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Development of PRESTA-CG Incorporating Combinatorial Geometry in EGS4/PRESTA

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Development of PRESTA-CG Incorporating Combinatorial Geometry in EGS4/PRESTA

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ABSTRACT

Since the PRESTA algorithm needs the macro to calculate the closest distance between the particle position and a boundary of each material region, it is difficult to calculate the response function for a radiation detector with a complex geometry. In order to calculate particle transport easily in various geometrical configurations, we have developed an EGS4/PRESTA user code, named PRESTA-CG, by making the macro HOWNEAR, and related subroutines, specialized for using a combinatorial geometry method. This paper reports the development of PRESTA-CG and its applications. The calculated results from this code agreed well with those from another Monte Carlo code ITS/ACCEPT and with experimental results.

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Contents

1. Introduction

EGS4 code [1] is an electron-photon transport Monte Carlo code used as a standard in high energy physics, and increasingly in the low energy region such as medical physics and health physics. In recent years, papers on the response calculations of radiation detectors used in low energy fields of nuclear laboratories and facilities have been reported frequently [2, 3, 4]. However, in order to calculate the responses with the EGS4 code in the low energy region, it is recommended to use either the ESTEPE option, which reduces the step size of an electron from the default value [5], or the PRESTA algorithm [6], which has been developed by Bielajew and Rogers to improve the electron transport in EGS4 in the low energy region. In recent years, many reported works have used the PRESTA algorithm as a more logical and convenient method.

A radiation detector generally has a complex geometry, and must be modeled using simple shapes, such as spheres, cylinders and so on, or with a combination of these shapes in a combinatorial geometry (CG) method as employed in MORSE-CG [7] and QAD-CG [8, 9]. The CG package has already been used for the EGS4 code, and a sample user code of EGS4 is shown as UCSAMPCG in SLAC-265 [1]. Furthermore, a user code incorporating the MARS (Multiple Array System) geometry package [10], with which it is possible to model a complex geometry with a repeated structure, has also been developed by Sato et al. [11] However, it is difficult in EGS4/PRESTA to apply the conventional CG packages, because the EGS4/PRESTA code must include the macro HOWNEAR to calculate the closest distance between the current position of the particle and a boundary of each region even for a complex geometry. We have therefore developed a new user code of EGS4/PRESTA, named PRESTA-CG [12, 13] to calculate the response of a radiation detector with a complex geometry. We also adopted the LSCAT [14] in PRESTA-CG to evaluate low energy photon treatment more precisely. This paper describes the method in Section 2, and Section 3 shows sample calculations and comparisons with other code and experiments.

2. Geometry Description in PRESTA-CG

PRESTA-CG provides users with a method for the solution of electron-photon transport through three-dimensional multi-material geometry described by the CG method. In the combinatorial scheme, the problem input zones (regions) are built up out of simple bodies (fundamental shapes). In the present version of PRESTA-CG code, the bodies that can be used are as follows:

- RPP – Rectangular Parallelepiped,
- SPH – Sphere,
- RCC – Right Circular Cylinder,
- TRC – Truncated Right Angle Cone,
- TOR – Torus.

The definitions of the above bodies are illustrated in Appendix A. Each input zone is described as a combination which may consist of complex intersections, unions and differences of these bodies. The main features of PRESTA-CG are the definition of the macro $CALL-HOWNEAR and the subroutine HOWFAR which are specialized to use the above input zones. The mathematical considerations in PRESTA-CG are also shown in Appendix B.

The outline and related improvements in PRESTA-CG can be summarized as follows:

1) Definition of the macro $CALL-HOWNEAR(#)

The original macro $CALL-HOWNEAR(#) is replaced when using the CG method, as shown in List 1. By calling from this macro, the shortest distance between the current position of the particle and the boundary of each primitive body which includes the particle is calculated in the subroutine HWNEAR. The mathematical considerations of HWNEAR in PRESTA-CG are shown in Appendix C.

2) Definition of the macros calculating the distance between the present position of the particle and all boundaries of bodies in flight direction

In order to calculating a boundary of each body in the flight direction, we wrote the macros $RPPCG1, $SPHCG1, $RCCCG1, $TRCCG1, and $TORCG1 for RPP, SPH, RCC, TRC, and TOR mentioned above, respectively.

3) Definition of the macros for the relation of a particle and bodies

In order to find whether bodies include a particle or not, we wrote the macros $RPPCGSH, $SPHCGSH, $RCCCGSH, $TRCCGSH and $TORCGSH for each body in the CG method. The macro $SEARCHZON was also written for finding the zone number including the particle.

4) The subroutine HOWFAR

A subroutine representing geometry for calculation, called HOWFAR (see List 2), was written corresponding to above CG method.

5) Input method of SYSIN data

In order to calculate the responses of various detectors, we made a SYSIN data including the items listed below.

- Calculation Condition
  - Input switches, such as PRESTA ON/Off, ECUT/PCUT selection, and so on.
- Media and Geometry
  - Input the material data, and geometry using by CG method.
  - Specify the calculation condition at each zone.
- Radiation Source data
  - Input the emitted particle energy, position, and shape of source
- Calculated Results
  - Energy deposition, flux, and so on.

By applying this SYSIN data, it is possible conveniently to calculate the response for an arbitrary shape of radiation source and/or detector. Input specification of SYSIN data of PRESTA-CG is shown in Appendix D.

We attached the program list of PRESTA-CG in Appendix F, and the explanation of the macros and related variables in Appendix G.

3. Application of PRESTA-CG

In order to verify the PRESTA-CG code, we calculated the response functions for three detectors.

First, we calculated the response function of an ionization chamber. The ionization chamber (VICTOREEN Inc.: Radcon 550-3) selected is a standard chamber which is used for calibration of radiation monitors and dosimeters. This has a finger tip geometry which is constructed from a combination of hemispheres and a cylinder, as illustrated in Fig. 1a. We have calculated the response of this chamber using by PRESTA-CG and another Monte Carlo code ITS/ACCEPT [15], which is another code using the CG method. Experimental data for this chamber had already been obtained. Comparisons were made with experimental data and the results from the ITS/ACCEPT code.

In this calculation, irradiation was by a broad parallel beam of monoenergetic photons on one side of the chamber, and energy deposited in the cavity of the chamber was calculated.

