^{(1)}$	2.58E+00	3.00E+00	4.50E-01	5.56E-01	9.57E-01
		$\phi^{(2)}$	3.37E+00	3.21E+00	3.00E-01	5.67E-01	2.11E+00
		$\phi^{(8)}$	5.28E+00	3.59E+00	1.60E-01	7.38E-01	8.72E-01
	Ω2	$\phi^{(1)}$	8.38E-01	3.25E+00	1.50E+00	3.33E-01	9.96E-01
		$\phi^{(2)}$	1.64E+00	3.77E+00	4.80E-01	3.54E-01	7.30E-01
		$\phi^{(8)}$	4.06E+00	4.42E+00	1.20E-01	7.00E-01	7.22E-01
	iso	$\phi^{(1)}$	1.19E+00	3.06E+00	2.25E-01	3.48E-01	8.16E-01
		$\phi^{(2)}$	1.69E+00	3.27E+00	1.42E-01	5.42E-01	7.74E-01
		$\phi^{(8)}$	4.06E+00	4.00E+00	3.70E-02	7.37E-01	6.52E-01
3	Ω1	$\phi^{(1)}$	2.85E+00	2.79E+00	4.30E-01	5.35E-01	1.40E+00
		$\phi^{(2)}$	3.73E+00	3.11E+00	3.00E-01	1.67E-01	6.76E-01
		$\phi^{(8)}$	5.51E+00	3.16E+00	1.70E-01	8.12E-01	6.71E-01
	Ω2	$\phi^{(1)}$	1.01E+00	3.27E+00	1.50E+00	3.33E-01	1.04E+00
		$\phi^{(2)}$	1.82E+00	3.58E+00	4.80E-01	3.75E-01	8.11E-01
		$\phi^{(8)}$	4.49E+00	4.28E+00	1.20E-01	7.00E-01	7.78E-01
	iso	$\phi^{(1)}$	1.33E+00	2.99E+00	1.60E-01	3.31E-01	6.00E-01
		$\phi^{(2)}$	1.85E+00	3.14E+00	9.20E-02	5.38E-01	6.13E-01
		$\phi^{(8)}$	4.47E+00	3.79E+00	2.40E-02	7.35E-01	6.09E-01
4	Ω1	$\phi^{(1)}$	2.73E+00	2.52E+00	4.70E-01	5.74E-01	1.11E+00
		$\phi^{(2)}$	3.92E+00	2.93E+00	3.00E-01	5.67E-01	1.90E+00
		$\phi^{(8)}$	6.01E+00	3.08E+00	1.60E-01	7.38E-01	6.69E-01
	Ω2	$\phi^{(1)}$	1.07E+00	3.17E+00	1.50E+00	3.33E-01	8.37E-01
		$\phi^{(2)}$	1.86E+00	3.50E+00	4.80E-01	3.96E-01	1.02E+00
		$\phi^{(8)}$	4.83E+00	4.11E+00	1.20E-01	7.00E-01	7.31E-01
	iso	$\phi^{(1)}$	1.23E+00	2.71E+00	1.20E-01	3.17E-01	6.69E-01
		$\phi^{(2)}$	1.94E+00	3.07E+00	7.00E-02	5.43E-01	9.99E-01
		$\phi^{(8)}$	4.63E+00	3.57E+00	1.80E-02	7.33E-01	6.35E-01

Ω1：$0.879 < \mu \leqq 1$
Ω2：$0 \leqq \mu < 0.879$
iso：isotropic source

Table 2-4 Fitting Parameters for Annulus

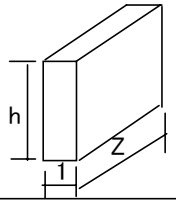


$$\phi^{(n)}(Z) = \frac{C_n}{1+\left(\frac{Z}{a_n}\right)^{b_n}}\{1-\xi\exp(-\theta_n Z)\}$$

r2/r1	Ωj	$\phi^{(n)}$	an	bn	cn	ξn	θn
0.5	Ω1	$\phi^{(1)}$	3.20E+00	3.16E+00	8.01E-01	8.00E-01	5.00E-01
		$\phi^{(2)}$	2.88E+00	2.95E+00	8.01E-01	7.00E-01	7.00E-01
		$\phi^{(8)}$	3.68E+00	3.10E+00	8.01E-01	9.50E-01	5.00E-01
	Ω2	$\phi^{(1)}$	1.21E+00	2.67E+00	1.18E+00	8.00E-01	1.00E+00
		$\phi^{(2)}$	1.89E+00	3.00E+00	7.07E-01	7.00E-01	7.00E-01
		$\phi^{(8)}$	4.35E+00	3.80E+00	1.88E-01	7.00E-01	1.00E+00
0.75	Ω1	$\phi^{(1)}$	2.38E+00	3.05E+00	2.75E-01	7.00E-01	1.00E+00
		$\phi^{(2)}$	2.31E+00	3.05E+00	3.02E-01	7.00E-01	7.00E-01
		$\phi^{(8)}$	2.77E+00	3.48E+00	4.40E-01	9.50E-01	7.00E-01
	Ω2	$\phi^{(1)}$	1.23E+00	2.57E+00	1.51E-01	6.00E-01	2.00E+00
		$\phi^{(2)}$	1.57E+00	2.81E+00	1.72E-01	6.00E-01	7.00E-01
		$\phi^{(8)}$	2.49E+00	3.54E+00	1.37E-01	8.00E-01	7.00E-01
0.87	Ω1	$\phi^{(1)}$	1.71E+00	3.15E+00	1.07E-01	8.00E-01	1.00E+00
		$\phi^{(2)}$	1.94E+00	3.04E+00	8.40E-02	7.00E-01	7.00E-01
		$\phi^{(8)}$	2.33E+00	3.38E+00	7.64E-02	7.00E-01	7.00E-01
	Ω2	$\phi^{(1)}$	9.90E-01	2.42E+00	2.75E-02	6.00E-01	2.00E+00
		$\phi^{(2)}$	1.35E+00	2.61E+00	3.36E-02	6.00E-01	7.00E-01
		$\phi^{(8)}$	1.94E+00	3.56E+00	4.96E-02	6.00E-01	7.00E-01
0.95	Ω1	$\phi^{(1)}$	1.42E+00	3.02E+00	1.04E-01	7.00E-01	1.50E+00
		$\phi^{(2)}$	1.67E+00	3.10E+00	9.19E-03	6.00E-01	7.00E-01
		$\phi^{(8)}$	1.82E+00	3.47E+00	1.07E-02	6.00E-01	7.00E-01
	Ω2	$\phi^{(1)}$	1.28E+00	2.68E+00	1.84E-03	7.00E-01	1.00E+00
		$\phi^{(2)}$	1.13E+00	2.35E+00	2.76E-03	7.00E-01	1.00E+00
		$\phi^{(8)}$	1.33E+00	2.93E+00	3.98E-03	6.00E-01	7.00E-01

Ω1：$0.879 < \mu \leqq 1$
Ω2：$0 \leqq \mu < 0.879$
iso：isotropic source

Table 2-5 Fitting Parameters for Slit



$$\phi^{(n)}(Z) = \frac{C_n}{1+\left(\frac{Z}{a_n}\right)^{b_n}}\{1-\xi\exp(-\theta_n Z)\}$$

h	Ωj	$\phi^{(n)}$	an	bn	cn	ξn	θn
8	Ω1	$\phi^{(1)}$	3.00E+00	2.92E+00	1.91E+00	9.50E-01	1.00E-01
		$\phi^{(2)}$	3.00E+00	2.92E+00	1.91E+00	9.50E-01	1.00E-01
		$\phi^{(8)}$	6.00E+00	3.22E+00	3.38E-01	9.60E-01	1.10E-01
	Ω2	$\phi^{(1)}$	3.90E+00	4.40E+00	9.10E-01	8.70E-01	1.00E-01
		$\phi^{(2)}$	3.90E+00	4.40E+00	9.10E-01	8.70E-01	1.00E-01
		$\phi^{(8)}$	1.05E+01	5.32E+00	5.37E-02	8.70E-01	2.00E-01
	Ω3	$\phi^{(1)}$	1.50E+00	3.40E+00	1.45E+00	7.90E-01	3.00E-01
		$\phi^{(2)}$	1.50E+00	3.40E+00	1.45E+00	7.90E-01	3.00E-01
		$\phi^{(8)}$	9.40E+00	5.01E+00	3.05E-02	7.90E-01	4.90E-01
20	Ω1	$\phi^{(1)}$	3.90E+00	2.50E+00	7.00E-01	8.00E-01	2.55E-01
		$\phi^{(2)}$	3.90E+00	2.50E+00	7.00E-01	8.00E-01	2.55E-01
		$\phi^{(8)}$	1.22E+01	2.99E+00	9.00E-02	8.00E-01	4.52E-01
	Ω2	$\phi^{(1)}$	3.00E+00	2.72E+00	4.96E-01	6.50E-01	9.00E-01
		$\phi^{(2)}$	3.00E+00	2.72E+00	4.96E-01	6.50E-01	9.00E-01
		$\phi^{(8)}$	9.11E+00	3.70E+00	8.50E-02	8.00E-01	2.52E-01
	Ω3	$\phi^{(1)}$	2.36E+00	3.30E+00	5.40E-01	5.00E-01	7.25E-01
		$\phi^{(2)}$	2.36E+00	3.30E+00	5.40E-01	5.00E-01	7.25E-01
		$\phi^{(8)}$	9.20E+00	4.41E+00	6.00E-02	8.30E-01	1.94E-01
60	Ω1	$\phi^{(1)}$	2.97E+00	2.08E+00	7.00E-01	8.00E-01	3.30E-01
		$\phi^{(2)}$	2.97E+00	2.08E+00	7.00E-01	8.00E-01	3.30E-01
		$\phi^{(8)}$	1.10E+01	2.67E+00	1.20E-01	8.40E-01	2.50E-01
	Ω2	$\phi^{(1)}$	2.49E+00	2.49E+00	7.00E-01	7.50E-01	7.00E-01
		$\phi^{(2)}$	2.49E+00	2.49E+00	7.00E-01	7.50E-01	7.00E-01
		$\phi^{(8)}$	8.82E+00	3.13E+00	1.30E-01	8.77E-01	1.50E-01
	Ω3	$\phi^{(1)}$	1.86E+00	2.63E+00	6.00E-01	5.20E-01	1.00E+00
		$\phi^{(2)}$	1.86E+00	2.63E+00	6.00E-01	5.20E-01	1.00E+00
		$\phi^{(8)}$	9.19E+00	3.68E+00	6.00E-02	8.17E-01	2.30E-01
200	Ω1	$\phi^{(1)}$	3.40E+00	2.03E+00	5.00E-01	7.20E-01	5.56E-01
		$\phi^{(2)}$	3.40E+00	2.03E+00	5.00E-01	7.20E-01	5.56E-01
		$\phi^{(8)}$	1.20E+01	2.76E+00	1.05E-01	8.19E-01	3.07E-01
	Ω2	$\phi^{(1)}$	2.48E+00	2.16E+00	5.00E-01	6.40E-01	1.10E+00
		$\phi^{(2)}$	2.48E+00	2.16E+00	5.00E-01	6.40E-01	1.10E+00
		$\phi^{(8)}$	1.00E+01	2.96E+00	8.50E-02	8.05E-01	3.50E-01
	Ω3	$\phi^{(1)}$	1.49E+00	2.32E+00	7.00E-01	4.14E-01	1.08E+00
		$\phi^{(2)}$	1.49E+00	2.32E+00	7.00E-01	4.14E-01	1.08E+00
		$\phi^{(8)}$	9.95E+00	3.38E+00	5.00E-02	7.80E-01	4.60E-01

Ω1 : $0.956 < \mu \leqq 1$
Ω2 : $0.879 \leqq \mu < 0.956$
Ω3 : $0 \leqq \mu < 0.879$

Table 2-6 Albedo Matrix for Neutrons with Low Energy Structure (E<15MeV)

Energy	Albedo matrix of concrete											
group	1	2	3	4	5	6	7	8	9	10	11	12
1	5.33E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1.44E-01	1.57E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1.19E-01	1.94E-01	3.31E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	8.28E-02	8.82E-02	1.62E-01	3.56E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	4.19E-02	5.03E-02	7.23E-02	1.87E-01	3.95E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	2.34E-02	2.78E-02	3.99E-02	7.50E-02	1.74E-01	3.79E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	2.32E-02	2.78E-02	3.78E-02	6.36E-02	1.06E-01	2.27E-01	3.98E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	1.44E-02	1.70E-02	2.25E-02	3.40E-02	4.93E-02	8.47E-02	1.99E-01	3.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	1.11E-02	1.30E-02	1.68E-02	2.38E-02	3.14E-02	4.69E-02	8.55E-02	2.06E-01	3.92E-01	0.00E+00	0.00E+00	0.00E+00
10	8.79E-03	1.03E-02	1.31E-02	1.78E-02	2.21E-02	3.04E-02	4.76E-02	8.68E-02	2.07E-01	3.92E-01	0.00E+00	0.00E+00
11	7.06E-03	8.24E-03	1.04E-02	1.37E-02	1.64E-02	2.14E-02	3.08E-02	4.75E-02	8.68E-02	2.06E-01	3.90E-01	0.00E+00
12	2.28E-02	2.66E-02	3.35E-02	4.28E-02	4.86E-02	5.70E-02	6.95E-02	8.51E-02	1.32E-01	2.26E-01	3.63E-01	8.16E-01

Energy	Albedo matrix of iron											
group	1	2	3	4	5	6	7	8	9	10	11	12
1	1.26E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	4.78E-02	4.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	5.86E-02	6.13E-02	1.09E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1.61E-01	1.36E-01	1.73E-01	2.32E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	2.01E-01	1.54E-01	1.65E-01	1.70E-01	4.38E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1.15E-01	9.53E-02	1.01E-01	1.15E-01	9.47E-02	4.75E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	5.63E-02	4.71E-02	4.46E-02	5.03E-02	2.79E-02	8.39E-02	6.69E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	2.27E-03	2.12E-03	1.45E-03	1.20E-03	1.74E-03	1.60E-03	1.23E-02	6.29E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	5.49E-04	5.20E-04	3.50E-04	4.35E-04	4.48E-04	5.66E-04	2.23E-03	7.89E-02	6.69E-01	0.00E+00	0.00E+00	0.00E+00
10	2.58E-04	2.19E-04	2.23E-04	2.78E-04	2.02E-04	3.63E-04	9.64E-04	2.05E-02	9.11E-02	6.58E-01	0.00E+00	0.00E+00
11	8.36E-05	6.68E-05	7.26E-05	8.51E-05	5.59E-05	1.11E-04	2.51E-04	5.32E-03	1.32E-02	5.34E-02	6.20E-01	0.00E+00
12	1.80E-06	1.44E-06	1.56E-06	1.82E-06	1.18E-06	2.37E-06	5.25E-06	1.11E-04	2.49E-04	8.31E-04	8.07E-03	3.76E-01

Energy	Albedo matrix of polyethylene											
group	1	2	3	4	5	6	7	8	9	10	11	12
1	3.17E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1.67E-01	9.83E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	8.20E-02	1.56E-01	1.54E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	7.37E-02	9.96E-02	1.83E-01	1.79E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	3.77E-02	5.03E-02	7.86E-02	1.42E-01	1.76E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	2.01E-02	2.79E-02	4.37E-02	7.69E-02	1.47E-01	1.64E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	2.08E-02	2.86E-02	4.37E-02	7.46E-02	1.34E-01	2.46E-01	2.59E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	1.44E-02	1.92E-02	2.76E-02	4.34E-02	6.81E-02	1.08E-01	2.12E-01	2.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	1.21E-02	1.59E-02	2.18E-02	3.22E-02	4.60E-02	6.37E-02	9.77E-02	2.20E-01	2.62E-01	0.00E+00	0.00E+00	0.00E+00
10	1.06E-02	1.37E-02	1.81E-02	2.56E-02	3.41E-02	4.35E-02	5.76E-02	9.89E-02	2.19E-01	2.62E-01	0.00E+00	0.00E+00
11	9.43E-03	1.20E-02	1.54E-02	2.10E-02	2.66E-02	3.21E-02	3.93E-02	5.75E-02	9.83E-02	2.19E-01	2.61E-01	0.00E+00
12	5.83E-02	7.09E-02	8.34E-02	1.03E-01	1.16E-01	1.26E-01	1.38E-01	1.73E-01	2.32E-01	3.43E-01	5.91E-01	8.14E-01

Energy	Albedo matrix of stainless steel											
group	1	2	3	4	5	6	7	8	9	10	11	12
1	1.40E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	4.02E-02	3.94E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	5.14E-02	6.16E-02	9.24E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	9.66E-02	1.03E-01	1.16E-01	1.68E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	6.85E-02	5.92E-02	7.66E-02	8.51E-02	2.02E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	3.16E-02	2.92E-02	3.77E-02	4.68E-02	6.82E-02	1.76E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	2.82E-02	2.64E-02	3.32E-02	4.20E-02	7.01E-02	1.51E-01	3.16E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	1.54E-02	1.43E-02	1.74E-02	2.11E-02	3.39E-02	6.80E-02	1.44E-01	3.44E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	1.08E-02	9.94E-03	1.19E-02	1.41E-02	2.13E-02	3.88E-02	6.81E-02	1.55E-01	3.83E-01	0.00E+00	0.00E+00	0.00E+00
10	8.40E-03	7.67E-03	9.00E-03	1.06E-02	1.52E-02	2.54E-02	3.82E-02	7.01E-02	1.54E-01	3.82E-01	0.00E+00	0.00E+00
11	6.19E-03	5.63E-03	6.52E-03	7.56E-03	1.05E-02	1.66E-02	2.25E-02	3.55E-02	6.42E-02	1.42E-01	3.63E-01	0.00E+00
12	4.75E-03	4.31E-03	4.95E-03	5.70E-03	7.80E-03	1.19E-02	1.51E-02	2.19E-02	3.52E-02	6.69E-02	1.60E-01	4.65E-01

Table 2-7 Albedo Matrix for Photons

Energy group	Albedo matrix of concrete				
	1	2	3	4	5
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1.49E-02	2.87E-02	2.21E-02	0.00E+00	0.00E+00
5	5.14E-03	1.13E-02	9.40E-02	2.90E-01	4.00E-01

Energy group	Albedo matrix of iron				
	1	2	3	4	5
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1.49E-02	1.99E-02	1.58E-02	0.00E+00	0.00E+00
5	5.14E-03	7.84E-03	6.71E-02	1.51E-01	1.62E-01

Table 2-8 Albedo Matrix for Neutrons and Photons with Low Energy Structure

Energy group	Albedo matrix of concrete																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	7.06E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1.59E-01	2.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	9.44E-02	1.15E-01	3.35E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	8.61E-02	7.74E-02	1.82E-01	3.44E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	3.22E-02	3.60E-02	5.48E-02	1.66E-01	3.16E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1.68E-02	1.84E-02	3.09E-02	5.93E-02	1.75E-01	3.22E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	1.62E-02	1.78E-02	2.95E-02	5.35E-02	9.44E-02	2.20E-01	3.86E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	1.01E-02	1.10E-02	1.78E-02	3.00E-02	4.59E-02	7.57E-02	1.74E-01	3.74E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	5.49E-03	5.98E-03	9.46E-03	1.53E-02	2.14E-02	3.09E-02	5.85E-02	1.45E-01	3.13E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	5.38E-03	5.85E-03	9.18E-03	1.44E-02	1.92E-02	2.56E-02	4.40E-02	8.56E-02	1.95E-01	3.42E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	4.86E-03	5.27E-03	8.22E-03	1.26E-02	1.61E-02	2.01E-02	3.22E-02	5.30E-02	9.00E-02	2.00E-01	3.63E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1.54E-02	1.67E-02	2.58E-02	3.83E-02	4.57E-02	5.25E-02	7.68E-02	1.04E-01	1.34E-01	2.02E-01	3.93E-01	6.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	9.75E-02	6.58E-02	1.60E-03	2.30E-03	2.69E-03	3.00E-03	4.27E-03	5.39E-03	6.15E-03	8.13E-03	1.15E-02	1.59E-02	3.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	8.38E-02	7.38E-02	7.71E-03	4.58E-03	5.11E-03	5.72E-03	8.15E-03	1.04E-02	1.21E-02	1.62E-02	2.34E-02	3.25E-02	3.52E-02	1.89E-02	0.00E+00	0.00E+00	0.00E+00
15	1.81E-01	1.67E-01	2.55E-02	1.26E-02	8.19E-03	9.06E-03	1.28E-03	1.61E-02	1.83E-02	2.38E-02	3.23E-02	4.42E-02	4.30E-01	4.45E-01	4.65E-01	0.00E+00	0.00E+00
16	2.56E-04	4.51E-04	2.68E-04	3.56E-05	1.97E-05	2.29E-05	3.39E-05	5.35E-05	5.67E-05	8.82E-05	1.73E-04	3.19E-04	1.59E-04	1.51E-04	4.23E-03	8.05E-02	0.00E+00
17	4.54E-08	1.33E-07	9.46E-08	9.95E-08	4.11E-09	4.81E-09	7.21E-09	1.31E-08	1.29E-08	2.13E-08	4.68E-08	1.00E-07	8.48E-14	7.96E-14	6.77E-13	1.55E-03	4.98E-03

Energy group	Albedo matrix of iron																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	7.78E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	6.07E-02	1.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	7.32E-02	7.63E-02	2.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	2.16E-01	1.87E-01	2.13E-01	4.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	2.68E-01	1.93E-01	2.24E-01	2.08E-01	5.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1.38E-01	1.14E-01	1.18E-01	1.34E-01	1.27E-01	4.92E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	4.83E-02	4.30E-02	3.78E-02	4.66E-02	1.50E-02	9.16E-02	4.68E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	2.23E-03	2.01E-03	1.24E-03	1.18E-03	9.59E-04	7.37E-04	2.73E-02	5.56E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	3.48E-04	3.12E-04	2.04E-04	2.23E-04	1.35E-04	1.42E-04	3.25E-03	8.72E-02	5.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	1.78E-04	1.60E-04	1.14E-04	1.30E-04	6.47E-05	9.16E-05	2.01E-03	3.68E-02	1.87E-01	4.96E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	4.44E-05	3.98E-05	2.99E-05	3.46E-05	1.61E-05	2.58E-05	5.53E-04	8.66E-03	2.41E-02	1.05E-01	4.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	3.01E-07	2.71E-07	2.00E-07	2.31E-07	1.05E-07	1.76E-07	3.74E-06	5.41E-05	1.21E-04	3.40E-04	1.15E-02	1.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	6.78E-02	7.28E-02	1.14E-03	1.09E-03	1.31E-03	1.30E-03	3.03E-03	2.31E-02	1.94E-02	3.40E-02	6.26E-02	9.43E-02	2.99E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	1.37E-01	1.91E-01	6.29E-02	1.36E-03	1.13E-03	1.08E-03	2.05E-03	1.48E-02	1.21E-02	2.08E-02	3.74E-02	5.35E-02	2.94E-02	1.81E-02	0.00E+00	0.00E+00	0.00E+00
15	5.16E-01	6.10E-01	3.15E-01	1.44E-01	4.89E-03	2.22E-03	4.73E-03	3.61E-02	2.93E-02	5.07E-02	9.10E-02	1.27E-01	4.62E-01	3.67E-01	3.29E-01	0.00E+00	0.00E+00
16	3.40E-05	3.10E-05	1.87E-06	2.55E-06	4.47E-06	4.43E-06	5.17E-06	3.95E-05	1.77E-05	3.97E-05	1.13E-04	4.14E-04	9.69E-10	8.20E-10	1.64E-04	1.26E-03	0.00E+00
17	8.24E-10	7.68E-10	4.57E-11	6.25E-11	1.10E-10	1.09E-10	1.27E-10	9.69E-10	4.31E-10	9.69E-10	2.77E-09	1.03E-08	8.48E-27	7.96E-27	8.43E-23	1.65E-04	9.16E-06

