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CREPT-MCNP 1.1 (Calibration Code for the Representative Point Method with MCNP) : User Manual -Version 1.1.0

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JAEA-Data/Code

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The representative point method is a novel method which enables efficiency calibrations using a standard point source. A calculation code for use in implementation of the method has been developed. The code is named CREPT-MCNP (Calibration Code for the Representative Point Method with MCNP).

The code estimates the position of a representative point which is intrinsic to each volume sample shape, and also provides self-absorption factors that correct the efficiencies measured at the representative point with a standard point source. It can deal with photons between 20 keV and 2 MeV with p- or n-type germanium semiconductor detectors. CREPT-MCNP runs in the Windows PC environment as a GUI based application. This manual describes the features of the CREPT-MCNP code.

CREPT-MCNP 1.1
（代表点法を用いたゲルマニウム半導体検出器の効率校正用コード）
ユーザーマニュアル　1.1.0 版

日本原子力研究開発機構　東海研究開発センター
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　代表点法は、標準点状線源を用いてゲルマニウム半導体検出器の効率校正を精度よく行うための方法である。代表点法を円滑に実施するための計算コードとして、今回、CREPT-MCNP 1.1（Calibration Code for the Representative Point Method with MCNP）を整備した。

　この計算コードには、体積試料の計数効率曲線に等価な計数効率曲線を与える点（代表点）を探索するための機能や、代表点で測定した計数効率に対し自己吸収効果の補正を行う機能などが含まれており、これらの機能を実行することにより目的とする計数効率を得る。評価対象は、p型および n 型 Ge 半導体検出器により測定可能な、エネルギー範囲が 20 keV から 2 MeV の光子である。CREPT-MCNP1.1 は、Windows PC 環境で GUI 形式で動作する。本報は、CREPT-MCNPの機能と使用方法についてとりまとめたものである。

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Disclaimer & Intellectual Property Statement

CREPT-MCNP is a calculation code for use in carrying out efficiency calibrations with the representative point method. The code can be found in the PRODAS database administered by the Center for Computational Science & e-Systems, Japan Atomic Energy Agency. Users must obtain the code through the center and use it in compliance with the administrative computer program rules set by the center.

The CREPT-MCNP code is provided free of charge to the academic research community or public organisations for non-commercial, non-profit internal research use. Prior to use of the code, users will need to individually obtain and install the MCNP code as it is not included with the CREPT-MCNP code. Note that neither the author or any Japan Atomic Energy Agency member can be held responsible for results obtained using the code and/or that the representative point method will meet the users' requirements, nor any damage or loss resulting from its use.

A request for the representative point method is to be examined for a Japanese patent by the Japan Patent Office and has been made with an Application Kokai Publication Number of 2002-98768.

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1 Introduction

One of the most important tasks with the radiation control work is precisely and promptly measuring radioactivity in environmental samples. And in addition, with the rapid widespread use of accelerators these days, the urgent need to be able to estimate the induced radioactivity in activated samples of various shapes and materials has arisen. Radioactivity measurements for these purposes are generally based on gamma-ray spectrometry using HPGe detectors. In order to quantify the radioactivity, an efficiency calibration, viz. determination of the peak-efficiency curves versus energy, must be achieved for various combinations of sample-detector geometries. The shape and magnitude of the peak-efficiency curve depends on the detector, sample shape and sample material.

Generally, efficiency calibrations are performed by manufacturing a standard volume source spiked with a known amount of radioactivity and then measuring it with the detector. Manufacturing standard volume sources, however, requires skilful and complicated techniques [Sa95], and the procedure must be repeated periodically as they contain rather short-lived nuclides. Furthermore, differing standard volume sources must be prepared depending on the individual sample's shape and material, which can result in an undesirable increase in radioactive waste as one has to get rid of them. Although peak-efficiency curves can be determined using only computational approaches, the reliability of the results cannot be ensured, mainly due to difficulties in modelling the detector, on particular with parameters such as the dead layer or the ineffective region of the germanium crystal [Jo06] [He03].

To overcome this problem, the representative point method, a novel method which enables efficiency calibrations using a standard point source, has been previously proposed [Sa00] [Sa04], and a calculation code for implementing the method newly developed [Sa08]. The code is named CREPT-MCNP (Calibration Code for the Representative Point Method with MCNP).

The code finds the position of the representative point, the position where a point source efficiency curve better approximates that one for the volume source. Self-absorption correction factors are also computed to make correction on the efficiencies measured at the representative point with a standard point source. It involves the general-purpose Monte Carlo code MCNP [Br00] [XM05] for simulating radiation transport in and around the sample and detector. The developed CREPT-MCNP code has MCNP control functions, e.g., creation of input files and simulation with MCNP, as a GUI (Graphical User Interface) based application. Even novice MCNP users can carry out efficiency calibrations through use of this code.

2 CREPT-MCNP Code User Manual

2.1 System Requirements

The CREPT-MCNP code is packaged software for readily implementing efficiency calibrations. It was developed using Microsoft Visual Basic.NET, Lahey Fortran 95, and SPREAD for .NET Windows Forms Edition (version 1.0.9.0).

The code works under Microsoft Windows® operating systems version 2000 or XP, and allows users easy and interactive operation with a GUI. The recommended amount of PC RAM memory is at least 256 megabytes.

Either MCNP code version 4 [Br00] or 5 [XM05] and their associated cross-section library data are necessary and should be located in a selected directory within the system. When version 5 MCNP is used, the X-windows system need to be run in order to make the geometric models draw on the display. The X-windows system can be freely established on Windows PCs using the Cygwin tool [CY08], which is available via the internet. The geometry plotting itself is done with a built-in function, originally included in MCNP as the "-ip" protocol.

2.2 Installation

CREPT-MCNP can be installed according to the following steps (1) to (5).

(1) Double-click the "Setup.msi" icon on the installation CD. If .NET Framework has not been installed on the PC, the following message appears. In the case, users should install it by clicking [Yes], which then directs users to the Microsoft .NET Framework website. If installation was successful, go to the step (3), otherwise, step (2).
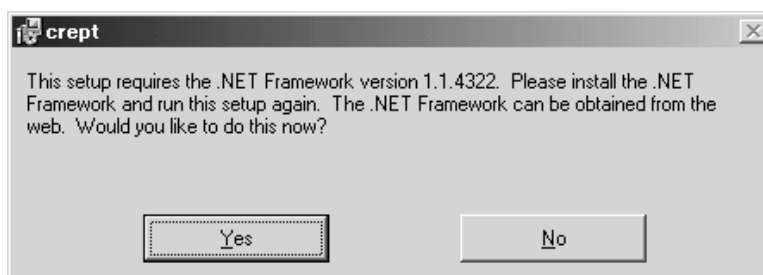
(2) Double-click the "dotnetfix.exe" icon on the installation CD to install .NET Framework 1.1. Note that the "dotnetfix.exe" file on the CD is not the latest version.

(3) When the following window appears, click the [Next] button.

(4) Select a folder (directory) in which to install the code. Select whether a user or users can run the code, and then click the [Next] button.

(5) When the following window appears click [Next] to commence installation.

(6) Once installation is complete, the following window appears. Click [Close] to exit.
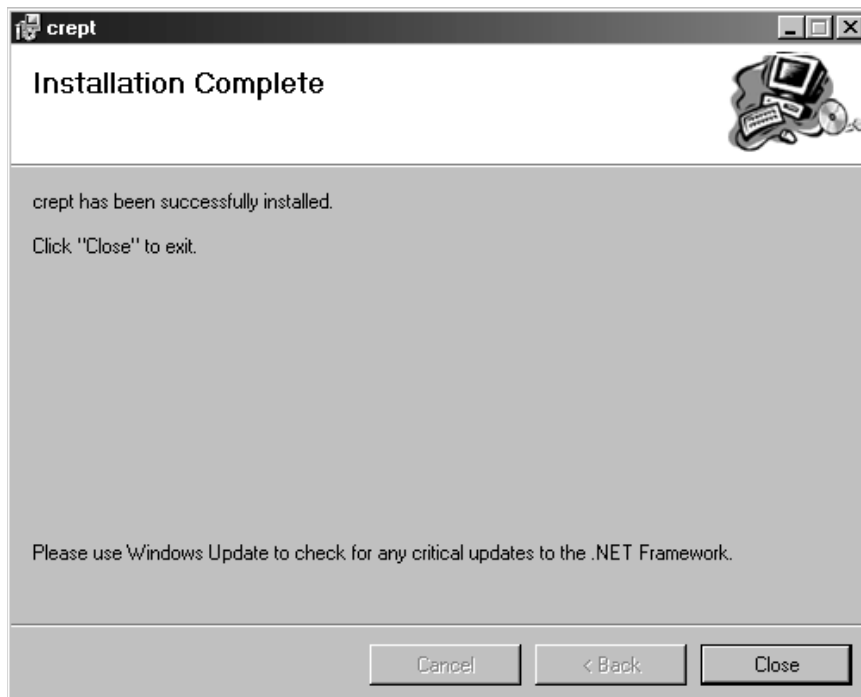
2.3 Directory Configuration

Execution of the code will automatically create the subdirectory structure shown in Fig. 2-1 within the directory designated in step (4) of the previous section.

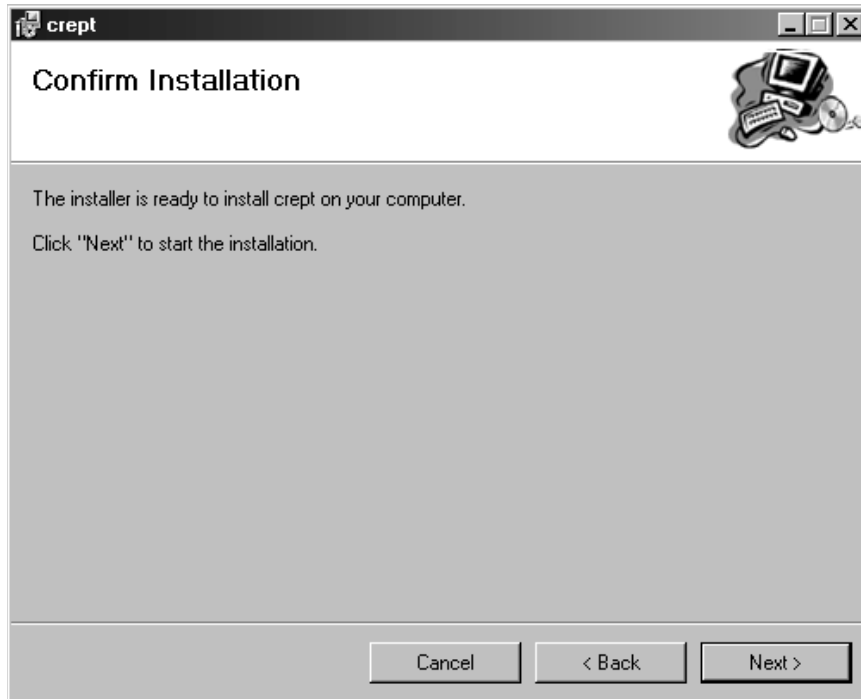|			
crept			Stores main program, .dll files and help files
	system		Stores data required for system execution
		lib	Stores dummy libraries used in chkregion.exe
		parts	Stores data of default parts (stylised detectors, samples, etc.)
			detector — Stores data of default "detectors"
			cover — Stores data of default "covers"
			tray — Stores data of default "trays"
			jig — Stores data of default "support jigs"
			object — Stores data of default "measured samples"
			space — Stores data of default "calculation areas"
	work		Stores data created by the system, and calculation results
		angle	Stores data of angulat dependency (not used in this version of the code)
		ExportExcel	Stores data used for post-processing with the Microsoft Excel
		effA	Stores data of efficiency-curves group A
		effB	Stores data of efficiency-curves group B
		effC	Stores data of "representative point (RP)" and "parameter *t*"
		material	Stores data of material compositions and densities
		meas	Stores measured efficiency data at RP with a standard point source
		model	Stores geometrical model data for MCNP calculations
		parts	Stores data of parts (user-established data)
			detector — Stores data of "detectors"
			cover — Stores data of "covers"
			tray — Stores data of "trays"
			jig — Stores data of "support jigs"
			object — Stores data of "measured samples"
			space — Stores data of "calculation areas"
		selfcoef	Stores data of calculated self-absorption (SA) correction factors
		selfeff	Stores results (final efficiency data)
		selfshield	Stores efficiency data of volume sample (with/without SA effect)
		srcenergy	Stores data of source energy
		srcmesh	Stores data of spatial alignment conditions of a point source
		srcoption	Stores data of source conditions for a standard volume source

Fig. 2.1 CREPT-MCNP Directory structure

2.4 Basic Operation

Run "crept.exe" by clicking its icon or the equivalent shortcut icon on the desktop and the main window will appear. All CREPT-MCNP code functions can be accessed through the main menus on the menu-bar at the top of the main window.

The code has six main menus. Each of them has several sub menus, as summarized in Table 2-1. More details on them are given in section 2.5.

Table 2-1 List of CREPT-MCNP code menus

Main menu	Sub menu	Example of function / Remarks
File (F)	F1. Setting	MCNP path setting
	F2. Exit	
Data (D)	D1. Material	Material registration
	D2. Detector	Geometric definition for each part
	D3. Cover	
	D4. Tray	
	D5. Support jig	
	D6. Measured sample	
	D7. Calculation area	Positional relationship between the parts
	D8. Geometry	
	D9. Source energy point	
	D10. Volume sample	
	D11. Alignment of point source	Coordinates and intervals for point source alignment
Calculation (C)	C1. Efficiency-curves group A	Efficiency curves of a volume sample by means of "point integration"
	C2. Efficiency curve for volume sample without self-absorption, representative point	
	C3. Efficiency curve for volume sample with and without self-absorption	
	C4. Final efficiency curve	
Calculation Results (R)	R1. Efficiency-curves group A	Efficiency curve at a specified position is depicted graphically
	R2. Efficiency-curves group B	
	R3. Comparison of efficiency curve at a representative point and that of volume sample without self-absorption	
	R4. Contour map of parameter t	
	R5. Detailed contour map of parameter t around a representative point	
	R6. Comparison of efficiency curves of a volume sample by means of "point integration" and by MCNP	For cross-checking
	R7. Final efficiency curve	
Window (W)	W1 - W4. Align in tiles, in piles, horizontally, vertically	
Help (H)	H1. Help	
	H2. System version	

2.5 Operation Menus

2.5.1 [File] Menu

2.5.1.1 [File]-[Setting] Menu

Environmental settings required for operation are given in this menu.
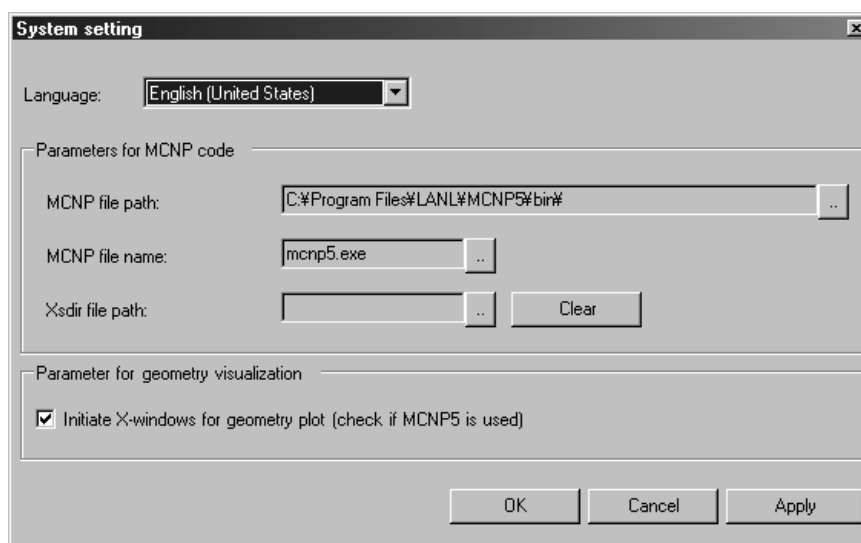
(1) Language:

Select either English (United States) or Japanese (Japan) environment from the drop-down list. Note that users can change the language whenever they need.

(2) MCNP file path:

A directory that includes the MCNP execution file need to be designated. By clicking the [...] button on the right side of the line users can browse and select the necessary directory.

(3) MCNP file name:

A name for the MCNP execution file need to be entered. By clicking the [...] button on the right side of the blank line users can browse and select the necessary file.

(4) Xsdir file path:

When version 5 MCNP is used leave this space blank. Otherwise (i.e. when version 4 MCNP is used), the directory containing the "xsdir" file needs to be designated. Clicking the [...] button on the right side of the blank line allows users to browse and select the necessary directory.

(5) Parameters for geometric visualization:

The CREPT-MCNP code uses the X-Windows system in illustrating a cross-sectional view of the calculation geometries. Check the box if you wish to be notified before geometric depictions are drawn on the display. Leave it blank if using version 4 MCNP.

2.5.1.2 [File]-[Exit] Menu

Selecting the [Exit] menu prompts the user a dialog box for a confirmation. Select [Yes] on that box to exit.
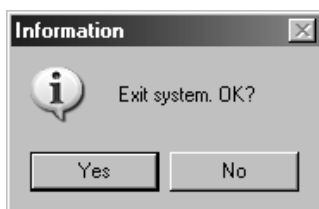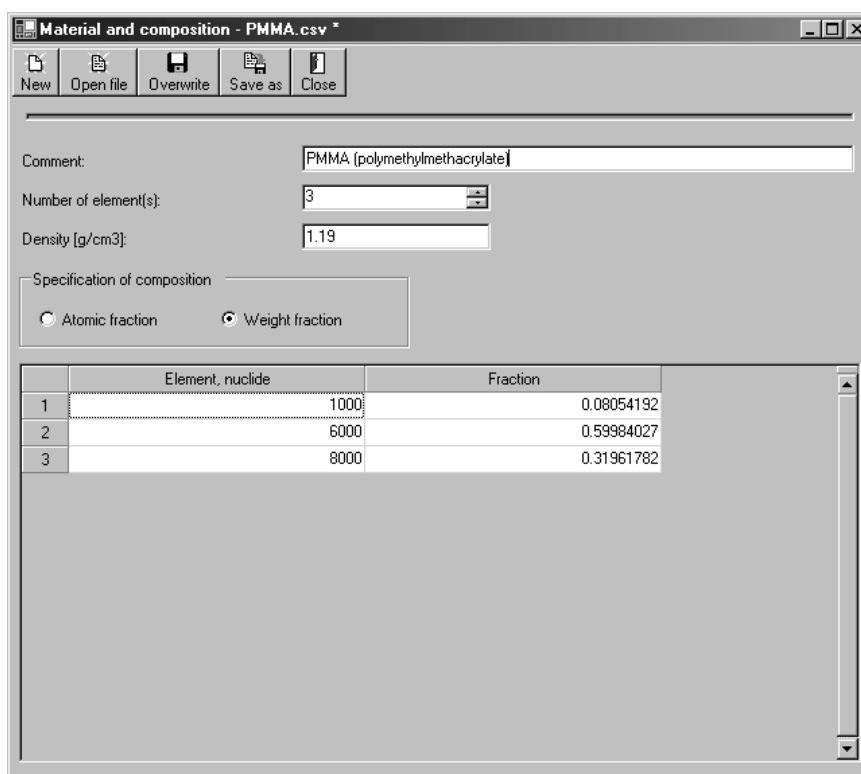

2.5.2 [Data] Menu

There are eleven sub menus in the [Data] Menu.

2.5.2.1 [Data]-[Material] Menu

Materials used in each detector, sample and sample container, etc. are defined with this menu. Compositions and a density of each material are required for the definition. These data are stored as a material database.

(1) Comment:

Space provided just for user made comments.

(2) Number of element(s):

Specify the number of element(s) or nuclide(s) which constitute a material. This will automatically change the number of rows in the data grid at the bottom of the window.

(3) Density [g/cm^3]:

Assign a density of the material in g cm^{-3}.

(4) Specification of composition:

Select an input form to specify the material composition. Either "Atomic fraction" or "Weight fraction" can be selected.