The energy range of irradiating photons was from 30 keV to 800 keV for the chamber without any build-up cap (BC), and from 500 keV to 5 MeV for that with a 3 mm thick BC. In order to reduce statistical uncertainties below 3%, the calculations were performed up to a billion histories for above 800 keV, and ten billion histories for other photons. The calculated results and experimental values are shown in Fig. 1b. The results from the PRESTA-CG and the ITS/ACCEPT modeled as a finger tip geometry are in good agreement within 5%, and there are no significant differences. The calculated results were also in good agreement with the experimental data. Input and output lists of this calculation are shown in Appendix E.

Next, we calculated the response of an effluent monitor which is used for monitoring the concentration of radioactive liquid waste at a nuclear power plant [16]. This monitor uses an NaI(Tl) scintillation detector(7/4"ϕ x 2") located in the inner well of a sampling tank, as shown in Fig. 2a. The effluent water is pumped continuously to the sampling tank (volume approx. 260 ℓ, and radioactivity in the water is measured by the detector. The characteristic test for this monitor was carried out using liquid standard sources (K-40, Cr-51, Co-60, and Cs-137), and point sources (Cs-137 x 2) set outside of a collimator hole in the lead shielding. The feature of this calculation is complexity of the source region which has the geometry of a cylinder combined with a cone. Furthermore, we can model a collimator hole for external point sources which has a different axis to that of the detector, as shown in Fig. 2a.

Fig. 2b shows the results of the simulation and the experiment using liquid sources. The calculated results are in good agreement with the experimental data, within 9%, for all nuclides we tested. For the point sources, it shows excellent agreement with the experimental results with differences within 3%. These results show that the code can be used to estimate the concentration of liquid radioactive waste in cases where the response is hard to obtain by experiment.

Finally, we applied the user code PRESTA-CG to designing a radioactive gas monitor using scintillating optical fibers as a radiation detector [17, 18]. As illustrated in Fig. 3, the geometry is a "half-doughnut" to enlarge detecting volume and to enhance geometrical efficiency of detection. Fig. 6 also shows the trajectories of β+ rays emitted from N-13 gas.

4. Conclusions

We developed PRESTA-CG, which incorporates the CG method in the EGS4/ PRESTA code, and calculated the responses of three detectors. The calculated results from this code were compared with the data calculated by the ITS/ACCEPT code and experimental values. These data agreed well with sufficiently small uncertainties. PRESTA-CG is a versatile and easily extended user code, which can be applied to the response calculation of radiation detectors with a complex geometry and realistic calculations in various other fields. We will extend this code with additional primitive bodies such as a wedge, an ellipsoid, and so on.

Acknowledgements

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```
REPLACE{$CALL-HOWNEAR(#);} WITH
 {$CALL-HOWNEAR-FOR-COMBINATORIAL-GEOMETRY({P1});}
"++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+"
"THIS IS THE MACRO THAT SHOULD RETURN THE CLOSEST PERPENDICULAR DISTANCE TO   "
"ANY SURFACE WHICH FORMS A BOUNDARY FOR THE CURRENT REGION. IN THIS APPLICATION"
"IT IS REPLACED BY THE MACRO FOLLOWING WHICH IS SPECIALIZED FOR THE COMBINATORI"
"AL GEOMETRY                                                                   "
"IT IS THE USER'S RESPONSIBILITY TO PROVIDE THIS MACRO FOR HIS OWN GEOMETRY.   "
"++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+"

REPLACE{$CALL-HOWNEAR-FOR-COMBINATORIAL-GEOMETRY(#);} WITH
   {;XL=X(NP);YL=Y(NP);ZL=Z(NP);IRL=IR(NP);
    CALL HWNEAR({P1},XL,YL,ZL,IRL);}

"-------------------------------------------------------------"

SUBROUTINE HWNEAR(TPERP,XLS,YLS,ZLS,IRL);
    REAL*4 XLS,YLS,ZLS;
    REAL*8 XL,YL,ZL;
    REAL*8 P1MIN,CLONG1,CLONG2,CLONG3,CLONG4,CLONG5,CLONG6;
    REAL*8 ACYL,BCYL,CCYL,DCYL,ECYL;
    REAL*8 TORLL1,TORLL2,TORLL3,ATOR,BTOR,THATOR,THSTOR,THETOR;
    REAL*8 ETOR1,FTOR1,ETOR2,FTOR2,GTOR,CTOR;
    XL=XLS;YL=YLS;ZL=ZLS;
    P1MIN=$MAXDELL;
    DO I=1,NBBODY(IRL) [
      DO J=1,IRPPIN [                                  "Calc. for RPP"
       IF(IABS(NBZONE(I,IRL)).EQ.NBRPP(J)) [
         IXYZFG=0;
         IF(XL.LT.RPPPNT(1,J))      [IXFG=1;]
         ELSEIF(XL.GT.RPPPNT(2,J)) [IXFG=2;]
         ELSE                      [IXFG=3;IXYZFG=IXYZFG+1;]
         IF(YL.LT.RPPPNT(3,J))      [IYFG=1;]
         ELSEIF(YL.GT.RPPPNT(4,J)) [IYFG=2;]
         ELSE                      [IYFG=3;IXYZFG=IXYZFG+1;]
         IF(ZL.LT.RPPPNT(5,J))      [IZFG=1;]
         ELSEIF(ZL.GT.RPPPNT(6,J)) [IZFG=2;]
         ELSE                      [IZFG=3;IXYZFG=IXYZFG+1;]
         IF(IXYZFG.EQ.3) [
           CLONG1=DABS(XL-RPPPNT(1,J));
           CLONG2=DABS(XL-RPPPNT(2,J));
           CLONG3=DABS(YL-RPPPNT(3,J));
           CLONG4=DABS(YL-RPPPNT(4,J));
           CLONG5=DABS(ZL-RPPPNT(5,J));
           CLONG6=DABS(ZL-RPPPNT(6,J));
           P1MIN=DMIN1(CLONG1,CLONG2,CLONG3,CLONG4,CLONG5,CLONG6,P1MIN);]
         ELSEIF(IXYZFG.EQ.2) [
           IF(IXFG.NE.3)      [CLONG1=DABS(XL-RPPPNT(IXFG,J));]
           ELSEIF(IYFG.NE.3) [CLONG1=DABS(YL-RPPPNT(IYFG+2,J));]
           ELSE              [CLONG1=DABS(ZL-RPPPNT(IZFG+4,J));]
           P1MIN=DMIN1(CLONG1,P1MIN);]
         ELSEIF(IXYZFG.EQ.1) [
           IF(IXFG.EQ.3)      [
             CLONG1=DSQRT((YL-RPPPNT(IYFG+2,J))*(YL-RPPPNT(IYFG+2,J))
                    +(ZL-RPPPNT(IZFG+4,J))*(ZL-RPPPNT(IZFG+4,J)));]
           IF(IYFG.EQ.3)      [
             CLONG1=DSQRT((XL-RPPPNT(IXFG,J))*(XL-RPPPNT(IXFG,J))
                    +(ZL-RPPPNT(IZFG+4,J))*(ZL-RPPPNT(IZFG+4,J)));]
           IF(IZFG.EQ.3)      [
```

List 1 (1/4)   The macro HOWNEAR and related subroutines