Energy group	Albedo matrix of polyethylene																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	2.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1.31E-01	1.28E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	5.36E-02	7.83E-02	1.06E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	5.55E-02	6.98E-02	1.15E-01	1.25E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	2.92E-02	3.67E-02	5.73E-02	7.94E-02	9.93E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1.67E-02	2.14E-02	3.47E-02	4.90E-02	6.58E-02	8.15E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	1.76E-02	2.26E-02	3.64E-02	5.12E-02	6.93E-02	8.33E-02	1.01E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	1.21E-02	1.54E-02	2.34E-02	3.17E-02	4.01E-02	4.67E-02	6.58E-02	8.40E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	7.16E-03	9.03E-03	1.32E-02	1.72E-02	2.06E-02	2.28E-02	3.12E-02	4.36E-02	6.35E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	7.56E-03	9.47E-03	1.34E-02	1.71E-02	1.96E-02	2.09E-02	2.79E-02	3.64E-02	5.14E-02	7.53E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	7.46E-03	9.28E-03	1.27E-02	1.57E-02	1.73E-02	1.79E-02	2.33E-02	2.85E-02	3.65E-02	5.93E-02	2.07E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	6.67E-02	7.94E-02	9.03E-02	9.84E-02	9.24E-02	8.46E-02	1.03E-01	1.08E-01	1.13E-01	1.59E-01	3.06E-01	9.05E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	5.40E-02	5.27E-02	3.59E-04	1.90E-04	1.45E-04	1.16E-04	1.30E-04	1.20E-04	1.07E-04	1.34E-04	1.65E-04	5.22E-04	4.25E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	6.24E-02	6.82E-02	5.52E-02	5.08E-02	3.93E-02	3.16E-02	3.56E-02	3.28E-02	2.94E-02	3.72E-02	4.61E-02	1.29E-01	3.73E-02	1.92E-02	0.00E+00	0.00E+00	0.00E+00
15	8.59E-02	8.91E-02	5.14E-02	4.48E-02	3.27E-02	2.53E-02	2.80E-02	2.49E-02	2.15E-02	2.66E-02	3.16E-02	1.57E-01	4.12E-01	4.90E-01	5.61E-01	0.00E+00	0.00E+00
16	3.16E-03	3.25E-03	1.85E-03	1.57E-03	1.12E-03	8.54E-04	9.38E-04	8.27E-04	7.09E-04	8.70E-04	1.02E-03	6.37E-03	1.32E-02	1.34E-02	3.60E-02	3.34E-01	0.00E+00
17	2.52E-06	2.59E-06	1.47E-06	1.24E-06	8.80E-07	6.70E-07	7.35E-07	6.48E-07	5.54E-07	6.79E-07	7.98E-07	5.20E-06	1.04E-05	1.02E-05	1.51E-05	1.40E-02	1.45E-01

Energy group	Albedo matrix of 80 % iron and 20 % water																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	7.32E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	6.88E-02	1.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	7.15E-02	7.66E-02	2.09E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1.62E-01	1.45E-01	1.74E-01	3.31E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 2-9 Albedo Matrix for Neutrons with High Energy Structure (<3GeV)

Energy group	Albedo matrix of concrete											
	1	2	3	4	5	6	7	8	9	10	11	12
1	2.95E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1.60E-02	8.23E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	6.68E-02	3.64E-02	2.10E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	5.80E-01	3.69E-01	2.66E-01	8.47E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	1.03E+00	6.25E-01	4.00E-01	2.26E-01	8.13E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1.79E+00	1.12E+00	7.22E-01	3.96E-01	3.06E-01	4.58E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	7.26E-01	4.63E-01	3.07E-01	1.87E-01	1.57E-01	1.16E-01	5.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	2.67E-01	1.70E-01	1.14E-01	6.63E-02	5.26E-02	3.37E-02	1.62E-01	4.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	2.09E-01	1.27E-01	8.35E-02	4.81E-02	3.25E-02	2.18E-02	6.39E-02	2.20E-01	4.27E-01	0.00E+00	0.00E+00	0.00E+00
10	1.52E-01	9.30E-02	6.06E-02	3.57E-02	2.32E-02	1.38E-02	3.17E-02	7.15E-02	1.97E-01	3.95E-01	0.00E+00	0.00E+00
11	1.16E-01	7.21E-02	4.69E-02	2.68E-02	1.70E-02	9.98E-03	1.93E-02	3.69E-02	6.96E-02	1.99E-01	3.68E-01	0.00E+00
12	7.55E-01	4.48E-01	2.92E-01	1.64E-01	8.86E-02	5.28E-02	6.84E-02	1.01E-01	1.42E-01	2.29E-01	4.40E-01	8.07E-01

Energy group	Albedo matrix of iron											
	1	2	3	4	5	6	7	8	9	10	11	12
1	2.63E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1.22E-02	6.37E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	4.99E-02	2.56E-02	1.55E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	5.21E-01	3.23E-01	2.18E-01	6.78E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	1.17E+00	6.65E-01	4.00E-01	2.06E-01	4.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	4.99E+00	3.05E+00	1.87E+00	9.22E-01	5.34E-01	3.95E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	1.04E+01	6.15E+00	3.77E+00	1.92E+00	9.80E-01	4.18E-01	8.66E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	3.35E+00	1.92E+00	1.14E+00	5.51E-01	2.09E-01	6.01E-02	5.03E-02	7.82E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	2.59E-01	1.50E-01	8.82E-02	4.25E-02	1.53E-02	4.40E-03	3.17E-03	5.72E-02	8.61E-01	0.00E+00	0.00E+00	0.00E+00
10	6.03E-02	3.45E-02	2.03E-02	9.42E-03	3.32E-03	9.70E-04	7.57E-04	8.38E-03	3.45E-02	8.28E-01	0.00E+00	0.00E+00
11	1.22E-02	7.09E-03	4.08E-03	1.90E-03	6.53E-04	1.98E-04	1.55E-04	1.50E-03	3.24E-03	1.81E-02	7.36E-01	0.00E+00
12	3.84E-04	2.21E-04	1.39E-04	6.12E-05	2.14E-05	6.50E-06	5.42E-06	4.29E-05	7.96E-05	2.51E-04	4.40E-03	4.50E-01

Table 2-10 Average cosθ of Bottom and Side Currents

Ωj	$\phi^{(n)}$	Average cosθ	
		Bottom Current	Side Current
Ω1	$\phi^{(1)}$	0.26	0.117
	$\phi^{(2)}$	0.221	0.13
	$\phi^{(8)}$	0.189	0.117
Ω2	$\phi^{(1)}$	0.585	0.241
	$\phi^{(2)}$	0.475	0.195
	$\phi^{(8)}$	0.208	0.13
iso	$\phi^{(1)}$	0.39	0.176
	$\phi^{(2)}$	0.449	0.163
	$\phi^{(8)}$	0.247	0.117

Ω1：$0.879 < \mu \leqq 1$
Ω2：$0 \leqq \mu < 0.879$
iso：isotropic source

Table 3-1 Normalized 1/E Neutron Spectra with Low and High Energy Structures

	1/E Spectra			
	with High Energy Structure		with Low Energy Structure	
No.	Upper Energy (MeV)	Value	Upper Energy (MeV)	Value
1	3.00E+03	2.23E-02	1.50E+01	6.11E-03
2	1.50E+03	2.03E-02	1.30E+01	3.68E-02
3	8.00E+02	2.23E-02	5.49E+00	3.41E-02
4	4.00E+02	4.47E-02	2.47E+00	4.28E-02
5	1.00E+02	5.19E-02	9.07E-01	4.26E-02
6	2.00E+01	8.69E-02	3.34E-01	4.70E-02
7	1.35E+00	8.85E-02	1.11E-01	1.07E-01
8	8.65E-02	1.05E-01	9.12E-03	1.07E-01
9	3.35E-03	1.13E-01	7.49E-04	1.07E-01
10	1.01E-04	9.66E-02	6.14E-05	1.07E-01
11	5.04E-06	8.05E-02	5.04E-06	1.07E-01
12	4.14E-07	2.68E-01	4.14E-07	2.57E-01
	1.00E-10		1.00E-09	
total		1.00E+00		1.00E+00

Table 3-2 Fission Neutron Spectra of U-235 with Low and High Energy Structures

	Fission Neutron Spectra of U-235			
	with High Energy Structure		with Low Energy Structure	
No.	Upper Energy (MeV)	Value	Upper Energy (MeV)	Value
1	3.00E+03	0.0	1.50E+01	4.12E-05
2	1.50E+03	0.0	1.30E+01	3.57E-02
3	8.00E+02	0.0	5.49E+00	2.59E-01
4	4.00E+02	0.0	2.47E+00	4.28E-01
5	1.00E+02	0.0	9.07E-01	2.00E-01
6	2.00E+01	5.73E-01	3.34E-01	6.11E-02
7	1.35E+00	4.16E-01	1.11E-01	1.54E-02
8	8.65E-02	1.04E-02	9.12E-03	0.0
9	3.35E-03	0.0	7.49E-04	0.0
10	1.01E-04	0.0	6.14E-05	0.0
11	5.04E-06	0.0	5.04E-06	0.0
12	4.14E-07	0.0	4.14E-07	0.0
	1.00E-10		1.00E-09	
Total		1.0		1.0

Table 3-3 Normalized Neutron Spectra Emitted from Iron Target and 3 GeV Protons Calcualted by NMTC Code

No.	Upper Energy (MeV)	Spectrum emitted at 90 deg	Scattered Spectrum
1	3.00E+03	0.00E+00	0.00E+00
2	1.50E+03	2.77E-06	9.17E-07
3	8.00E+02	2.96E-04	1.34E-05
4	4.00E+02	3.71E-02	0.00E+00
5	1.00E+02	4.21E-01	4.97E-03
6	2.00E+01	3.81E-01	2.73E-01
7	1.35E+00	1.56E-01	3.53E-01
8	8.65E-02	5.14E-03	1.10E-01
9	3.35E-03	3.91E-05	6.83E-02
10	1.01E-04	0.00E+00	4.59E-02
11	5.04E-06	0.00E+00	2.92E-02
12	4.14E-07	0.00E+00	1.16E-01
	1.00E-10		
Total		1.0	1.0

Table 3-4 Neutron Energy Spectra from Thick Iron Target by Protons in the Energy Range 0.2 to 50 GeV Calculated by NMTC/MCNP

Proton Energy (GeV)	Emission Angle (cosθ)	Neutron Spectra with High Energy Structure (neutrons per proton)											
		1	2	3	4	5	6	7	8	9	10	11	12
0.2	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.68E-04	2.75E-01	1.42E-01	5.89E-03	8.04E-05	4.60E-07	2.21E-08	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.42E-04	2.74E-01	1.42E-01	5.88E-03	8.14E-05	4.61E-07	2.52E-08	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.41E-03	2.68E-01	1.40E-01	5.80E-03	8.04E-05	4.73E-07	2.04E-08	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	2.62E-07	3.35E-03	2.64E-01	1.39E-01	5.73E-03	7.92E-05	4.24E-07	2.04E-08	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.34E-06	6.10E-03	2.67E-01	1.40E-01	5.73E-03	7.91E-05	4.28E-07	1.61E-08	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	1.97E-05	1.35E-02	2.70E-01	1.40E-01	5.68E-03	7.86E-05	4.43E-07	1.60E-08	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.23E-04	3.34E-02	2.69E-01	1.37E-01	5.46E-03	7.47E-05	4.59E-07	1.24E-08	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	0.00E+00	1.59E-03	7.71E-02	2.74E-01	1.37E-01	5.49E-03	7.70E-05	4.80E-07	1.76E-08	0.00E+00
	5.55E-01	0.00E+00	0.00E+00	0.00E+00	8.27E-03	1.37E-01	2.73E-01	1.34E-01	5.42E-03	7.72E-05	4.74E-07	1.29E-08	0.00E+00
	7.07E-01	0.00E+00	0.00E+00	0.00E+00	2.56E-02	1.89E-01	2.67E-01	1.32E-01	5.34E-03	7.61E-05	4.64E-07	8.78E-09	0.00E+00
	8.95E-01	0.00E+00	0.00E+00	0.00E+00	1.14E-01	2.60E-01	2.66E-01	1.30E-01	5.30E-03	7.65E-05	5.02E-07	4.44E-09	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	0.00E+00	2.52E-01	2.84E-01	2.77E-01	1.33E-01	5.39E-03	7.72E-05	4.24E-07	5.24E-09	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	0.00E+00	2.47E-01	2.67E-01	2.80E-01	1.33E-01	5.39E-03	7.72E-05	5.02E-07	3.40E-09	0.00E+00
0.4	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	5.16E-04	1.15E-02	9.87E-01	9.85E-01	4.35E-02	8.74E-04	1.10E-05	3.30E-07	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	3.79E-04	1.51E-02	9.89E-01	9.92E-01	4.40E-02	8.99E-04	1.14E-05	3.74E-07	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	3.77E-04	2.11E-02	9.71E-01	9.90E-01	4.41E-02	9.28E-04	1.18E-05	3.59E-07	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	6.34E-04	3.75E-02	9.20E-01	9.68E-01	4.32E-02	9.25E-04	1.25E-05	3.58E-07	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.23E-03	5.68E-02	8.89E-01	9.54E-01	4.23E-02	9.08E-04	1.26E-05	3.40E-07	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	3.98E-03	9.67E-02	8.39E-01	9.26E-01	4.06E-02	8.65E-04	1.28E-05	3.62E-07	3.44E-09
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E-02	1.71E-01	7.73E-01	8.83E-01	3.84E-02	8.09E-04	1.23E-05	3.08E-07	6.46E-09
	3.16E-01	0.00E+00	0.00E+00	0.00E+00	6.44E-02	2.78E-01	7.76E-01	8.78E-01	3.85E-02	8.27E-04	1.23E-05	3.94E-07	0.00E+00
	5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.61E-01	3.51E-01	7.41E-01	8.50E-01	3.77E-02	8.16E-04	1.20E-05	2.84E-07	3.11E-09
	7.07E-01	0.00E+00	0.00E+00	0.00E+00	2.71E-01	3.83E-01	7.10E-01	8.24E-01	3.69E-02	8.02E-04	1.17E-05	2.63E-07	3.00E-09
	8.95E-01	0.00E+00	0.00E+00	0.00E+00	5.29E-01	4.37E-01	7.11E-01	8.02E-01	3.59E-02	7.63E-04	1.08E-05	2.35E-07	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	0.00E+00	9.09E-01	4.90E-01	7.39E-01	8.00E-01	3.54E-02	7.18E-04	9.95E-06	2.22E-07	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	0.00E+00	9.55E-01	4.98E-01	7.45E-01	7.93E-01	3.48E-02	6.93E-04	9.34E-06	1.55E-07	0.00E+00
0.6	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	3.40E-03	6.88E-02	2.01E+00	3.47E+00	2.05E-01	9.12E-03	6.15E-04	7.03E-05	1.66E-06
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	4.19E-03	6.92E-02	2.02E+00	3.52E+00	2.08E-01	9.46E-03	6.47E-04	7.39E-05	1.56E-06
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	4.78E-03	8.18E-02	1.98E+00	3.52E+00	2.10E-01	9.86E-03	6.87E-04	7.93E-05	1.94E-06
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	6.55E-03	1.14E-01	1.76E+00	3.34E+00	2.02E-01	9.79E-03	7.16E-04	8.33E-05	1.83E-06
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	9.90E-03	1.45E-01	1.55E+00	3.17E+00	1.94E-01	9.60E-03	7.18E-04	8.37E-05	1.94E-06
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	2.08E-02	1.92E-01	1.21E+00	2.91E+00	1.83E-01	9.26E-03	7.24E-04	8.60E-05	2.18E-06
	0.00E+00	0.00E+00	0.00E+00	4.90E-07	5.79E-02	2.67E-01	9.65E-01	2.73E+00	1.75E-01	9.04E-03	7.27E-04	8.58E-05	1.98E-06
	3.16E-01	0.00E+00	0.00E+00	3.43E-05	1.52E-01	3.67E-01	9.32E-01	2.65E+00	1.70E-01	8.83E-03	7.11E-04	8.44E-05	1.98E-06
	5.55E-01	0.00E+00	0.00E+00	5.74E-04	2.78E-01	4.08E-01	8.62E-01	2.50E+00	1.63E-01	8.44E-03	6.77E-04	8.09E-05	2.25E-06
	7.07E-01	0.00E+00	0.00E+00	3.41E-03	3.78E-01	4.18E-01	8.21E-01	2.38E+00	1.57E-01	8.11E-03	6.52E-04	7.89E-05	2.09E-06
	8.95E-01	0.00E+00	0.00E+00	3.78E-02	6.02E-01	4.74E-01	8.20E-01	2.25E+00	1.49E-01	7.45E-03	6.06E-04	7.32E-05	1.77E-06
	9.70E-01	0.00E+00	0.00E+00	1.63E-01	9.22E-01	5.52E-01	8.32E-01	2.19E+00	1.44E-01	6.84E-03	5.60E-04	6.69E-05	1.69E-06
	9.92E-01	0.00E+00	0.00E+00	2.34E-01	1.12E+00	5.84E-01	8.27E-01	2.14E+00	1.40E-01	6.43E-03	5.24E-04	6.31E-05	1.56E-06
1.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	1.72E-02	2.23E-01	3.81E+00	1.34E+01	1.73E+00	1.15E-01	2.21E-02	4.49E-03	1.73E-04
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	1.92E-02	2.22E-01	3.90E+00	1.38E+01	1.78E+00	1.20E-01	2.33E-02	4.74E-03	1.85E-04
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	2.29E-02	2.56E-01	3.82E+00	1.36E+01	1.79E+00	1.21E-01	2.38E-02	4.88E-03	1.88E-04
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	3.08E-02	3.04E-01	2.93E+00	1.16E+01	1.63E+00	1.05E-01	2.15E-02	4.49E-03	1.78E-04
	-5.55E-01	0.00E+00	0.00E+00	2.32E-06	3.96E-02	3.06E-01	1.98E+00	9.62E+00	1.50E+00	9.47E-02	2.01E-02	4.27E-03	1.72E-04
	-3.16E-01	0.00E+00	0.00E+00	1.23E-05	5.07E-02	2.30E-01	7.45E-01	7.46E+00	1.38E+00	8.88E-02	2.00E-02	4.36E-03	1.72E-04
	0.00E+00	0.00E+00	0.00E+00	2.19E-04	9.69E-02	2.39E-01	4.82E-01	7.15E+00	1.40E+00	9.33E-02	2.15E-02	4.72E-03	1.89E-04
	3.16E-01	0.00E+00	0.00E+00	1.74E-03	1.71E-01	2.56E-01	4.18E-01	6.26E+00	1.26E+00	8.07E-02	1.85E-02	4.08E-03	1.65E-04
	5.55E-01	0.00E+00	2.16E-06	5.93E-03	2.12E-01	2.32E-01	3.81E-01	5.38E+00	1.12E+00	6.97E-02	1.59E-02	3.53E-03	1.43E-04
	7.07E-01	0.00E+00	1.78E-05	1.06E-02	2.19E-01	2.14E-01	3.74E-01	4.86E+00	1.04E+00	6.49E-02	1.49E-02	3.29E-03	1.33E-04
	8.95E-01	0.00E+00	7.60E-04	2.91E-02	3.09E-01	2.33E-01	3.81E-01	4.39E+00	9.66E-01	6.01E-02	1.39E-02	3.09E-03	1.24E-04
	9.70E-01	0.00E+00	9.62E-03	7.17E-02	4.75E-01	2.67E-01	3.71E-01	4.16E+00	9.20E-01	5.47E-02	1.27E-02	2.83E-03	1.16E-04
	9.92E-01	0.00E+00	1.56E-02	9.24E-02	6.56E-01	2.74E-01	3.56E-01	3.99E+00	8.85E-01	5.05E-02	1.18E-02	2.61E-03	1.06E-04
3.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	1.01E-01	9.78E-01	9.53E+00	5.20E+01	1.28E+01	1.05E+00	2.56E-01	5.86E-02	2.42E-03
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	1.25E-01	1.09E+00	1.01E+01	5.46E+01	1.35E+01	1.12E+00	2.74E-01	6.25E-02	2.62E-03
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	1.43E-01	1.24E+00	1.01E+01	5.44E+01	1.36E+01	1.12E+00	2.74E-01	6.24E-02	2.57E-03
	-7.07E-01	0.00E+00	0.00E+00	3.10E-05	1.81E-01	1.18E+00	6.30E+00	3.80E+01	1.08E+01	8.24E-01	2.03E-01	4.71E-02	1.97E-03
	-5.55E-01	0.00E+00	0.00E+00	1.57E-04	1.64E-01	7.25E-01	2.70E+00	2.39E+01	8.86E+00	6.67E-01	1.70E-01	4.01E-02	1.70E-03
	-3.16E-01	0.00E+00	4.04E-06	3.56E-04	9.82E-02	2.16E-01	3.15E-01	1.67E+01	8.59E+00	7.18E-01	1.90E-01	4.58E-02	1.96E-03
	0.00E+00	0.00E+00	4.09E-05	1.94E-03	1.50E-01	2.22E-01	3.35E-01	1.64E+01	8.73E+00	7.80E-01	2.08E-01	5.02E-02	2.15E-03
	3.16E-01	0.00E+00	2.83E-04	5.05E-03	1.66E-01	1.86E-01	2.60E-01	1.24E+01	7.00E+00	5.91E-01	1.57E-01	3.79E-02	1.62E-03
	5.55E-01	1.21E-05	6.47E-04	7.02E-03	1.43E-01	1.42E-01	2.24E-01	8.94E+00	5.32E+00	4.17E-01	1.09E-01	2.64E-02	1.12E-03
	7.07E-01	4.48E-05	1.10E-03	7.42E-03	1.25E-01	1.33E-01	2.51E-01	7.62E+00	4.66E+00	3.74E-01	9.79E-02	2.36E-02	1.02E-03
	8.95E-01	1.01E-03	6.07E-03	2.28E-02	1.93E-01	1.65E-01	3.01E-01	7.12E+00	4.40E+00	3.75E-01	9.96E-02	2.41E-02	1.02E-03
	9.70E-01	6.91E-03	2.28E-02	4.81E-02	2.74E-01	1.83E-01	2.94E-01	6.76E+00	4.20E+00	3.46E-01	9.19E-02	2.23E-02	9.49E-04
	9.92E-01	1.69E-02	5.04E-02	6.49E-02	3.12E-01	1.75E-01	2.74E-01	6.40E+00	4.00E+00	3.15E-01	8.38E-02	2.02E-02	8.55E-04
15.0	-9.92E-01	0.00E+00	0.00E+00	3.05E-03	3.84E-01	2.52E+00	1.55E+01	1.27E+02	3.79E+01	3.08E+00	7.72E-01	1.79E-01	7.46E-03
	-9.70E-01	0.00E+00	0.00E+00	3.76E-04	3.98E-01	2.28E+00	1.63E+01	1.33E+02	3.97E+01	3.29E+00	8.28E-01	1.92E-01	8.26E-03
	-8.94E-01	0.00E+00	0.00E+00	3.11E-04	4.46E-01	2.50E+00	1.58E+01	1.32E+02	4.00E+01	3.32E+00	8.36E-01	1.94E-01	8.20E-03
	-7.07E-01	0.00E+00	0.00E+00	1.04E-03	4.61E-01	1.96E+00	9.17E+00	9.51E+01	3.32E+01	2.56E+00	6.49E-01	1.51E-01	6.43E-03
	-5.55E-01	0.00E+00	3.55E-05	1.80E-03	3.56E-01	1.14E+00	3.85E+00	6.65E+01	2.90E+01	2.22E+00	5.72E-01	1.35E-01	5.66E-03
	-3.16E-01	0.00E+00	1.34E-05	1.66E-03	2.88E-01	6.11E-01	9.62E-01	5.65E+01	3.02E+01	2.55E+00	6.73E-01	1.61E-01	6.78E-03
	0.00E+00	0.00E+00	2.40E-04	6.62E-03	4.51E-01	7.17E-01	1.10E+00	5.88E+01	3.19E+01	2.88E+00	7.64E-01	1.83E-01	7.90E-03
	3.16E-01	1.57E-05	7.86E-04	1.65E-02	5.40E-01	6.55E-01	9.19E-01	4.72E+01	2.66E+01	2.26E+00	5.97E-01	1.43E-01	6.08E-03
	5.55E-01	6.52E-05	2.40E-03	2.50E-02	5.53E-01	6.29E-01	1.18E+00	3.73E+01	2.11E+01	1.66E+00	4.35E-01	1.03E-01	4.41E-03
	7.07E-01	1.88E-04	4.87E-03	4.16E-02	6.73E-01	7.99E-01	1.81E+00	3.62E+01	1.96E+01	1.57E+00	4.11E-01	9.68E-02	4.17E-03
	8.95E-01	1.73E-02	6.68E-02	1.96E-01	1.36E+00	1.20E+00	2.59E+00	3.91E+01	1.99E+01	1.67E+00	4.44E-01	1.04E-01	4.49E-03
	9.70E-01	2.15E-01	2.39E-01	4.41E-01	1.80E+00	1.35E+00	2.61E+00	3.84E+01	1.93E+01	1.58E+00	4.20E-01	9.86E-02	4.31E-03
	9.92E-01	6.98E-01	3.94E-01	5.52E-01	1.95E+00	1.28E+00	2.48E+00	3.65E+01	1.84E+01	1.45E+00	3.84E-01	9.03E-02	3.90E-03
50.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	7.59E-01	4.17E+00	2.58E+01	2.61E+02	8.56E+01	6.96E+00	1.76E+00	4.13E-01	1.70E-02
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	8.35E-01	4.39E+00	2.70E+01	2.73E+02	8.97E+01	7.46E+00	1.89E+00	4.42E-01	1.83E-02
	-8.94E-01	0.00E+00	0.00E+00	1.24E-03	9.01E-01	4.52E+00	2.59E+01	2.71E+02	9.06E+01	7.57E+00	1.91E+00	4.50E-01	1.87E-02
	-7.07E-01	0.00E+00	0.00E+00	1.89E-03	8.51E-01	3.38E+00	1.47E+01	1.99E+02	7.68E+01	5.99E+00	1.51E+00	3.59E-01	1.46E-02
	-5.55E-01	0.00E+00	0.00E+00	2.51E-03	6.46E-01	1.98E+00	6.31E+00	1.48E+02	6.93E+01	5.35E+00	1.37E+00	3.27E-01	1.41E-02
	-3.16E-01	0.00E+00	0.00E+00	3.37E-03	6.39E-01	1.37E+00	2.21E+00	1.37E+02	7.47E+01	6.32E+00	1.66E+00	4.01E-01	1.74E-02
	0.00E+00	0.00E+00	3.28E-04	1.43E-02	1.05E+00	1.70E+00	2.63E+00	1.47E+02	8.05E+01	7.25E+00	1.92E+00	4.65E-01	1.98E-02
	3.16E-01	2.32E-05	2.28E-03	3.59E-02	1.31E+00	1.63E+00	2.30E+00	1.22E+02	6.84E+01	5.81E+00	1.53E+00	3.70E-01	1.60E-02
	5.55E-01	1.63E-04	5.45E-03	6.29E-02	1.50E+00	1.82E+00	3.67E+00	1.02E+02	5.58E+01	4.37E+00	1.14E+00	2.73E-01	1.17E-02
	7.07E-01	9.91E-04	1.59E-02	1.31E-01	2.09E+00	2.61E+00	6.33E+00	1.06E+02	5.35E+01	4.25E+00	1.11E+00	2.62E-01	1.14E-02
	8.95E-01	4.65E-02	2.18E-01	6.82E-01	4.42E+00	4.17E+00	9.59E+00	1.21E+02	5.59E+01	4.71E+00	1.25E+00	2.93E-01	1.24E-02
	9.70E-01	6.70E-01	7.86E-01	1.44E+00	5.88E+00	4.56E+00	9.66E+00	1.20E+02	5.45E+01	4.49E+00	1.19E+00	2.79E-01	1.20E-02
	9.92E-01	2.57E+00	1.23E+00	1.81E+00	6.25E+00	4.32E+00	9.21E+00	1.14E+02	5.20E+01	4.13E+00	1.10E+00	2.57E-01	1.10E-02