(5) [Data grid] Element, nuclide:

Specify elements or nuclides which constitute a material in ZA format. With the ZA format, a nuclide with the atomic number of Z and the mass number of A is expressed as $Z \times 1000 + A$. A is zero for a natural element. (Example) H (hydrogen): 1000, Co (cobalt): 27000, ^{3}H (tritium): 1003, and ^{60}Co (cobalt 60): 27060.

(6) [Data grid] Fraction:

In accordance with the specification of composition, assign the appropriate fractions for the constituents specified in the left columns. The sum of the fractions does not need to be unity, as the MCNP code will renormalize the fractions if they do not sum to one.

2.5.2.2 [Data]-[Detector] Menu

Parameters that specify the geometric configurations and materials of a detector are assigned in the following window.
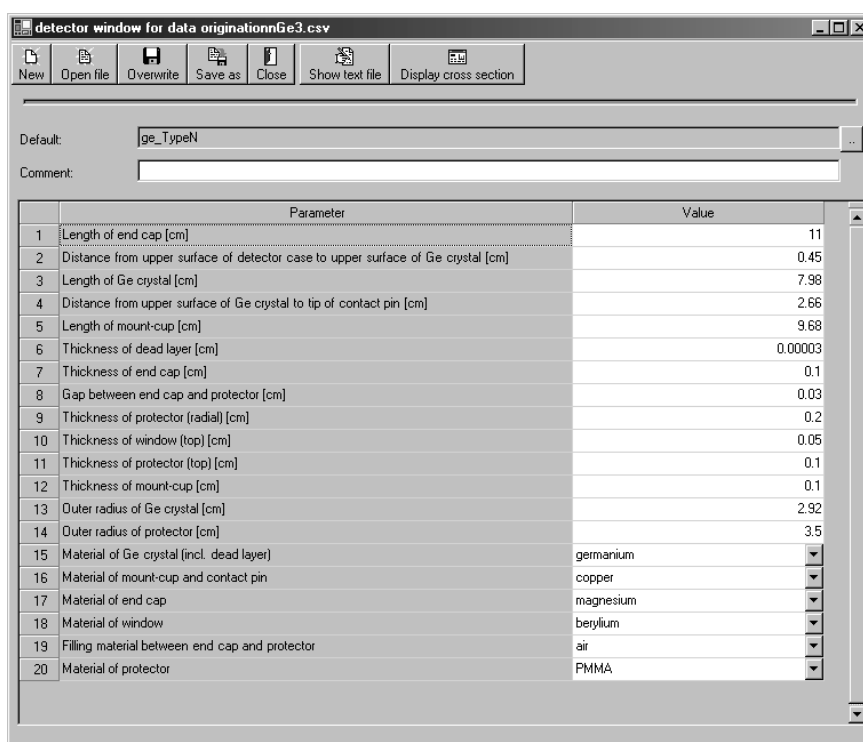
(1) Default:

First, a default style of a detector should be selected. By clicking the [...] button on the right side of the blank line users can browse and select the necessary file. Parameter values of the default detector are then modified to specify the intended detector. The default style itself cannot be modified in the GUI window but can be modified or newly added in a text file. The format of the text file is described in Appendix A.8.

Originally, the CREPT-MCNP code has a p-type HPGe and an n-type HPGe as the default detectors. Geometries of these detectors are shown schematically in Figs. 2-2 (for p-type HPGe) and 2-3 (for n-type HPGe), along with their parameters and default parameter values in Tables 2-2 (for p-type HPGe) and 2-3 (for n-type HPGe).

Fig. 2-2 Half sectional view of a default p-type HPGe (units in cm)

Table 2-2 Parameters, data type and default parameter values for a p-type HPGe

(File name: ge_TypeP.csv)

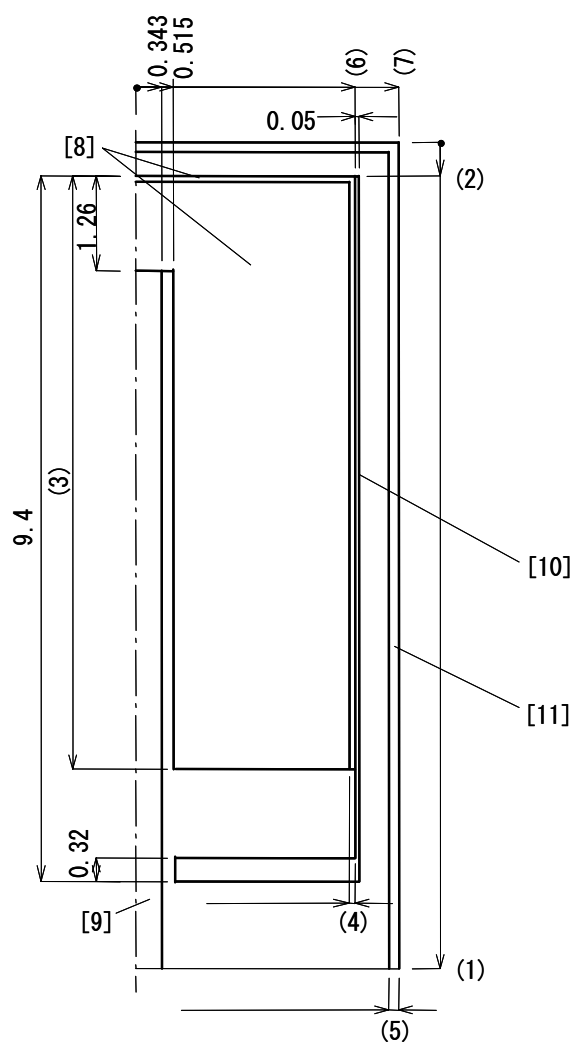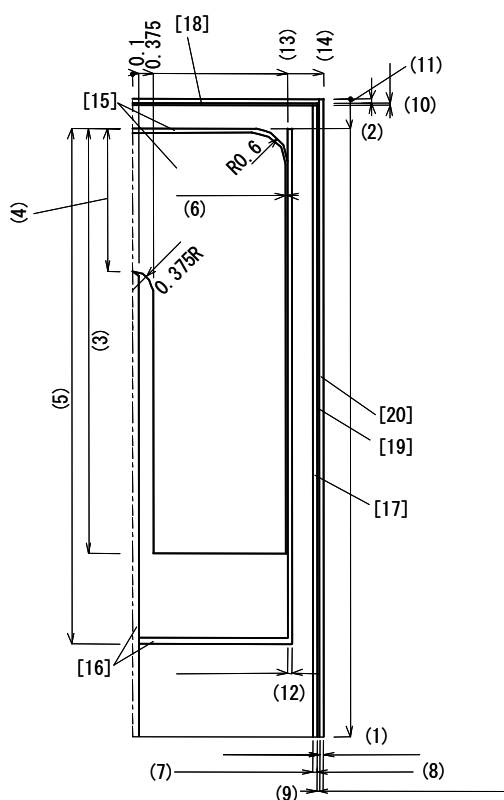|	Parameter	Data type	Default
(1)	Total length of detector [cm]	Floating-point	11
(2)	Distance from upper surface of detector case to upper surface of Ge crystal [cm]	Floating-point	0.43
(3)	Length of Ge crystal [cm]	Floating-point	7.9
(4)	Thickness of dead layer [cm]	Floating-point	0.09
(5)	Thickness of end cap [cm]	Floating-point	0.13
(6)	Outer radius of Ge crystal [cm]	Floating-point	2.925
(7)	Outer radius of end cap [cm]	Floating-point	3.5
[8]	Material of Ge crystal	Character	-
[9]	Material of contact pin	Character	-
[10]	Material of mount-cup	Character	-
[11]	Material of end cap	Character	-

Fig. 2-3 Half sectional view of a default n-type HPGe (units in cm)

Table 2-3 Parameters, data type and default parameter values for an n-type HPGe

(File name: ge_TypeN.csv)

	Parameter	Data type	Default
(1)	Length of end cap [cm]	Floating-point	11
(2)	Distance from upper surface of detector case to upper surface of Ge crystal [cm]	Floating-point	0.45
(3)	Length of Ge crystal [cm]	Floating-point	7.6
(4)	Distance from upper surface of Ge crystal to tip of contact pin [cm]	Floating-point	2.47
(5)	Length of mount-cup [cm]	Floating-point	9.6
(6)	Thickness of dead layer [cm]	Floating-point	0.00003
(7)	Thickness of end cap [cm]	Floating-point	0.1
(8)	Gap between end cap and protector [cm]	Floating-point	0.03
(9)	Thickness of protector (radial) [cm]	Floating-point	0.2
(10)	Thickness of window [cm]	Floating-point	0.05
(11)	Thickness of protector (top) [cm]	Floating-point	0.1
(12)	Thickness of mount-cup [cm]	Floating-point	0.1
(13)	Outer radius of Ge crystal [cm]	Floating-point	2.92
(14)	Outer radius of protector [cm]	Floating-point	3.73
[15]	Material of Ge crystal (including dead layer)	Character	-
[16]	Material of mount-cup and contact pin	Character	-
[17]	Material of end cap	Character	-
[18]	Material of window	Character	-
[19]	Filling material between end cap and protector	Character	-
[20]	Material of protector	Character	-

(2) [Data grid] Parameter:

Parameters which constitutes a detector are listed. Users cannot change, add or remove these parameters (items) through the GUI window.

This rule is also applicable for the [Data]-[Cover] Menu, [Data]-[Tray] Menu, [Data]-[Support jig] Menu, [Data]-[Measured sample] Menu and [Data]-[Calculation area] Menu, all of which will be described hereinafter.

(3) [Data grid] Value:

Users can modify the parameter values if necessary. If the data type of a value is "matter", select it from the drop-down list. If no material is selected from the list, i.e. blank, the material is considered void in the MCNP calculations.

This rule also holds true for the [Data]-[Cover] Menu, [Data]-[Tray] Menu, [Data]-[Support jig] Menu, [Data]-[Measured sample] Menu and [Data]-[Calculation area] Menu, all of which will be described hereinafter.

(4) [Button in toolbar] Show text file:

Clicking the [Show text file] button pops up the MCNP input file created by the code automatically. It is helpful as reference although users cannot change the file in this window.

This rule also holds true for the [Data]-[Cover] Menu, [Data]-[Tray] Menu, [Data]-[Support jig] Menu, [Data]-[Measured sample] Menu and [Data]-[Calculation area] Menu, all of which will be described hereinafter.

```
nGe3.csv                                          _ □ ×
c
c      ********************************
c      ** cell card for geometry  **
c      ********************************
c
c
c
   1   1 -8.96000E+00 -22 9 -12
          imp:p 1.000 imp:e 1.000
   2   0              (-23 7 #1):(8 -7 -13 #1):(9 -8 -16 #1)
          imp:p 1.000 imp:e 1.000
   3   2 -5.36000E+00 (6 -5 -14):(-24 6 14):(8 -6 -15 #1 #2)
          imp:p 1.000 imp:e 1.000
   4   2 -5.36000E+00 (5 -4 -14):(24 -25 6 14):(8 -6 15 -16)
          imp:p 1.000 imp:e 1.000
   5   1 -8.96000E+00 (10 -9 -17):(9 -4 16 -17)
          imp:p 1.000 imp:e 1.000
   6   0              11 -3 -18 #1 #2 #3 #4 #5
          imp:p 1.000 imp:e 1.000
   7   3 -1.74000E+00 18 -19 11 -3
          imp:p 1.000 imp:e 1.000
   8   4 -1.85000E+00 3 -2 -19
          imp:p 1.000 imp:e 1.000
   9   5 -1.20490E-03 11 -2 19 -20
          imp:p 1.000 imp:e 1.000
  10   6 -1.19000E+00 (2 -1 -20):(11 -1 20 -21)
          imp:p 1.000 imp:e 1.000


c
c      ***********************************
c      ** surface card for geometry  **
c      ***********************************
c
c
c
   1 PZ 0
   2 PZ -0.1
   3 PZ -0.15
   4 PZ -0.45
   5 PZ -0.45003
   6 PZ -1.05
   7 PZ -3.485
   8 PZ -8.43
   9 PZ -10.03
  10 PZ -10.13
  11 PZ -11
```

```
nGe3.csv                                          _ □ ×
   9 PZ -10.03
  10 PZ -10.13
  11 PZ -11
  12 CZ 0.1
  13 CZ 0.375
  14 CZ 2.32
  15 CZ 2.91997
  16 CZ 2.92
  17 CZ 3.02
  18 CZ 3.17
  19 CZ 3.27
  20 CZ 3.3
  21 CZ 3.5
  22 KZ -3.11 1 -1
  23 SZ -3.485 0.375
  24 TZ 0 0 -1.05 2.32 0.59997 0.59997
  25 TZ 0 0 -1.05 2.32 0.6 0.6

c
c      *********************
c      ** material cards **
c      *********************
c
c
c   ---- no.  1 material: copper
m1    29000 -1.0000000E+00
c
c   ---- no.  2 material: germanium
m2    32000 -1.0000000E+00
c
c   ---- no.  3 material: magnesium
m3    12000 -1.0000000E+00
c
c   ---- no.  4 material: berylium
m4     4000 -1.0000000E+00
c
c   ---- no.  5 material: air
m5     1000 -1.0000000E-05   6000 -1.2154000E-04
       7000 -7.5470000E-01   8000 -2.3233000E-01
      18000 -1.2834000E-02
c
c   ---- no.  6 material: PMMA
m6     1000 -8.0541920E-02   6000 -5.9984027E-01
       8000 -3.1961782E-01
mode   p,e
```

(5) [Button in toolbar] Display cross section:

Users can view a graphic representation of geometric models they have created. A cross-section view will appear in a new window after clicking the [Display cross section] button. This is done by the MCNP geometry plotter (with the -ip option) and while X-Windows is being used, the plot window supports a variety of interactive features (refer to the MCNP Manual [XM05]). When version 5 of MCNP and Cygwin [CY08] are being used, X-Window needs to be launched before the [Display cross section] button is clicked. To activate the window, in brief, (1) run Cygwin by double clicking its icon, (2) type the "startx" command in the Cygwin console window, and (3) click the tab blinking at the bottom of the PC screen. When version 4 of MCNP is being used, there is no need to start the X-Window system.

This rule also holds true for the [Data]-[Cover] Menu, [Data]-[Tray] Menu, [Data]-[Support jig] Menu, [Data]-[Measured sample] Menu and [Data]-[Calculation area] Menu, all of which will be described hereinafter.
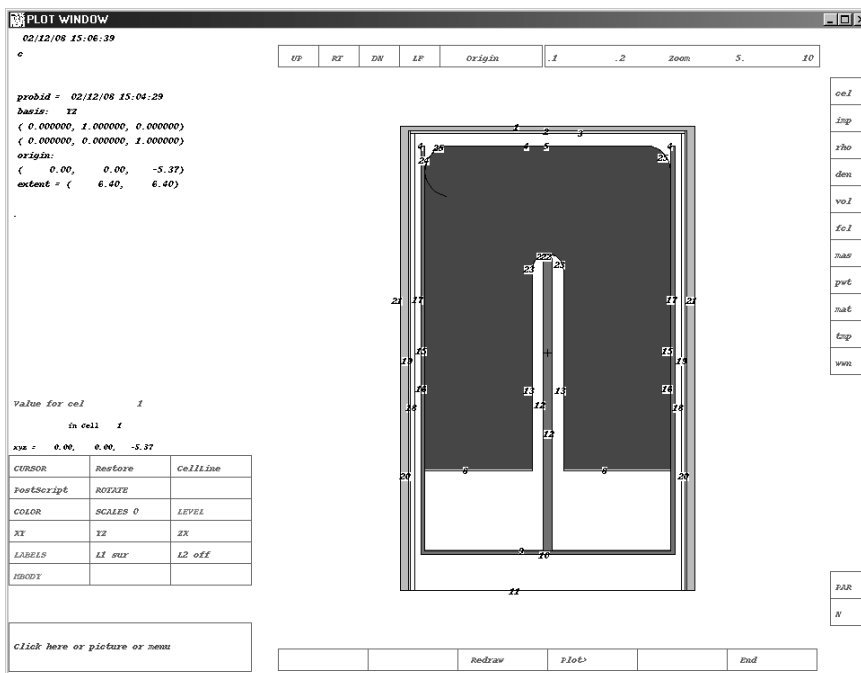
2.5.2.3 [Data]-[Cover] Menu

"Cover" refers to one of the parts around a detector. It might be used to protect a detector from radioactive contamination or physical damage. Parameters to specify the geometric configuration and material of the cover can be assigned in the following window.
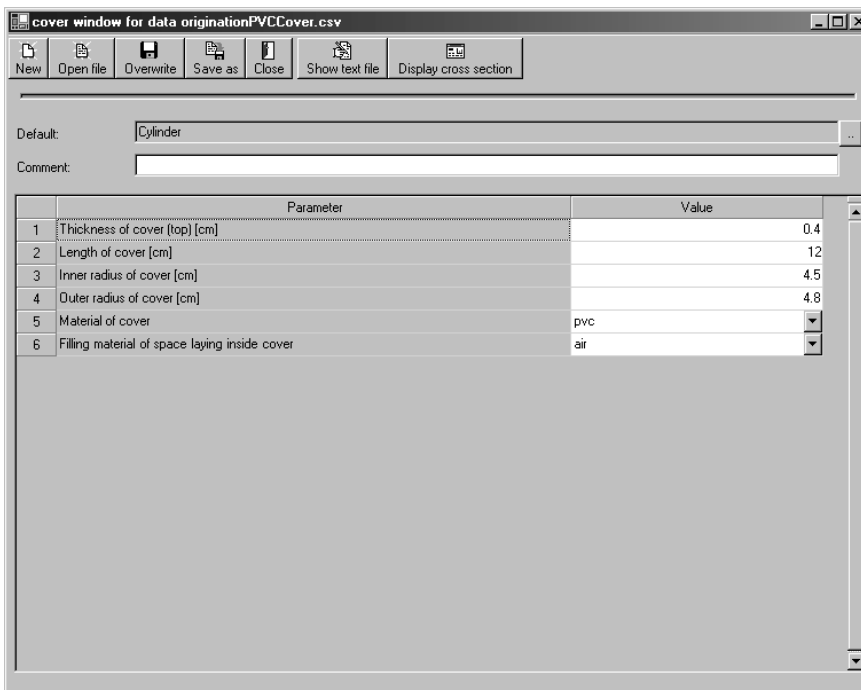
(1) Default:

A default cover can be selected by clicking the [...] button on the right side of the blank line and users can then browse and select the necessary file. The parameter values of the default cover are then modified to specify the intended cover. And while the default style itself cannot be modified in the GUI window, it can be modified or newly added using a text file of which the format is given in Appendix A.8.