```
        CLONG1=DSQRT((XL-RPPPNT(IXFG,J))*(XL-RPPPNT(IXFG,J))
                    +(YL-RPPPNT(IYFG+2,J))*(YL-RPPPNT(IYFG+2,J)));]
      P1MIN=DMIN1(CLONG1,P1MIN);]
    ELSE [
      CLONG1=DSQRT((XL-RPPPNT(IXFG,J))*(XL-RPPPNT(IXFG,J))
                  +(YL-RPPPNT(IYFG+2,J))*(YL-RPPPNT(IYFG+2,J))
                  +(ZL-RPPPNT(IZFG+4,J))*(ZL-RPPPNT(IZFG+4,J)));
      P1MIN=DMIN1(CLONG1,P1MIN);]
]]
;
DO J=1,ISPHIN [                                           "Calc. for SPH"
 IF(IABS(NBZONE(I,IRL)).EQ.NBSPH(J)) [
   CLONG1=DABS(XL-SPHPNT(1,J));
   CLONG2=DABS(YL-SPHPNT(2,J));
   CLONG3=DABS(ZL-SPHPNT(3,J));
   CLONG4=DABS(SPHPNT(4,J)
        -DSQRT(CLONG1*CLONG1+CLONG2*CLONG2+CLONG3*CLONG3));
   P1MIN=DMIN1(CLONG4,P1MIN);
 ]]
;
DO J=1,IRCCIN [                                           "Calc. for RCC"
 IF(IABS(NBZONE(I,IRL)).EQ.NBRCC(J)) [
   ACYL=DSQRT(RCCPNT(4,J)*RCCPNT(4,J)+RCCPNT(5,J)*RCCPNT(5,J)
       +RCCPNT(6,J)*RCCPNT(6,J));
   BCYL=((XL-RCCPNT(1,J))*RCCPNT(4,J)+(YL-RCCPNT(2,J))*RCCPNT(5,J)
       +(ZL-RCCPNT(3,J))*RCCPNT(6,J))/ACYL;
   CCYL=(XL-RCCPNT(1,J))*(XL-RCCPNT(1,J))
       +(YL-RCCPNT(2,J))*(YL-RCCPNT(2,J))
       +(ZL-RCCPNT(3,J))*(ZL-RCCPNT(3,J));
   CLONG1=DSQRT(DABS(CCYL-BCYL*BCYL));
   CLONG2=DABS(BCYL);
   CLONG3=DABS(ACYL-BCYL);
   IF(CLONG1.LE.RCCPNT(7,J)) [
     IF(CLONG2+CLONG3.LE.ACYL) [
       CLONG4=DABS(RCCPNT(7,J)-CLONG1);
       P1MIN=DMIN1(CLONG2,CLONG3,CLONG4,P1MIN);]
     ELSE [
       P1MIN=DMIN1(CLONG2,CLONG3,P1MIN);]
   ]
   ELSE [
     IF(CLONG2+CLONG3.LE.ACYL) [
       CLONG4=DABS(RCCPNT(7,J)-CLONG1);
       P1MIN=DMIN1(CLONG4,P1MIN);]
     ELSE [
       CLONG4=DABS(RCCPNT(7,J)-CLONG1);
       CLONG5=DSQRT(CLONG2*CLONG2+CLONG4*CLONG4);
       CLONG6=DSQRT(CLONG3*CLONG3+CLONG4*CLONG4);
       P1MIN=DMIN1(CLONG5,CLONG6,P1MIN);]
   ]
 ]]

DO J=1,ITRCIN [                                           "Calc. for TRC"
 IF(IABS(NBZONE(I,IRL)).EQ.NBTRC(J)) [
   ACYL=DSQRT(TRCPNT(4,J)*TRCPNT(4,J)+TRCPNT(5,J)*TRCPNT(5,J)
       +TRCPNT(6,J)*TRCPNT(6,J));
   BCYL=((XL-TRCPNT(1,J))*TRCPNT(4,J)+(YL-TRCPNT(2,J))*TRCPNT(5,J)
       +(ZL-TRCPNT(3,J))*TRCPNT(6,J))/ACYL;
   CCYL=(XL-TRCPNT(1,J))*(XL-TRCPNT(1,J))
       +(YL-TRCPNT(2,J))*(YL-TRCPNT(2,J))
       +(ZL-TRCPNT(3,J))*(ZL-TRCPNT(3,J));
   CLONG1=DSQRT(DABS(CCYL-BCYL*BCYL));
```

List 1 (2/4) The macro HOWNEAR and related subroutines