Table 3-5 Neutron Energy Spectra from Thick Copper Target by Protons in the Energy Range 0.2 to 50 GeV Calculated by NMTC/MCNP

Proton Energy (GeV)	Emission Angle (cosθ)	Neutron Spectra with High Energy Structure (neutrons per proton)											
		1	2	3	4	5	6	7	8	9	10	11	12
0.2	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	3.41E-01	2.31E-01	1.06E-02	1.21E-04	7.07E-07	0.00E+00	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.11E-04	3.39E-01	2.31E-01	1.06E-02	1.20E-04	7.96E-07	0.00E+00	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E-03	3.33E-01	2.28E-01	1.05E-02	1.19E-04	8.54E-07	0.00E+00	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.53E-03	3.22E-01	2.23E-01	1.02E-02	1.14E-04	8.01E-07	0.00E+00	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	3.05E-06	6.37E-03	3.22E-01	2.23E-01	1.01E-02	1.14E-04	6.72E-07	0.00E+00	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	2.31E-05	1.38E-02	3.23E-01	2.21E-01	9.81E-03	1.13E-04	7.75E-07	0.00E+00	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.23E-04	3.38E-02	3.17E-01	2.13E-01	9.21E-03	1.07E-04	7.14E-07	0.00E+00	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	0.00E+00	1.62E-03	7.66E-02	3.21E-01	2.11E-01	9.14E-03	1.06E-04	6.99E-07	0.00E+00	0.00E+00
	5.55E-01	0.00E+00	0.00E+00	0.00E+00	8.08E-03	1.34E-01	3.13E-01	2.02E-01	8.80E-03	1.02E-04	6.93E-07	0.00E+00	0.00E+00
	7.07E-01	0.00E+00	0.00E+00	0.00E+00	2.48E-02	1.82E-01	3.03E-01	1.95E-01	8.50E-03	9.90E-05	7.22E-07	0.00E+00	0.00E+00
	8.95E-01	0.00E+00	0.00E+00	0.00E+00	1.06E-01	2.49E-01	2.98E-01	1.91E-01	8.34E-03	9.92E-05	6.46E-07	0.00E+00	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	0.00E+00	2.36E-01	2.72E-01	3.13E-01	1.95E-01	8.42E-03	1.01E-04	6.53E-07	0.00E+00	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	0.00E+00	2.35E-01	2.47E-01	3.17E-01	1.95E-01	8.38E-03	1.01E-04	7.13E-07	0.00E+00	0.00E+00
0.4	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	2.32E-04	1.50E-02	1.08E+00	1.34E+00	7.40E-02	5.17E-04	3.95E-06	7.64E-09	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	4.34E-04	1.60E-02	1.08E+00	1.36E+00	7.56E-02	5.25E-04	4.14E-06	0.00E+00	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	3.73E-04	2.13E-02	1.05E+00	1.37E+00	7.67E-02	5.27E-04	4.41E-06	0.00E+00	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	6.33E-04	3.86E-02	9.96E-01	1.33E+00	7.54E-02	5.11E-04	4.21E-06	3.68E-09	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.25E-03	5.82E-02	9.65E-01	1.30E+00	7.36E-02	4.96E-04	4.49E-06	4.04E-09	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	4.09E-03	9.91E-02	9.14E-01	1.25E+00	6.98E-02	4.65E-04	4.21E-06	8.61E-09	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E-02	1.75E-01	8.37E-01	1.16E+00	6.48E-02	4.25E-04	3.98E-06	1.16E-08	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	0.00E+00	6.42E-02	2.87E-01	8.45E-01	1.17E+00	6.60E-02	4.38E-04	4.01E-06	1.63E-08	0.00E+00
	5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.60E-01	3.66E-01	8.13E-01	1.14E+00	6.54E-02	4.40E-04	4.10E-06	6.56E-08	0.00E+00
	7.07E-01	0.00E+00	0.00E+00	0.00E+00	2.72E-01	4.00E-01	7.80E-01	1.11E+00	6.43E-02	4.38E-04	3.99E-06	6.86E-08	0.00E+00
	8.95E-01	0.00E+00	0.00E+00	0.00E+00	5.32E-01	4.55E-01	7.83E-01	1.07E+00	6.19E-02	4.32E-04	3.88E-06	1.29E-07	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	0.00E+00	9.25E-01	5.08E-01	8.19E-01	1.05E+00	5.96E-02	4.25E-04	3.80E-06	1.02E-07	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	0.00E+00	9.81E-01	5.21E-01	8.26E-01	1.03E+00	5.78E-02	4.15E-04	3.59E-06	9.21E-08	0.00E+00
0.6	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	3.72E-03	6.58E-02	2.03E+00	4.20E+00	4.05E-01	2.01E-03	1.87E-05	1.54E-07	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	4.07E-03	7.18E-02	2.04E+00	4.27E+00	4.17E-01	2.06E-03	1.89E-05	1.48E-07	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	4.53E-03	8.29E-02	1.99E+00	4.28E+00	4.27E-01	2.11E-03	1.96E-05	1.23E-07	6.67E-09
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	6.51E-03	1.16E-01	1.77E+00	4.00E+00	4.17E-01	2.03E-03	1.90E-05	1.31E-07	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	9.78E-03	1.48E-01	1.57E+00	3.73E+00	4.02E-01	1.95E-03	1.80E-05	1.32E-07	5.68E-09
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	2.09E-02	2.02E-01	1.26E+00	3.32E+00	3.80E-01	1.81E-03	1.68E-05	2.16E-07	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	4.06E-07	5.83E-02	2.85E-01	9.95E-01	3.00E+00	3.62E-01	1.70E-03	1.54E-05	1.54E-07	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	3.29E-05	1.56E-01	3.98E-01	9.82E-01	2.96E+00	3.58E-01	1.70E-03	1.50E-05	1.90E-07	4.28E-09
	5.55E-01	0.00E+00	0.00E+00	5.41E-04	2.92E-01	4.55E-01	9.33E-01	2.85E+00	3.47E-01	1.68E-03	1.49E-05	2.20E-07	4.11E-09
	7.07E-01	0.00E+00	0.00E+00	3.37E-03	4.09E-01	4.77E-01	9.00E-01	2.75E+00	3.35E-01	1.64E-03	1.48E-05	2.36E-07	0.00E+00
	8.95E-01	0.00E+00	0.00E+00	4.08E-02	6.65E-01	5.42E-01	9.19E-01	2.60E+00	3.13E-01	1.56E-03	1.42E-05	2.24E-07	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	1.84E-01	1.02E+00	6.26E-01	9.46E-01	2.46E+00	2.93E-01	1.48E-03	1.33E-05	2.58E-07	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	2.65E-01	1.24E+00	6.78E-01	9.44E-01	2.36E+00	2.79E-01	1.42E-03	1.25E-05	2.41E-07	0.00E+00
1.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	1.97E-02	2.21E-01	3.71E+00	1.34E+01	4.13E+00	1.42E-01	4.53E-03	1.86E-04	2.95E-07
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	1.91E-02	2.27E-01	3.78E+00	1.36E+01	4.25E+00	1.49E-01	4.81E-03	1.97E-04	3.02E-07
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	2.25E-02	2.59E-01	3.68E+00	1.32E+01	4.24E+00	1.56E-01	5.10E-03	2.10E-04	2.94E-07
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	3.03E-02	3.09E-01	2.87E+00	1.02E+01	3.71E+00	1.53E-01	5.09E-03	2.13E-04	2.08E-07
	-5.55E-01	0.00E+00	0.00E+00	7.32E-07	3.86E-02	3.20E-01	2.03E+00	7.70E+00	3.31E+00	1.50E-01	5.14E-03	2.17E-04	3.65E-07
	-3.16E-01	0.00E+00	0.00E+00	9.80E-06	5.28E-02	2.62E-01	8.35E-01	4.97E+00	2.95E+00	1.53E-01	5.39E-03	2.30E-04	3.15E-07
	0.00E+00	0.00E+00	0.00E+00	2.12E-04	1.01E-01	2.68E-01	4.50E-01	4.31E+00	2.95E+00	1.61E-01	5.81E-03	2.50E-04	3.76E-07
	3.16E-01	0.00E+00	0.00E+00	1.73E-03	1.85E-01	2.96E-01	4.08E-01	3.76E+00	2.62E+00	1.46E-01	5.29E-03	2.27E-04	3.31E-07
	5.55E-01	0.00E+00	2.66E-06	6.41E-03	2.40E-01	2.75E-01	3.90E-01	3.28E+00	2.28E+00	1.33E-01	4.86E-03	2.08E-04	2.53E-07
	7.07E-01	0.00E+00	1.72E-05	1.24E-02	2.56E-01	2.56E-01	3.92E-01	3.04E+00	2.09E+00	1.26E-01	4.69E-03	2.01E-04	2.70E-07
	8.95E-01	0.00E+00	9.28E-04	3.53E-02	3.62E-01	2.80E-01	4.09E-01	2.75E+00	1.86E+00	1.17E-01	4.48E-03	1.94E-04	2.69E-07
	9.70E-01	0.00E+00	1.16E-02	9.11E-02	5.51E-01	3.14E-01	4.03E-01	2.49E+00	1.70E+00	1.08E-01	4.15E-03	1.81E-04	2.10E-07
	9.92E-01	0.00E+00	2.18E-02	1.16E-01	7.55E-01	3.21E-01	3.89E-01	2.31E+00	1.59E+00	1.00E-01	3.90E-03	1.68E-04	3.31E-07
3.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	9.93E-02	1.02E+00	9.16E+00	3.95E+01	2.04E+01	1.70E+00	1.01E-01	5.51E-03	9.87E-06
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	1.18E-01	1.13E+00	9.58E+00	4.11E+01	2.12E+01	1.80E+00	1.07E-01	5.95E-03	1.12E-05
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	1.39E-01	1.25E+00	9.50E+00	3.94E+01	2.07E+01	1.80E+00	1.08E-01	6.00E-03	1.04E-05
	-7.07E-01	0.00E+00	0.00E+00	2.73E-05	1.72E-01	1.21E+00	6.33E+00	2.41E+01	1.44E+01	1.43E+00	8.93E-02	5.06E-03	9.98E-06
	-5.55E-01	0.00E+00	0.00E+00	1.41E-04	1.73E-01	8.64E-01	3.22E+00	1.24E+01	9.92E+00	1.21E+00	8.06E-02	4.67E-03	9.34E-06
	-3.16E-01	0.00E+00	1.07E-06	3.68E-04	1.17E-01	2.99E-01	3.08E-01	3.67E+00	7.31E+00	1.19E+00	8.60E-02	5.05E-03	8.38E-06
	0.00E+00	0.00E+00	3.56E-05	1.96E-03	1.72E-01	2.73E-01	3.36E-01	3.85E+00	7.51E+00	1.28E+00	9.51E-02	5.63E-03	9.27E-06
	3.16E-01	0.00E+00	2.95E-04	6.05E-03	2.07E-01	2.40E-01	2.74E-01	2.89E+00	5.74E+00	9.75E-01	7.37E-02	4.42E-03	7.69E-06
	5.55E-01	1.08E-05	9.27E-04	9.49E-03	1.88E-01	1.94E-01	2.75E-01	2.31E+00	4.26E+00	7.15E-01	5.47E-02	3.32E-03	5.96E-06
	7.07E-01	7.14E-05	1.66E-03	1.10E-02	1.72E-01	1.82E-01	3.13E-01	2.26E+00	3.66E+00	6.15E-01	4.81E-02	2.94E-03	5.02E-06
	8.95E-01	1.22E-03	8.71E-03	3.34E-02	2.58E-01	2.20E-01	3.67E-01	2.39E+00	3.31E+00	5.49E-01	4.48E-02	2.80E-03	5.72E-06
	9.70E-01	9.98E-03	3.19E-02	7.19E-02	3.59E-01	2.33E-01	3.58E-01	2.26E+00	3.06E+00	4.88E-01	4.05E-02	2.56E-03	4.97E-06
	9.92E-01	2.59E-02	6.13E-02	1.06E-01	3.96E-01	2.26E-01	3.38E-01	2.09E+00	2.85E+00	4.40E-01	3.66E-02	2.32E-03	3.99E-06
15.0	-9.92E-01	0.00E+00	0.00E+00	2.05E-03	3.70E-01	2.23E+00	1.46E+01	8.04E+01	5.29E+01	5.11E+00	3.16E-01	1.79E-02	2.39E-05
	-9.70E-01	0.00E+00	0.00E+00	5.24E-04	4.05E-01	2.39E+00	1.51E+01	8.36E+01	5.51E+01	5.41E+00	3.39E-01	1.96E-02	2.84E-05
	-8.94E-01	0.00E+00	0.00E+00	2.36E-04	4.40E-01	2.51E+00	1.46E+01	8.01E+01	5.39E+01	5.47E+00	3.46E-01	1.97E-02	3.43E-05
	-7.07E-01	0.00E+00	1.01E-05	9.70E-04	4.64E-01	2.09E+00	9.05E+00	4.97E+01	3.94E+01	4.53E+00	2.97E-01	1.71E-02	2.18E-05
	-5.55E-01	0.00E+00	0.00E+00	1.79E-03	4.00E-01	1.39E+00	4.45E+00	2.73E+01	2.96E+01	4.03E+00	2.79E-01	1.62E-02	3.79E-05
	-3.16E-01	0.00E+00	1.34E-05	1.96E-03	3.33E-01	7.71E-01	9.55E-01	1.20E+01	2.53E+01	4.22E+00	3.09E-01	1.82E-02	4.05E-05
	0.00E+00	0.00E+00	1.21E-04	7.17E-03	5.25E-01	8.81E-01	1.10E+00	1.34E+01	2.73E+01	4.71E+00	3.53E-01	2.08E-02	3.76E-05
	3.16E-01	4.90E-06	9.23E-04	2.01E-02	6.72E-01	8.37E-01	9.52E-01	1.07E+01	2.20E+01	3.74E+00	2.81E-01	1.68E-02	2.89E-05
	5.55E-01	1.52E-04	3.34E-03	3.44E-02	7.24E-01	8.61E-01	1.47E+00	1.08E+01	1.79E+01	2.91E+00	2.19E-01	1.31E-02	2.41E-05
	7.07E-01	5.36E-04	7.83E-03	5.71E-02	8.78E-01	1.06E+00	2.13E+00	1.33E+01	1.73E+01	2.69E+00	2.03E-01	1.22E-02	2.10E-05
	8.95E-01	2.15E-02	8.66E-02	2.55E-01	1.66E+00	1.52E+00	2.97E+00	1.73E+01	1.82E+01	2.65E+00	2.02E-01	1.23E-02	2.62E-05
	9.70E-01	2.68E-01	3.02E-01	5.13E-01	2.22E+00	1.64E+00	2.98E+00	1.72E+01	1.76E+01	2.45E+00	1.88E-01	1.14E-02	2.16E-05
	9.92E-01	9.78E-01	5.25E-01	6.37E-01	2.43E+00	1.75E+00	2.85E+00	1.63E+01	1.66E+01	2.25E+00	1.72E-01	1.05E-02	2.04E-05
50.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	8.34E-01	4.35E+00	2.38E+01	1.48E+02	1.11E+02	1.15E+01	7.39E-01	4.25E-02	6.58E-05
	-9.70E-01	0.00E+00	0.00E+00	9.42E-04	8.08E-01	4.58E+00	2.46E+01	1.54E+02	1.16E+02	1.23E+01	7.91E-01	4.49E-02	6.17E-05
	-8.94E-01	0.00E+00	0.00E+00	6.03E-04	8.91E-01	4.66E+00	2.34E+01	1.47E+02	1.14E+02	1.25E+01	8.14E-01	4.66E-02	7.65E-05
	-7.07E-01	0.00E+00	0.00E+00	1.95E-03	8.60E-01	3.61E+00	1.42E+01	9.27E+01	8.57E+01	1.06E+01	7.11E-01	4.12E-02	6.15E-05
	-5.55E-01	0.00E+00	0.00E+00	2.36E-03	7.30E-01	2.44E+00	7.09E+00	5.35E+01	6.76E+01	9.68E+00	6.79E-01	3.97E-02	6.73E-05
	-3.16E-01	0.00E+00	1.67E-05	3.62E-03	7.30E-01	1.70E+00	2.18E+00	2.84E+01	6.19E+01	1.05E+01	7.73E-01	4.59E-02	7.65E-05
	0.00E+00	0.00E+00	2.05E-04	1.51E-02	1.21E+00	2.09E+00	2.60E+00	3.27E+01	6.84E+01	1.19E+01	8.92E-01	5.33E-02	9.70E-05
	3.16E-01	1.92E-05	2.29E-03	4.65E-02	1.60E+00	2.07E+00	2.33E+00	2.69E+01	5.64E+01	9.64E+00	7.24E-01	4.31E-02	7.77E-05
	5.55E-01	2.13E-04	6.81E-03	8.87E-02	1.96E+00	2.45E+00	4.63E+00	3.12E+01	4.84E+01	7.74E+00	5.74E-01	3.47E-02	6.05E-05
	7.07E-01	1.38E-03	2.24E-02	1.75E-01	2.68E+00	3.38E+00	7.39E+00	4.22E+01	4.96E+01	7.39E+00	5.47E-01	3.27E-02	5.74E-05
	8.95E-01	6.54E-02	2.79E-01	8.34E-01	5.34E+00	5.10E+00	1.07E+01	5.84E+01	5.54E+01	7.61E+00	5.63E-01	3.41E-02	5.93E-05
	9.70E-01	8.64E-01	1.03E+00	1.74E+00	7.00E+00	5.76E+00	1.08E+01	5.92E+01	5.44E+01	7.15E+00	5.29E-01	3.19E-02	5.03E-05
	9.92E-01	3.34E+00	1.62E+00	2.10E+00	7.52E+00	5.41E+00	1.04E+01	5.63E+01	5.17E+01	6.61E+00	4.88E-01	2.95E-02	4.63E-05