Originally, the CREPT-MCNP code has a cylindrical closed-end cover as a default cover. The geometry of the cover is shown schematically in Fig. 2-4, along with its parameters and default parameter values in Table 2-4.
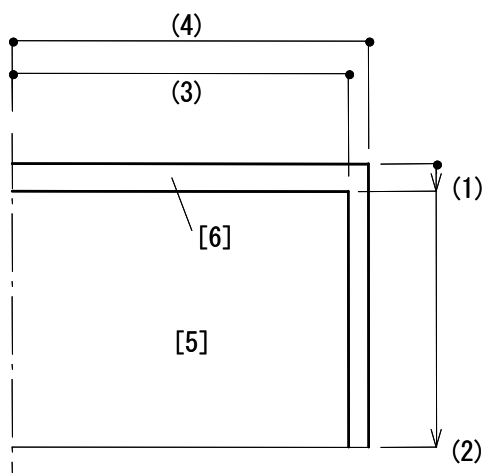

Fig. 2-4 Half sectional view of a default cover

Table 2-4 Parameters, data type and parameter values of the default cover

(File name: cover.csv)

	Parameter	Data type	Default
(1)	Thickness of cover (top) [cm]	Floating-point	0.2
(2)	Length of cover [cm]	Floating-point	12
(3)	Inner radius of cover [cm]	Floating-point	3.7
(4)	Outer radius of cover [cm]	Floating-point	3.8
[5]	Material of cover	Character	-
[6]	Filling material of space laying inside cover	Character	-

2.5.2.4 [Data]-[Tray] Menu

　　"Tray" is another part around a detector and may be used as a stage to set a sample to be measured above the detector. Parameters to specify the geometric configuration and material of the tray can be assigned in the following window.
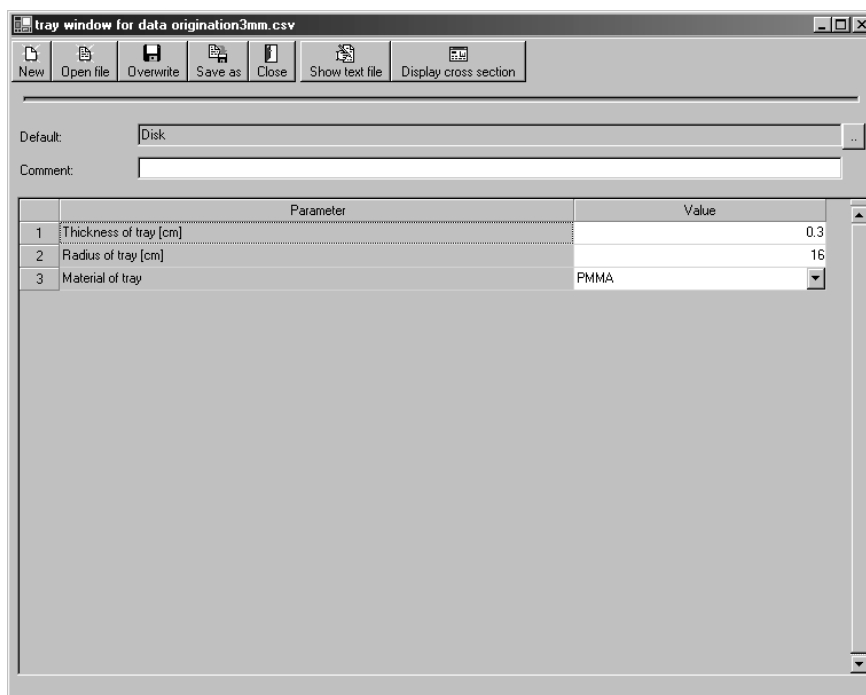
(1) Default:

　　A default style of a tray is selected by clicking the [...] button on the right side of the blank line. Users can browse and select the intended file. Parameter values of the default tray are then modified to specify the intended tray. The default style itself cannot be modified on the GUI window, but it can be modified or newly added in a text file. The description format of the file is in Appendix A.8.

　　Originally, the CREPT-MCNP code has a plate-shaped tray as a default style tray. Geometry of the tray is shown schematically in Fig. 2-5, along with its parameters and default parameter values in Table 2-5.
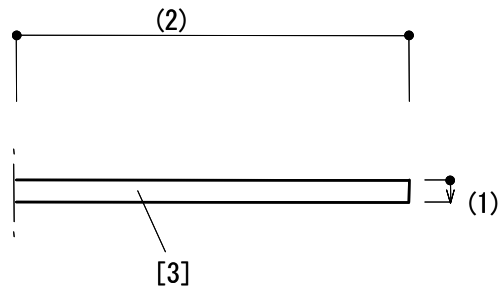
Fig. 2-5 Half sectional view of a default tray

Table 2-5 Parameters, data type and parameter values of the default tray

(File name: disk.csv)

	Parameter	Data type	Default
(1)	Thickness of tray [cm]	Floating-point	0.2
(2)	Radius of tray [cm]	Floating-point	16
[3]	Material of tray	Character	-

2.5.2.5 [Data]-[Support jig] Menu

"Support jig" is another part around a detector. It might be used as an attachment to join the end cap of a detector and a cover. Parameters to specify the geometric configuration and material of the support jig can be assigned in the following window.
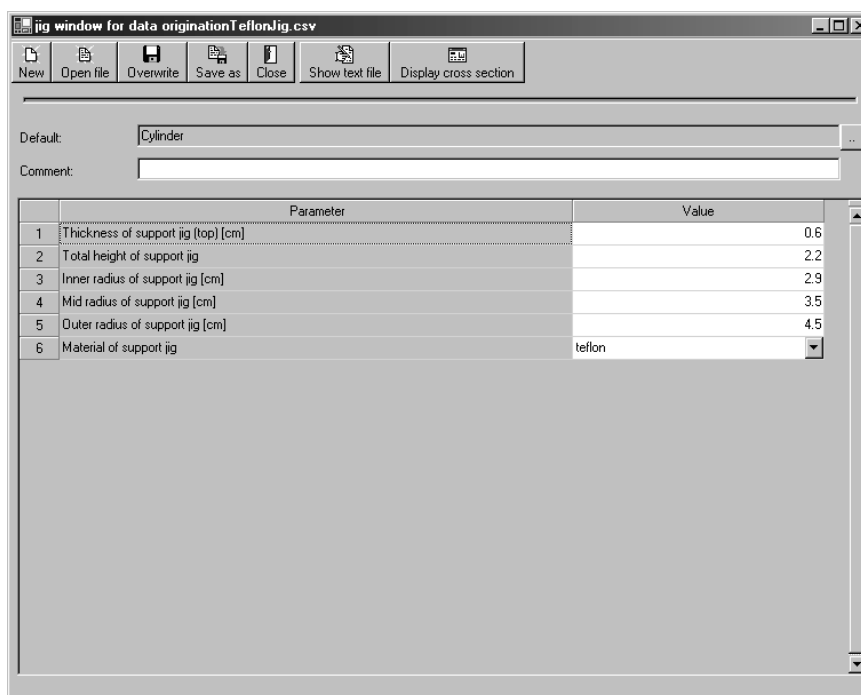
(1) Default:

A default style of a support jig is selected by clicking the [...] button on the right side of the blank line. Users can browse and select the necessary file. The parameter values of the default support jig are then modified to specify the intended support jig. The default style itself cannot be modified in the GUI window, but it can be modified or newly added in a text file. The description format of the text file is given in Appendix A.8.

Originally, the CREPT-MCNP code has an annular support jig as a default style. The geometry of the support jig is shown schematically in Fig. 2-6, along with its parameters and default parameter values in Table 2-6.
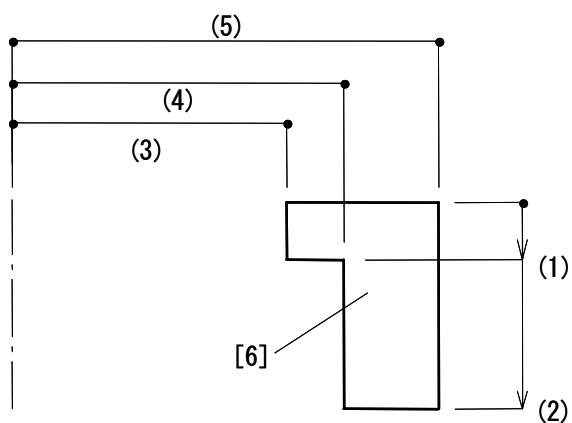
Fig. 2-6 Half sectional view of a default support jig

Table 2-6 Parameters, data type and parameter values of the default support jig

(File name: annular.csv)

	Parameter	Data type	Default
(1)	Thickness of support jig (top) [cm]	Floating-point	0.5
(2)	Total height of support jig [cm]	Floating-point	2
(3)	Inner radius of support jig [cm]	Floating-point	3
(4)	Mid radius of support jig [cm]	Floating-point	3.6
[5]	Outer radius of support jig [cm]	Floating-point	3.7
[6]	Material of support jig	Character	-

2.5.2.6 [Data]-[Measured sample] Menu

A measured sample consists of sample material (sample matrix) and a sample container. It is modelled in order to calculate the self-absorption correction factors. Usually, users create two types of measured sample in obtaining an efficiency curve. One is with sample material and with sample container, and the other is without either of them. With this version of the code the shape of sample is limited to rotationally symmetrical ones.
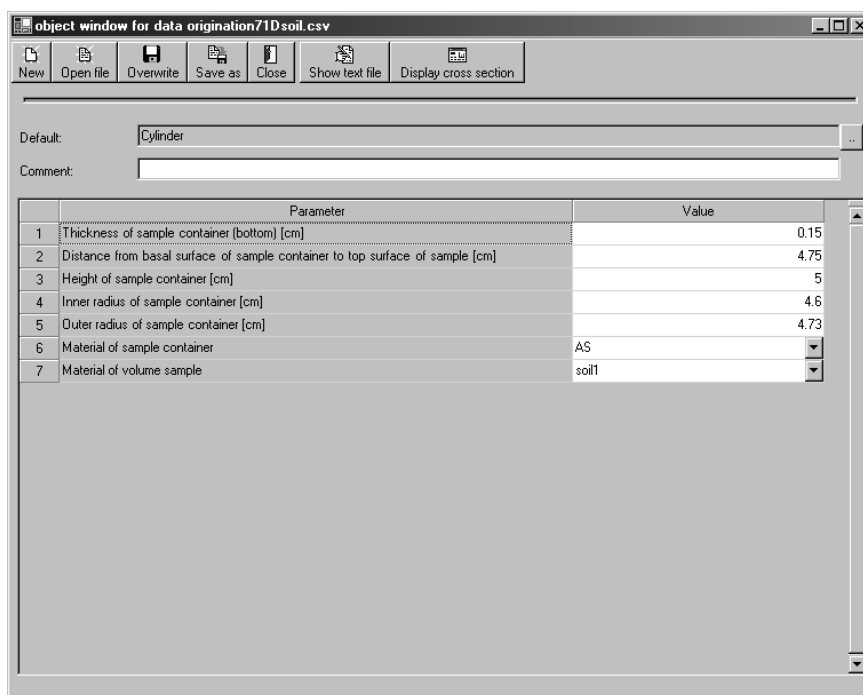
(1) Default:

First, a default style of a sample should be selected. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file. Parameter values of the default sample are then modified to specify the intended sample. The default style itself cannot be modified in the GUI window, but it can be modified or newly added in a text file. The description format of the text file is given in Appendix A.8.

Originally, the CREPT-MCNP code has a cylindrical sample and the Marinelli-shaped [IE78] sample as default style samples. The geometries of these samples are shown schematically in Figs. 2-7 (for the cylindrical sample) and 2-8 (for the Marinelli-shaped sample), along with their parameters and default parameter values in Tables 2-7 (for the cylindrical sample) and 2-8 (for the Marinelli-shaped sample).

Fig. 2-7 Half sectional view of a default style cylindrical sample

Table 2-7 Parameters, data types and parameter values of the default cylindrical sample
(File name: cylinder.csv)

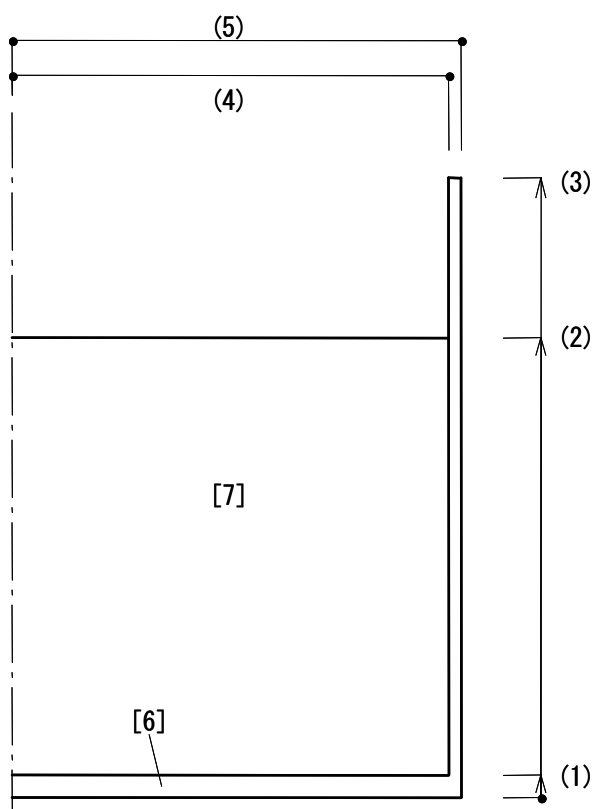|		Parameter	Data type	Default
(1)		Thickness of sample container (bottom) [cm]	Floating-point	0.2
(2)		Distance from basal surface of sample container to top surface of sample [cm]	Floating-point	5
(3)		Height of sample container [cm]	Floating-point	16
(4)		Inner radius of sample container [cm]	Floating-point	4
(5)		Outer radius of sample container [cm]	Floating-point	4.2
[6]		Material of sample container	Character	-
[7]		Material of volume sample	Character	-
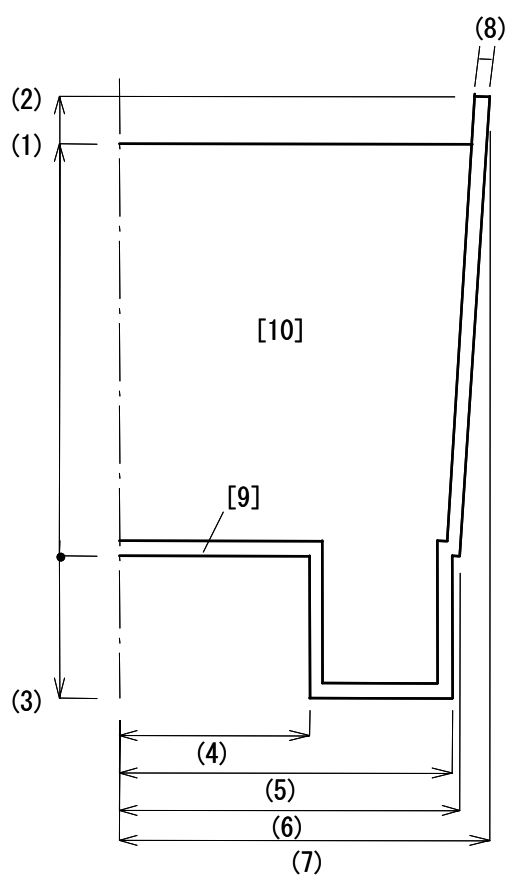
Fig. 2-8 Half sectional view of a default Marinelli-shaped sample

Table 2-8 Parameters, data types and parameter values of the default Marinelli-shaped sample
(File name: Marinelli.csv)

		Parameter	Data type	Default
(1)		Height of volume sample [cm]	Floating-point	8.9
(2)		Height of sample container [cm]	Floating-point	8.9
(3)		Length of sub-part of Marinelli beaker (base to base) [cm]	Floating-point	7.6
(4)		Inner radius of sub-part of Marinelli beaker [cm]	Floating-point	4.15
(5)		Outer radius of sub-part of Marinelli beaker [cm]	Floating-point	6.85
(6)		Outer radius of basal surface of sample container [cm]	Floating-point	7.25
(7)		Outer radius of top surface of sample container [cm]	Floating-point	7.65
(8)		Thickness of sample container [cm]	Floating-point	0.2
[9]		Material of sample container	Character	-
[10]		Material of volume sample	Character	-

2.5.2.7 [Data]-[Calculation area] Menu

Users need to specify "calculation area", which denotes the region in which a detector and all of other parts, *i.e.*, the cover, tray, support jig and measured sample, are encompassed. In that region photons are transported with MCNP.

Parameters to specify the area and its filling material are assigned on the following window.
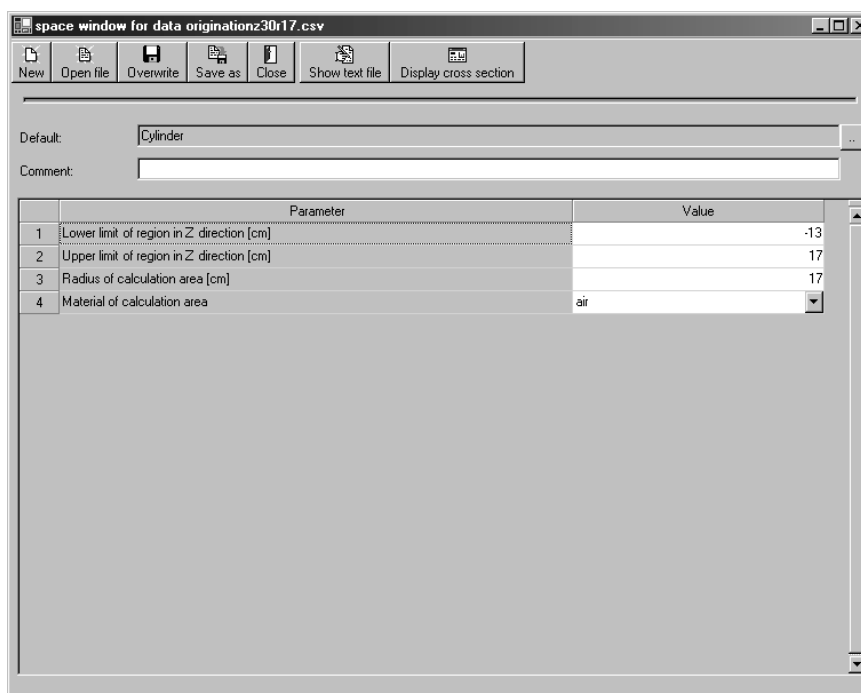
(1) Default:

A default calculation area is selected by clicking the [...] button on the right side of the blank line. Users can browse and select the intended file. The parameter values are then modified to specify the intended region. The default style itself cannot be modified in the GUI window, but it can be modified or newly added in a text file. The description format of the text file is given in Appendix A.8.

Originally, the CREPT-MCNP code has a cylindrical calculation area as a default style. Geometry of the region is shown schematically in Fig. 2-9, along with its parameters and default parameter values in Table 2-9.
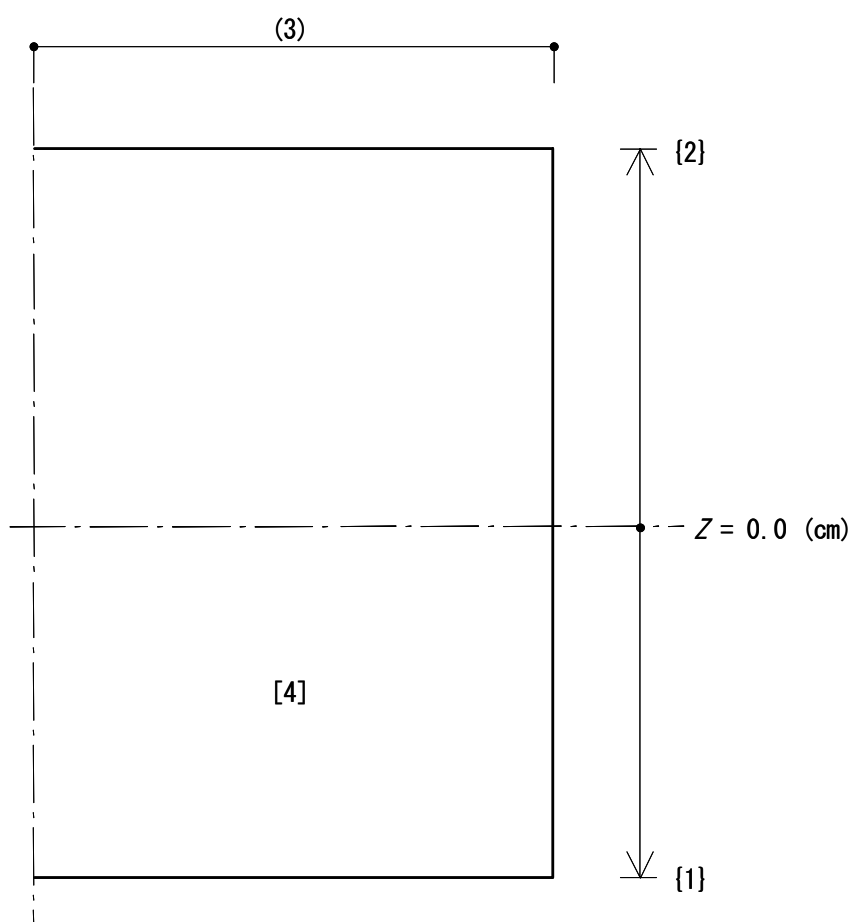
Fig. 2-9 Half sectional view of a default style calculation area

Table 2-9 Parameters, data types and parameter values of the default calculation area

(File name: cylinder.csv)

	Parameter	Data type	Default
{1}	Lower limit of region in Z direction [cm]	Floating-point	-13
{2}	Upper limit of region in Z direction [cm]	Floating-point	17
(3)	Radius of calculation area [cm]	Floating-point	17
[4]	Material of calculation area	Character	-

2.5.2.8 [Data]-[Geometry] Menu

In the [Data]-[Geometry] Menu, users can complete a geometric model used in the MCNP calculations. This is done by selecting the parts used, *i.e.*, a detector, cover and/or measured sample etc., and by providing positional relationships among the selected parts, in the following window.
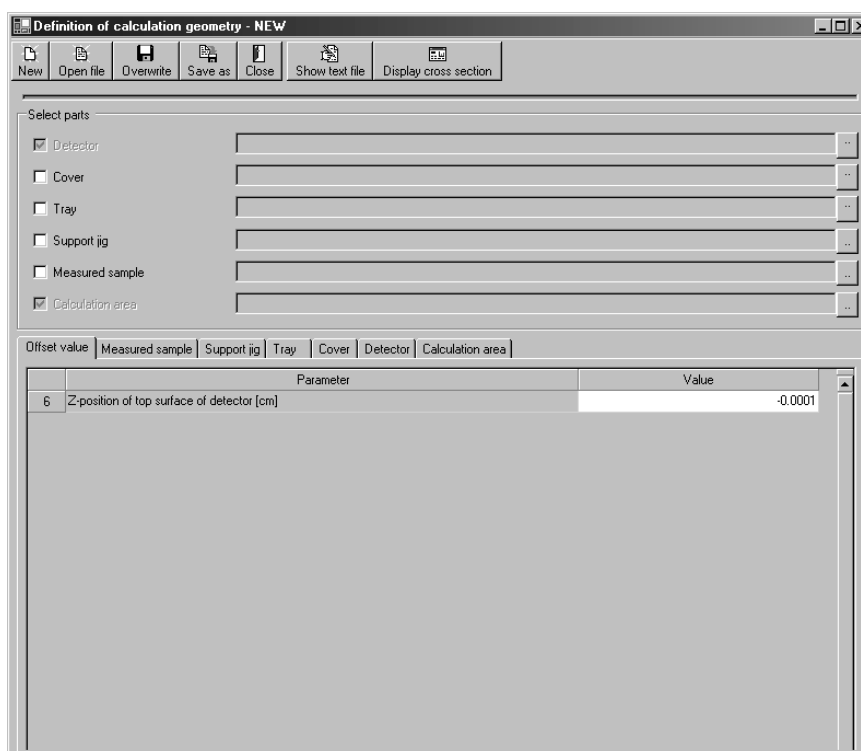
(1) Select parts:

Of the six different types of parts, users must select those necessary to create a geometric model by checking the checkboxes and assigning necessary file names by clicking the [...] buttons. Note that because a detector and a calculation area are both essential to the calculations, their file names must be assigned without exception.