```
      CLONG2=DABS(BCYL);
      CLONG3=DABS(ACYL-BCYL);
      DCYL=(TRCPNT(8,J)-TRCPNT(7,J))/ACYL;
      ECYL=TRCPNT(7,J)+BCYL*DCYL;
      CLONG4=(CLONG1-ECYL)/DSQRT(1.+DCYL*DCYL);
      IF( (ECYL.GE.TRCPNT(7,J).AND.ECYL.LE.TRCPNT(8,J)).OR.
          (ECYL.GE.TRCPNT(8,J).AND.ECYL.LE.TRCPNT(7,J))) [
          P1MIN=DMIN1(CLONG4,P1MIN);
      ]
      IF(BCYL.LE.0.) [
        IF(CLONG1.LE.TRCPNT(7,J)) [
          P1MIN=DMIN1(CLONG2,P1MIN);
        ]
        ELSE [
          CLONG5=DSQRT(BCYL*BCYL
                +(TRCPNT(7,J)-CLONG1)*(TRCPNT(7,J)-CLONG1));
          CLONG6=DSQRT(BCYL*BCYL
                +(TRCPNT(8,J)-CLONG1)*(TRCPNT(8,J)-CLONG1));
          P1MIN=DMIN1(CLONG5,CLONG6,P1MIN);
        ]
      ]
      IF(BCYL.GE.ACYL) [
        IF(CLONG1.LE.TRCPNT(8,J)) [
          P1MIN=DMIN1(CLONG3,P1MIN);
        ]
        ELSE [
          CLONG5=DSQRT(BCYL*BCYL
                +(TRCPNT(7,J)-CLONG1)*(TRCPNT(7,J)-CLONG1));
          CLONG6=DSQRT(BCYL*BCYL
                +(TRCPNT(8,J)-CLONG1)*(TRCPNT(8,J)-CLONG1));
          P1MIN=DMIN1(CLONG5,CLONG6,P1MIN);
        ]
      ]
      IF(BCYL.GT.0.0.AND.BCYL.LT.ACYL) [
        IF(CLONG1.LE.TRCPNT(7,J)) [
          P1MIN=DMIN1(CLONG2,P1MIN);
        ]
        IF(CLONG1.LE.TRCPNT(8,J)) [
          P1MIN=DMIN1(CLONG3,P1MIN);
        ]
        CLONG5=DSQRT(BCYL*BCYL
              +(TRCPNT(7,J)-CLONG1)*(TRCPNT(7,J)-CLONG1));
        CLONG6=DSQRT(BCYL*BCYL
              +(TRCPNT(8,J)-CLONG1)*(TRCPNT(8,J)-CLONG1));
        P1MIN=DMIN1(CLONG5,CLONG6,P1MIN);
      ]
    ]]

   DO J=1,ITORIN [                                         "Calc. for TOR"
    IF(IABS(NBZONE(I,IRL)).EQ.NBTOR(J)) [
      IF(NINT(TORPNT(8,J)).EQ.1) [
        TORLL1=XL-TORPNT(1,J);
        TORLL2=YL-TORPNT(2,J);
        TORLL3=ZL-TORPNT(3,J);
      ]
      IF(NINT(TORPNT(8,J)).EQ.2) [
        TORLL1=YL-TORPNT(2,J);
        TORLL2=ZL-TORPNT(3,J);
        TORLL3=XL-TORPNT(1,J);
      ]
      IF(NINT(TORPNT(8,J)).EQ.3) [
```

List 1 (3/4) The macro HOWNEAR and related subroutines

```
      TORLL1=ZL-TORPNT(3,J);
      TORLL2=XL-TORPNT(1,J);
      TORLL3=YL-TORPNT(2,J);
    ]
    ATOR=TORLL2*TORLL2+TORLL3*TORLL3;
    BTOR=TORLL1*TORLL1;
    IF(TORLL2.EQ.0.0.AND.TORLL3.EQ.0.0) [THATOR=0.;]
    ELSE [THATOR=ATAN2(TORLL3,TORLL2);]
    THSTOR=TORPNT(6,J)/180.*3.1415927;
    THETOR=TORPNT(7,J)/180.*3.1415927;
    ETOR1=(TORLL2-TORPNT(4,J)*DCOS(THSTOR))**2
         +(TORLL3-TORPNT(4,J)*DSIN(THSTOR))**2
         +TORLL1*TORLL1;
    FTOR1=(TORLL2-TORPNT(4,J)*DCOS(THSTOR))*(-DSIN(THSTOR))
         +(TORLL3-TORPNT(4,J)*DSIN(THSTOR))*DCOS(THSTOR);
    ETOR2=(TORLL2-TORPNT(4,J)*DCOS(THETOR))**2
         +(TORLL3-TORPNT(4,J)*DSIN(THETOR))**2
         +TORLL1*TORLL1;
    FTOR2=(TORLL2-TORPNT(4,J)*DCOS(THETOR))*(-DSIN(THETOR))
         +(TORLL3-TORPNT(4,J)*DSIN(THETOR))*DCOS(THETOR);
    GTOR=ETOR1-FTOR1*FTOR1;
    IF(GTOR.LE.TORPNT(5,J)*TORPNT(5,J)) [
      CLONG2=DABS(FTOR1);
    ]
    ELSE [
      CLONG2=DSQRT(FTOR1*FTOR1
            +(GTOR-TORPNT(5,J))*(GTOR-TORPNT(5,J)));
    ]
    GTOR=ETOR2-FTOR2*FTOR2;
    IF(GTOR.LE.TORPNT(5,J)*TORPNT(5,J)) [
      CLONG3=DABS(FTOR2);
    ]
    ELSE [
      CLONG3=DSQRT(FTOR2*FTOR2
            +(GTOR-TORPNT(5,J))*(GTOR-TORPNT(5,J)));
    ]
    CTOR=DSQRT(ATOR)-TORPNT(4,J);
    CLONG1=DABS(DSQRT(CTOR*CTOR+BTOR)-TORPNT(5,J));
    IF(THETOR.EQ.THSTOR) [P1MIN=DMIN1(CLONG1,P1MIN);]
    IF(THETOR.GT.THSTOR) [
      IF(THATOR.GE.THSTOR.AND.THATOR.LE.THETOR) [
        P1MIN=DMIN1(CLONG1,CLONG2,CLONG3,P1MIN);
      ]
      ELSE [P1MIN=DMIN1(CLONG2,CLONG3,P1MIN);]
    ]
    IF(THETOR.LT.THSTOR) [
      IF(THATOR.GE.THSTOR.OR.THATOR.LE.THETOR) [
        P1MIN=DMIN1(CLONG1,CLONG2,CLONG3,P1MIN);
      ]
      ELSE [P1MIN=DMIN1(CLONG2,CLONG3,P1MIN);]
    ]
  ]]
```

"Write here if the user add new body types"