Table 3-6 Neutron Energy Spectra from Thick Aluminum Target by Protons in the Energy Range 0.2 to 50 GeV Calculated by

Proton Energy (GeV)	Emittion Angle (cosθ)	Neutron Spectra with High Energy Structure (neutrons per proton)											
		1	2	3	4	5	6	7	8	9	10	11	12
0.2	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-03	2.00E-01	9.82E-02	5.23E-03	3.58E-05	2.67E-07	0.00E+00	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.74E-04	1.99E-01	9.88E-02	5.24E-03	3.51E-05	2.99E-07	0.00E+00	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E-03	1.96E-01	9.81E-02	5.19E-03	3.37E-05	3.28E-07	0.00E+00	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.33E-03	1.92E-01	9.62E-02	5.11E-03	3.43E-05	3.20E-07	0.00E+00	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.54E-06	6.13E-03	1.93E-01	9.58E-02	5.10E-03	3.42E-05	2.69E-07	0.00E+00	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	1.60E-05	1.41E-02	1.96E-01	9.45E-02	5.04E-03	3.47E-05	3.20E-07	0.00E+00	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-04	3.56E-02	1.95E-01	9.09E-02	4.88E-03	3.33E-05	3.42E-07	0.00E+00	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	0.00E+00	1.92E-03	8.39E-02	1.99E-01	9.05E-02	4.85E-03	3.32E-05	3.33E-07	0.00E+00	0.00E+00
	5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.01E-02	1.50E-01	1.95E-01	8.78E-02	4.73E-03	3.18E-05	2.98E-07	0.00E+00	0.00E+00
	7.07E-01	0.00E+00	0.00E+00	0.00E+00	3.24E-02	2.06E-01	1.91E-01	8.57E-02	4.64E-03	3.22E-05	3.58E-07	0.00E+00	0.00E+00
	8.95E-01	0.00E+00	0.00E+00	0.00E+00	1.46E-01	2.88E-01	1.93E-01	8.50E-02	4.61E-03	3.19E-05	3.47E-07	0.00E+00	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	0.00E+00	3.16E-01	3.12E-01	2.01E-01	8.59E-02	4.66E-03	3.22E-05	3.31E-07	0.00E+00	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	0.00E+00	3.05E-01	2.74E-01	2.03E-01	8.55E-02	4.65E-03	3.31E-05	3.76E-07	0.00E+00	0.00E+00
0.4	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	1.16E-04	6.83E-03	2.93E-01	1.28E-01	6.32E-03	4.10E-05	1.37E-07	1.18E-08	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	2.97E-04	7.92E-03	2.93E-01	1.29E-01	6.35E-03	4.13E-05	1.41E-07	1.15E-08	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	3.09E-04	1.00E-02	2.88E-01	1.29E-01	6.30E-03	4.08E-05	1.62E-07	1.07E-08	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	3.89E-04	1.85E-02	2.90E-01	1.30E-01	6.31E-03	4.13E-05	1.25E-07	1.15E-08	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	7.05E-04	2.94E-02	2.96E-01	1.31E-01	6.34E-03	4.05E-05	1.24E-07	1.32E-08	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	2.35E-03	5.48E-02	3.02E-01	1.31E-01	6.33E-03	4.09E-05	9.86E-08	1.45E-08	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-02	1.08E-01	2.99E-01	1.27E-01	6.19E-03	4.04E-05	1.15E-07	1.52E-08	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	0.00E+00	5.13E-02	1.89E-01	3.11E-01	1.31E-01	6.33E-03	4.10E-05	1.18E-07	1.49E-08	0.00E+00
	5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.49E-01	2.40E-01	3.11E-01	1.31E-01	6.32E-03	4.11E-05	1.10E-07	1.46E-08	0.00E+00
	7.07E-01	0.00E+00	0.00E+00	0.00E+00	2.78E-01	2.39E-01	3.07E-01	1.30E-01	6.27E-03	4.07E-05	9.98E-08	1.70E-08	0.00E+00
	8.95E-01	0.00E+00	0.00E+00	0.00E+00	5.18E-01	2.43E-01	3.07E-01	1.30E-01	6.27E-03	3.98E-05	1.07E-07	1.89E-08	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	0.00E+00	9.22E-01	2.78E-01	3.16E-01	1.31E-01	6.31E-03	4.07E-05	1.29E-07	1.94E-08	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	0.00E+00	1.01E+00	3.72E-01	3.18E-01	1.30E-01	6.30E-03	4.11E-05	9.32E-08	1.94E-08	0.00E+00
0.6	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	2.79E-03	2.60E-02	4.27E-01	1.65E-01	7.41E-03	4.41E-05	1.81E-07	1.83E-08	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	2.50E-03	2.85E-02	4.26E-01	1.67E-01	7.44E-03	4.41E-05	1.79E-07	1.82E-08	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	2.74E-03	3.08E-02	4.19E-01	1.67E-01	7.42E-03	4.33E-05	2.40E-07	1.79E-08	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	3.55E-03	4.27E-02	4.21E-01	1.68E-01	7.43E-03	4.39E-05	1.96E-07	1.63E-08	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	4.74E-03	5.67E-02	4.30E-01	1.69E-01	7.50E-03	4.46E-05	2.11E-07	1.42E-08	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	0.00E+00	9.15E-03	8.63E-02	4.37E-01	1.70E-01	7.51E-03	4.47E-05	1.68E-07	1.35E-08	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.68E-02	1.44E-01	4.33E-01	1.65E-01	7.36E-03	4.33E-05	1.48E-07	1.37E-08	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	2.15E-05	8.47E-02	2.29E-01	4.49E-01	1.71E-01	7.53E-03	4.47E-05	1.48E-07	1.30E-08	0.00E+00
	5.55E-01	0.00E+00	0.00E+00	5.41E-04	1.99E-01	2.88E-01	4.49E-01	1.71E-01	7.54E-03	4.46E-05	1.30E-07	1.18E-08	0.00E+00
	7.07E-01	0.00E+00	0.00E+00	5.35E-03	3.17E-01	3.17E-01	4.42E-01	1.70E-01	7.48E-03	4.35E-05	1.27E-07	1.03E-08	0.00E+00
	8.95E-01	0.00E+00	0.00E+00	1.48E-01	5.26E-01	3.85E-01	4.44E-01	1.69E-01	7.48E-03	4.32E-05	1.11E-07	9.10E-09	0.00E+00
	9.70E-01	0.00E+00	0.00E+00	5.20E-01	7.74E-01	4.22E-01	4.57E-01	1.70E-01	7.52E-03	4.44E-05	9.24E-08	9.89E-09	0.00E+00
	9.92E-01	0.00E+00	0.00E+00	6.70E-01	1.91E+00	4.63E-01	4.59E-01	1.69E-01	7.50E-03	4.36E-05	1.39E-07	1.01E-08	0.00E+00
1.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	8.65E-03	6.13E-02	5.88E-01	2.06E-01	8.62E-03	4.71E-05	3.09E-07	0.00E+00	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	0.00E+00	7.62E-03	6.26E-02	5.87E-01	2.08E-01	8.65E-03	4.71E-05	2.18E-07	0.00E+00	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	0.00E+00	7.98E-03	6.72E-02	5.77E-01	2.08E-01	8.64E-03	4.67E-05	2.64E-07	0.00E+00	0.00E+00
	-7.07E-01	0.00E+00	0.00E+00	0.00E+00	9.93E-03	8.37E-02	5.81E-01	2.10E-01	8.69E-03	4.67E-05	2.43E-07	0.00E+00	0.00E+00
	-5.55E-01	0.00E+00	0.00E+00	0.00E+00	1.23E-02	1.03E-01	5.94E-01	2.13E-01	8.77E-03	4.76E-05	2.91E-07	0.00E+00	0.00E+00
	-3.16E-01	0.00E+00	0.00E+00	4.76E-07	2.00E-02	1.45E-01	6.04E-01	2.14E-01	8.80E-03	4.83E-05	2.66E-07	0.00E+00	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	4.41E-05	4.86E-02	2.22E-01	5.98E-01	2.09E-01	8.65E-03	4.71E-05	2.31E-07	0.00E+00	0.00E+00
	3.16E-01	0.00E+00	0.00E+00	1.02E-03	1.39E-01	3.19E-01	6.19E-01	2.16E-01	8.86E-03	4.85E-05	2.54E-07	0.00E+00	0.00E+00
	5.55E-01	0.00E+00	1.88E-07	8.87E-03	2.89E-01	3.75E-01	6.19E-01	2.17E-01	8.89E-03	4.73E-05	2.45E-07	0.00E+00	0.00E+00
	7.07E-01	0.00E+00	5.09E-05	3.97E-02	4.24E-01	3.98E-01	6.10E-01	2.16E-01	8.83E-03	4.68E-05	2.13E-07	0.00E+00	0.00E+00
	8.95E-01	0.00E+00	1.81E-02	2.45E-01	8.22E-01	4.28E-01	6.12E-01	2.15E-01	8.82E-03	4.73E-05	2.45E-07	0.00E+00	0.00E+00
	9.70E-01	0.00E+00	4.37E-01	4.43E-01	1.25E+00	4.61E-01	6.29E-01	2.16E-01	8.85E-03	4.80E-05	2.30E-07	0.00E+00	0.00E+00
	9.92E-01	0.00E+00	7.17E-01	5.85E-01	1.73E+00	4.73E-01	6.32E-01	2.14E-01	8.81E-03	4.73E-05	2.48E-07	0.00E+00	0.00E+00
3.0	-9.92E-01	0.00E+00	0.00E+00	4.90E-05	2.76E-02	2.16E-01	9.91E-01	3.07E-01	1.19E-02	6.18E-05	4.39E-07	0.00E+00	0.00E+00
	-9.70E-01	0.00E+00	1.23E-05	1.45E-04	2.95E-02	2.16E-01	9.89E-01	3.11E-01	1.20E-02	6.20E-05	5.08E-07	0.00E+00	0.00E+00
	-8.94E-01	0.00E+00	6.29E-06	1.28E-04	2.95E-02	2.19E-01	9.73E-01	3.13E-01	1.20E-02	6.24E-05	4.41E-07	0.00E+00	0.00E+00
	-7.07E-01	0.00E+00	5.25E-06	1.23E-04	3.59E-02	2.50E-01	9.85E-01	3.19E-01	1.22E-02	6.37E-05	4.54E-07	0.00E+00	0.00E+00
	-5.55E-01	0.00E+00	4.87E-06	1.34E-04	4.33E-02	2.85E-01	1.01E+00	3.25E-01	1.23E-02	6.39E-05	4.32E-07	1.60E-09	0.00E+00
	-3.16E-01	0.00E+00	4.31E-06	1.71E-04	6.43E-02	3.51E-01	1.03E+00	3.28E-01	1.24E-02	6.46E-05	4.20E-07	0.00E+00	0.00E+00
	0.00E+00	0.00E+00	7.43E-06	8.36E-04	1.28E-01	4.66E-01	1.02E+00	3.23E-01	1.23E-02	6.44E-05	4.01E-07	0.00E+00	0.00E+00
	3.16E-01	0.00E+00	1.61E-04	7.98E-03	3.10E-01	6.08E-01	1.06E+00	3.34E-01	1.26E-02	6.62E-05	4.55E-07	0.00E+00	0.00E+00
	5.55E-01	8.67E-06	3.00E-03	4.87E-02	5.18E-01	6.71E-01	1.06E+00	3.37E-01	1.27E-02	6.59E-05	4.28E-07	0.00E+00	0.00E+00
	7.07E-01	3.07E-04	2.37E-02	1.38E-01	6.72E-01	6.98E-01	1.05E+00	3.35E-01	1.27E-02	6.55E-05	3.76E-07	0.00E+00	0.00E+00
	8.95E-01	6.17E-02	2.83E-01	4.59E-01	1.09E+00	7.48E-01	1.06E+00	3.35E-01	1.27E-02	6.56E-05	3.59E-07	0.00E+00	0.00E+00
	9.70E-01	3.98E-01	9.65E-01	1.02E+00	1.54E+00	7.92E-01	1.08E+00	3.34E-01	1.27E-02	6.59E-05	3.58E-07	1.70E-09	0.00E+00
	9.92E-01	1.18E+00	2.93E+00	1.69E+00	1.81E+00	8.03E-01	1.09E+00	3.32E-01	1.26E-02	6.65E-05	4.05E-07	1.70E-09	0.00E+00
15.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	4.08E-02	2.24E-01	9.58E-01	3.43E-01	1.50E-02	1.04E-04	8.81E-07	8.85E-08	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	5.23E-05	4.11E-02	2.12E-01	9.57E-01	3.47E-01	1.51E-02	1.04E-04	9.49E-07	8.03E-08	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	6.78E-05	4.27E-02	2.16E-01	9.44E-01	3.51E-01	1.51E-02	1.04E-04	9.20E-07	7.58E-08	0.00E+00
	-7.07E-01	5.58E-07	0.00E+00	1.34E-04	5.12E-02	2.45E-01	9.70E-01	3.61E-01	1.54E-02	1.04E-04	7.95E-07	1.21E-07	0.00E+00
	-5.55E-01	9.85E-07	6.77E-07	2.26E-04	6.08E-02	2.78E-01	1.01E+00	3.71E-01	1.58E-02	1.08E-04	7.49E-07	1.36E-07	0.00E+00
	-3.16E-01	4.89E-07	3.43E-06	6.24E-04	8.41E-02	3.39E-01	1.04E+00	3.79E-01	1.60E-02	1.08E-04	9.72E-07	7.39E-08	0.00E+00
	0.00E+00	1.61E-06	3.22E-05	2.69E-03	1.50E-01	4.45E-01	1.04E+00	3.76E-01	1.59E-02	1.08E-04	8.61E-07	5.79E-08	0.00E+00
	3.16E-01	4.35E-06	5.59E-04	1.37E-02	3.06E-01	5.74E-01	1.09E+00	3.94E-01	1.65E-02	1.10E-04	8.79E-07	5.65E-08	0.00E+00
	5.55E-01	8.89E-05	4.87E-03	5.32E-02	4.95E-01	6.49E-01	1.11E+00	4.01E-01	1.67E-02	1.10E-04	8.30E-07	7.75E-08	0.00E+00
	7.07E-01	1.27E-03	2.38E-02	1.30E-01	6.73E-01	6.90E-01	1.11E+00	4.03E-01	1.67E-02	1.10E-04	8.12E-07	6.32E-08	0.00E+00
	8.95E-01	7.60E-02	2.57E-01	4.78E-01	1.11E+00	7.65E-01	1.12E+00	4.07E-01	1.69E-02	1.10E-04	7.26E-07	3.85E-08	0.00E+00
	9.70E-01	1.22E+00	1.05E+00	9.94E-01	1.46E+00	8.17E-01	1.15E+00	4.07E-01	1.69E-02	1.14E-04	8.32E-07	6.44E-08	0.00E+00
	9.92E-01	7.06E+00	1.79E+00	1.27E+00	1.56E+00	8.36E-01	1.15E+00	4.04E-01	1.68E-02	1.12E-04	9.49E-07	4.04E-08	0.00E+00
50.0	-9.92E-01	0.00E+00	0.00E+00	0.00E+00	5.21E-02	2.83E-01	1.20E+00	4.24E-01	1.84E-02	1.27E-04	1.36E-06	2.51E-08	0.00E+00
	-9.70E-01	0.00E+00	0.00E+00	2.89E-05	5.67E-02	2.84E-01	1.20E+00	4.29E-01	1.85E-02	1.28E-04	1.34E-06	2.44E-08	0.00E+00
	-8.94E-01	0.00E+00	0.00E+00	1.17E-04	5.81E-02	2.88E-01	1.18E+00	4.34E-01	1.86E-02	1.25E-04	1.62E-06	2.23E-08	0.00E+00
	-7.07E-01	6.55E-06	0.00E+00	1.60E-04	6.96E-02	3.26E-01	1.22E+00	4.51E-01	1.91E-02	1.27E-04	1.47E-06	2.74E-08	0.00E+00
	-5.55E-01	0.00E+00	6.86E-07	2.94E-04	8.24E-02	3.66E-01	1.28E+00	4.66E-01	1.96E-02	1.32E-04	1.35E-06	3.12E-08	0.00E+00
	-3.16E-01	0.00E+00	3.70E-06	7.25E-04	1.12E-01	4.40E-01	1.33E+00	4.81E-01	2.01E-02	1.37E-04	1.34E-06	3.46E-08	0.00E+00
	0.00E+00	4.02E-06	4.06E-05	3.36E-03	1.94E-01	5.67E-01	1.34E+00	4.79E-01	2.01E-02	1.38E-04	1.26E-06	3.65E-08	0.00E+00
	3.16E-01	6.18E-06	7.15E-04	1.86E-02	3.89E-01	7.24E-01	1.41E+00	5.05E-01	2.09E-02	1.42E-04	1.32E-06	3.61E-08	0.00E+00
	5.55E-01	1.28E-04	7.05E-03	7.50E-02	6.28E-01	8.21E-01	1.44E+00	5.18E-01	2.13E-02	1.42E-04	1.12E-06	4.39E-08	0.00E+00
	7.07E-01	1.69E-03	3.28E-02	1.72E-01	8.44E-01	8.72E-01	1.45E+00	5.23E-01	2.14E-02	1.44E-04	1.19E-06	4.87E-08	0.00E+00
	8.95E-01	9.00E-02	3.20E-01	5.94E-01	1.37E+00	9.73E-01	1.48E+00	5.31E-01	2.17E-02	1.43E-04	1.15E-06	5.22E-08	0.00E+00
	9.70E-01	1.33E+00	1.29E+00	1.27E+00	1.80E+00	1.03E+00	1.51E+00	5.32E-01	2.18E-02	1.50E-04	9.99E-07	5.28E-08	0.00E+00
	9.92E-01	6.66E+00	2.22E+00	1.62E+00	1.98E+00	1.04E+00	1.51E+00	5.29E-01	2.17E-02	1.47E-04	1.22E-06	5.28E-08	0.00E+00

Table B-1 Description of Subroutines Which Make up the DUCT-III Code

Subroutine	Description	Parameters
MAIN	MAIN is the program to not only control the DUCT-III code but also output the calculated flux, response and so on.	
SRCF1	SRCF1 is a subroutine to set the radiation source currents for direct and scattered contributions for the first leg.	INP: Type of radiation energy structures
		NSI: Input method of radiation source
		ZMX: Duct length
		S: Source currents for scattered contribution
SRCWS	SRCWS is a subroutine to set the wall scattered radiation source currents in a cavity for the first leg.	INP: Type of radiation energy structures
		AX: Albedo matrix
		S: Source currents for scattered contribution
GCYL0	GCYL0 is a function to calculate the cross section directly seen from a radiation source point, the radiation incident angle relative to duct axis for the first leg of a cylindrical duct.	Z: Distance from duct inlet divided by δ.
		R0: Representative length δ
		XS, YS, ZS: Radiation source point
		GZM: Cosine of maximum incident angle
		GZN: Cosine of minimum incident angle
		SUM: Calculated cross section
GREC0	GREC0 is a function to calculate the cross section directly seen from a radiation source point, the radiation incident angle relative to duct axis for the first leg of a rectangular duct or a slit.	Z: Distance from duct inlet divided by δ
		R0: The representative length δ
		HEIGHT: Height of duct divided by δ
		K: Type of ducts (=KDUCT)
		XS, YS, ZS: Radiation source point
		GZM: Cosine of maximum incident angle
		GZN: Cosine of minimum incident angle
		SUM: Calculated cross section
GANN0	GANN0 is a function to calculate the cross section directly seen from a radiation source point, the radiation incident angle relative to duct axis for the first leg of an annulus.	Z: Distance from duct inlet divided by δ
		R2: Representative length δ
		R10: Inner radius of annuls divided by δ
		XS, YS, ZS: Radiation source point
		GZM: Cosine of maximum incident angle
		GZN: Cosine of minimum incident angle
		SUM: Calculated cross section
PARM	PARM is a subroutine to set fitting parameters used in calculation.	RINN: Inputted RINN divided by δ
		RDUCT: Inputted RDUCT divided by δ
		KDUCT: Type of ducts
		NPH: Number of angular bins
		INP: Type of radiation energy structures
		AL2: Parameter an at n=2
		B2: Parameter bn at n=2
		G2: Parameter cn at n=2
		GZI2: Parameter ξn at n=2
		THI2: Parameter θn at n=2
		AL8: Parameter an at n=8
		B8: Parameter bn at n=8
		G8: Parameter cn at n=8
		GZI8: Parameter ξn at n=8
		THI8: Parameter θn at n=8
		EYT2: Average cosθ at n=2 for side current
		EYT8: Average cosθ at n=8 for side current
		EMU2: Average cosθ at n=2 for bottom current
		EMU8: Average cosθ at n=8 for bottom current

Table B-1 Description of Subroutines Which Make up the DUCT-III Code

Subroutine	Description	Parameters
CINT	CINT is a function to interpolate fitting parameters with linear fit.	Y1: Y Value at X1
		Y2: Y Value at X2
		X1: X Value
		X2: X Value
		X: X Value to interpolate Y value
REFSRC	REFSRC is a subroutine to calculate the radiation source currents for the next leg .	AX: Albedo matrix
		S: Source currents for scattered contribution
		SB: Source currents for differential albedo contribution
		SD: Direct currents at duct outlet
		CB: Bottom currents at duct outlet
		CS: Side currents at duct outlet
		C: Boundaries of incident angular bins
		FMU: Cosine of incident angle
		ID: ID number
		NP: Number of angular bins
MAT3	MAT3 is a subroutine to set differential albedo data used in calculation.	SB: Source currents for differential albedo contribution
		CBB: Sum of bottom and side currents
		NP: Number of angular bins
		CR: =2
		CR2: =2
MAT1	MAT1 is a subroutine to calculate A^4 and A_2, where A is an albedo matrix.	AX: Albedo matrix
		A: Calculated A_2
		A4: Calculated A^4
MAT2	MAT2 is a subroutine to calculate A_8 for low radiation energy structure.	AX: Albedo matrix
		A4: Calculated A^4
		A: Calculated A_8
INV	INV is a subroutine to calculate 1/(I-A).	A: Albedo matrix
		AX: Calculated 1/(I-A)
LUINV	LUINV is a subroutine to calculate the inversion of a matrix.	A: (I-A) is inputted and 1/(I-A) is outputted
		N: Number of radiation energy bins
		NA: =20
		EPS: =1.0E-12
		IP: Flag whether calculation is normally ended or not
		WK: Working space
		WK2: Working space
MAT4	MAT4 is a subroutine to calculate A_8 for high radiation energy structure.	AX: Albedo matrix
		A4: Calculated A^4
		A8: Calculated A_8
DIRECT	DIRECT is a subroutine to calculate the direct contribution of the radiation flux at the first leg.	I: Subdivision number of duct
		X: Distance from duct inlet divided by δ
		R0: The representative length
		PH0: Radiation flux of direct contribution
DIRWS	DIRWS is a subroutine to calculate the direct radiation flux for wall scattered contribution at the first leg.	I: Subdivision number of duct
		X: Distance from duct inlet divided by δ
		PH0: Radiation flux of direct contribution
		PHX: Direct radiation flux for wall scattered contribution
GCYL	GCYL is a function to calculate the cross section directly seen from the inlet of each leg for the cylindrical duct except for the first leg..	X: Distance from duct inlet divided by δ
		N: Number of angular bins
		ID: ID number

Table B-1 Description of Subroutines Which Make up the DUCT-III Code

Subroutine	Description	Parameters
GREC	GREC is a function to calculate the cross section directly seen from the inlet of each leg for the rectangular duct except for the first leg.	X: Distance from duct inlet divided by δ
		N: Number of angular bins
		ID: ID number
GANN	GANN is a function to calculate the cross section directly seen from the inlet of each leg for the annulus except for the first leg.	X: Distance from duct inlet divided by δ
		N: Number of angular bins
		ID: ID number
PKN	PKN is the program of the PKN-H code.	