Attention should be paid when users are creating the geometric models for the self-absorption correction factor calculations. In calculations of the self-absorption correction factor, users will need to create two types of geometric models; one is with sample material and with sample container, and the other is without either of them. In the case users use a tray for a measurement of a volume sample, the tray should be selected in a calculation with sample material and a sample container, and should be checked off for a calculation without either of them, unless the tray is included in the calculation geometry for obtaining "efficiency-curves group A". In the calculations of the efficiency-curves group A, normally, the tray should be considered to be part of a sample container, rather than as part of a detector, because it intervenes with the setting of the Marinelli-shaped sample.

Once a geometric model has been saved in a file, it can be re-opened and re-edited in the window. Note, however, that any change given on parts through the [Data]-[Cover] Menu, [Data]-[Tray] Menu, [Data]-[Support jig] Menu, [Data]-[Measured sample] Menu and [Data]-[Calculation area] Menu (These data are stored in the [\work\parts] folder.) is not reflected automatically just by opening a geometric model file. If any of these parts were changed, users must click the [...] buttons and reselect the file to reflect the changes in the geometric model.

(2) [Tab] Offset value:

The positional relationships among the selected parts are set with the "Offset value" tab. There are a total of eleven parameters, but only those related to the selected parts are listed in the data grid. The eleven parameters are as follows.

1) Z-position of top surface of cover (Default value: -0.0001)

2) Gap between cover and detector (Default value: 0)

3) Gap between cover and support jig (Default value: 0)

4) Gap between cover and measured sample (Default value: 0)

5) Gap between tray and cover (Default value: 0)

6) Z-position of top surface of detector (Default value: -0.0001)

7) Gap between detector and measured sample (Default value: 0)

8) Gap between tray and detector (Default value: 0)

9) Gap between support jig and detector (Default value: 0)

10) Gap between tray and measured sample (Default value: 0)

11) Z-position of top surface of tray (Default value: -0.0001)

Ensure that the Z-position of a selected part has been correctly set, so that the detector locates the same position between when the efficiency-curves group is to be calculated and when the self-absorption correction factors are to be calculated.

(3) [Tabs] Measured sample, Support jig, Tray, Cover, Detector, Calculation area

The parameters and their values are listed for reference. Users can change these parameter values temporarily using these tabs but the change or changes are not reflected in the original data which has been stored in the [\work\parts] folder.

2.5.2.9 [Data]-[Source energy point] Menu

In the [Data]-[Source energy point] Menu, a data group is set in terms of energy points for a virtual multi-energy photon source, and of the region of interest (ROI) for detections of photons at a detector.
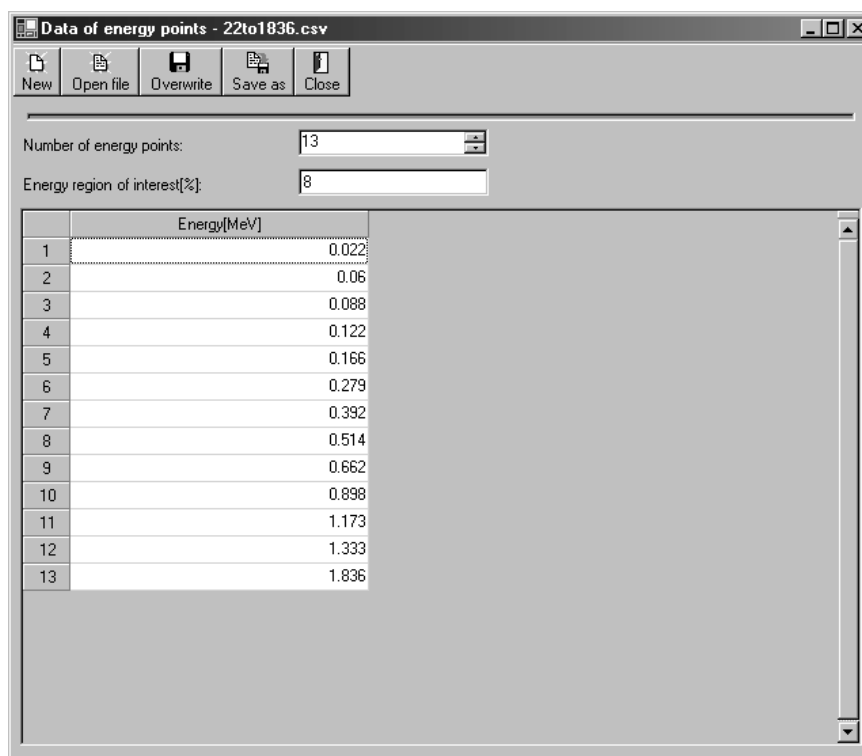
(1) Number of energy points:

Assign the number of energy points to be used in the MCNP calculations. The number of rows in the data grid will change in relation to that number.

(2) Energy region of interest (%):

The energy region of interest (ROI) is a region related to the pulse-height spectrum tally (the "F8 tally") in MCNP. Default value for the energy ROI is 8 %. For example, in the case the value is set at 8 %, a photon with initial energy 1 MeV will be tallied if it has deposited energy between 0.92 and 1.08 MeV on a detector. The value will be used with each individual energy point.

(3) Energy (MeV):

Photon energy points in MeV units must be assigned in ascending order. The energy points must be between 0.01 MeV and 10 MeV.

2.5.2.10 [Data]-[Volume sample] Menu

The conditions of a volume sample (source conditions) are set in order to estimate the self-absorption correction factors.
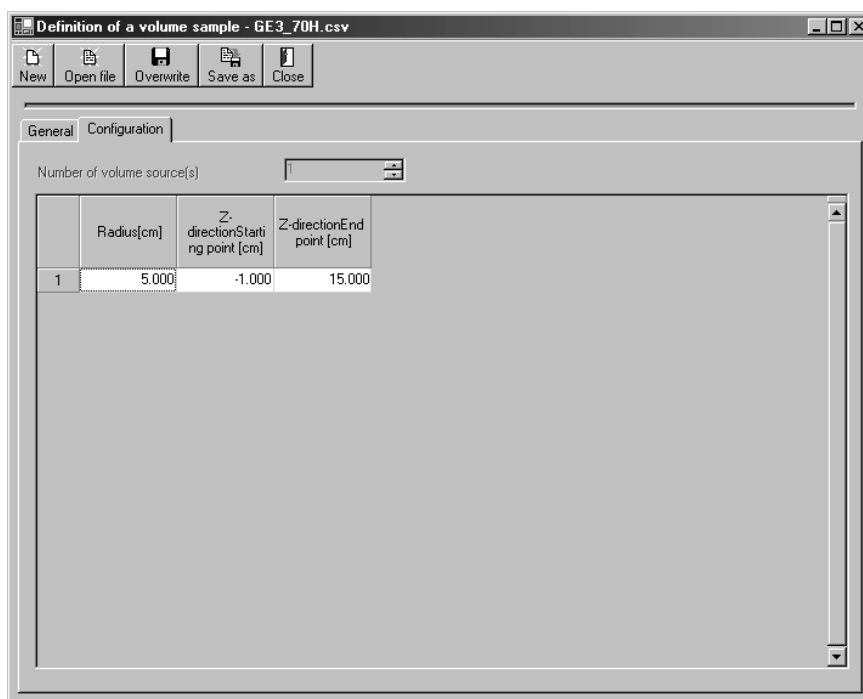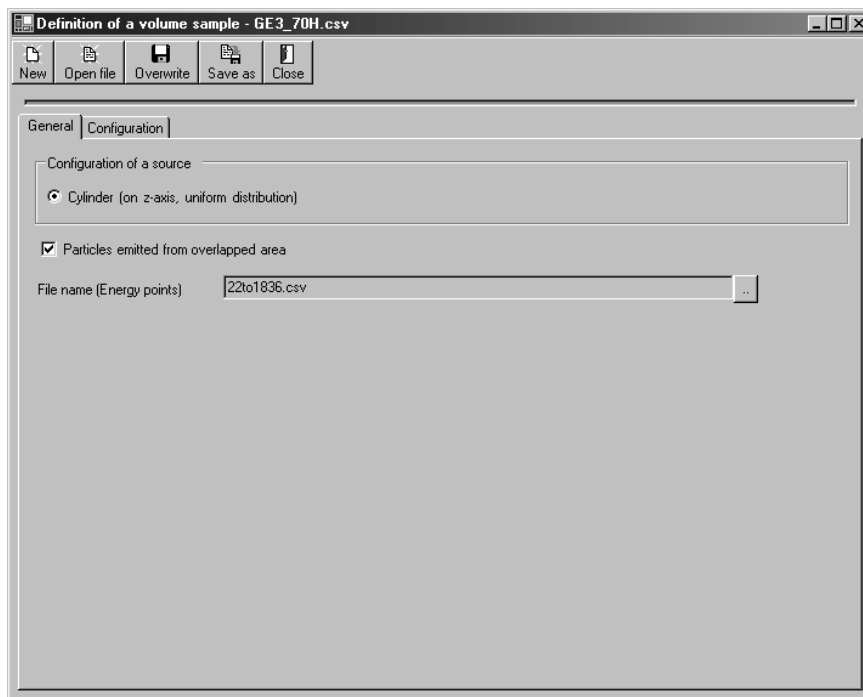
(1) [Tab] General; Configuration of a source:

In this version of the code, only a cylindrical volume sample with its axis coinciding with the detector axis, and of homogeneous material, can be treated. Users, therefore, should select "Cylinder (on z-axis, uniform distribution)".

(2) [Tab] Configuration; Number of volume source(s):

Users will not be able to change this number if "Cylinder (on z-axis), uniform distribution" was selected at the "Configuration of a source" item in the "General" tab.

(3) [Tab] Configuration; [Data grid]:

Users should provide a radius and positions (in *Z*-direction) of a cylindrical volume sample from which photons will be emitted (refer also to (4)).

(4) [Tab] General; [Checkbox] Particles emitted from overlapped area:

Should be checked when users intend to make photons be emitted from an overlapping region by a cylindrical region set with the "Configuration" tab and by a measured sample which is set with the [Data]-[Measured sample] Menu.

Examples of this concept are schematically shown in Fig. 2-10. In the case the cylindrical region is larger than the measured sample, as in pattern A of the figure, the source region will be identical to the measured sample. If the cylindrical region does not encompass the measured sample, as in pattern B, then the source region is the region that overlaps the two regions. In most cases, users will set the source region as in pattern A, and note that they have provided the parameters for the cylindrical region that are the same or somewhat larger, but not that larger, than the measured sample. Such settings will help improve the computational efficiency of sampling a source position with the Monte Carlo calculation.

(5) [Tab] General; File name (energy points):

A file defining a data group of source energy points should be selected by clicking the [...] button on the right side of the blank line. The file can be created with the [Data]-[Source energy point] Menu and users can browse and select the created file.

(6) [Tab] Configuration; Number of volume source(s):

In this version of the code, users cannot change this setting if "Cylinder (on z-axis), uniform distribution" was selected in the "Configuration of a source" item of the "General" tab.
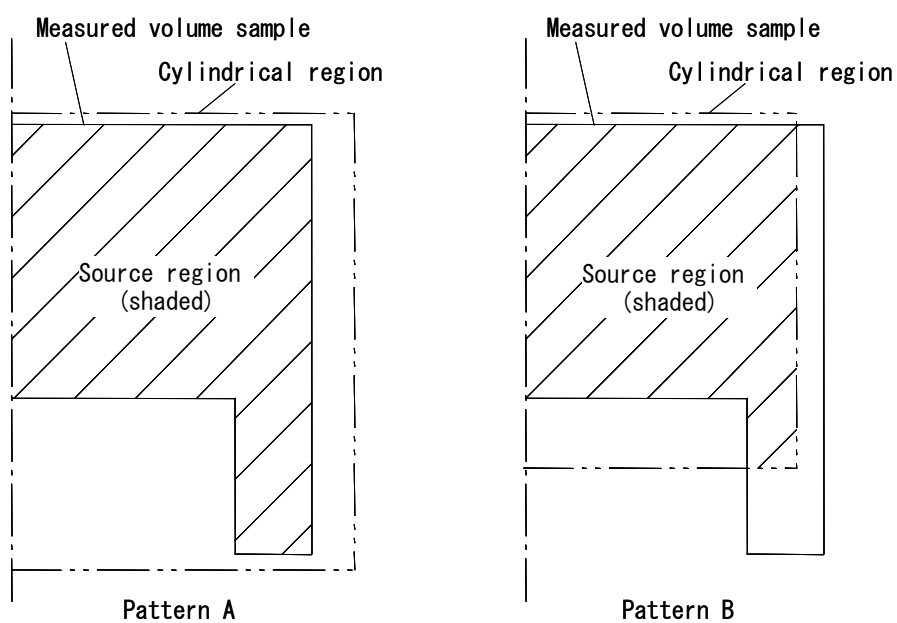
Fig. 2-10 Half sectional view of the positional relationship of the cylindrical region and measured sample

2.5.2.11 [Data]-[Alignment of point source] Menu

In this menu, a group of grid points (lattice points) is set for obtaining "efficiency-curves group A". The lattice points distributes around a detector in a two-dimensional (R-Z) space which includes a detector axis.
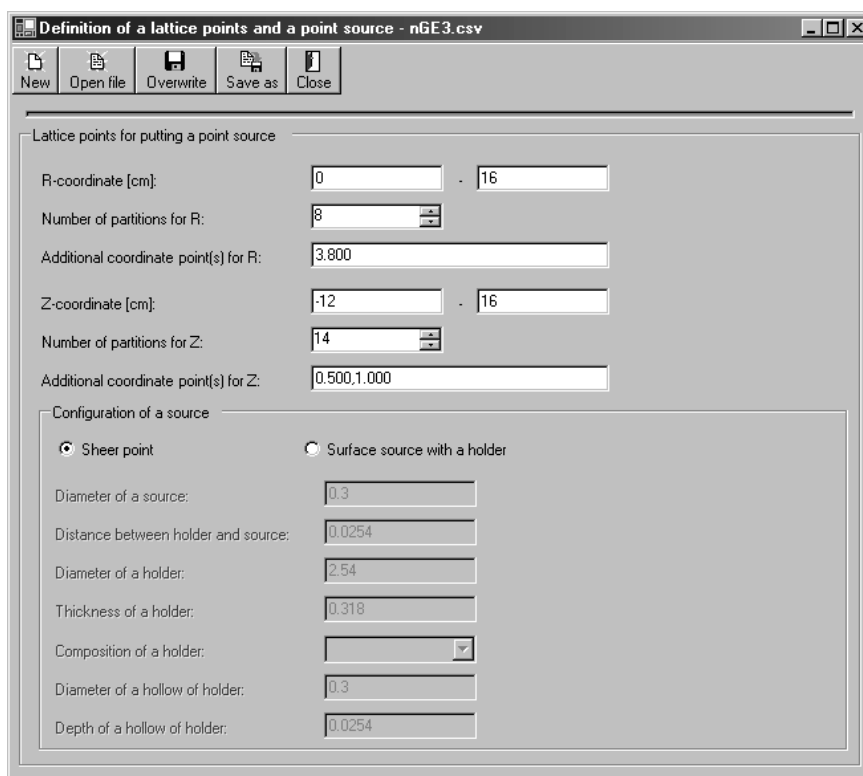
(1) *R*-coordinate, *Z*-coordinate [cm]:

Users should set *R* and *Z* ranges in which the virtual point source is placed. Note that the value in the left textbox is smaller than that in the right.

(2) Number of partitions for *R*, Number of partitions for *Z*:

Assign the number of partitions (division numbers) for each range set in either the *R*-coordinate or *Z*-coordinate columns. When the number of partitions is assigned as *n*, the number of lattice points becomes *n* +1. (Example) In the case a range of "0.0 to 4.0" is divided by the number of partitions "2", then three lattice points are set at "0.0", "2.0" and "4.0".

(3) Additional coordinate point(s) for *R*, Additional coordinate point(s) for *Z*:

Users can set coordinate point(s) in addition to the lattice points set in (1) and (2). More than one extra point can be set by entering a comma in between two values. (Example) "3.4,4.5,5.6". The additional

coordinate point is designed to supplement the lattice points which have fixed intervals. This should specifically be used for the following purposes.

One purpose is to improve reliability in the interpolated peak efficiencies at points near the detector, which are obtained by the Spline-interpolation with the "efficiency-curves group A" data. For example, because the peak efficiency in the vicinity of a detector tends to change drastically in the range between 0 and 2 cm from the top surface of a detector (or a cover), it is effective to set additional coordinate points at 0.5 cm and 1.0 cm in the Z direction. Introducing this setting will reduce the difference between the interpolated and actual efficiencies.