```
]
TPERP=P1MIN;
RETURN;
END; "END OF SUBROUTINE HWNEAR"
```

List 1 (4/4) The macro HOWNEAR and related subroutines

```
"*********************************************************************"
SUBROUTINE HOWFAR;
"*********************************************************************"
;COMIN/DEBUG,EPCONT,GEOM,STACK,THRESH/;
REAL*8 XIDD,YIDD,ZIDD;

IRL=IR(NP); "Set local variable"

IF(IRL.LT.1.OR.IRL.GE.IZONIN) [IDISC=1; RETURN;]

TVAL=1.E+30;
ITVALM=0;

DO I=1,NBBODY(IRL) [              " Number of bodies containing the particle position"
  DO J=1,IRPPIN [
    IF(ABS(NBZONE(I,IRL)).EQ.NBRPP(J)) [
      $RPPCG1(J);                 "Distance between the particle position and surface of RPP"
    ]
  ]
  DO J=1,ISPHIN [
    IF(ABS(NBZONE(I,IRL)).EQ.NBSPH(J)) [
      $SPHCG1(J);                 "Distance between the particle position and surface of SPH"
    ]
  ]
  DO J=1,IRCCIN [
    IF(ABS(NBZONE(I,IRL)).EQ.NBRCC(J)) [
      $RCCCG1(J);                 "Distance between the particle position and surface of RCC"
    ]
  ]
  DO J=1,ITRCIN [
    IF(ABS(NBZONE(I,IRL)).EQ.NBTRC(J)) [
      $TRCCG1(J);                 "Distance between the particle position and surface of TRC"
    ]
  ]
  DO J=1,ITORIN [
    IF(ABS(NBZONE(I,IRL)).EQ.NBTOR(J)) [
      $TORCG1(J);                 "Distance between the particle position and surface of TOR"
    ]
  ]

                                  "In case of new body type addition"

]


IRNEAR=IRL;
IF(ITVALM.EQ.0) [
  TVAL0=$DELHOWD;
  XISS=X(NP)+TVAL0*U(NP);
  YISS=Y(NP)+TVAL0*V(NP);
  ZISS=Z(NP)+TVAL0*W(NP);
  UNTIL (X(NP).NE.XISS.OR.Y(NP).NE.YISS.OR.Z(NP).NE.ZISS) [
    TVAL0=TVAL0*10.;
    XISS=X(NP)+TVAL0*U(NP);
    YISS=Y(NP)+TVAL0*V(NP);
    ZISS=Z(NP)+TVAL0*W(NP);
  ]
  XIDD=DBLE(X(NP))+DBLE(TVAL0)*DBLE(U(NP));
  YIDD=DBLE(Y(NP))+DBLE(TVAL0)*DBLE(V(NP));
  ZIDD=DBLE(Z(NP))+DBLE(TVAL0)*DBLE(W(NP));
  $SEARCHZON(XIDD,YIDD,ZIDD,IRNEXT);
```

List 2 (1/2) The subroutine HOWFAR

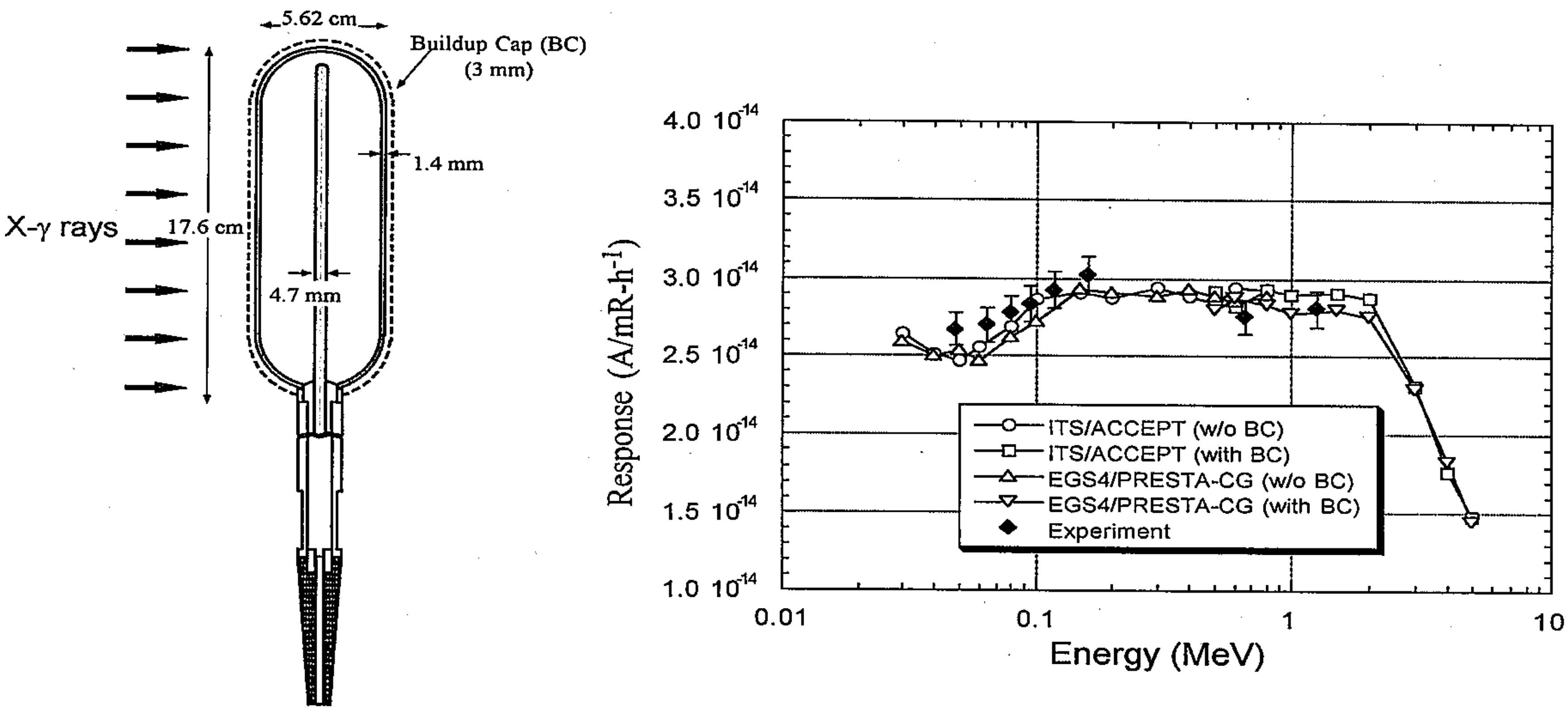
```
    IF(IRNEXT.EQ.IRL)  [TVAL=TVAL0;]
    ELSE  [TVAL=0.0;IRNEAR=IRNEXT;]
  ]