Table B-2 Description of Symbols in Main Common Blocks of the DUCT-III Code

Common	Symbol	Description	
PARAM	PARMS(5,3,3,14)	Fitting parameters	
		5	an, bn, cn, ξn, θn
		3	Number n in ϕ(n)
		3	Number j in Ωj
		14	Total number of parameters a/b, r2/r1 and h
	ETAMU(2,3,3)	Average cosθ for bottom and side currents	
		2	= 1or 2 for bottom or side currents
		3	Number of ϕ(n)
		3	Number of Ωj
	ENERG(18,4)	Radiation energy structures	
		18	Number of energy bins
		4	Types of energy structures
	SPTN(12,6)	Normalized neutron spectra	
		12	Number of energy bins
		6	Number of types
MU	CTH(5)	Boundaries of angular bins	
		5	Number of angular bins
DD	DX	Length of subdivisions of duct axis divided by δ	
RADS	RDUCT	RDUCT / RDUCT	
	RSRC	RSORC / RDUCT	
	RINN	RINN / RDUCT	
GRP	NM	Number of energy bins	
ANG	IANG	Option for bent duct (=0; θ>70, =1; θ<=70)	
	ANGLE	Bent angle	
MM	MDUCT	Material number	
	INP	Type of energy structures	
KIND	KDUCT	Type of ducts	
NNN	NPH	Number of angular bins	
SINF	NSN	Type of radiation sources	
	NSR	Subdivided number of line source	
	XS,YS,ZS	Radiation source position	
	XE,YE,ZE	Direction vector of radiation source	
	SSD(20,50)	Source currents for direct contribution	
		20	Number of energy bins
		50	Number of subdivisions
	NPH1(50)	Type of angular distributions	
		50	Number of subdivisions
	NNS0	Neutron spectrum number in block data	
	SN0	Radiation source intensity	

Table B-2 Description of Symbols in Main Common Blocks of the DUCT-III Code

Common	Symbol	Description	
PTNS	PEN(7)	Proton energies	
		7	Number of proton energies
	PTHE(11)	Emission angles	
		11	Number of emission angles
	PNSP(12,11,7,3)	Neutron spectra per source protons	
		12	Number of radiation energy bins
		11	Number of emission angles
		7	Number of proton energies
		3	Number of target materials
SINFW	IFWS	Flag to calculate wall scattered radiation	
	WSA	Wall area	
	SSDW(20,4)	Source currents for direct contribution	
		20	Number of energy bins
		4	Number of subdivisions

Table D-1 Neutron Energy Structure of HILO86 Library

No.	Upper Energy (MeV)
1	4.00E+02[a]
2	3.75E+02
3	3.50E+02
4	3.25E+02
5	3.00E+02
6	2.75E+02
7	2.50E+02
8	2.25E+02
9	2.00E+02
10	1.80E+02
11	1.60E+02
12	1.40E+02
13	1.20E+02
14	1.10E+02
15	1.00E+02
16	9.00E+01
17	8.00E+01
18	7.00E+01
19	6.50E+01
20	6.00E+01
21	5.50E+01
22	5.00E+01
23	4.50E+01
24	4.00E+01
25	3.50E+01
26	3.00E+01
27	2.75E+01
28	2.50E+01
29	2.25E+01
30	2.00E+01
31	1.75E+01
32	1.49E+01
33	1.35E+01

No.	Upper Energy (MeV)
34	1.22E+01
35	1.00E+01
36	8.19E+00
37	6.70E+00
38	5.49E+00
39	4.49E+00
40	3.68E+00
41	3.01E+00
42	2.46E+00
43	2.02E+00
44	1.65E+00
45	1.35E+00
46	1.11E+00
47	9.07E-01
48	7.43E-01
49	4.98E-01
50	3.34E-01
51	2.24E-01
52	1.50E-01
53	8.65E-02
54	3.18E-02
55	1.50E-02
56	7.10E-03
57	3.35E-03
58	1.58E-03
59	4.54E-04
60	1.01E-04
61	2.26E-05
62	1.07E-05
63	5.04E-06
64	2.38E-06
65	1.12E-06
66	4.14E-07
	1.00E-10

a: Read as 4.00×10^2

Table D-2　Atomic Number Densities of Concrete and Iron

Material	Concrete [1)]		Iron	
Density (g/cm^3)	2.15		7.87	
Element	Fraction (w/o)	Number Density ($\times 10^{24}\ cm^{-3}$)	Fraction (w/o)	Number Density ($\times 10^{24}\ cm^{-3}$)
H	1.02	1.311E-02		
C	1.00	1.092E-04		
O	53.85	4.349E-02		
Mg	0.22	1.173E-04		
Al	3.44	1.649E-03		
Si	34.21	1.574E-02		
K	1.32	4.376E-04		
Ca	4.41	1.423E-03		
Fe	1.41	3.269E-04	100	8.486E-02

1）ANL-5800 type02-a concrete

Table D-3 Albedo Data of Concrete for High-Energy Neutron Structure

Group	Upper Energy (MeV)	Group 1（2.12E+3MeV)	fsd	Group 2（1.01E+3MeV)	fsd	Group 3（566MeV)	fsd	Group 4（200MeV)	fsd	Group 5（44.7MeV)	fsd
1	3.00E+03	2.9501E-03	0.0411	-	-	-	-	-	-	-	-
2	1.50E+03	1.5945E-02	0.0176	8.2299E-03	0.0245	-	-	-	-	-	-
3	8.00E+02	6.6784E-02	0.0084	3.6375E-02	0.0115	2.1035E-02	0.0153	-	-	-	-
4	4.00E+02	5.7990E-01	0.0019	3.6939E-01	0.0029	2.6621E-01	0.0037	8.4669E-02	0.006	-	-
5	1.00E+02	1.0310E+00	0.0001	6.2460E-01	0.0017	3.9966E-01	0.0027	2.2634E-01	0.0034	8.1312E-02	0.0048
6	2.00E+01	1.7917E+00	0.0041	1.1235E+00	0.004	7.2186E-01	0.004	3.9557E-01	0.0032	3.0554E-01	0.0065
7	1.35E+00	7.2638E-01	0.0069	4.6302E-01	0.0067	3.0729E-01	0.0066	1.8663E-01	0.005	1.5662E-01	0.01
8	8.65E-02	2.6677E-01	0.0117	1.7031E-01	0.0112	1.1381E-01	0.0111	6.6269E-02	0.0086	5.2611E-02	0.0181
9	3.35E-03	2.0882E-01	0.0132	1.2652E-01	0.013	8.3523E-02	0.0129	4.8051E-02	0.0101	3.2459E-02	0.0232
10	1.01E-04	1.5163E-01	0.0155	9.3003E-02	0.0152	6.0589E-02	0.0152	3.5713E-02	0.0117	2.3193E-02	0.0275
11	5.04E-06	1.1637E-01	0.0177	7.2102E-02	0.0172	4.6915E-02	0.0172	2.6842E-02	0.0135	1.6950E-02	0.0321
12	4.14E-07	7.5482E-01	0.0053	4.4783E-01	0.0053	2.9209E-01	0.0053	1.6393E-01	0.0042	8.8598E-02	0.0109
	total	5.7130E+00		3.5349E+00		2.3130E+00		1.2340E+00		7.5729E-01	

Group	Upper Energy (MeV)	Group 6（5.20MeV)	fsd	Group 7（0.342MeV)	fsd	Group 8（1.70E-2MeV)	fsd	Group 9（5.82E-4MeV)	fsd	Group 10（2.26E-5MeV)	fsd
6	2.00E+01	4.5745E-01	0.001	-	-	-	-	-	-	-	-
7	1.35E+00	1.1567E-01	0.0085	5.0951E-01	0.001	-	-	-	-	-	-
8	8.65E-02	3.3673E-02	0.0164	1.6231E-01	0.0072	4.1418E-01	0.0011	-	-	-	-
9	3.35E-03	2.1776E-02	0.0205	6.3871E-02	0.0121	2.2021E-01	0.0059	4.2693E-01	0.0011	-	-
10	1.01E-04	1.3783E-02	0.0257	3.1722E-02	0.0174	7.1454E-02	0.0114	1.9690E-01	0.0064	3.9504E-01	0.0011
11	5.04E-06	9.9831E-03	0.0301	1.9270E-02	0.0224	3.6903E-02	0.0161	6.9634E-02	0.0115	1.9862E-01	0.0063
12	4.14E-07	5.2763E-02	0.0107	6.8431E-02	0.01	1.0079E-01	0.0082	1.4152E-01	0.0068	2.2914E-01	0.0052
	total	7.0510E-01		8.5512E-01		8.4353E-01		8.3498E-01		8.2280E-01	

Group	Upper Energy (MeV)	Group 11（1.44E-6MeV)	fsd	Group 12（2.50E-8MeV)	fsd
11	5.04E-06	3.6782E-01	0.0011	-	-
12	4.14E-07	4.3985E-01	0.0032	8.0693E-01	0.0005
	total	8.0767E-01		8.0693E-01	

Table D-4 Albedo Data of Iron for High-Energy Neutron Structure

Group	Upper Energy (MeV)	Group 1（2.12E+3MeV)	fsd	Group 2（1.01E+3MeV)	fsd	Group 3（566MeV)	fsd	Group 4（200MeV)	fsd	Group 5（44.7MeV)	fsd
1	3.00E+03	2.6300E-03	0.0435	-	-	-	-	-	-	-	-
2	1.50E+03	1.2210E-02	0.0201	6.3650E-03	0.0279	-	-	-	-	-	-
3	8.00E+02	4.9908E-02	0.0098	2.5600E-02	0.0138	1.5520E-02	0.0178	-	-	-	-
4	4.00E+02	5.2131E-01	0.0021	3.2250E-01	0.0032	2.1785E-01	0.0042	6.7788E-02	0.0068	-	-
5	1.00E+02	1.1670E+00	0.0001	6.6447E-01	0.0016	4.0026E-01	0.0027	2.0603E-01	0.0036	4.9068E-02	0.0062
6	2.00E+01	4.9933E+00	0.0021	3.0524E+00	0.0019	1.8721E+00	0.0016	9.2180E-01	0.0017	5.3431E-01	0.0017
7	1.35E+00	1.0381E+01	0.0013	6.1474E+00	0.0011	3.7727E+00	0.001	1.9234E+00	0.001	9.7992E-01	0.001
8	8.65E-02	3.3499E+00	0.0025	1.9173E+00	0.0023	1.1420E+00	0.0021	5.5069E-01	0.0022	2.0869E-01	0.0028
9	3.35E-03	2.5884E-01	0.0091	1.4993E-01	0.0083	8.8164E-02	0.0076	4.2459E-02	0.0079	1.5321E-02	0.0103
10	1.01E-04	6.0331E-02	0.0157	3.4484E-02	0.0144	2.0303E-02	0.0131	9.4210E-03	0.0139	3.3152E-03	0.0182
11	5.04E-06	1.2232E-02	0.0217	7.0860E-03	0.0198	4.0764E-03	0.0183	1.9043E-03	0.0192	6.5325E-04	0.0254
12	4.14E-07	3.8432E-04	0.0396	2.2119E-04	0.0355	1.3855E-04	0.0323	6.1201E-05	0.0343	2.1367E-05	0.0449
	total	2.0809E+01		1.2328E+01		7.5332E+00		3.7236E+00		1.7913E+00	

Group	Upper Energy (MeV)	Group 6（5.20MeV)	fsd	Group 7（0.342MeV)	fsd	Group 8（1.70E-2MeV)	fsd	Group 9（5.82E-4MeV)	fsd	Group 10（2.26E-5MeV)	fsd
6	2.00E+01	3.9479E-01	0.0001	-	-	-	-	-	-	-	-
7	1.35E+00	4.1777E-01	0.0003	8.6576E-01	0.0001	-	-	-	-	-	-
8	8.65E-02	6.0064E-02	0.0008	5.0344E-02	0.0007	7.8184E-01	0.0001	-	-	-	-
9	3.35E-03	4.4035E-03	0.003	3.1718E-03	0.0025	5.7234E-02	0.0018	8.6143E-01	0.0001	-	-
10	1.01E-04	9.6955E-04	0.0054	7.5650E-04	0.0043	8.3799E-03	0.004	3.4537E-02	0.0029	8.2819E-01	0.0002
11	5.04E-06	1.9817E-04	0.0095	1.5514E-04	0.0076	1.4947E-03	0.0072	3.2416E-03	0.0067	1.8101E-02	0.0068
12	4.14E-07	6.4948E-06	0.0528	5.4215E-06	0.0411	4.2914E-05	0.0432	7.9591E-05	0.043	2.5084E-04	0.0522
	total	8.7820E-01		9.2019E-01		8.4899E-01		8.9929E-01		8.4654E-01	

Group	Upper Energy (MeV)	Group 11（1.44E-6MeV)	fsd	Group 12（2.50E-8MeV)	fsd
11	5.04E-06	7.3601E-01	0.0006	-	-
12	4.14E-07	4.4017E-03	0.0286	4.5044E-01	0.0007
	total	7.4041E-01		4.5044E-01	

Table E-1 Effective Range by Target Materials

Proton Energy (GeV)	Effective Range (m)		
	Al	Fe	Cu
0.2	0.14	0.05	0.05
0.4	0.42	0.16	0.14
0.6	0.79	0.31	0.26
1	1.8	0.7	0.6
3	2.7	1.23	1.05
15	2.7	1.23	1.05
50	2.7	1.23	1.05
Density(g/cm^3)	2.7	7.86	8.94