The other purpose is to obtain point-source efficiency data ("efficiency-curves group B" data) at a region which intervenes the outermost part (an end cap of a detector or cover) and the innermost lattice points (the shaded region in Fig. 2-11). Setting the additional coordinate points just over the outermost part (line B in the figure) enables the Spline-interpolation in a region between the added points and the original lattice points.
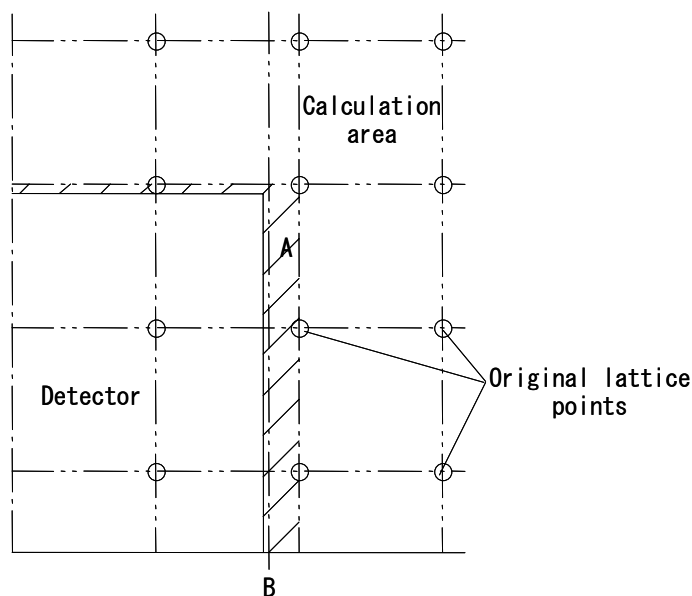
Fig. 2-11 Lattice points around a detector (half sectional view)

(4) Configuration of a source:

At the time of writing, only a point source without a source holder had been verified as an option. Users, therefore, should select "Sheer point" at this stage. In most cases this will bring about reasonable results.

2.5.3 [Calculation] Menu

2.5.3.1 [Calculation]-[Efficiency-curves group A] Menu

With this menu, a series of Monte Carlo calculations is carried out in order to obtain the "Efficiency-curves group A".
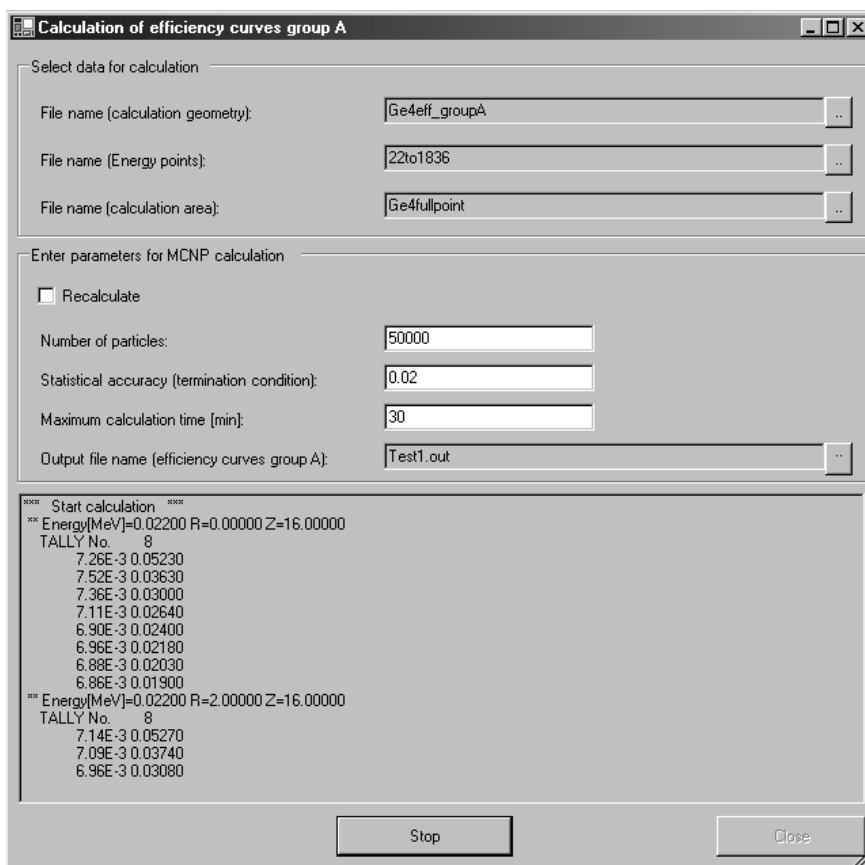
(1) File name (Calculation geometry):

A file defining a geometric model which includes a detector, a calculation area, and other optional parts (possibly a cover and/or support jig, but usually excludes a tray because it hampers the setting of a Marinelli-shaped sample) should be selected by clicking the [...] button on the right side of the blank line. The file can be created in the [Data]-[Geometry] Menu and users can browse and select the created file.

(2) File name (Energy points):

A file defining a data group of the source energy points should be selected by clicking the [...] button on the right side of the blank line. The file can be created in the [Data]-[Source energy point] Menu and users can browse and select the created file.

(3) File name (Calculation area):

A file defining the lattice point should be selected by clicking the [...] button on the right side of the blank line. The file can be created in the [Data]-[Alignment of point source] Menu and users can browse and select the created file.

(4) [Checkbox] Recalculate:

Users can recalculate a series of calculations by checking the checkbox. This option takes effect by assigning an uncompleted output file located in the [\work\effA] directory and allows users to resume any calculations which has been accidentally or purposely suspended.

(5) Number of particles:

The number of source particles per batch (refer to the following (6) and (7) for more details on the batch) is set in the textbox. The default value is 100000.

(6) Statistical accuracy (termination condition):

Assign the statistical accuracy to terminate a calculation. An MCNP calculation is carried out for obtaining a peak efficiency at each lattice point (or at the additional coordinate point) and for each energy point, but the calculation actually consists of several sub-calculations which are segmented into source particles batches. That is, the sub-calculations are automatically repeated until the statistical accuracy is equal or less than the assigned value. The default value is 0.01.

(7) Maximum calculation time (min):

Assign the maximum calculation time to terminate a calculation. This option is useful for calculations that users expect long calculation time to reduce the statistical accuracy, such as those with predominant interactions between photons and high-shielding material. A calculation consists of several sub-calculations which are segmented into source particle batches. Sub-calculations are automatically repeated until the calculation time reaches the assigned value. In other words, it automatically stops once the time has been reached, irrespective of the statistical accuracy value set in (6). The default time value is 0, and in this case a calculation stops based only on the statistical accuracy. Note that the maximum calculation time must be set for one MCNP calculation, through which an efficiency value for a point source with photon energy E, located at P(r,z), is obtained.

(8) Output file name (efficiency-curves group A):

An output file name must be assigned by clicking the [...] button on the right side of the blank line. Users can browse and select an existing file in the case the "Recalculate" checkbox is checked, otherwise a new file name must be given. The extension for this type of file is ".out".

(9) [Button] Run (or Stop):

By pressing the run button users can start or resume a series of calculations. Progress of calculations is displayed in the window. Users can suspend a series of calculations by pressing the stop button.

2.5.3.2 [Calculation]-[Efficiency curve for volume sample without self-absorption, representative point] Menu

The main purpose of this menu is to calculate the following data, based on the data of the efficiency-curves group A.

· Efficiency-curves group B (Spline-interpolated data of the efficiency-curves group A)
· Efficiency-curves group C (finely Spline-interpolated data of the efficiency-curves group A)
· Efficiency curve of an air-equivalent measured volume sample (volume weighted average of the efficiency-curves group C)
· Position of a representative point (selected from the data of efficiency-curves group B)
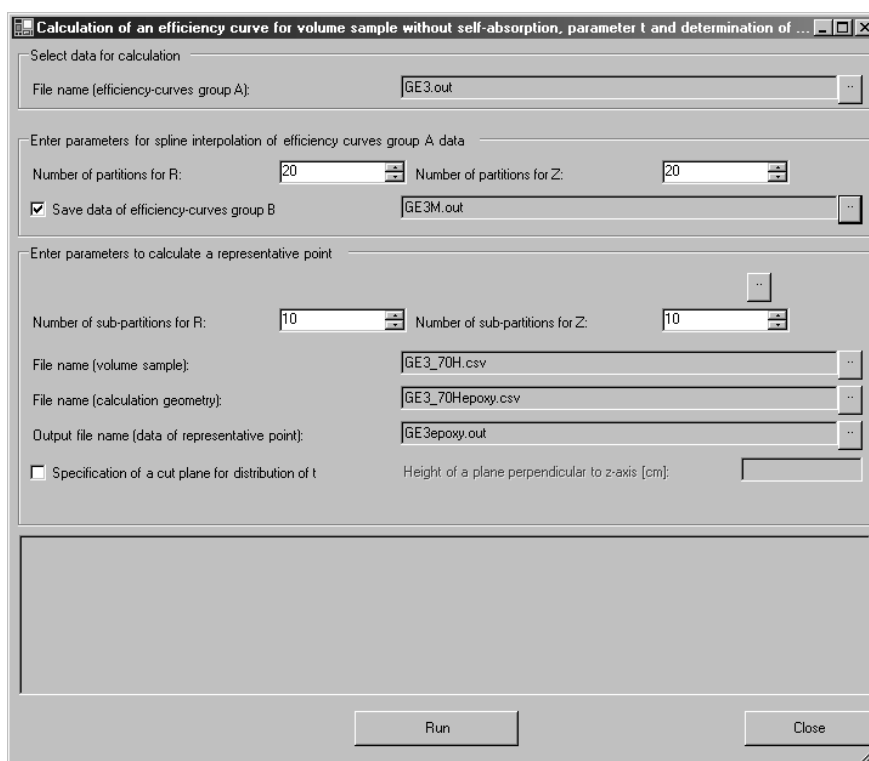
(1) File name (efficiency-curves group A):

A file containing the data of efficiency-curves group A should be selected. The file can be created in the [Calculation]-[Efficiency-curves group A] Menu. By clicking the [...] button on the right side of the blank line users can browse and select the intended file.

(2) Number of partitions for *R*:

A division number should be provided to calculate the data of the efficiency-curves group B from that of the efficiency-curves group A. For example, in the case the number of the partitions which is set in the [Data]-[Alignment of point source] Menu is 9 and this value is 20, the lattice points for the efficiency curves group becomes 161 (= (9-1)×20 +1). The default value is 20.

(3) Number of partitions for *Z*:

Same as above.

(4) [Checkbox] Save data of efficiency-curves group:

Users should check the checkbox if they want to keep the data of efficiency-curves group B in a file. In the case, an output file name must be assigned by clicking the [...] button on the right side of the blank line.

(5) [Hidden menu] File name (angular dependence of efficiency):

This option cannot currently be used. Select nothing.

(6) Number of sub-partitions for *R*:

An additional division number should be provided to calculate the data of the efficiency-curves group C from that of the efficiency-curves group A (not B). The number should be given to the lattice interval used in the efficiency-curves group B. For example, in the case the number of the partitions of the efficiency-curves group B is 161 and the value given is 10, the number of lattice points in the efficiency-curves group C will be 1601 (= (161-1)×10 +1). The default value is 10.

(7) Number of sub-partitions for *Z*:

Same as above.

(8) File name (volume sample):

A file containing the data of volume sample (volume source) should be selected. The file is created in the [Data]-[Volume sample] Menu. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

Users are strongly recommended to check over that the position (and size) of a volume sample and detector coincides with the geometries which are used in the calculation of the efficiency-curves group A.

(9) File name (calculation geometry):

A file containing a data of calculation geometry for the calculation of the self-absorption correction factor should be selected. The file is created in the [Data]-[Geometry] Menu. Users will possibly find two types of files to select. One is a file with sample material and the other is that without sample material (air-equivalent sample). Users can select either, because they will give the same result. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

Users are strongly recommended to check over that the position (and size) of a volume sample and detector in the selected file coincides with the geometries which are used in the calculation of the efficiency-curves group A, and with the volume sample mentioned in (9). In the case the "Particles emitted from overlapped area" checkbox (see [Data]-[Volume sample] Menu) was checked when the volume sample file was created, this option ((9) calculation geometry) is not activated.

(10) Output file name (data of representative point):

An output file name must be assigned by clicking the [...] button on the right side of the blank line. The extension for this type of file is ".out".

(11) [Checkbox] Specification of a cut plane for distribution of t:

This option is not currently available. Leave unchecked.

(12) [Button] Run:

A calculation starts by pressing the run button. It will typically take a few minutes to finish if both files ((8) volume sample and (9) calculation geometry) are involved, but less if only (8) volume sample file is used for discrimination of a source region from the efficiency-curves group C.

2.5.3.3 [Calculation]-[Efficiency curve for a volume sample with and without self-absorption] Menu

    With this menu, a series of Monte Carlo calculations is carried out in order to obtain the self-absorption correction factors. This includes calculations of the,

    · The efficiency curve of a volume source with sample material and sample container,
    · The efficiency curve of a volume source without sample material and without sample container (air-equivalent sample).

(1) File name (calculation geometry) (with material/container):

    A file containing the data of calculation geometry for the calculation of the self-absorption correction factor should be selected. The file is created in the [Data]-[Geometry] Menu. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

    Users are strongly recommended to check over that the position (and size) of a volume sample and detector in the selected file coincides with the geometries which are used in the calculation of the efficiency-curves group A, and with the volume sample mentioned in the following (3).

(2) File name (calculation geometry) (without material/container):

A file containing the data of calculation geometry for the calculation of the self-absorption correction factor should be selected. The file is created in the [Data]-[Geometry] Menu. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

Users are strongly recommended to check over that the position (and size) of a volume sample and detector in the selected file coincides with the geometries which are used in the calculation of the efficiency-curves group A, and in the volume sample mentioned in the following (3).

Confirm that in the case users use a tray for a measurement of a volume sample, the tray should be removed, or filled with air, for a calculation without sample material and without container, unless the tray is included in the calculation geometry for obtaining the efficiency-curves group A.

(3) File name (volume sample):

A file containing the data of volume sample (volume source) should be selected. The file is created in the [Data]-[Volume sample] Menu. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

Users are strongly recommended to check over that the position (and size) of a volume sample and detector coincides with the geometries which are used in the calculation of the efficiency-curves group A.

(4) [Data grid] Arbitrary uncertainty:

Each calculated efficiency value is accompanied by its statistical uncertainty, which is automatically estimated by the MCNP code. There is, however, the non-statistical uncertainty other than the statistical one. The non-statistical uncertainty originates from various factors related to the calculation, e.g., reliability in the geometric model, cross section data and so on. Users can assign non-statistical uncertainties as their best estimates in the data grid. The uncertainties should be set in their relative values. If users wish to put uniform values in the data grid irrespective of the source energy, it can be done by assigning the value in the "Set all" textbox.

(5) Number of particles:

The number of source particles per batch (refer to the following (6) and (7) with regard to the batch) is set in the textbox. The default value is 100000.

(6) Statistical accuracy (termination condition):

Assign the statistical accuracy at which to terminate a calculation. Each calculation consists of several sub-calculations which are segmented into source particle batches. That is, the sub-calculations are automatically repeated until the statistical accuracy is equal or less than the assigned value. The default value is 0.01.

(7) Maximum calculation time (min):

Assign the maximum calculation time to terminate a calculation. This option is useful for calculations which users expect a long calculation time to reduce the statistical accuracy, such as those with predominant interactions between photons and high-shielding material. A calculation consists of several sub-calculations which are segmented into source particles batches. The sub-calculations are automatically repeated until the calculation time reaches the assigned value. In other words, it automatically stops once the time has been reached, irrespective of the statistical accuracy value set in (6). The default value for the time is 0, and in this case a calculation stops based only on the statistical accuracy. Note that the maximum calculation time must be set for one MCNP calculation, through which an efficiency value for a point source with photon energy E, located at P(r,z), is obtained.

(8) Output file of an efficiency curve (with material/container):

An output file name must be assigned by clicking the [...] button on the right side of the blank line. The extension for this type of file is ".out".

(9) Output file of an efficiency curve (without material/container):

An output file name must be assigned by clicking the [...] button on the right side of the textbox. The extension for this type of file is ".out".

(10) [Button] Run:

A series of calculations starts by pressing the run button. Progress of calculations is displayed on the window. Users can stop the calculations by pressing the stop button but do note there is no "recalculate" option.

2.5.3.4 [Calculation]-[Final efficiency curve] Menu

In this menu, the efficiency curve of a volume sample (the final efficiency curve) is calculated by multiplying the measured efficiency curve at the representative point by the calculated self-absorption correction factor.
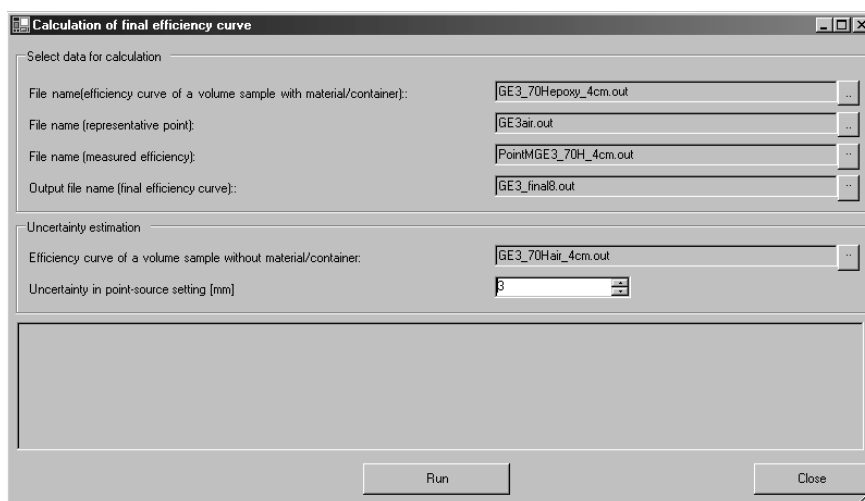
(1) File name (Efficiency curve of a volume sample with material/container):

A file containing the efficiency curve data of a volume sample (with both material and container) should be selected. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(2) File name (representative point):

A file containing calculated results of the representative point should be selected. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(3) File name (measured efficiency):

A file containing measured efficiency curve data with a point standard source should be selected. Users must prepare the file in the format shown in Appendix A.7. The file should be stored in the [\work\meas] folder and will appear through clicking the [...] button on the right side of the blank line.

If the energy points in this file differ from those used in (1) or (2), the energy point group used in this (measured) data are adopted to the output file (4). This is done based on the Spline-interpolation or extrapolation.

(4) Output file name (final efficiency curve):

An output file name must be assigned by clicking the [...] button on the right side of the blank line. The extension for this type of file is ".out".

(5) Efficiency curve of a volume sample without material/container:

A file containing the efficiency curve data of a volume sample (without material and without container) should be selected. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(6) Uncertainty in point-source setting [mm]:

This option is used to take in to account any uncertainty in the setting position of a standard point source at the representative point. The uncertainty, r, should be given in millimetres. The resultant uncertainty in the efficiency will be the maximum difference between the calculated efficiency at the original point and that at a point which has a distance r from the original point.

(7) [Button] Run:

Calculation starts by pressing the run button, and it will finish instantly.

2.5.4 [Calculation Results] Menu

2.5.4.1 [Calculation Results]-[Efficiency-curves group A] Menu

Users can plot the calculated efficiency curve in a graph on the screen. Both the horizontal axis (photon energy) and vertical axis (peak efficiency) are in logarithmic scales. Users cannot change ranges of these scales. However, if needed, users can export the data to a Microsoft Excel spreadsheet.

(1) File name (efficiency-curves group A):

A file containing the data of efficiency-curves group A should be selected. The file is created in the [Calculation]-[Efficiency-curves group A] Menu. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(2) File name (angular dependence of efficiency):

This option cannot be used at the moment. Leave the space blank.

(3) *R*-direction, *Z*-direction:

The lattice number in the *R* (or *Z*) direction should be selected. The corresponding coordinate value (cm) for the lattice number will then be displayed to the right of the lattice number.