  ELSE [
    ITVLFG=0;
    TVALMN=TVAL;
    DO JJJ=1,ITVALM [
      IF(TVALMN.GT.ATVAL(JJJ)) [TVALMN=ATVAL(JJJ);]
      DELHOW=$DELHOWD;
      TVAL0=ATVAL(JJJ)+DELHOW;
      XISS=X(NP)+TVAL0*U(NP);
      YISS=Y(NP)+TVAL0*V(NP);
      ZISS=Z(NP)+TVAL0*W(NP);
      UNTIL (X(NP).NE.XISS.OR.Y(NP).NE.YISS.OR.Z(NP).NE.ZISS) [
        DELHOW=DELHOW*10.;
        TVAL0=ATVAL(JJJ)+DELHOW;
        XISS=X(NP)+TVAL0*U(NP);
        YISS=Y(NP)+TVAL0*V(NP);
        ZISS=Z(NP)+TVAL0*W(NP);
      ]
      XIDD=DBLE(X(NP))+DBLE(TVAL0)*DBLE(U(NP));
      YIDD=DBLE(Y(NP))+DBLE(TVAL0)*DBLE(V(NP));
      ZIDD=DBLE(Z(NP))+DBLE(TVAL0)*DBLE(W(NP));
      $SEARCHZON(XIDD,YIDD,ZIDD,IRNEXT);
      IF((IRNEXT.NE.IRL.OR.ATVAL(JJJ).GE.$DELHOWC).AND.TVAL.GT.ATVAL(JJJ))
        [TVAL=ATVAL(JJJ);IRNEAR=IRNEXT;ITVLFG=1;]
    ]
    IF(ITVLFG.EQ.0) [
      TVAL0=$DELHOWD;
      XISS=X(NP)+TVAL0*U(NP);
      YISS=Y(NP)+TVAL0*V(NP);
      ZISS=Z(NP)+TVAL0*W(NP);
      UNTIL (X(NP).NE.XISS.OR.Y(NP).NE.YISS.OR.Z(NP).NE.ZISS) [
        TVAL0=TVAL0*10.;
        XISS=X(NP)+TVAL0*U(NP);
        YISS=Y(NP)+TVAL0*V(NP);
        ZISS=Z(NP)+TVAL0*W(NP);
      ]
      IF(TVALMN.GT.TVAL0) [TVAL=TVALMN;]
      ELSE [TVAL=TVAL0;]
    ]
  ]

  $CHGTRCG(TVAL,IHITCG);
  IF(IHITCG.EQ.1) [
    IF(IRNEAR.EQ.0) [
      OUTPUT IQ(NP),IR(NP),X(NP),Y(NP),Z(NP),U(NP),V(NP),W(NP),TVAL;
      (' TVAL ERROR : IQ,IR,X,Y,X,U,V,W,TVAL=',2I3,1P7E12.5);
      IDISC=1;
      ITVERR=ITVERR+1;
      IF(ITVERR.GE.100) [STOP;]
      RETURN;
    ]
  IRNEW=IRNEAR;]