Figures

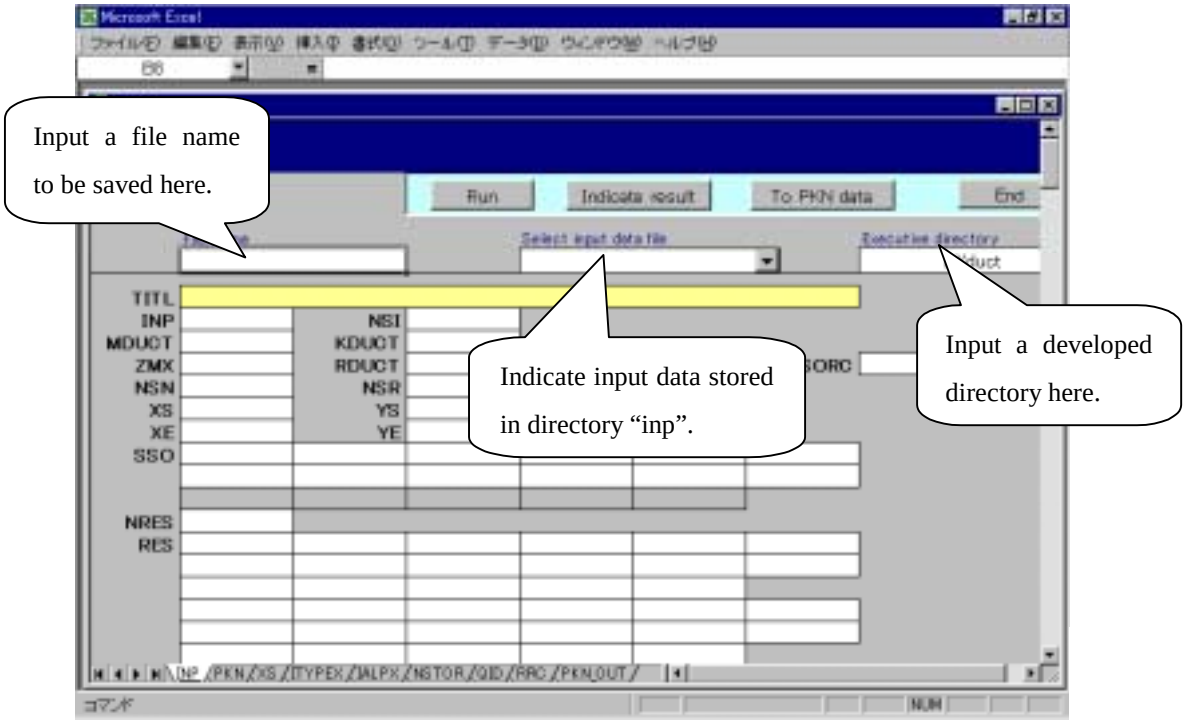


Fig. 4-1 Input Data Sheet for DUCT-III Visual Basic Version

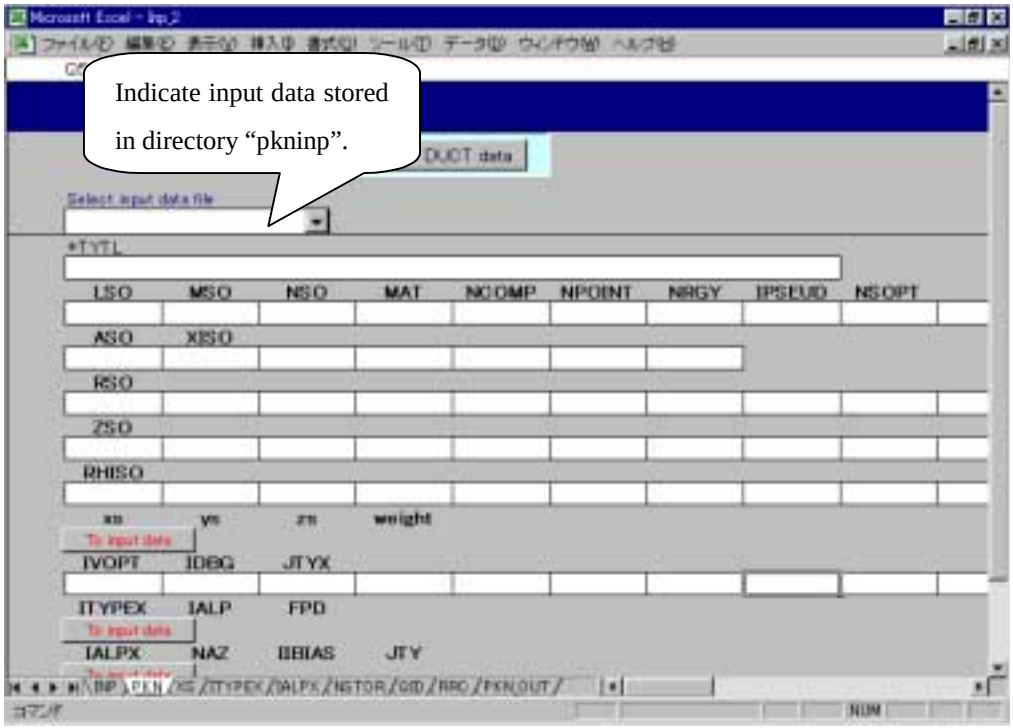


Fig. 4-2 Input Data Sheet for PKN-H Visual Basic Version

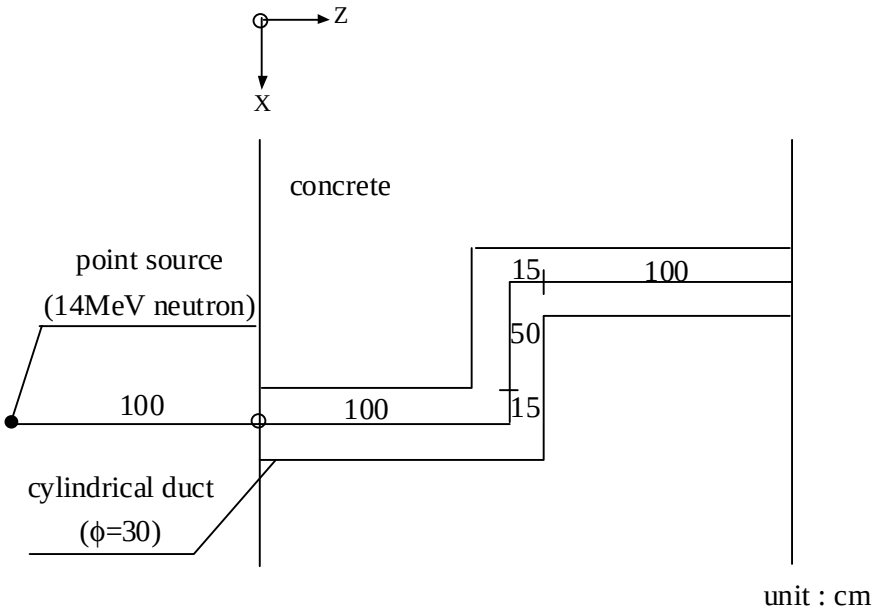


Fig. 4-3 Calculational Model of Sample Problem 1

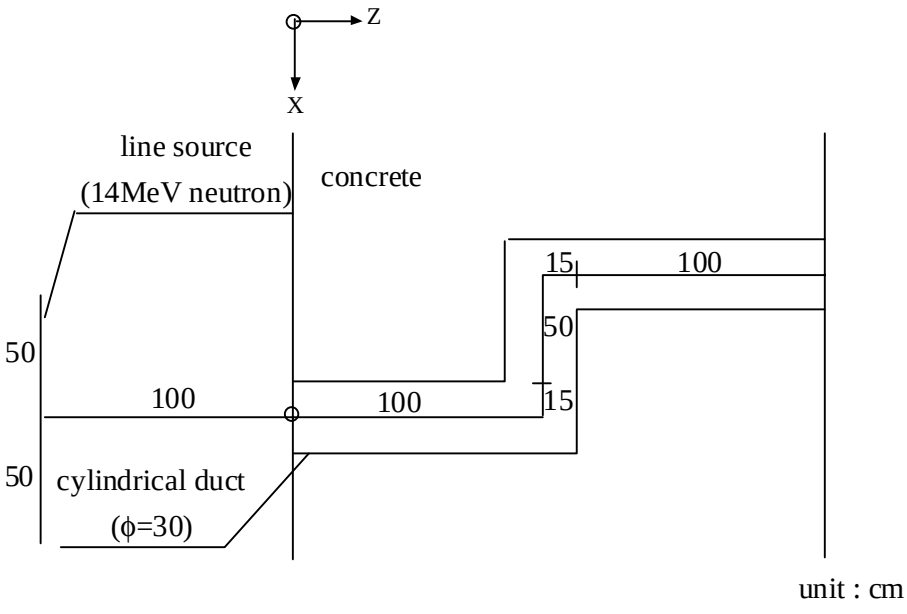
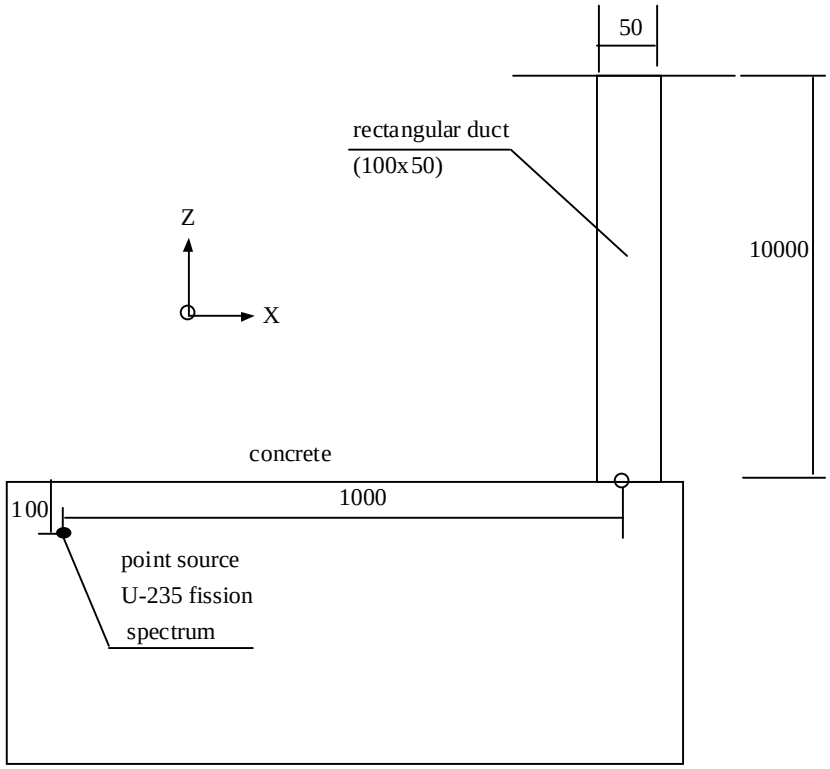
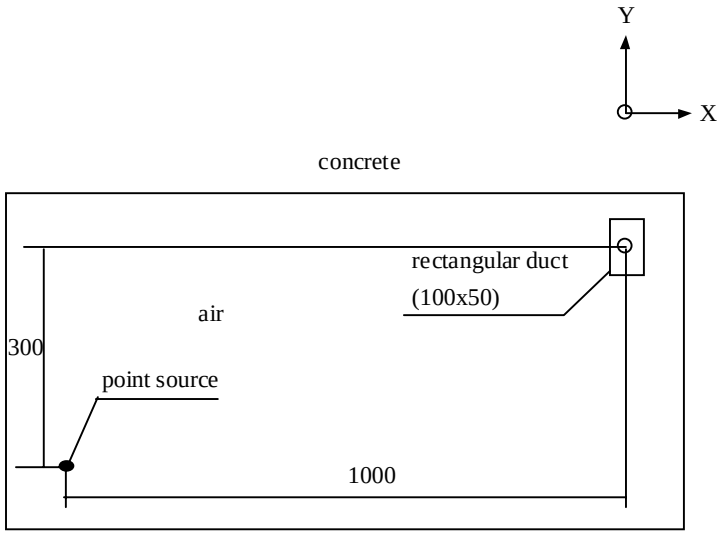


Fig. 4-4 Calculational Model of Sample Problem 2



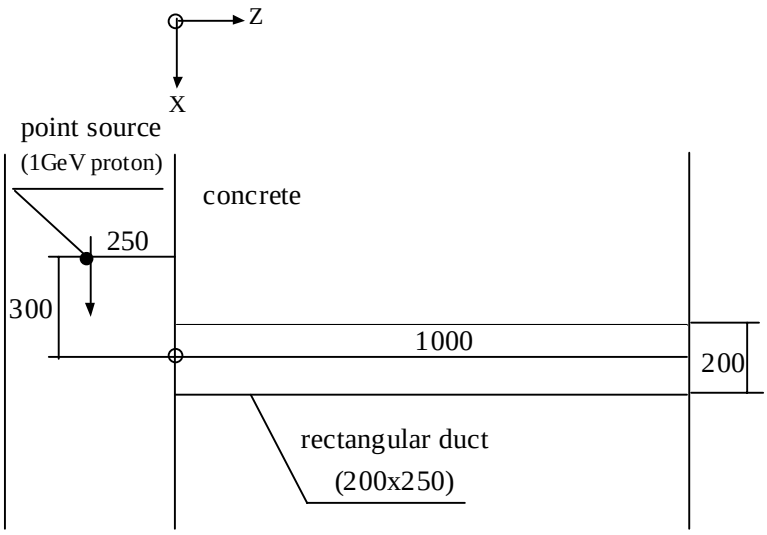
horizontal cross section



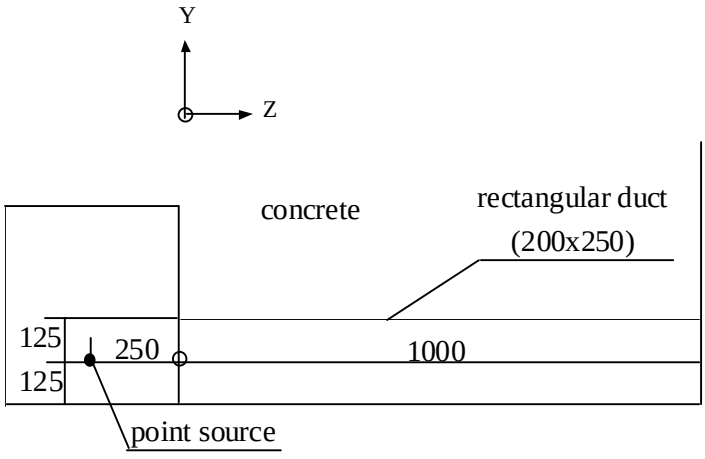
vertical cross section

unit: cm

Fig. 4-5 Calculational Model of Sample Problem 3



horizontal cross section



vertical cross section

unit : cm

Fig. 4-6 Calculational Model of Sample Problem 4

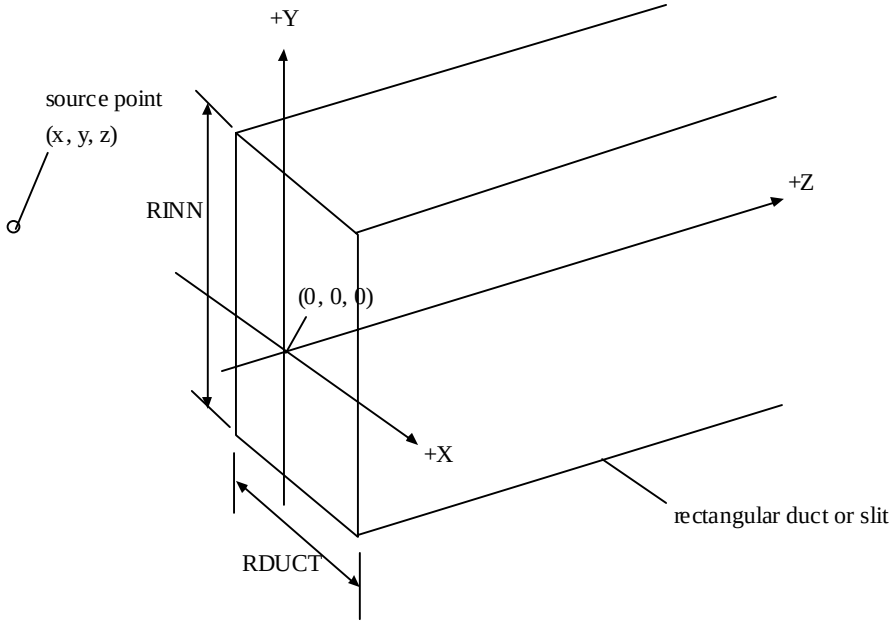


Fig. A-1 Geometry and Source Point Defined by DUCT-III

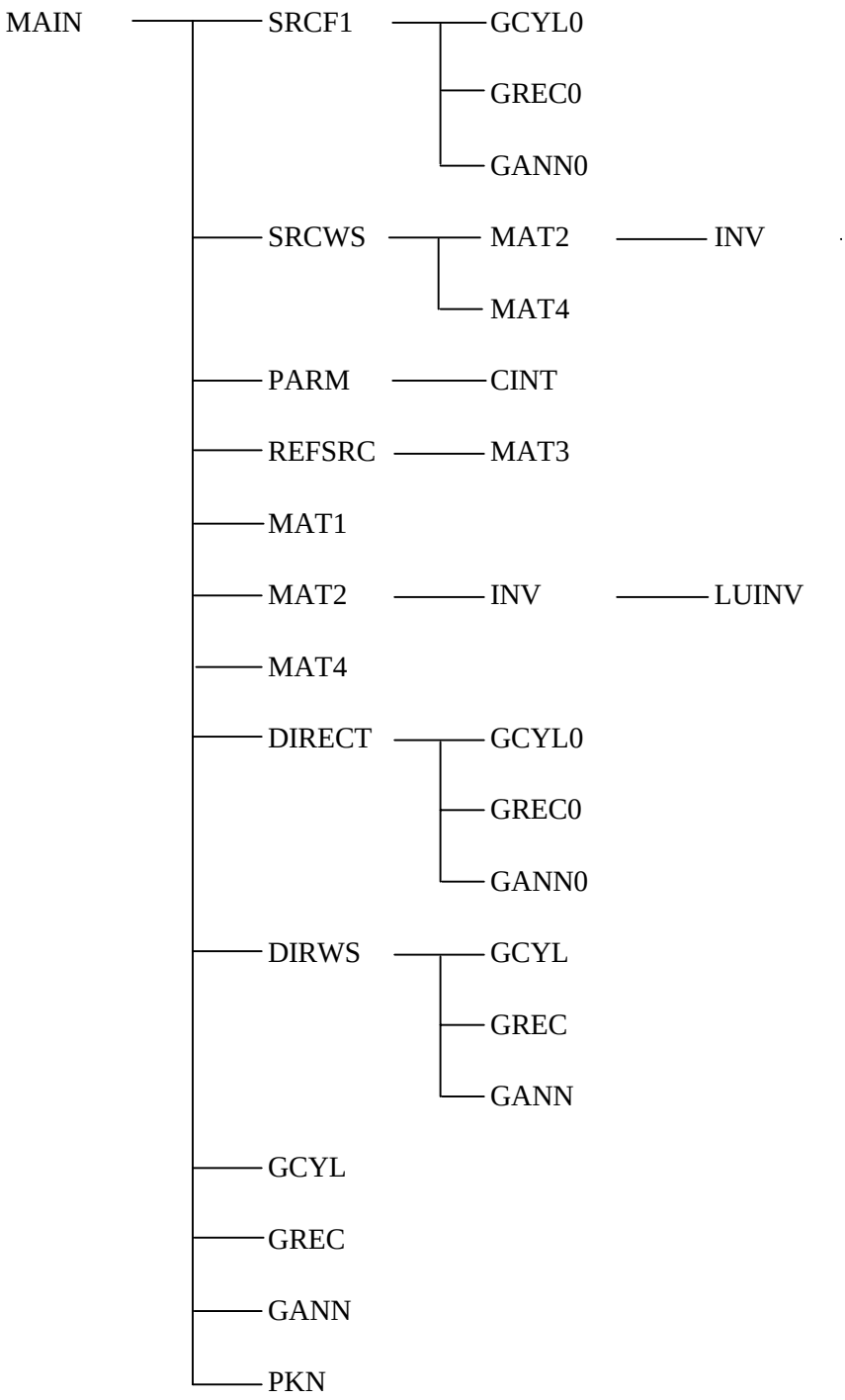


Fig. B-1 Tree Structure of the DUCT-III Code

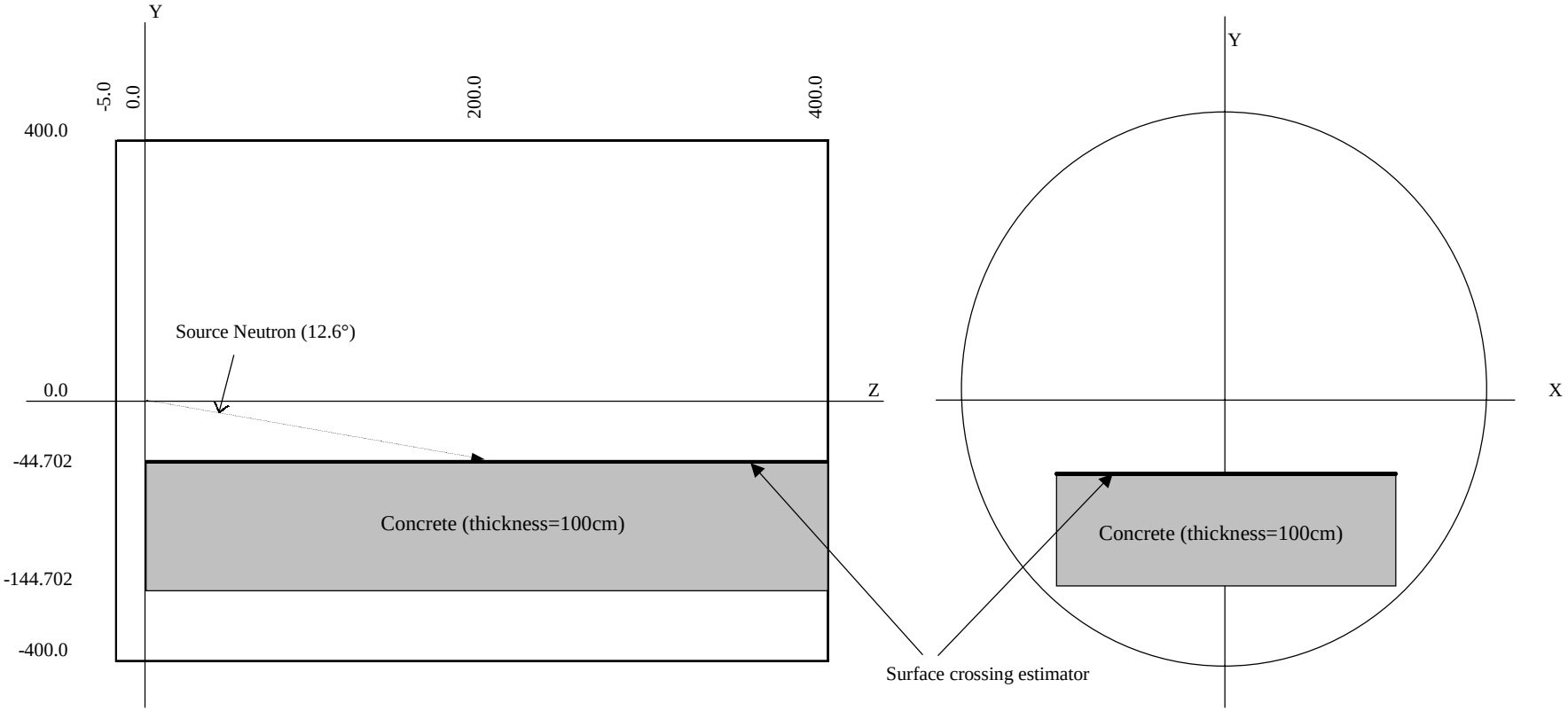


Fig. D-1 Calculational Model of Albedo Matrix of Concrete for High-Energy Neutrons

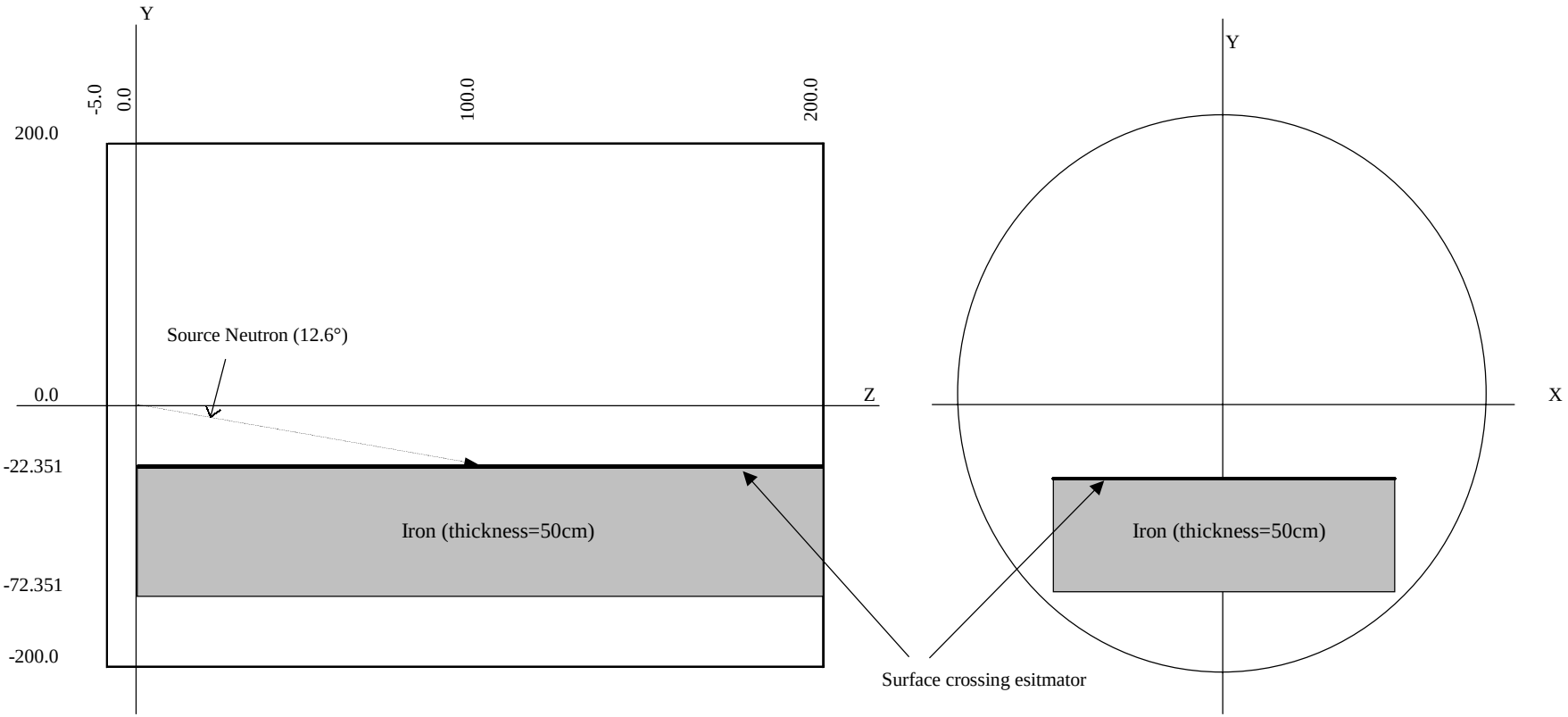


Fig. D-2 Calculational Model of Albedo Matrix of Iron for High-Energy Neutrons

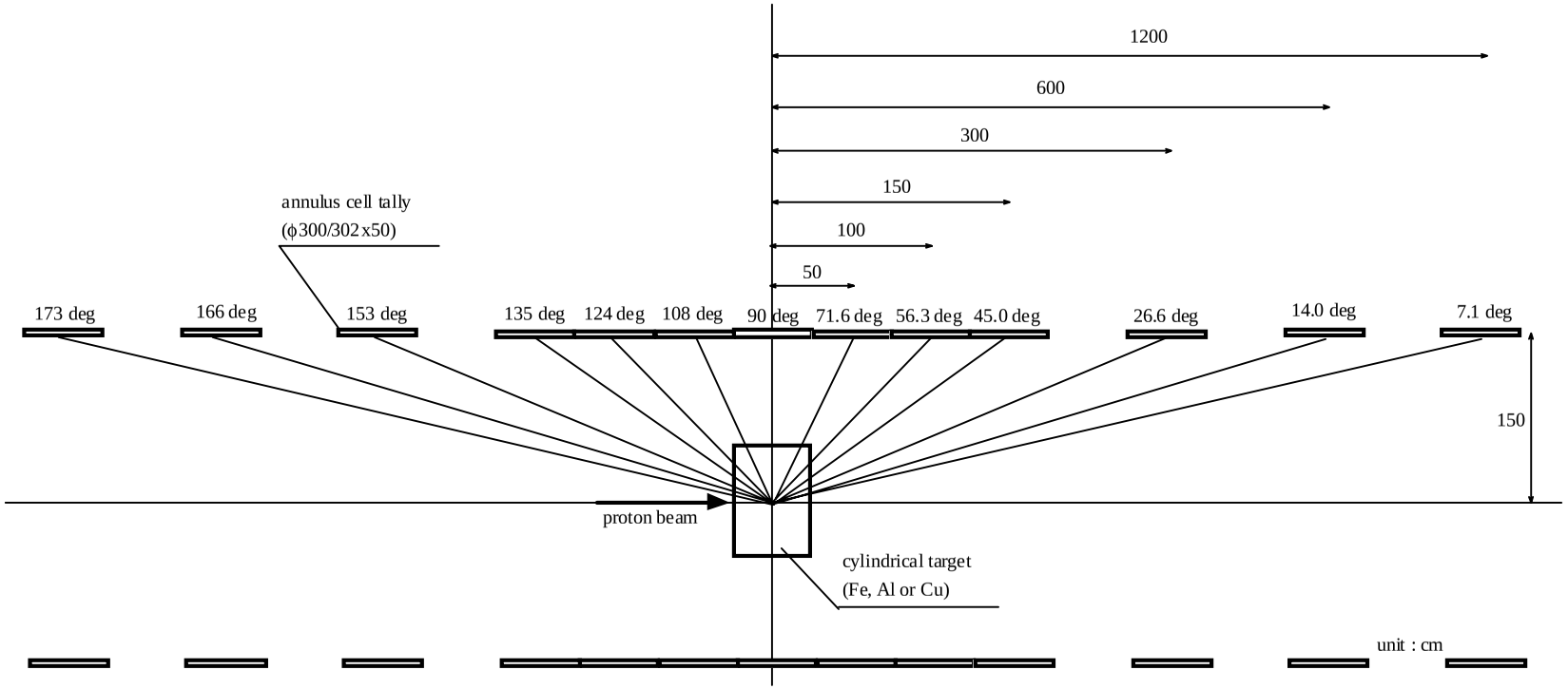


Fig. E-1 A Monte Carlo Model for Calculating Secondary Neutron Spectra for Protons