(4) [Button] Call EXCEL:

By clicking this button, the efficiency data and graph can be exported to a Microsoft Excel[*1] spreadsheet as follows.
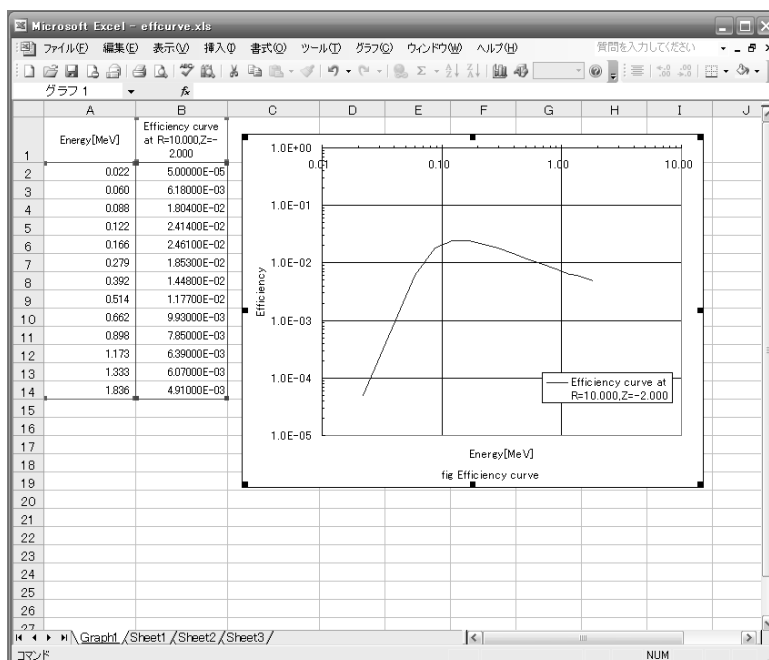
2.5.4.2 [Calculation Results]-[Efficiency curves group B] Menu

Users can plot the calculated efficiency curve in a graph on the screen. Both the horizontal axis (photon energy) and vertical axis (peak efficiency) are in logarithmic scales. Users cannot change ranges of these scales. However, if needed, users can export the data to a Microsoft Excel spreadsheet.

[*1] Microsoft Excel® version 2002 or later is necessary.
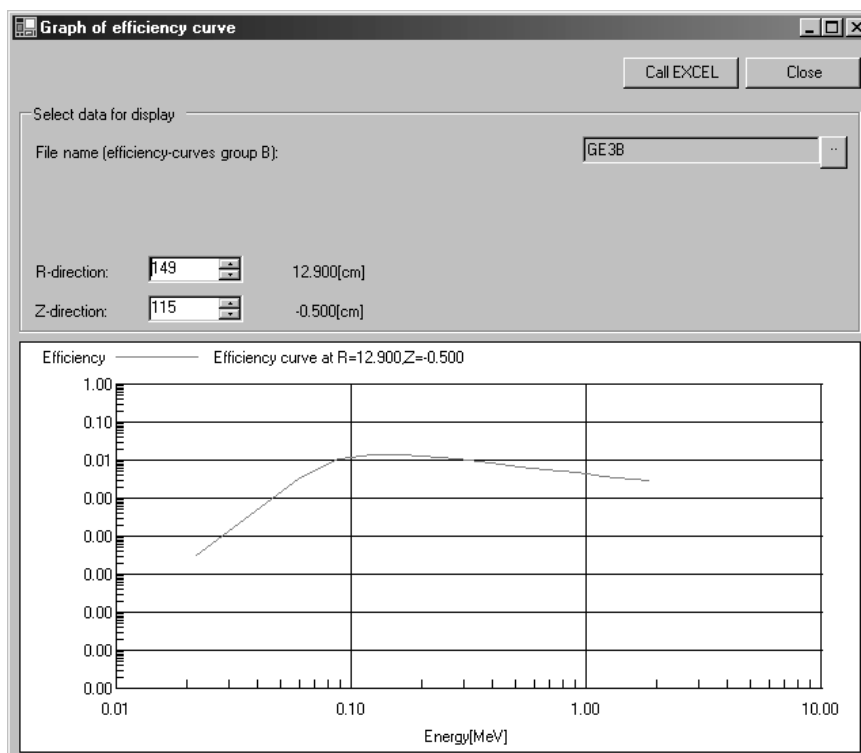
(1) File name (efficiency-curves group B):

A file containing the data of efficiency-curves group B should be selected. The file is created in the [Calculation]-[Calculation of efficiency curve for volume sample without self-absorption, representative point] Menu. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(2) File name (angular dependence of efficiency):

This option cannot be used at the moment. Leave the space blank.

(3) *R*-direction, *Z*-direction:

The lattice number in the *R* (or *Z*) direction should be selected. The corresponding coordinate value (cm) for the lattice number will then be displayed to the right of the lattice number.

(4) [Button] Call EXCEL:

By clicking this button, the efficiency data and graph can be exported to a Microsoft Excel® spreadsheet.

2.5.4.3 [Calculation Results]-[Comparison of efficiency curve at a representative point and that of volume
    sample] Menu

With this menu, users can compare two types of efficiency curves, one being a calculated efficiency
curve at the representative point (red curve in the figure) while the other is that of a volume sample without
any self-absorption effect (blue curve). Both curves are determined through the data of efficiency-curves
group C.

The two curves should have similarity in their shapes and magnitudes. Degree of agreement between
two curves means the minimum t (%). If these curves do not show similarity, the user should check over the
source conditions.

Both the horizontal axis (photon energy) and vertical axis (peak efficiency) are in logarithmic scales.
Users cannot change ranges of these scales. However, if needed, users can export the data to a Microsoft Excel
spreadsheet.
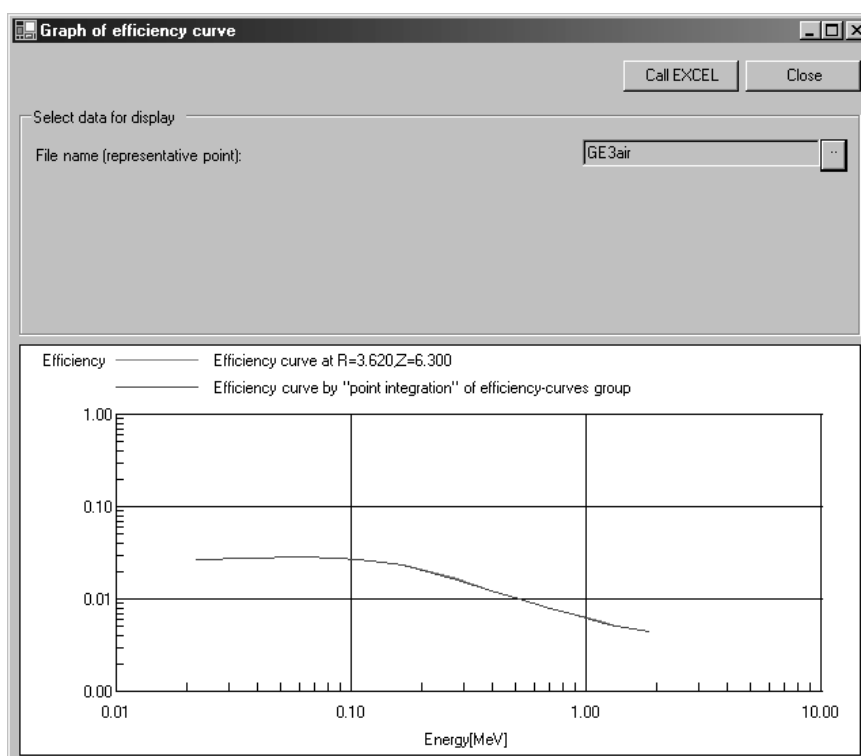
(1) File name (representative point):
    A file containing calculated results of the representative point should be selected. By clicking the [...]
button on the right side of the blank line, users can browse and select the intended file.

(2) [Button] Call EXCEL:
   By clicking this button, the efficiency data and graph can be exported to a Microsoft Excel® spreadsheet.

2.5.4.4 [Calculation Results]-[Contour map of parameter *t*] Menu

In this menu, a contour map of the parameter *t* which is calculated in the [Calculation]-[Efficiency curve for volume sample without self-absorption, representative point] Menu is displayed in an *R-Z* graph. In the graph, a region which is occupied by a detector (or a cover) is blacked out.

(1) File name (representative point):

A file containing calculated results of the representative point should be selected. By clicking the [...] button on the right side of the blank line, users can browse and select the intended file.

(2) Representative point and parameter *t*:

The values of a calculated representative point and parameter *t* at the point are displayed.

(3) [Button] File output:

Users can refer the *t* values by pressing this button. The output file includes a data group of (*R*, *Z*, *t*) in a tabular format.

2.5.4.5 [Calculation Results]-[Detailed contour map of parameter *t* around a representative point] Menu

In this menu, a detailed contour map of parameter *t* which is calculated in the [Calculation]-[Efficiency curve for volume sample without self-absorption, representative point] Menu is displayed in an *R-Z* graph. In the graph, a region which is occupied by a detector (or a cover), if present, is blacked out. Displayed range in the *R* and *Z* directions is limited to within ±2 cm from a representative point.
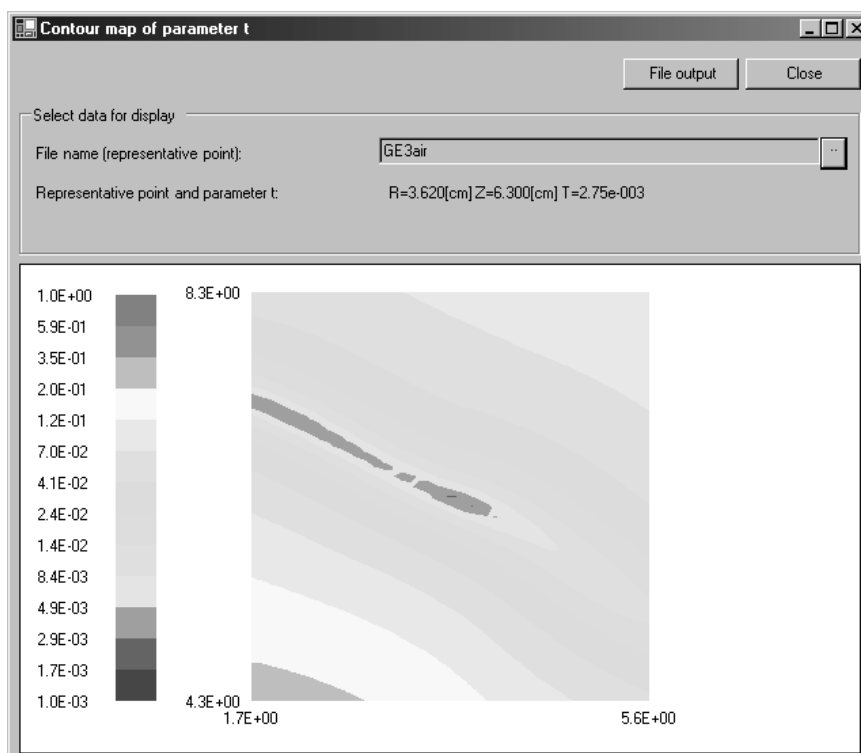
(1) File name (representative point):

A file containing calculated results of the representative point should be selected. By clicking the [...] button on the right of the blank line, users can browse and select the necessary file.

(2) Representative point and parameter *t*:

The values of a calculated representative point and parameter *t* at the point are displayed.

(3) [Button] File output:

Users can refer the *t* values by pressing this button. The output file includes a data group of (*R, Z, t*) in a tabular format. *R* and *Z* are limited to ±2 cm from a representative point.

2.5.4.6 [Calculation Results]-[Comparison of efficiency curves of a volume sample by means of "point integration" and by MCNP] Menu

In this menu, users can compare two efficiency curves. Both are efficiency curves of an air-equivalent volume sample, but processes used to estimate each curve differ. One curve (red curve in the figure) is obtained by means of the "point integration" with the data of efficiency-curves group C, and the other (blue curve) is calculated by simulating volume source (bulk sample) in MCNP. These two efficiency curves may well be identical, if the accuracy of the Spline-interpolation was sufficient. Otherwise, users should check over the geometric models used for the calculations. Both the horizontal axis (photon energy) and vertical axis (peak efficiency) are in logarithmic scales. Users cannot change ranges of these scales. However, if needed, users can export the data to a Microsoft Excel spreadsheet.

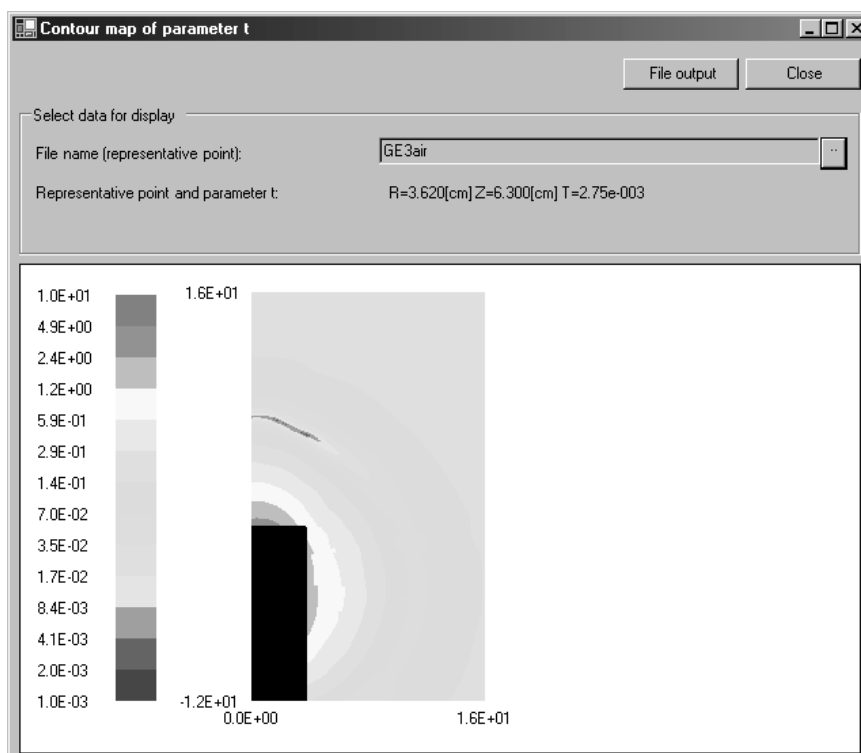(1) File name (representative point):
    A file containing the calculated results of the representative point should be selected. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(2) File name (efficiency curve for volume sample without material/container):
    A file containing the efficiency curve data of a volume sample (without material and without container) should be selected. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(3) [Button] Call EXCEL:

By clicking this button, the efficiency data and graph can be exported to a Microsoft Excel® spreadsheet.

2.5.4.7 [Calculation Results]-[Final efficiency curve] Menu

Users can plot on a graph the efficiency curve which was determined by the representative point method (final efficiency curve; shown in blue line). In the graph, a measured efficiency curve (red curve) at a representative point is also shown for comparison.

Both the horizontal axis (photon energy) and vertical axis (peak efficiency) are in logarithmic scales. Users cannot change the ranges of these scales. However, if needed, users can export the data to a Microsoft Excel spreadsheet.

(1) File name (final efficiency curve):

A file containing the final efficiency curve data should be selected. The file is created in the [Calculation]-[Final efficiency curve] Menu. By clicking the [...] button on the right side of the blank line, users can browse and select the necessary file.

(2) [Button] Call EXCEL:

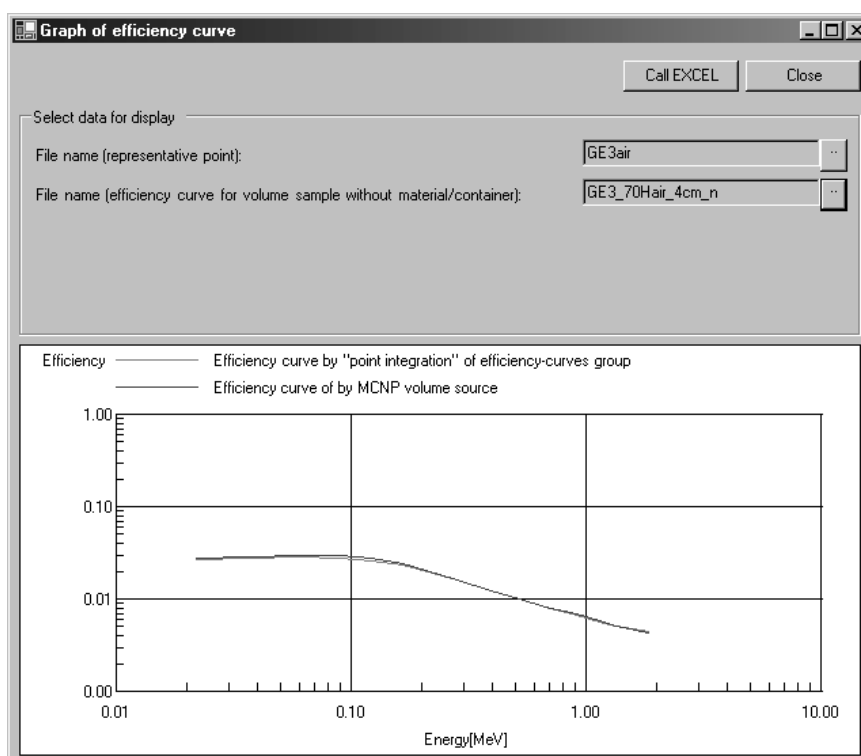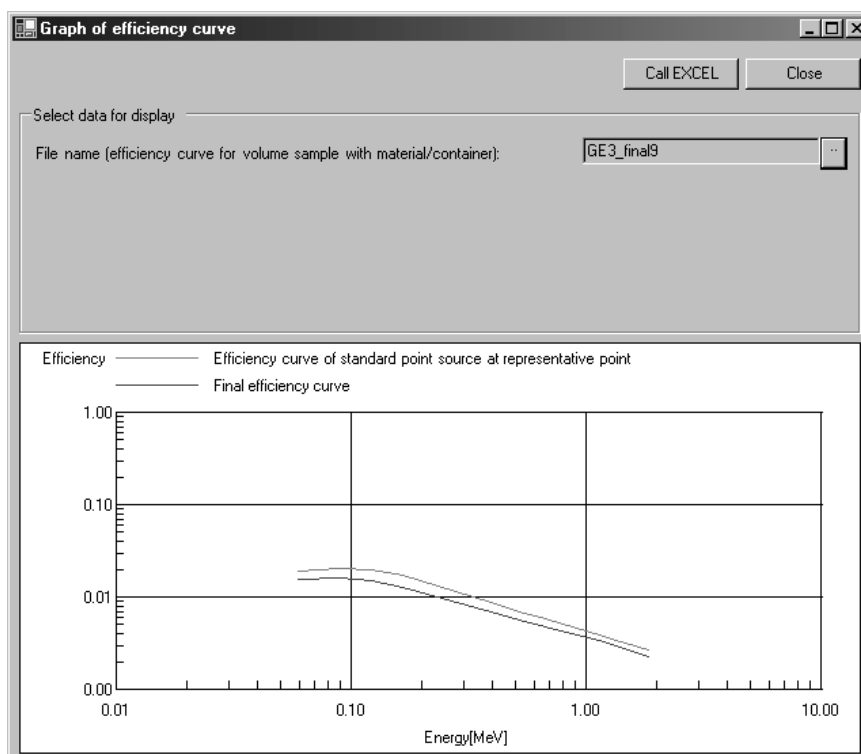By clicking this button, the efficiency data and graph can be exported to a Microsoft Excel® spreadsheet.

3 Efficiency Calibration of Radioactivity Measuring Instrument with the Representative Point Method

3.1 Present Status of Efficiency Calibration

In order to estimate the radioactivity in a volume sample nondestructively, the gamma-ray spectrometry method with a germanium semi-conductor detector is generally used. In the method, the peak efficiency curve must be evaluated in advance of the measurement. Procedures for obtaining the peak efficiency curve are called "efficiency calibration". There are many studies related to the efficiency calibration for radioactivity quantification for a volume sample. Most of them are classified into three types such as; comparative measurement with a standard volume source, analytical calculation, and the Monte Carlo calculation.

In the first method, the comparative measurement, the peak efficiency is estimated from the peak counting rate measured by a germanium detector on which a standard volume source is set. And for this the standard volume sources with known radioactivity are prepared. Reliable peak efficiency curves can be obtained by providing the standard volume source which has identical characteristics with the volume sample to be measured. However, in its implementation phase, there arise some problems.

1) It is not always easy to prepare a lot of standard volume sources each of which has the same shape, composition and density with that of a measured sample. In the Nuclear Science Research Institute (NSRI) of the Japan Atomic Energy Agency (JAEA), only limited types of standard sources, as shown in Photo 3-1, have been prepared. Manufacture of these sources requires skillful techniques [Sa95] [Ka04].

2) The efficiency calibration with a standard volume source that does not fit the measured sample causes undesirable results. Especially, the impact is not negligible for lower energy photons (below 100 keV) due to difference of the self-absorption effect between the standard source and a measured sample.