  RETURN;
  END; "END OF HOWFAR"
```

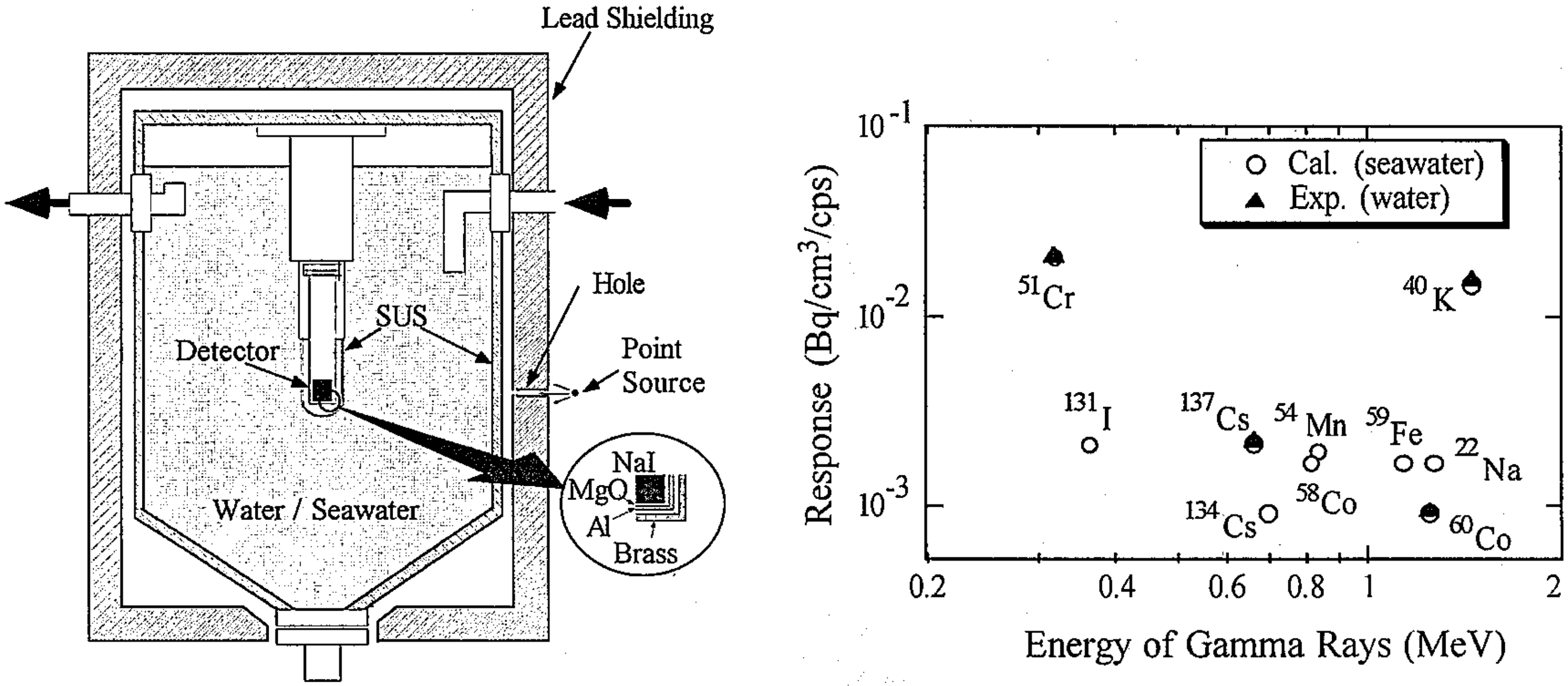
List 2 (2/2)　The subroutine HOWFAR



(a) Sectional View of the ionization chamber

(b) Response of the ionization chamber

Fig. 1 Ionization chamber ond its response



(a) Sectional View of Effluent Monitor

(b) Response of Effluent Monitor

Fig. 2 Effluent Monitor and its response

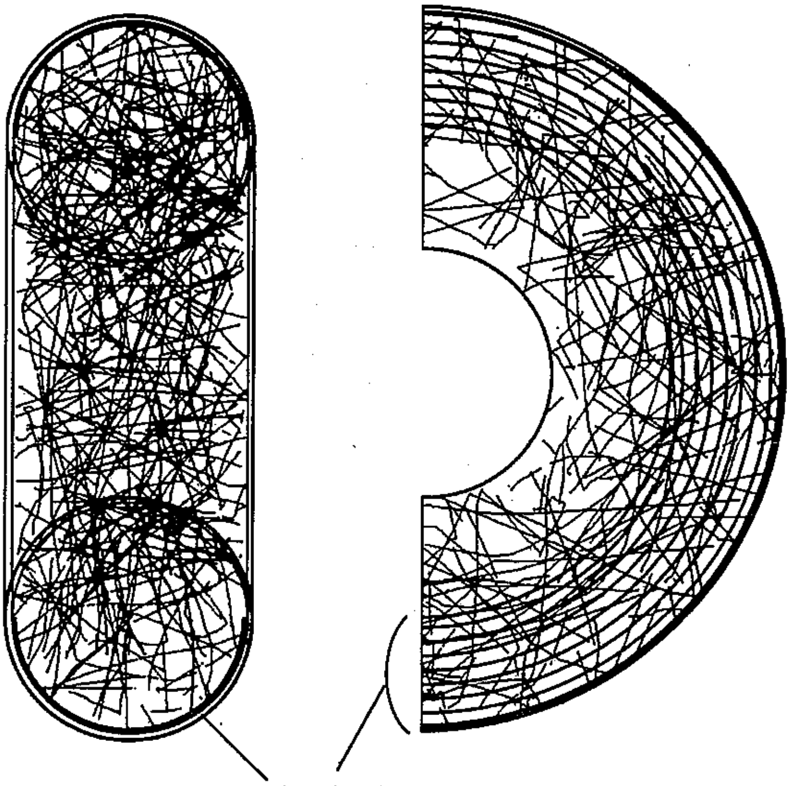
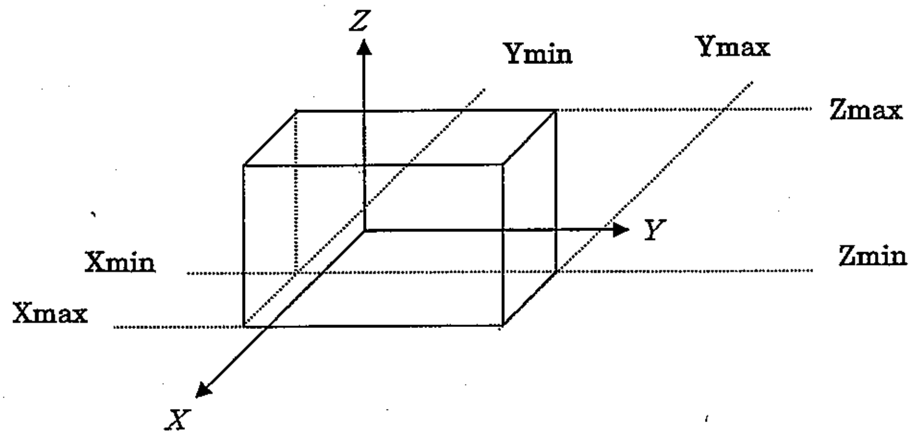


Fig. 3 Trajectories of beta-rays in the gas monitor using scintillating fibers

Appendix A Body Definition

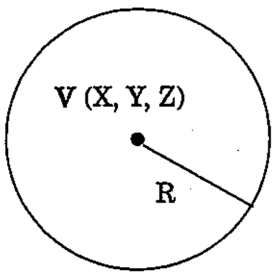
A) Rectangular Parallelepiped (RPP)

Specify the minimum and maximum values of x-, y-, and z-coordinates that bound a rectangular parallelepiped whose six sides are perpendicular to the coordinate axes.



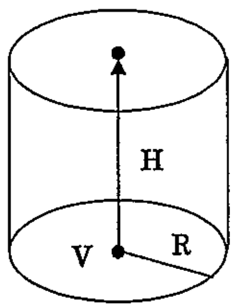
B) Sphere (SPH)

Specify the components of the radius vector **V** to the center of the sphere and the radius R of the sphere.



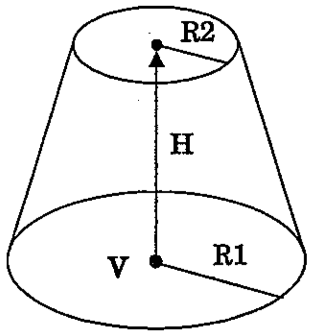
C) Right Circular Cylinder (RCC)

Specify the components of a radius vector **V** to the center of one base, the components of a vector **H** from the center of that base to the center of the other base, and the radius of the cylinder.



D) Truncated Right Angle Cone (TRC)

Specify the components of a radius vector V to the center of one base, the components of a vector H from the center of that base to the center of the other base, and the radii R1 and R2 of the lower and upper bases, respectively.



E) Torus (TOR)

Specify the components of a radius vector V to the center of the torus, and the torus is configured parallel to one of the axes. R1 is the length between the center of torus and the center of tube, and R2 is the radius of the tube. Also, input the direction number of torus (n: x/y/z-axis = 1/2/3). Furthermore, input starting angle θ1 and ending angle θ2 of the sector for the calculation of a part of torus. For the calculation of "complete" torus, set θ1=0, and θ2=360, respectively.

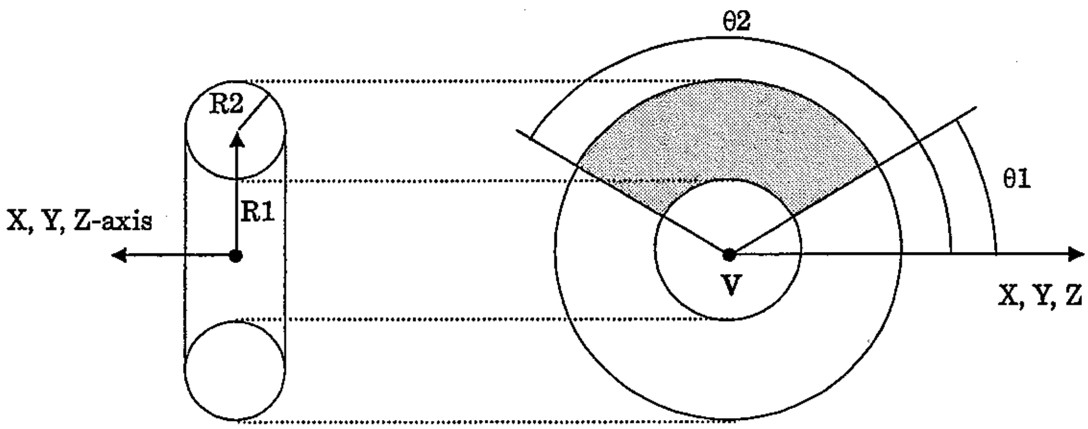


Table A1 Data requied to described each body type

Body Type	Inp. #	Real Data Defining Particular Body					
RPP	#	Xmin	Xmax	Ymin	Ymax	Zmin	Zmax
SPH	#	Vx	Vy	Vz	R		
RCC	#	Vx	Vy	Vz	Hx	Hy	Hz
		R					
TRC	#	Vx	Vy	Vz	Hx	Hy	Hz
		R1	R2				
TOR	#	Vx	Vy	Vz	R1	R2	
		θ1	θ2	n			

Appendix B Mathematical considerations in PRESTA-CG

1. Calculation of Intersecting point of a particle with each body