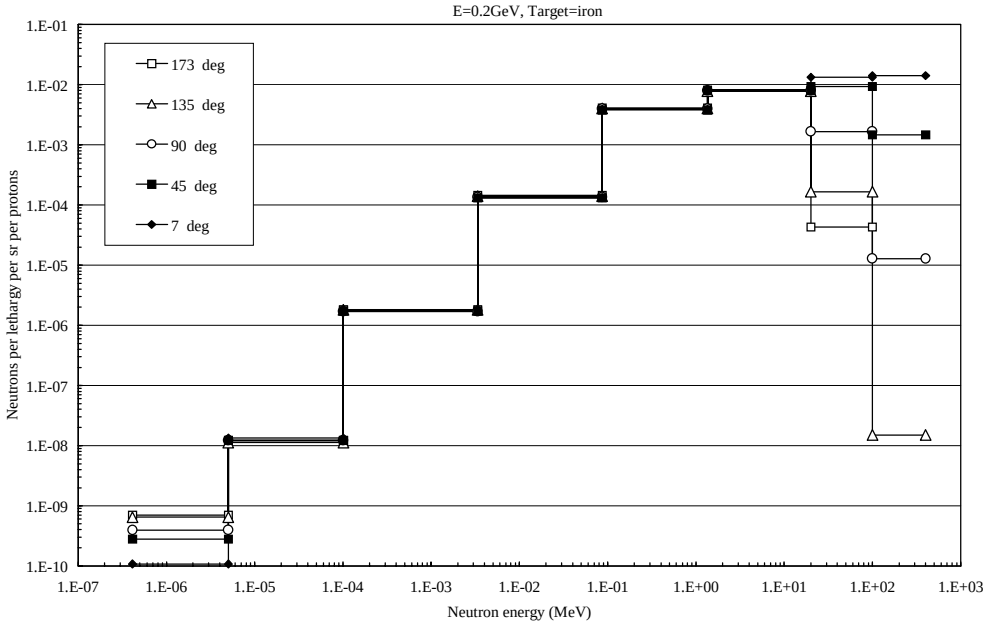


Fig. E-2 Calculated Neutron Yields from Thick Iron Target for 0.2 GeV Protons

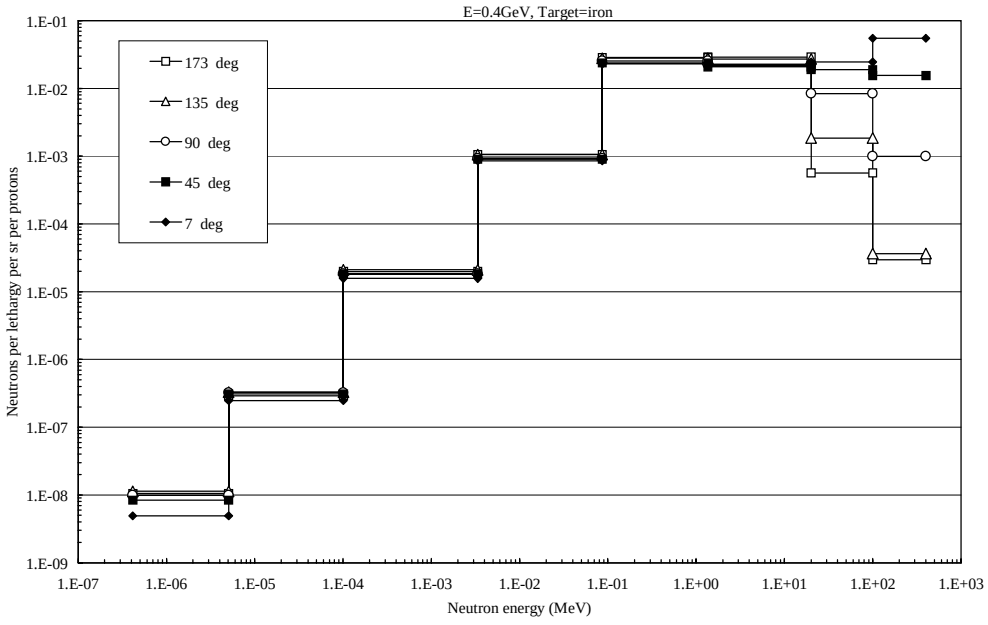


Fig. E-3 Calculated Neutron Yields from Thick Iron Target for 0.4 GeV Protons

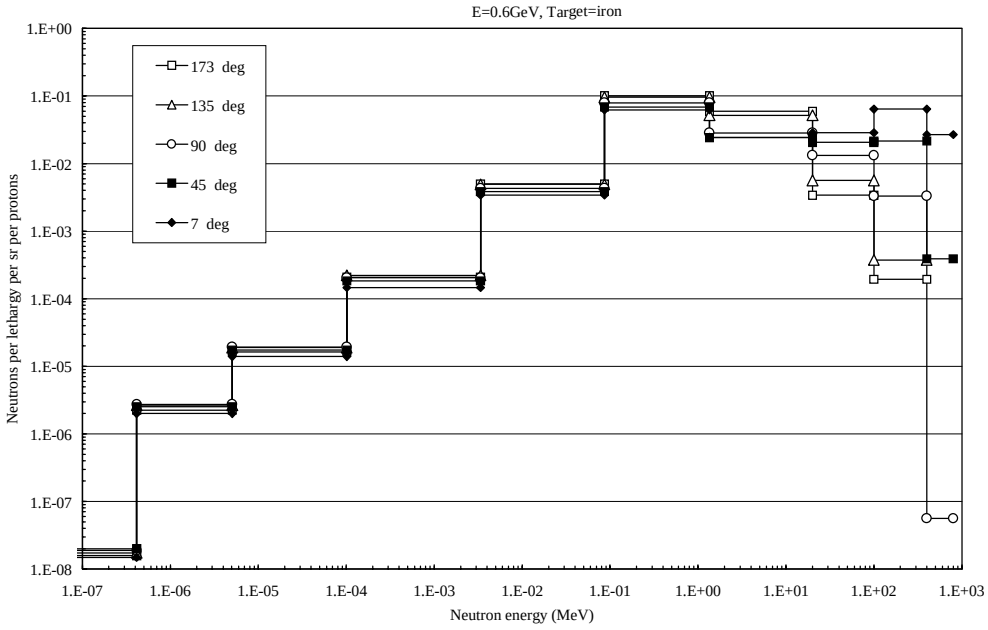


Fig. E-4 Calculated Neutron Yields from Thick Iron Target for 0.6 GeV Protons

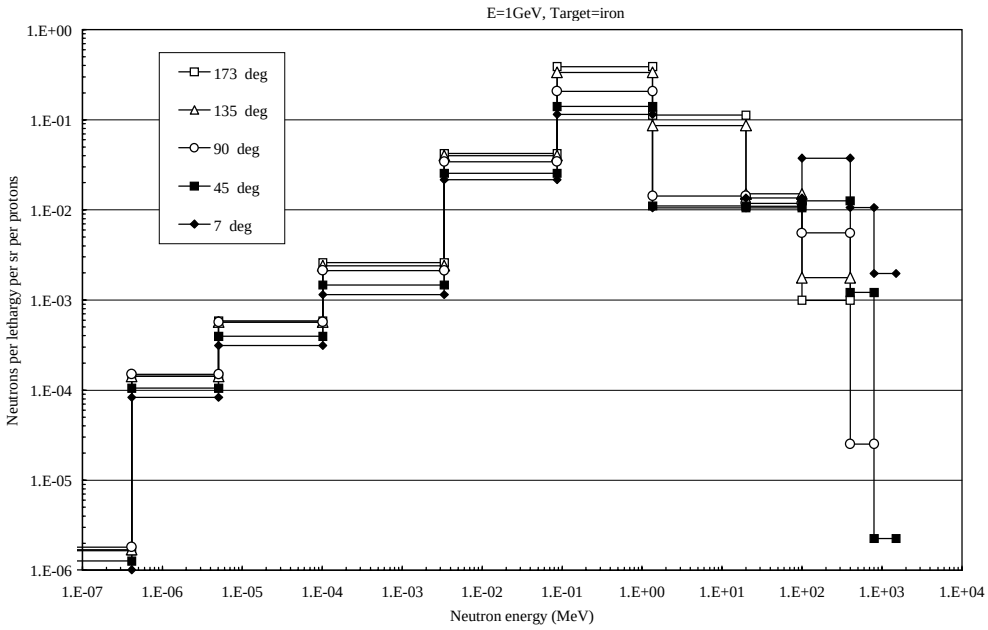


Fig. E-5 Calculated Neutron Yields from Thick Iron Target for 1.0 GeV Protons

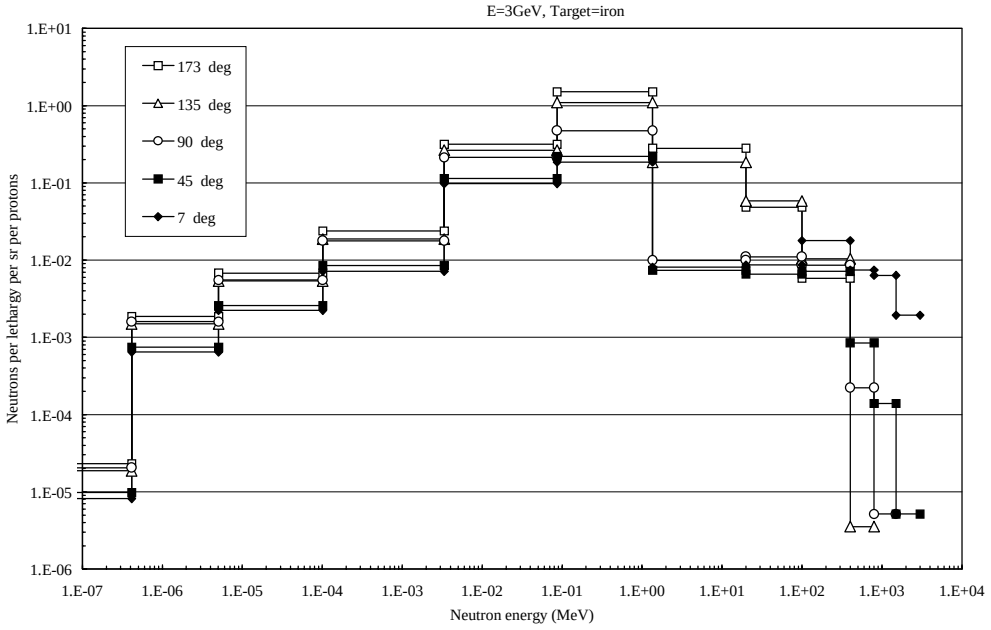


Fig. E-6 Calculated Neutron Yields from Thick Iron Target for 3.0 GeV Protons

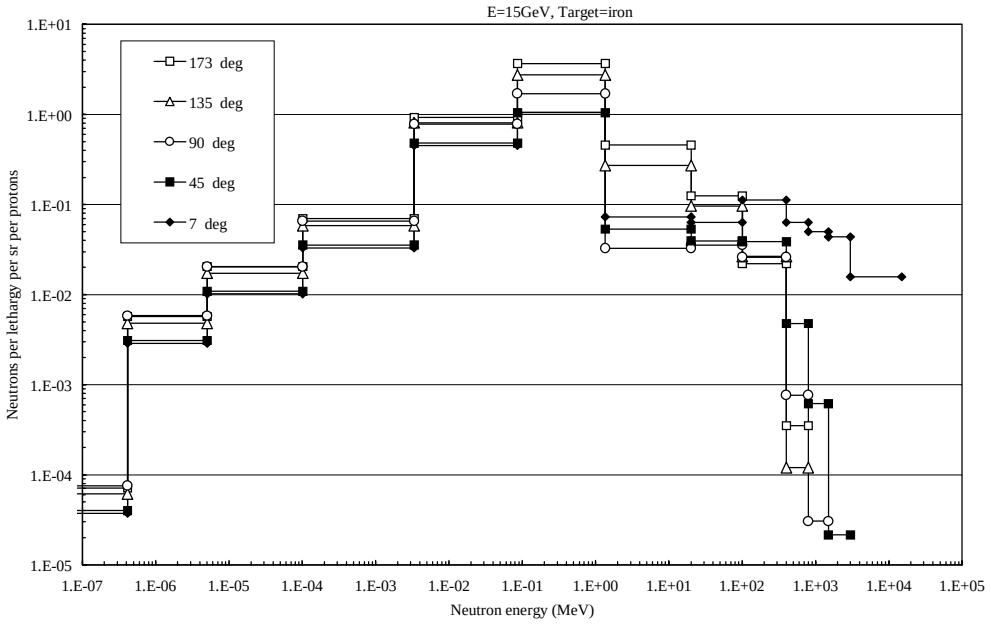


Fig. E-7 Calculated Neutron Yields from Thick Iron Target for 15 GeV Protons

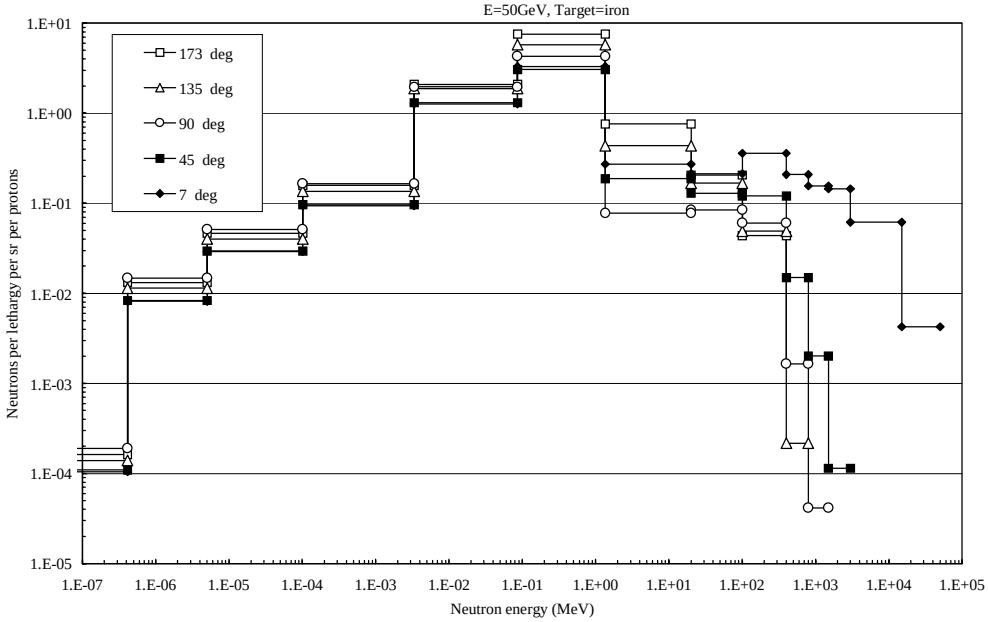


Fig. E-8 Calculated Neutron Yields from Thick Iron Target for 50 GeV Protons

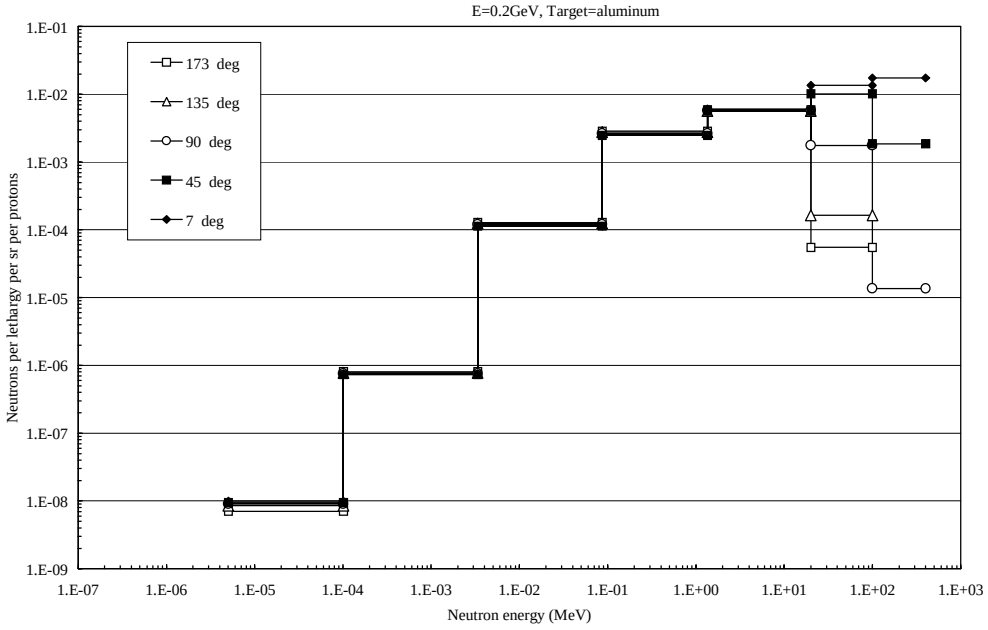


Fig. E-9 Calculated Neutron Yields from Thick Aluminum Target for 0.2 GeV Protons

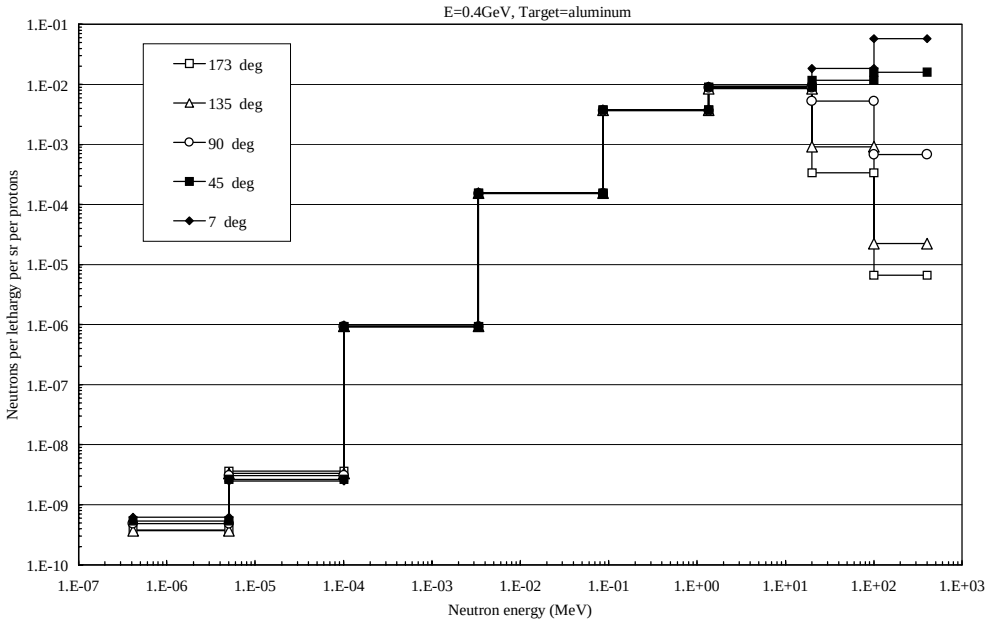


Fig. E-10 Calculated Neutron Yields from Thick Aluminum Target for 0.4 GeV Protons

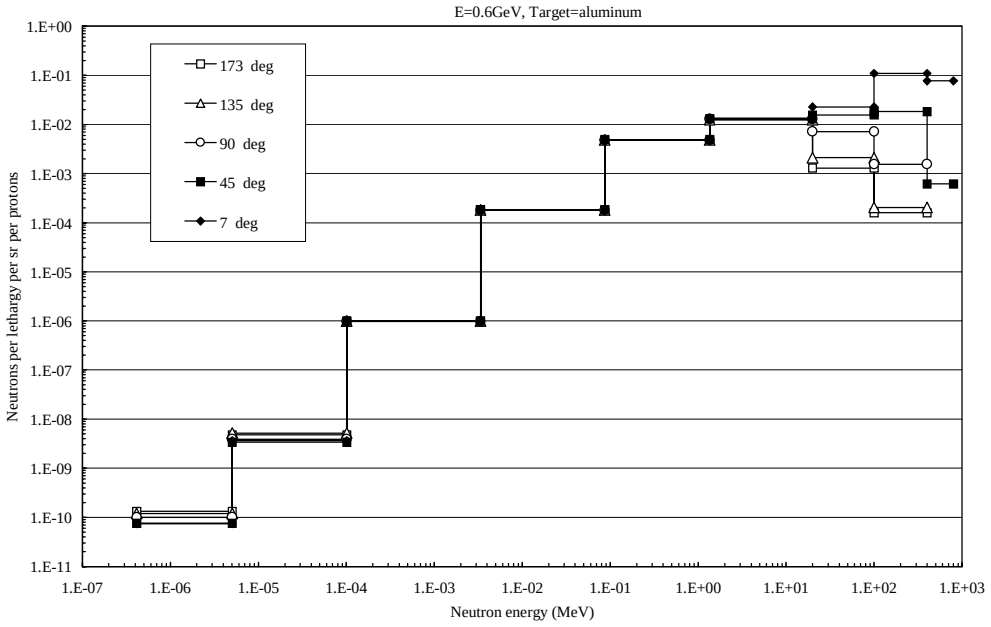


Fig. E-11 Calculated Neutron Yields from Thick Aluminum Target for 0.6 GeV Protons