3) In general, the standard sources includes short-lived radionuclides such as ^{51}Cr (half life: 27.7 days) and ^{85}Sr (half life: 64.8 days). The working lifetime of the sources, therefore, is two years at the longest. The preparation of the sources must be repeated and this leads to the increase of radioactive waste when the sources are useless.

The second method, the analytical calculation, is sometimes referred as the "extended source method". It is usually based on a combination of some form of analytical calculations and measurements of a standard source. The standard source may be point-like, planate or with a finite volume. In the calculation, rigorous modeling of a detector or volume source accompanies complicated mathematical formulae in a classificatory scheme, which hampers smooth efficiency calibration.

The third method, the Monte Carlo, makes it possible to describe the geometric model freely by

employing a three-dimensional treatment. The method has had a weakness that it usually requires a great investment of time to finish the calculations. However, recent advances in computer technology made it easier to get high-performance computers less costly, and because of this the Monte Carlo method is becoming increasingly more practical.

Both the analytical calculation and the Monte Carlo methods require detailed geometrical information inside a detector, which is often difficult to be determined. In particular, the dead layer of the crystal, and the distribution of charge collection efficiency inside the detector cannot be known accurately. To supplement these data, preliminary experiments, or the sensitivity analysis, are usually performed for the determination of geometric parameters [Na83], but this procedure is very complex and our experiences suggest that there still may exist considerable difference (as large as some ten percent) between the calculated peak efficiency and the measured one, even if the parameterization of a detector has been carried out carefully.

In short, as each method has both merits and demerits, the representative point method has been developed in consideration of these situations.

Photo 3-1 Examples of the standard volume sources. These sources are used in efficiency calibrations at the NSRI of JAEA. The filling material is the foamed Portland cement.

3.2 Efficiency Calibration with the Representative Point Method

The representative point method is comprised of the following three steps; (1) calculations to find the position of the representative point, (2) single calibration at the representative point using a real standard point source, and (3) correction of the self-absorption effect to the efficiencies obtained in step (2).

Step (1): The peak-efficiency values η_R (E_i,r,z) at multiple points P(r,z) around a detector are calculated by means of the MCNP code; E_i denotes the photon energy, P(r,z) locates on the plane (r-z coordinate) that includes the central axis of a cylindrical detector. The distances between two adjacent points are typically 20 mm. The detection efficiencies are presumed to have symmetry about the detector central axis. The Spline interpolation algorithm [FU89] is introduced to provide the detailed spatial relation $\eta(E_i,r,z)$ among the efficiency values (typical interval: 1 mm). An efficiency-curves group containing tens of thousands of $\eta(E_i,r,z)$ values is obtained through the interpolation. The efficiency-curves group data is then averaged on the space which should be occupied by the volume sample to be measured, as;

$$V\left(E_i\right) = 2\int_0^h \int_0^R \frac{\eta\left(E_i,r,z\right)\cdot r}{hR^2} dr dz, \qquad (1)$$

where $V(E_i)$ corresponds to the efficiency of a cylindrical sample with height h and radius R. The resulting efficiency curve is compared with each curve included in the efficiency-curves group. To find out the representative point, the degree of agreement between the two curves is estimated by the following parameter $t(r,z)$.

$$t\left(r,z\right) = \sqrt{\frac{1}{n}\cdot\sum_{i=1}^{n}\left\{\frac{D\left(E_i\right)}{u\left(E_i\right)}\right\}^2 \Bigg/ \sum_{i=1}^{n}\frac{1}{u^2\left(E_i\right)}} \times 100\,(\%), \qquad (2)$$

$$D\left(E_i\right) = \frac{\eta\left(E_i,r,z\right) - V\left(E_i\right)}{V\left(E_i\right)}, \qquad (3)$$

where n is the total number of the energy points, and $u(E_i)$ is the uncertainty of $D(E_i)$.
The position, P(r,z), where t(r,z) gives the minimum value is defined as the representative point P$^*(r_{RP},z_{RP})$. Typical values of the smallest t(r,z) are found elsewhere [Sa00].

Step (2): The single point calibration at the representative point gives a comparable efficiency curve with that of the volume sample measured, although the measured efficiency curve at the representative point does not take into account the radiation absorption in the sample container and the self-absorption in sample material. For the setting of a standard point source at a representative point, the use of a special apparatus, as shown in Photo 3-2, may be helpful.
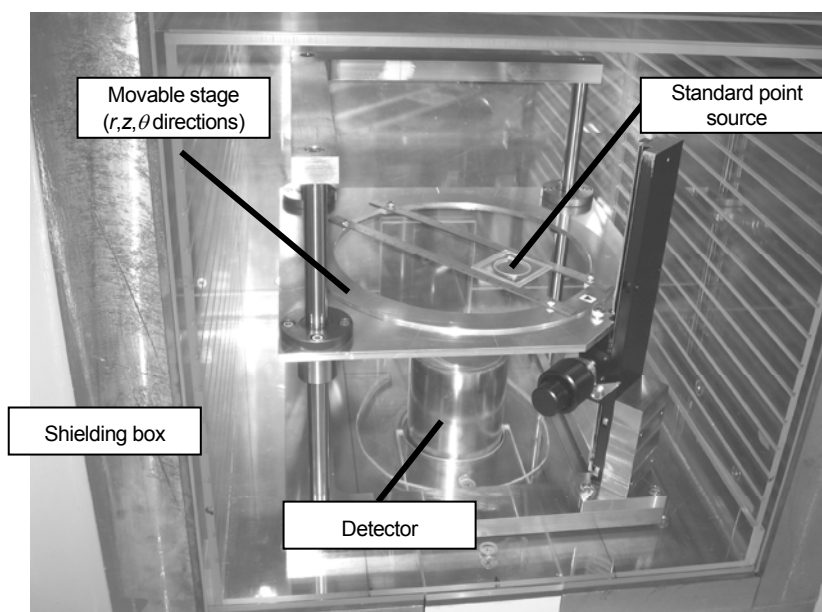
Photo 3-2 Example of an apparatus for setting a standard point source at the desired position.

Step (3): The absorption effects are corrected by multiplying the measured efficiency curve at the representative point $P^*(r_{RP}, z_{RP})$ by the correction factors $F(E_i)$ calculated with the MCNP code as;

$$F(E_i) = \frac{V_{matrix}(E_i)}{V_{air}(E_i)}, \qquad (4)$$

where $V_{matrix}(E_i)$ is the efficiency for a volume sample with sample material and sample container, and $V_{air}(E_i)$ is that with air. And consequently the intended peak-efficiency curves can be obtained.

3.3 Utilisation of CREPT-MCNP Code

3.3.1 Calculation time needed for efficiency calibration

For attaining a certain statistical level, calculation time of each MCNP run ranges from several tens of seconds to 30 minutes, depending on the photon energy, complexity of the calculation geometry, the source position and materials used. Accordingly, the total calculation time required for completing the efficiency-curves group is approximately one week, in a condition that the statistical uncertainty in each result is 2 % and that twelve energy points and 150 positional points, thus 1800 MCNP calculations, are assumed.

Although this may seem time-consuming, users do not have to repeat this process once the efficiency-curves group has been obtained with respect to each detector. That is, the typical time required for the efficiency calibration is within an hour; much of which is spent for the Monte Carlo calculations that evaluate

the self-absorption correction factors, and for the actual measurement at the representative point with a mixed-radionuclide standard source.

3.3.2 Uncertainty Estimation

The overall uncertainty in the efficiency evaluated by the method can be broken down into four components.

The first is the uncertainty in the measured results of a standard point source. The uncertainty originating from the sum-coincident effect is included in this component.

The second lays in the self-absorption correction factors. With the code, besides the statistical uncertainties in the Monte Carlo results, users can set values to cover the uncertainties to take account of discrepancies between the used chemical compositions and the true ones.

The third one is in the positioning accuracy when a standard point source is set at the representative point for the calibration. This factor has relatively small contribution compared with the other two. For example, the value of $t(r,z)$ for any point 2 mm from the representative point is typically 2-3 % or less, whereas that at the representative point is 0.5-2 %.

The last uncertainty is in the modeling of the detector, in particular the treatment of ambiguous information inside the detector. However, both the position of the representative point and the self-absorption correction factor are not significantly influenced by such indistinct and unclear information as the condition of the dead layer or the charge collection efficiency in the crystal, which is one of the advantages of the representative point method.

3.4 Application of the Method

By using the representative point method, non-destructive quantification of the radioactivity of various volume samples can be readily performed.

The efficiency calibration with the representative point method can be applied in the area of environmental monitoring around nuclear facilities, surveillance in emergency situations, and measurement of the induced radioactivity in activated samples.

The method has also been utilised as a radioactive gas monitor with a built-in germanium detector [Oi01]. The efficiency calibration for these monitors requires standard gas sources. Because it is generally rather difficult to prepare a variety of unsealed radioactive materials, only a limited number of energy points are available for the calibration. For such case, the representative point method can be applied for complementing the energy points and extending energy range.

4 Summary and Perspective for the Future

A GUI based application has been developed to provide the peak-efficiency curves of radioactive volume samples set around an HPGe detector. The code, CREPT-MCNP, facilitates implementation of the efficiency calibration based on the representative point method. For a variety of samples, the code allows users to determine the position of the representative point in a short amount of time once the efficiency-curves group, the data group characterizing a spatial distribution of the detection efficiencies around a detector, has been calculated and stored. The code can deal with a cylindrical or Marinelli-shaped sample in which radioactivity is homogeneously distributed.

The efficiency calibration with this code makes quantification of radioactivity smoother. It also contributes to reducing radioactive waste because the method does not need any standard volume sources. It can be utilized in measuring radioactivity promptly and nondestructively for a broad range of volume samples.

Acknowledgements

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Appendices - Format Description of Input and Output data

Note: In the following appendices, texts in red characters (font type: the Times New Roman) are merely comments for this manual.

A.1 Output File for the Efficiency-Curves Group A

This type of file is stored in the [\work\effa] folder. Any line beginning with a "*" means a comment line.

```
*# Model = ge
*# Energy = 12grp
*# Mesh = point
*# NPS = 10000
*# Precision = 0.05
*# MaxTime = 0
```

↑ Lines beginning with "*#" cannot be removed. They are used in the system.

```
* 1 Name    R[cm],  Z[cm],  Energy[MeV],Efficiency,Uncertainty
1 'detect' 4.00000 -12.00000 0.06000 0.03092 0.01770
1 'detect' 6.00000 -12.00000 0.06000 0.01783 0.02350
1 'detect' 8.00000 -12.00000 0.06000 0.01144 0.02940
1 'detect' 10.00000 -12.00000 0.06000 0.00875 0.03370
1 'detect' 12.00000 -12.00000 0.06000 0.00693 0.03790
1 'detect' 14.00000 -12.00000 0.06000 0.00547 0.04260
1 'detect' 16.00000 -12.00000 0.06000 0.00424 0.04850
1 'detect' 4.00000 -10.00000 0.06000 0.05087 0.01370
1 'detect' 6.00000 -10.00000 0.06000 0.02075 0.02170
1 'detect' 8.00000 -10.00000 0.06000 0.01249 0.02810
    ...
    ...
```

↑ The "1 'detect'" text is always printed. The uncertainty is expressed in its relative value.

Data corresponding to a region occupied by a detector (or a cover) is not listed in this file.

A.2 Output File for the Efficiency-Curves Group B

This type of file is stored in the [\work\effb] folder. Any line beginning with a "*" means a comment line.

```
*         IMAX          JMAX          NE
         161           281           3
```
↑ The number of coordinate points in the R direction, the Z direction, energy points
```
*     ENERGY
                 6.0000E-02      8.8000E-02        1.2200E-01
```
↑ Energy [MeV] (lists as many as the number of energy points (NE))
```
*     Z_DATA      R_DATA         DATA    ERROR_BAR
  -12.00000     0.00000   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  -12.00000     0.10000   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  -12.00000     0.20000   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  -12.00000     0.30000   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  -12.00000     0.40000   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
```
↑ Z coordinate [cm], R coordinate [cm], (peak efficiency, relative uncertainty)×NE
```
    *snip*
  -12.00000     4.00000   2.4200E-03   6.4200E-02   5.6800E-03   4.1800E-02
  -12.00000     4.10000   2.4401E-03   6.6899E-02   5.7532E-03   4.3158E-02
  -12.00000     4.20000   2.4445E-03   6.9451E-02   5.7928E-03   4.4375E-02
```

A.3 Output File for Position of the Representative Point and Parameter *t*

This type of file is stored in the [\work\effc] folder. Any line beginning with a "*" means a comment line. The format of this file may differ depending on whether users has assigned a file for the angular dependence characteristics of efficiencies in the [Calculation]-[Calculation of efficiency curve for volume sample without self-absorption, representative point] Menu.

(1) In the case a file related to the angular dependence was not assigned:

The distribution of parameter *t* on the *R-Z* plane is read out on the file.

```
  *# EffA = GE3.out
  *# RDiv = 20
  *# ZDiv = 20
  *# Angle =
  *# RDivS = 10
  *# ZDivS = 10
  *# Source = GE3_70H.csv
  *# Model = GE3_70Hair_4cm_airtray.csv
```
↑ Lines beginning with a "*#" cannot be removed. They are used in the system.
```
  *       IMAX    JMAX    NE   R-START    R-END    Z-START     Z-END  R-CHK-SPH
          181     321     13   0.00000   5.00000  -1.00000   15.00000   0.00000
```
↑ Number of positional points (*R*), Number of positional points (*Z*), Number of energy points,

Region occupied by a sample (Point of origin (*R*) [cm], Point of end (*R*) [cm], Point of

origin (*Z*) [cm], Point of end (*Z*) [cm]), Precision of a point source setting [cm]
```
  *     ir      iz    dr(ir)   dz(iz)   t(ir,iz)
        39      224   3.62000   6.30000  2.7539E-03
```
↑ Lattice number of a representative point (*R*), Lattice number of a representative point (*Z*), *R*

coordinate of a representative point [cm], *Z* coordinate of a representative point [cm], Parameter *t*

[0.01%]
```
  *      ENERGY     AVR_DATA    AVR_ERROR    POINT_DATA      P_ERROR    SPH_ERROR
    2.2000E-02   2.5914E-02   2.1556E-02   2.5879E-02   1.9031E-02   0.0000E+00
    6.0000E-02   2.7757E-02   2.0879E-02   2.7870E-02   1.8384E-02   0.0000E+00
    8.8000E-02   2.7180E-02   2.1097E-02   2.7313E-02   1.8442E-02   0.0000E+00
    1.2200E-01   2.5577E-02   2.1717E-02   2.5654E-02   1.9123E-02   0.0000E+00
    1.6600E-01   2.2543E-02   2.1355E-02   2.2710E-02   2.0151E-02   0.0000E+00
    2.7900E-01   1.5996E-02   2.2887E-02   1.6119E-02   2.4509E-02   0.0000E+00
    3.9200E-01   1.2097E-02   2.2341E-02   1.1914E-02   2.2411E-02   0.0000E+00
    5.1400E-01   9.7761E-03   2.2639E-02   9.6314E-03   2.2593E-02   0.0000E+00
    6.6200E-01   8.0396E-03   2.3461E-02   7.9396E-03   2.4337E-02   0.0000E+00
    8.9800E-01   6.5115E-03   2.4094E-02   6.5036E-03   2.4656E-02   0.0000E+00
    1.1730E+00   5.3705E-03   2.4398E-02   5.4267E-03   2.4018E-02   0.0000E+00
    1.3330E+00   4.9501E-03   2.3579E-02   4.9166E-03   2.2559E-02   0.0000E+00
    1.8360E+00   4.2566E-03   2.4589E-02   4.3054E-03   2.3493E-02   0.0000E+00
```
↑ Energy [MeV], Spline-interpolated efficiency of a volume sample, Relative uncertainty,

efficiency at a representative point, Relative uncertainty, Maximum difference of efficiencies

between that of at a representative point and at each position within R-CHK-SPH (absolute

value)
```
  *t map data
      Z : R =       0.00000     0.10000     0.20000
```

```
-12.00000  1.0000E+28  1.0000E+28  1.0000E+28
-11.90000  1.0000E+28  1.0000E+28  1.0000E+28
-11.80000  1.0000E+28  1.0000E+28  1.0000E+28
-11.70000  1.0000E+28  1.0000E+28  1.0000E+28        *snip*
-11.60000  1.0000E+28  1.0000E+28  1.0000E+28
-11.50000  1.0000E+28  1.0000E+28  1.0000E+28
-11.40000  1.0000E+28  1.0000E+28  1.0000E+28
-11.30000  1.0000E+28  1.0000E+28  1.0000E+28
     ↑ Map of parameter t

   *snip*
  Z : R =      1.00000     1.10000     1.20000
-12.00000  1.0000E+28  1.0000E+28  1.0000E+28
```

(2) In the case a file related to the angular dependence was assigned. (This option is not used in this version of the code)

In such case, distribution of parameter t on the R-Z plane and the R-A (angle) plane is read out on the file.

```
 =3D
  ↑ used as an identifier to specify that there is the angular dependence in the efficiencies
*  IMAX  JMAX  KMAX   NE  R-START   R-END   Z-START    Z-END   R-CHK-SPH
   161    281  120    12  0.00000   5.00000  0.20000   5.20000  0.000
```
↑ Number of positional points (R), Number of positional points (Z), Number of angular points, Number of energy points, Region occupied by a sample (Point of origin (R) [cm], Point of end (R) [cm], Point of origin (Z) [cm], Point of end (Z) [cm]), Precision of a point source setting [cm]

```
*  ir  iz   ia   dr(ir)  dz(iz)  ang(ia)  t(ir,iz,ia)
   32  142  10   3.10000  2.10000  20      1.7337E-03
```
↑ Lattice number of a representative point (R), Lattice number of a representative point (Z), Lattice number of a representative point (A), R coordinate of a representative point [cm], Z coordinate of a representative point [cm], Angle of a representative point [degree], Parameter t [0.01%]

```
*    ENERGY    AVR_DATA   AVR_ERROR   POINT_DATA    P_ERROR   SPH_ERROR
  6.0000E-02  1.1724E-03  8.2449E-02  1.2347E-03  7.5285E-02  0.000E+00
  8.8000E-02  6.2090E-03  4.7295E-02  6.0587E-03  4.1889E-02  0.000E+00
  1.2200E-01  1.5251E-02  3.0201E-02  1.4903E-02  2.6182E-02  0.000E+00
  1.6600E-01  2.7458E-02  2.2221E-02  2.7067E-02  1.9166E-02  0.000E+00
  2.7900E-01  4.8834E-02  1.6368E-02  4.8758E-02  1.4052E-02  0.000E+00
  3.9200E-01  6.0277E-02  1.4551E-02  6.0261E-02  1.2567E-02  0.000E+00
  5.1400E-01  6.6688E-02  1.3730E-02  6.6538E-02  1.1908E-02  0.000E+00
  6.6200E-01  7.1260E-02  1.3214E-02  7.1208E-02  1.1427E-02  0.000E+00
  8.9800E-01  7.5041E-02  1.2825E-02  7.5002E-02  1.1085E-02  0.000E+00
  1.1730E+00  7.8218E-02  1.2540E-02  7.8075E-02  1.0905E-02  0.000E+00
  1.3330E+00  7.9457E-02  1.2447E-02  7.9239E-02  1.0862E-02  0.000E+00
  1.8360E+00  8.1959E-02  1.2241E-02  8.1846E-02  1.0673E-02  0.000E+00
```
↑ Energy [MeV], Spline-interpolated efficiency of a volume sample, Relative uncertainty, efficiency at a representative point, Relative uncertainty, Maximum difference of efficiencies between that of at a representative point and at each position within R-CHK-SPH (absolute value)

```
*t map data
   Z : R =      0.00000    0.10000    0.20000
  -12.00000  1.0000E+28  1.0000E+28  1.0000E+28
  -11.90000  1.0000E+28  1.0000E+28  1.0000E+28
  -11.80000  1.0000E+28  1.0000E+28  1.0000E+28
```

↑ Map of parameter *t* on the *R-Z* plane

snip

```
*t map data
   R : A =      0.00000    0.10000    0.20000
  -12.00000  1.0000E+28  1.0000E+28  1.0000E+28
  -11.90000  1.0000E+28  1.0000E+28  1.0000E+28
  -11.80000  1.0000E+28  1.0000E+28  1.0000E+28
  -11.70000  1.0000E+28  1.0000E+28  1.0000E+28
```

↑ Map of parameter *t* on the *R-A* plane

snip

A.4 Output File for the Efficiency Curves Used for Self-Absorption Correction

This type of file is stored in the [\work\selfsheild] folder. Any line beginning with a "*" means a comment line.

```
*# Model = ge+box
*# Source = ge+box_exp
*# NPS = 10000
*# Precision = 0.05
*# MaxTime = 0
```
　　　↑ Lines beginning with a "*#" cannot be removed. They are used in the system.
```
* EnergyCount
12
```
↑ Number of energy points
```
* Energy[MeV],Efficiency,Uncertainty,Arbitrary uncertainty
0.06000 3.89e-003 0.04820 0.00000
0.08800 1.16e-002 0.04620 0.00000
0.12200 1.52e-002 0.04650 0.00000
0.16600 1.48e-002 0.04710 0.00000
0.27900 1.20e-002 0.04550 0.00000
0.39200 9.48e-003 0.04570 0.00000
0.51400 8.32e-003 0.04880 0.00000
0.66200 7.00e-003 0.04860 0.00000
0.89800 6.00e-003 0.04860 0.00000
1.17300 5.18e-003 0.04900 0.00000
1.33300 4.81e-003 0.04790 0.00000
1.83600 4.54e-003 0.04930 0.00000
```

A.5 Output File for the Final Efficiency Curve

This type of file is stored in the [\work\selfeff] folder. Any line beginning with a "*" means a comment line.

```
* Energy Count
12
```
↑ Number of energy points

```
* Energy   Measure     Det      bar1       bar2       bar3       bar4       bar5    bar_total(k=2)
6.000e-02 0.000e-01 4.6187e-02 1-00e-02 4.4085e-03 9.3620e-03 0.00e+000 4.3987e-04 4.3719e-02
8.800e-02 0.000e-01 6.1464e-02 0.00e-02 1.3324e-02 2.3561e-02 0.00e+000 6.6847e-04 5.6525e-02
1.220e-01 0.000e-01 7.1851e-02 0.00e-02 1.9638e-02 2.6414e-02 0.00e+000 7.3652e-04 6.8736e-02
1.660e-01 0.000e-01 7.2738e-02 0.00e-02 1.8735e-02 2.4929e-02 0.00e+000 7.1395e-04 7.0340e-02
2.790e-01 0.000e-01 7.3812e-02 0.00e-02 1.2967e-02 1.8405e-02 0.00e+000 6.1114e-04 6.8128e-02
3.920e-01 0.000e-01 8.2573e-02 0.00e-02 1.9400e-02 1.3360e-02 0.00e+000 5.2648e-04 7.8058e-02
5.140e-01 0.000e-01 8.4892e-02 0.00e-02 8.8484e-03 1.8190e-02 0.00e+000 4.7419e-04 7.8204e-02
6.620e-01 0.000e-01 8.5097e-02 0.00e-02 7.4614e-03 8.8143e-03 0.00e+000 4.3012e-04 8-3060e-02
8.980e-01 0.000e-01 8.5346e-02 0.00e-02 6.2797e-03 7.1783e-03 0.00e+000 3.9015e-04 8.2492e-02
1.173e+00 0.000e-01 8.1369e-02 0.00e-02 4.9718e-03 5.4960e-03 0.00e+000 3.5745e-04 7.8174e-02
1.333e+00 0.000e-01 8.2829e-02 0.00e-02 4.7216e-03 5.2586e-03 0.00e+000 3.4537e-04 8.0920e-02
1.836e+00 0.000e-01 8.4825e-02 0.00e-02 3.8937e-03 4.2047e-03 0.00e+000 3.1109e-04 8.1741e-02
```
↑ Energy [MeV], Measured efficiency, final efficiency, variance 1, variance 2, variance 3, variance 4, variance 5, total variance (variances are expressed in their absolute values)

A.6 Input File for Measured Efficiency Curve at the Representative Point

This type of file should be stored in the [\work\meas] folder. Any line beginning with a "*" means a comment line.

```
* EnergyCount
12
```

↑ Number of energy points

```
* Energy[MeV],Efficiency,Uncertainty
0.06000 0.10000 0.08540
0.08800 0.10000 0.03210
0.12200 0.10000 0.02040
0.16600 0.10000 0.01610
0.27900 0.10000 0.01280
0.39200 0.10000 0.01200
0.51400 0.10000 0.01150
0.66200 0.10000 0.01130
0.89800 0.10006 0.01110
1.17300 0.10000 0.01090
1.33300 0.10000 0.01090
1.83600 0.10000 0.01070
```

↑ Energy [MeV], Measured efficiency, Relative uncertainty [0.01%]. Values in each line should be delimited with space characters.

A.7 Input File for Angular Dependence of Efficiencies

    (This option is not used in this version of the code.)

     This type of file should be stored in the [\work\angle] folder.

     In the code, an efficiency data $P(E,R,Z)$ is multiplied by an angular dependence correction factor $\alpha(E,R,Z,\theta)$. As a result, an angular dependent efficiency $P(E,R,Z,\theta)$ is obtained. The format of this file is as follows.

```
12        3        2        4        12
```
    ↑ Number of measured energy points, Number of planes (Z), Number of planes (R), Number of measured

     angular points (Recommended number is at least 8), Number of angular partitions

```
0.0221  0.0595   0.088  0.1221  0.1365  0.1659  0.3917  0.6617  ...
```
    ↑ Measured energy points [MeV]

```
0.9     2.0      4.1
```
    ↑ Position of planes (Z) [cm]

```
0.0     2.6
```
    ↑ Position of planes (R) [cm]

```
0.0    90.0    180.0    270.0
```
    ↑ Measured angular points [degree]

```
1.0000  1.0000  1.0000  1.0000        1.0000  1.2436  1.3150  1.1213
1.0000  1.0000  1.0000  1.0000        1.0000  1.0385  0.9594  0.9615
1.0000  1.0000  1.0000  1.0000        1.0000  1.0485  1.0030  0.9667
1.0000  1.0000  1.0000  1.0000        1.0000  1.2212  1.2920  1.1062
1.0000  1.0000  1.0000  1.0000        1.0000  1.0498  0.9950  0.9684
1.0000  1.0000  1.0000  1.0000        1.0000  1.0458  1.0127  0.9669
1.0000  1.0000  1.0000  1.0000        1.0000  1.1947  1.2478  1.0885
1.0000  1.0000  1.0000  1.0000        1.0000  1.0718  0.9897  0.9863
1.0000  1.0000  1.0000  1.0000        1.0000  1.0395  1.0500  0.9763
```
    ...

    ↑ ((((efficiency data, i=1, Number of measured angular points), j=1, Number of planes (R)), k=1,

     Number of planes (Z)), l=1, Number of measured energy points)

A.8 Description of Basic Element

This type of file should be stored in a sub-folder located in the [\system\parts] folder. Any line beginning with a "#" means a comment line. An element is defined in an input file by considering the four arithmetic operations for the variables of each element.

```
#******************************************************
#**   Parts File                                    **
#******************************************************
#BODY count2
6                                    ← Number of BODYs to define
#BODYSymbol,Parameter count2,Parameter
#1
pz,1,$pos
#2
pz,1,$pos-0.05
#3
pz,1,$pos-0.55
#4
pz,1,$pos-$h1
#5
cz,1,1.0
#6
cz,1,$r1
```
↑ Definition of BODYs

The "BODY" has basically the same meaning with the "surface" used in MCNP. Data of BODY must be arranged in sequence on one line per single BODY, in the order of the body code, number of parameters used, parameters, parameters, (repeated as many as the number of parameters). These parameters are delimited by commas.

Positions in the Z direction must be set on the basis of "pos" variable, which will hereinafter be described.

BODY code: See the "surface card" section in the MCNP manual (px, cs, tr etc.)

Number of parameters: Number of parameters required in defining a BODY

(refer to the MCNP manual)

Parameter: Parameters are described with a combination of value(s) and/or variable(s) which will

hereinafter be described. A variable must be identified with a "$" symbol at the head.

```
#CELL count2
2                                    ← Number of CELLs to define
#Material File,Parameter,imp:p,imp:e,kind
#(kind =-1:Region Out  =0:Calculate Region =1:Detector(tally)
#      =2:Detector    =3:Cover In        =4:Cover
#      =5:Tray        =6:Jig             =7:Object
#      =8:Vessel)
#1
$mn0,2 -4 -5,1.0,1.0,1
#2
```

```
$mn1,1 -4 -6,1.0,1.0,2
```
↑ Definition of CELLs

   "CELL" has basically the same meaning with the "cell" used in MCNP. Data of CELL must be arranged in sequence on one line per single CELL, in the order of the material file name, parameter, imp:p, imp:e, kind (the meanings of the "imp:p", "imp:e", "kind" are described hereinafter). These parameters are delimited by commas.

  Material file name: Assign a variable which is defined in the last part of this file. If this part is left blank, the material is unconditionally regarded as being VOID.

  Parameter: Parameters are described by the combination of the BODY numbers defined above. Also refer to the "cell card" section in the MCNP manual. Variable(s) must not be used here.

  imp:p: Assign the importance (refer to the MCNP manual, if needed) of photons. Normally, this value should be 1.0, but can be 0.0 if photons are not transported in the CELL.

  imp:e: Assign the importance (refer to the MCNP manual, if needed) of electrons. Normally, this value should be 1.0, but can be 0.0 if electrons are not transported in the CELL.

  kind: Assign a type of the CELL. The type should be selected from the following list.

    -1: Out of the calculation area (See the [Data]-[Calculation area] Menu. This selection can be made only for the basic element of the calculation area.).

    0: The calculation area (See the [Data]-[Calculation area] Menu. This selection can be made only for the basic element of the calculation area.).

    1: Detection part (See the [Data]-[Detector] Menu. This selection can be made only for the basic element of the detector. This part is regarded as the tally cell in MCNP.).

    2: Detector part (See the [Data]-[Detector] Menu. This selection can be made only for the basic element of the detector. The detector part other than the detection part should be set as 2.).

    3: Inside cover (See the [Data]-[Cover] Menu. This selection can be made only for the basic element of the cover. The detector part, detection part and the support jig part are automatically removed from this region when each part is assembled geometrically.).

    4: Cover (See the [Data]-[Cover] Menu. This selection can be made only for the basic element of the cover. The cover part other than the "inside cover" should be set as 4.).

    5: Tray (See the [Data]-[Tray] Menu. This selection can be made only for the basic element of the tray.).

    6: Support jig (See the [Data]-[Support jig] Menu. This selection can be made only for the basic element of the support jig.).

    7: Measured sample (See the [Data]-[Measured sample] Menu. This selection can be made only for the basic element of the measured sample.).

    8: Sample container (See the [Data]-[Measured sample] Menu. This selection can be made only for the basic element of the sample container.).

```
#Parameter count2
5                                              ← Number of variables to define
#Variable Name,Comment,Type,Default
pos,Distance from surface Z=0[cm] to basal surface of sample
container[cm] | 基準面Z=0[cm]から容器底までの距離   [cm],DBL,0.0
```

↑ The variable "pos" must be given except in the case that this file is for defining the calculation area. It is a variable to set a reference position of a "basic element". The reference position differs depending on the basic element, which must be selected from the following list. "Type" and "Default" must invariably be "DBL" and "0.0", respectively.

    1) Detector: Top surface of a detector

    2) Cover: Top surface of a cover

    3) Tray: Top surface of a tray

    4) Support jig: Top surface of a support jig

    5) Measured sample: A surface which comes in contact with a detector, cover or tray (normally, a basal surface of a sample container)

```
thick,Thickness of tray[cm] | トレイの厚み   [cm],DBL+1,0.0
```

↑ The variable "thick" must be given in the case that this file is for defining the cover, tray or support jig. It is used as a variable to set an offset value between "basic elements" of different types. "Type" and "Default" must invariably be "DBL+1" and "0.0", respectively.

    1) Cover: Thickness (top end) of a cover

    2) Tray: Thickness of a tray

    3) Support jig: Gap (in Z direction) between top surface of a detector and inner surface of a cover

```
h1,Height [cm],DBL+1| 高さ   [cm],1.0
r1,Radius [cm],DBL+1| 半径   [cm],2.0
mn0,Material A| 材質   B,MAT,
mn1,Material B| 材質   B,MAT,
```

↑ These are user variables. A variable consists of "Variable Name", "Comment", "Type", "Default". It must be arranged on one line with comma delimiters.

    1) Variable name: The variable names are expressed in alphanumeric characters. Lower-case alphabets must be used.

    2) Comment: A meaning of the variable should be given. The comment appears on the GUI screen, and it can be expressed in either English or Japanese. A "pipe (|)" character must be placed in between the comments in two different languages. Japanese comments must be located after English comments. In the case that there is only an English comment, or only a Japanese comment, the pipe must be excluded.

    3) Type: Data type for the input data must be selected from the following list.

        (blank): none specified

        DBL: floating-point number

DBL+0: positive (includes zero) floating-point number

DBL+1: positive (excludes zero) floating-point number

DBL-0: negative (includes zero) floating-point number

DBL-1: negative (excludes zero) floating-point number

MAT: Material data

4) Default: In the case the type is MAT, the default should be left blank. Otherwise, assign an intended default value.

国際単位系（SI）

表1．SI 基本単位

基本量	SI 基本単位 名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表2．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位 名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度（質量密度）	キログラム毎立法メートル	kg/m^3
質量体積（比体積）	立法メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
（物質量の）濃度	モル毎立方メートル	mol/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率	（数の）1	1

表5．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	µ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表3．固有の名称とその独自の記号で表されるSI組立単位

組立量	SI 組立単位 名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン [a]	rad		$m \cdot m^{-1}=1$ [b]
立体角	ステラジアン [a]	sr [c]		$m^2 \cdot m^{-2}=1$ [b]
周波数	ヘルツ	Hz		s^{-1}
力	ニュートン	N		$m \cdot kg \cdot s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
エネルギー，仕事，熱量	ジュール	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
工率，放射束	ワット	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
電荷，電気量	クーロン	C		$s \cdot A$
電位差（電圧），起電力	ボルト	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
電気抵抗	オーム	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
磁束	ウエーバ	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
セルシウス温度	セルシウス度 [d]	℃		K
光束	ルーメン	lm	$cd \cdot sr$ [c]	$m^2 \cdot m^{-2} \cdot cd=cd$
照度	ルクス	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd=m^{-2} \cdot cd$
（放射性核種の）放射能	ベクレル	Bq		s^{-1}
吸収線量，質量エネルギー分与，カーマ	グレイ	Gy	J/kg	$m^2 \cdot s^{-2}$
線量当量，周辺線量当量，方向性線量当量，個人線量当量，組織線量当	シーベルト	Sv	J/kg	$m^2 \cdot s^{-2}$

(a)ラジアン及びステラジアンの使用は、同じ次元であっても異なった性質をもった量を区別するときの組立単位の表し方として利点がある。組立単位を形作るときのいくつかの用例は表4に示されている。

(b)実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号"1"は明示されない。

(c)測光学では、ステラジアンの名称と記号srを単位の表し方の中にそのまま維持している。

(d)この単位は、例としてミリセルシウス度m℃のようにSI接頭語を伴って用いても良い。

表6．国際単位系と併用されるが国際単位系に属さない単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86400 s
度	°	$1°=(\pi/180)$ rad
分	'	$1'=(1/60)° =(\pi/10800)$ rad
秒	"	$1''=(1/60)' =(\pi/648000)$ rad
リットル	l、L	$1l=1 dm^3=10^{-3}m^3$
トン	t	$1t=10^3 kg$
ネーパ	Np	1Np=1
ベル	B	1B=(1/2)ln10(Np)

表7．国際単位系と併用されこれに属さない単位でSI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位であらわされる数値
電子ボルト	eV	$1eV=1.60217733(49) \times 10^{-19}J$
統一原子質量単位	u	$1u=1.6605402(10) \times 10^{-27}kg$
天文単位	ua	$1ua=1.49597870691(30) \times 10^{11}m$

表8．国際単位系に属さないが国際単位系と併用されるその他の単位

名称	記号	SI 単位であらわされる数値
海里		1海里=1852m
ノット		1ノット=1海里毎時=(1852/3600)m/s
アール	a	$1 a=1 dam^2=10^2m^2$
ヘクタール	ha	$1 ha=1 hm^2=10^4m^2$
バール	bar	$1 bar=0.1MPa=100kPa=1000hPa=10^5Pa$
オングストローム	Å	$1 Å=0.1nm=10^{-10}m$
バーン	b	$1 b=100fm^2=10^{-28}m^2$

表4．単位の中に固有の名称とその独自の記号を含むSI組立単位の例

組立量	SI 組立単位 名称	記号	SI 基本単位による表し方
粘度	パスカル秒	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
力のモーメント	ニュートンメートル	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg \cdot s^{-2}$
角速度	ラジアン毎秒	rad/s	$m \cdot m^{-1} \cdot s^{-1}=s^{-1}$
角加速度	ラジアン毎平方秒	rad/s^2	$m \cdot m^{-1} \cdot s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg \cdot s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
質量熱容量（比熱容量），質量エントロピー	ジュール毎キログラム毎ケルビン	$J/(kg \cdot K)$	$m^2 \cdot s^{-2} \cdot K^{-1}$
質量エネルギー（比エネルギー）	ジュール毎キログラム	J/kg	$m^2 \cdot s^{-2} \cdot K^{-1}$
熱伝導率	ワット毎メートル毎ケルビン	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
体積電荷	クーロン毎立方メートル	C/m^3	$m^{-3} \cdot s \cdot A$
電気変位	クーロン毎平方メートル	C/m^2	$m^{-2} \cdot s \cdot A$
誘電率	ファラド毎メートル	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
透磁率	ヘンリー毎メートル	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
モルエントロピー，モル熱容量	ジュール毎モル毎ケルビン	$J/(mol \cdot K)$	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
照射線量（X線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1} \cdot s \cdot A$
吸収線量率	グレイ毎秒	Gy/s	$m^2 \cdot s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4 \cdot m^{-2} \cdot kg \cdot s^{-3}=m^2 \cdot kg \cdot s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2 \cdot sr)$	$m^2 \cdot m^{-2} \cdot kg \cdot s^{-3}=kg \cdot s^{-3}$

表9．固有の名称を含むCGS組立単位

名称	記号	SI 単位であらわされる数値
エルグ	erg	$1 erg=10^{-7} J$
ダイン	dyn	$1 dyn=10^{-5}N$
ポアズ	P	$1 P=1 dyn \cdot s/cm^2=0.1Pa \cdot s$
ストークス	St	$1 St =1cm^2/s=10^{-4}m^2/s$
ガウス	G	$1 G ≙10^{-4}T$
エルステッド	Oe	$1 Oe ≙(1000/4\pi)A/m$
マクスウェル	Mx	$1 Mx ≙10^{-8}Wb$
スチルブ	sb	$1 sb =1cd/cm^2=10^4cd/m^2$
ホト	ph	$1 ph=10^4 lx$
ガル	Gal	$1 Gal =1cm/s^2=10^{-2}m/s^2$

表10．国際単位に属さないその他の単位の例

名称	記号	SI 単位であらわされる数値
キュリー	Ci	$1 Ci=3.7 \times 10^{10}Bq$
レントゲン	R	$1 R = 2.58 \times 10^{-4}C/kg$
ラド	rad	$1 rad=1cGy=10^{-2}Gy$
レム	rem	$1 rem=1 cSv=10^{-2}Sv$
X 線単位		$1X unit=1.002 \times 10^{-4}nm$
ガンマ	γ	$1γ=1 nT=10^{-9}T$
ジャンスキー	Jy	$1 Jy=10^{-26}W \cdot m^{-2} \cdot Hz^{-1}$
フェルミ		$1 fermi=1 fm=10^{-15}m$
メートル系カラット		1 metric carat = 200 mg = $2 \times 10^{-4}kg$
トル	Torr	$1 Torr = (101 325/760) Pa$
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	
ミクロ	µ	$1 µ =1µm=10^{-6}m$