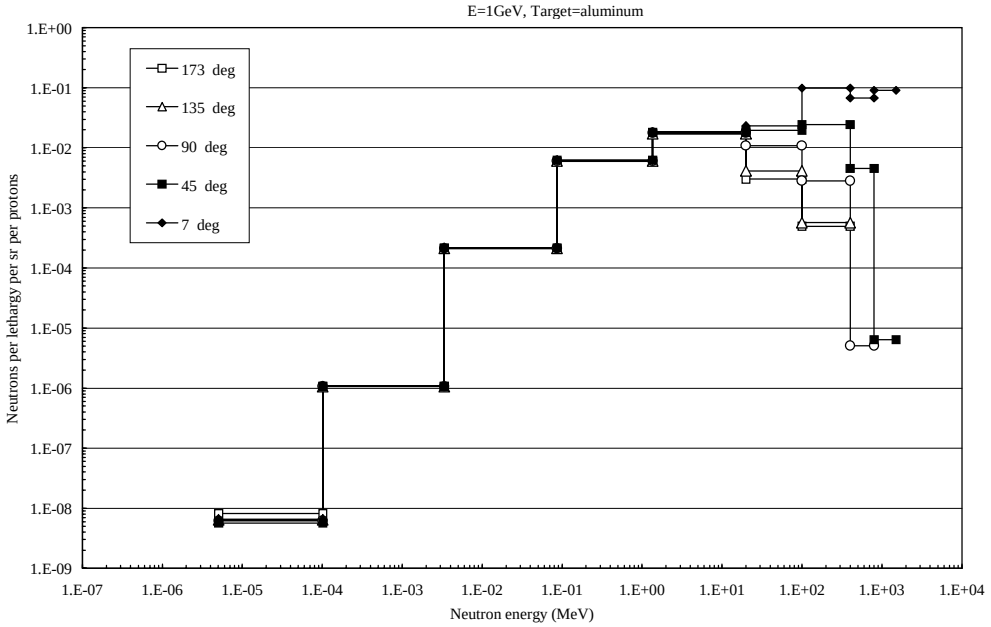


Fig. E-12 Calculated Neutron Yields from Thick Aluminum Target for 1.0 GeV Protons

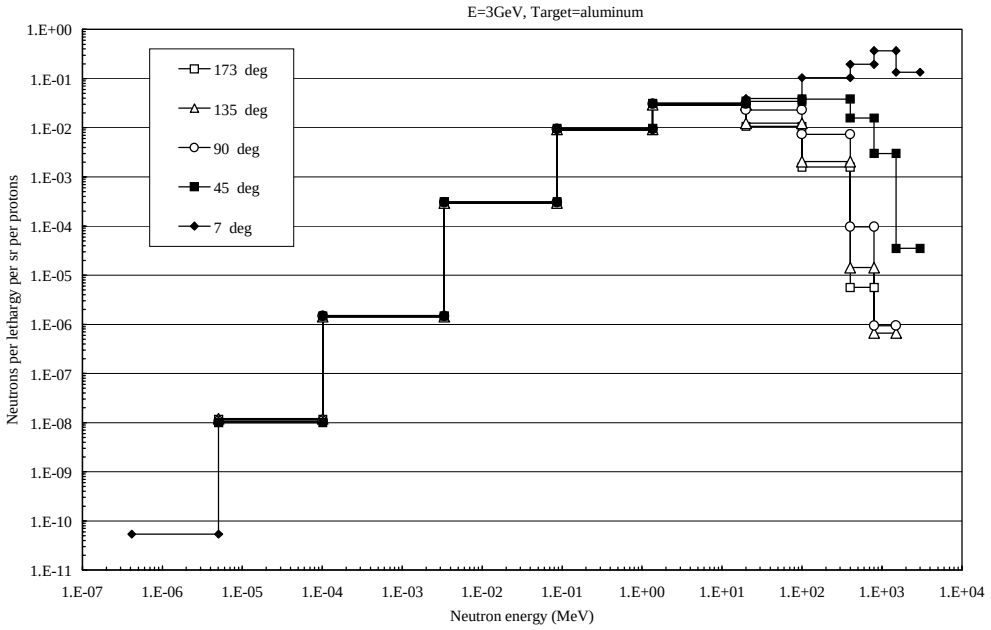


Fig. E-13 Calculated Neutron Yields from Thick Aluminum Target for 3.0 GeV Protons

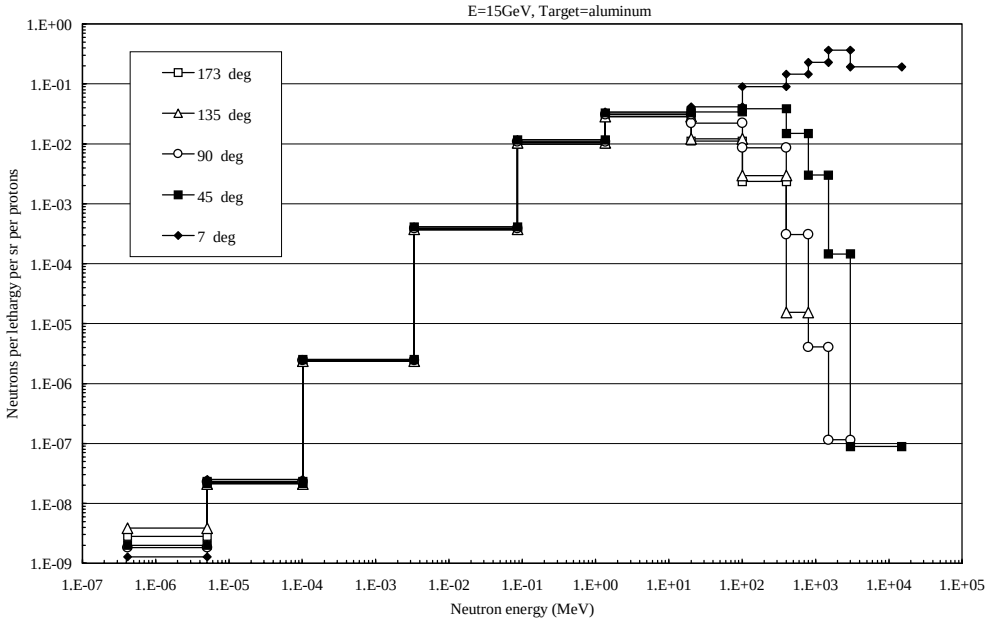


Fig. E-14 Calculated Neutron Yields from Thick Aluminum Target for 15 GeV Protons

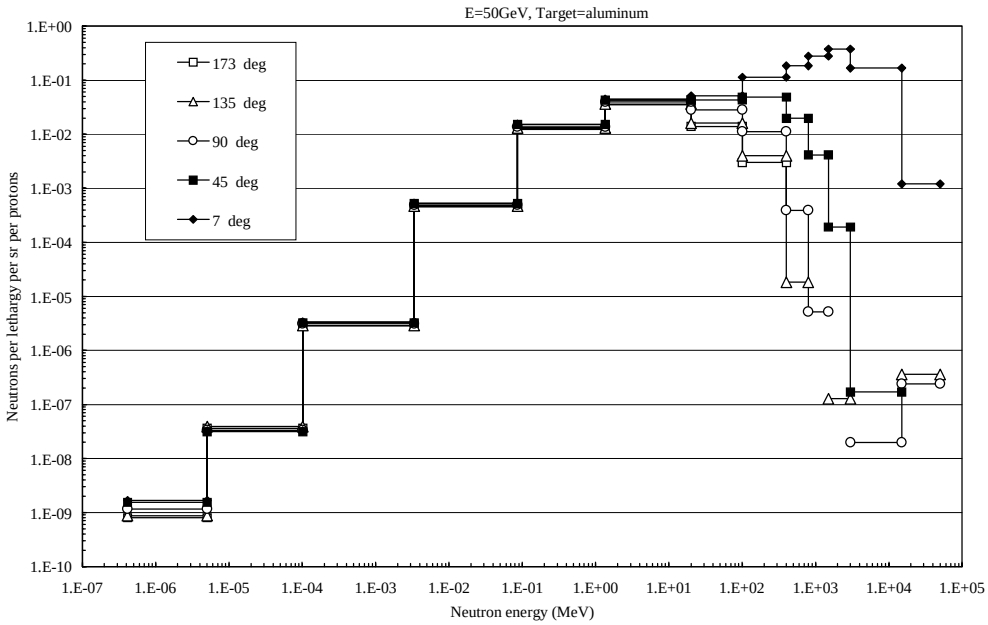


Fig. E-15 Calculated Neutron Yields from Thick Aluminum Target for 50 GeV Protons

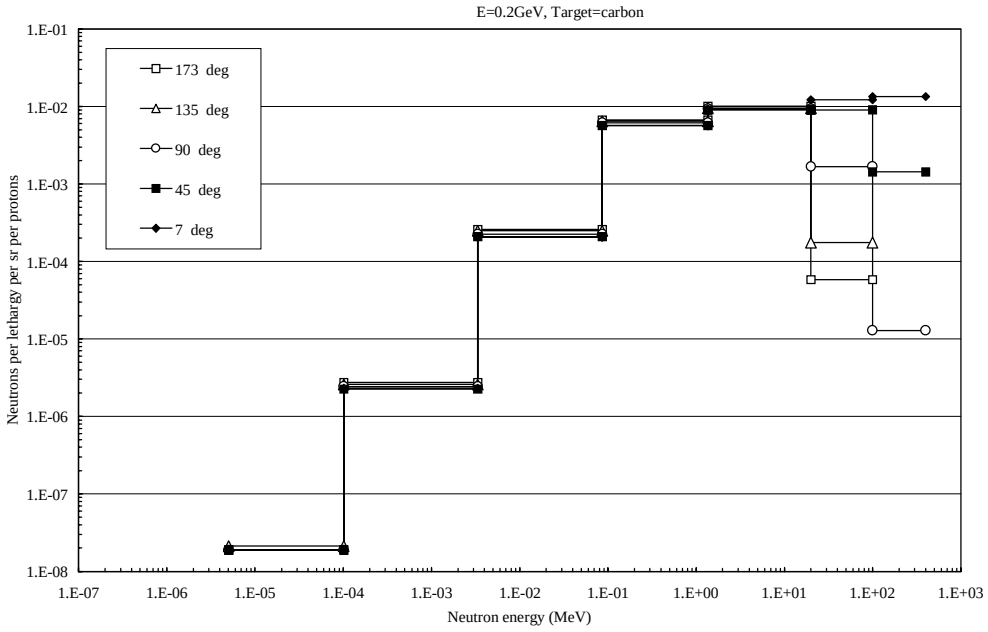


Fig. E-16 Calculated Neutron Yields from Thick Copper Target for 0.2 GeV Protons

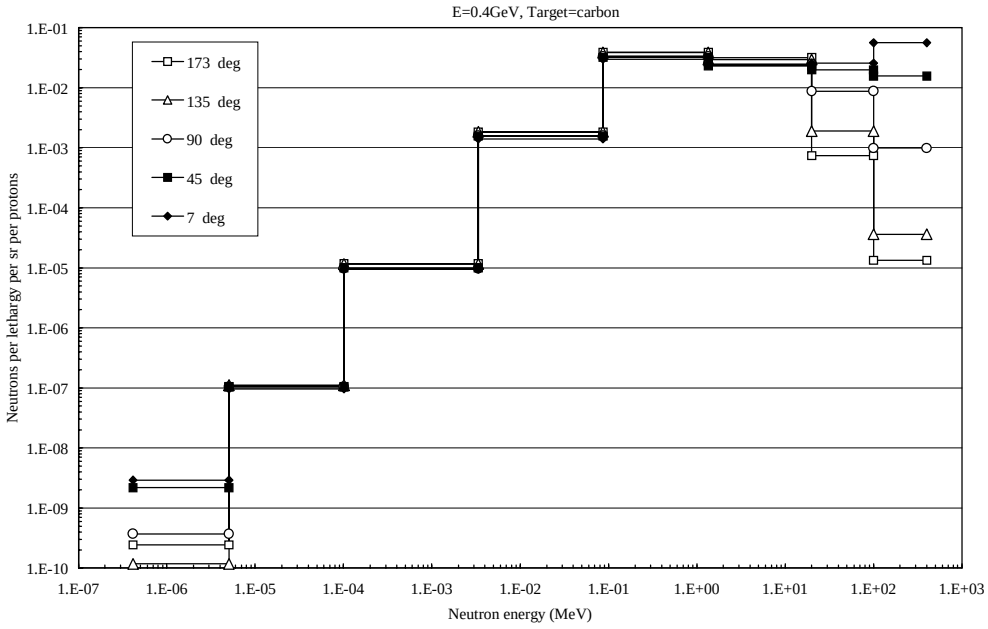


Fig. E-17 Calculated Neutron Yields from Thick Copper Target for 0.4 GeV Protons

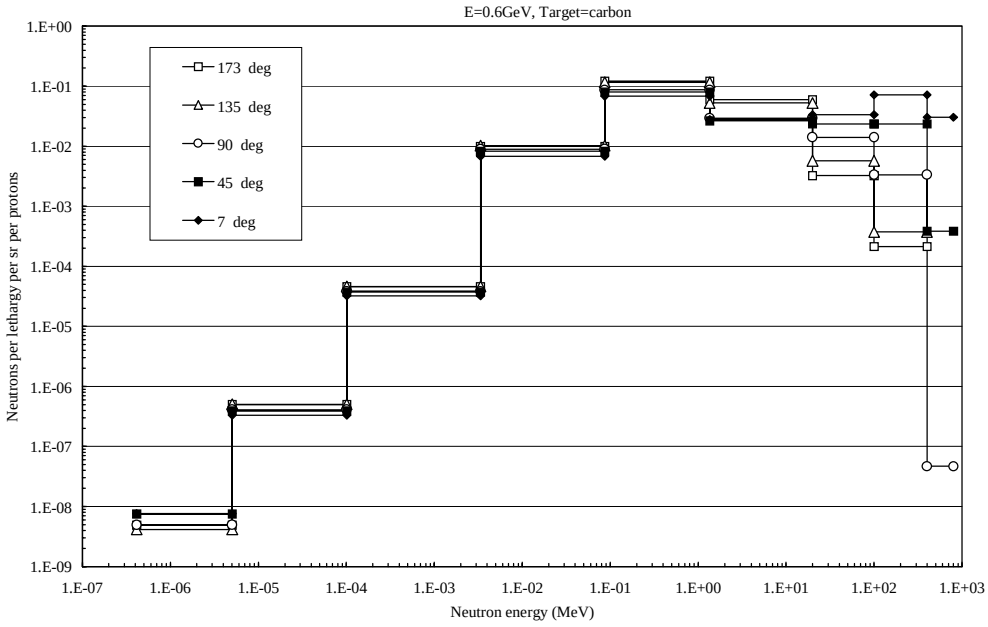


Fig. E-18 Calculated Neutron Yields from Thick Copper Target for 0.6 GeV Protons

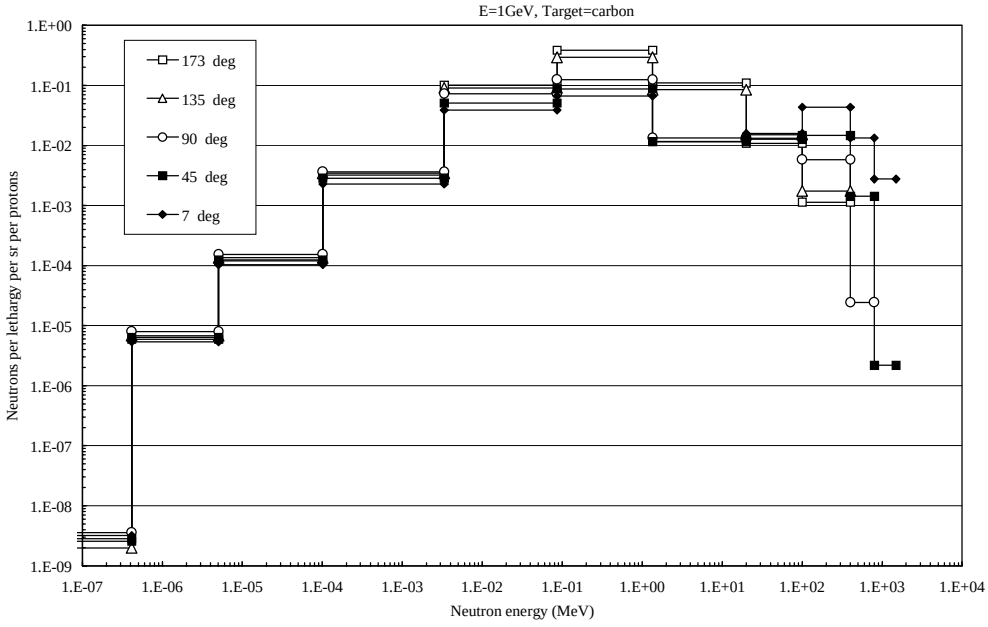


Fig. E-19 Calculated Neutron Yields from Thick Copper Target for 1.0 GeV Protons

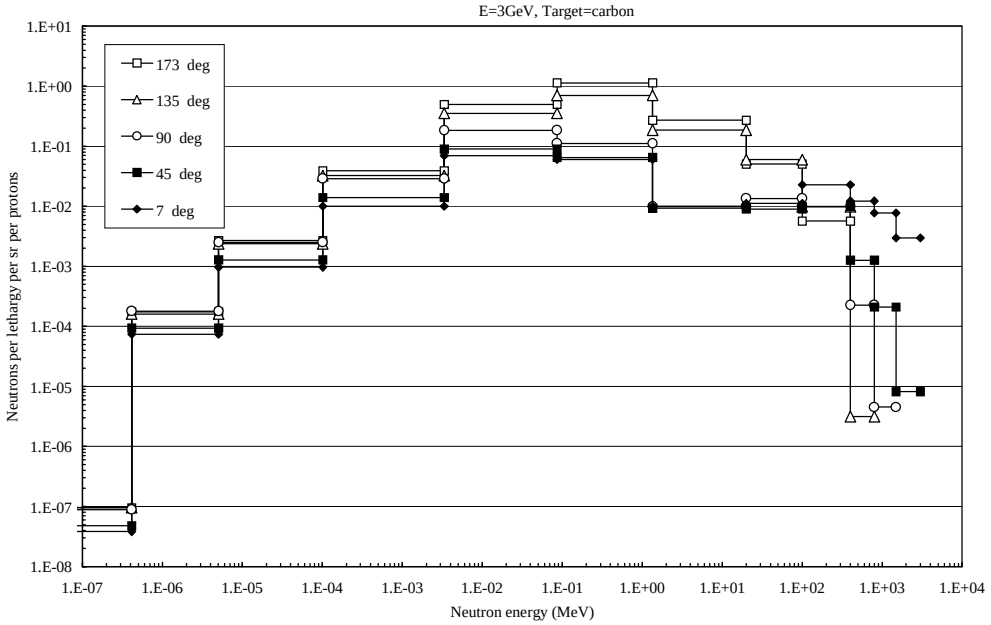


Fig. E-20 Calculated Neutron Yields from Thick Copper Target for 3.0 GeV Protons

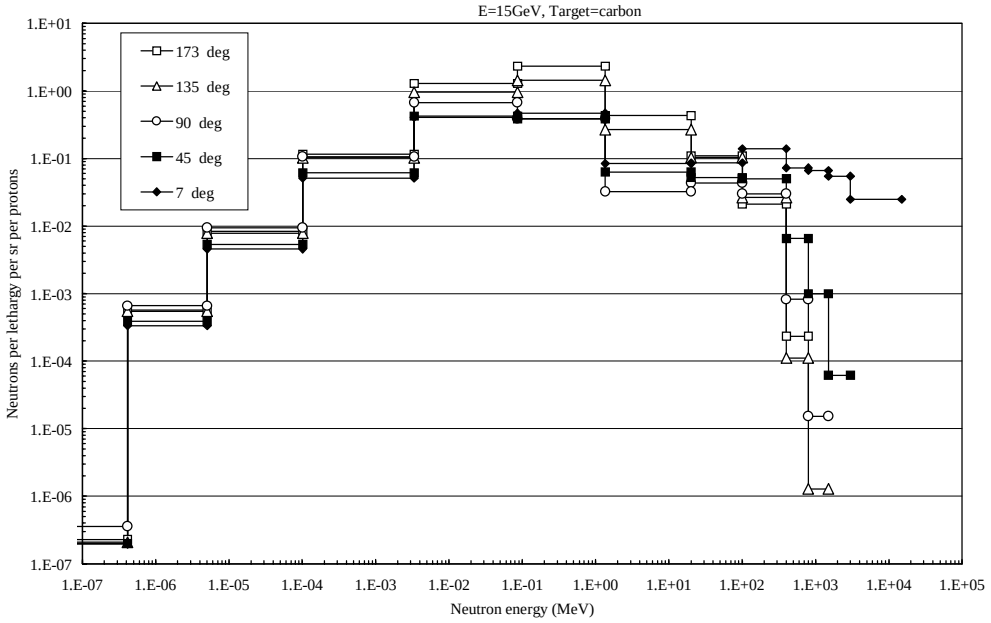


Fig. E-21 Calculated Neutron Yields from Thick Copper Target for 15 GeV Protons

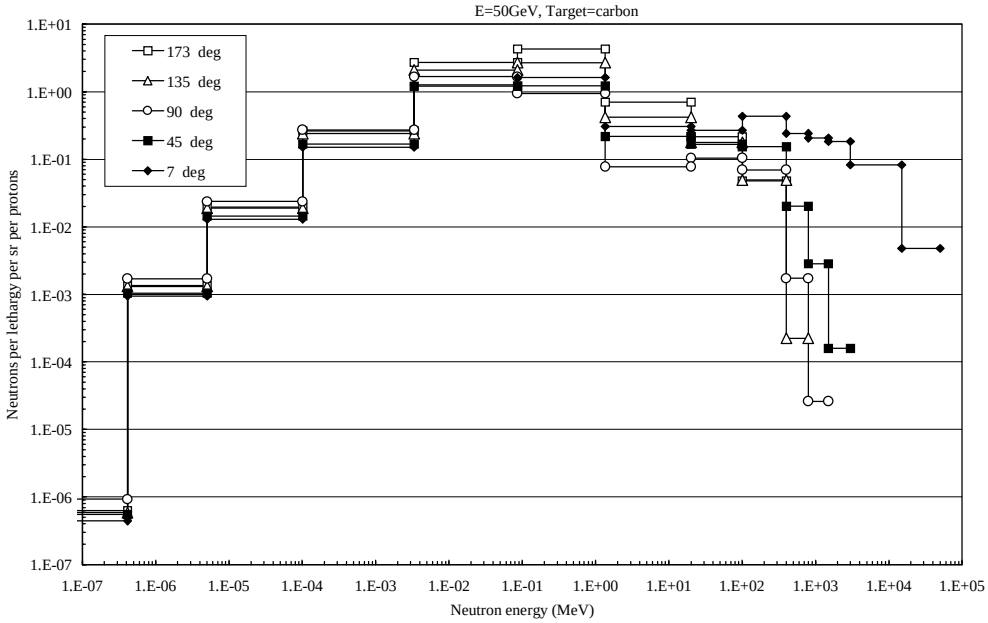


Fig. E-22 Calculated Neutron Yields from Thick Copper Target for 50 GeV Protons