We have made a subroutine HOWFAR to calculate particle transport in a complex geometrical shape as a combination of primitive bodies. Here, we will show mathematical considerations using at the subroutine HOWFAR in PRESTA-CG. At the present stage, it can be treated following five bodies in PRESTA-CG: rectangular parallelpiped (RPP), sphere (SPH), right circular cylinder (RCC), truncated right angle cone (TRC), and torus (TOR).

In general, the trajectory of a particle can be described by particle position ($x0$, $y0$, $z0$) and direction cosines (u, v, w). it can be treated in PRESTA-CG following primitive bodies.

1) RPP

RPP is defined corners ($x1, y1, z1$), and ($x2$, $y2$, $z2$), as shown in Fig. B1.

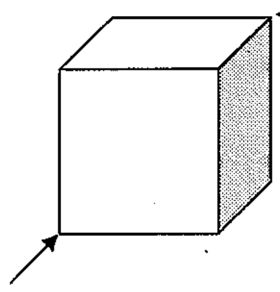


Fig. B1 RPP definition in PRESTA-CG

The intersection of a particle vector with a surface of RPP can be presented as following equations:

$$
\begin{aligned}
X &= x1 = x0 + u \cdot T, \\
X &= x2 = x0 + u \cdot T, \\
Y &= y1 = y0 + v \cdot T, \\
Y &= y2 = y0 + v \cdot T, \\
Z &= z1 = z0 + w \cdot T, \\
Z &= z2 = z0 + w \cdot T,
\end{aligned}
\qquad (1)
$$

where the coordinates (X, Y, Z) is the point of intersection, and T is distance between the present particle position and the intersecting surface of RPP, respectively. By the calculation of T, we can obtained (X, Y, Z).

$$
\begin{aligned}
T1 &= (x1 - x0)/u, \\
T2 &= (x2 - x0)/u, \\
T3 &= (y1 - y0)/v, \\
T4 &= (y2 - y0)/v, \\
T5 &= (z1 - z0)/w, \\
T6 &= (z2 - z0)/w.
\end{aligned} \qquad (2)
$$

The minimal positive value among above values ($T1$~$T6$) is the value of T. Furthermore, it can be obtained the coordinates of intersecting point for the value of T satisfied following equations.

$$
\begin{aligned}
& X = x0 + u \cdot T, \\
& Y = y0 + v \cdot T, \\
& Z = z0 + w \cdot T, \\
& y1 \le Y \le y2 \text{ and } z1 \le Z \le z2, \quad X = x1 \text{ or } X = x2, \\
& z1 \le Z \le z2 \text{ and } x1 \le X \le x2, \quad Y = y1 \text{ or } Y = y2, \\
& x1 \le X \le x2 \text{ and } y1 \le Y \le y2, \quad Z = z1 \text{ or } Z = z2.
\end{aligned} \qquad (3)
$$

2) SPH

SPH is specified by the center of the sphere ($x1, y1, z1$), and the radius (R).

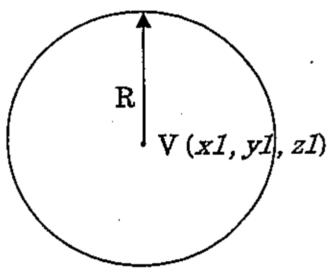


Fig. B2 SPH definition in PRESTA-CG

The intersection of a particle vector with a surface of SPH can be presented as following equations:

$$
\begin{aligned}
X &= R\cdot\sin\theta\cdot\cos\phi + x1 = x0 + u\cdot T,\\
Y &= R\cdot\sin\theta\cdot\sin\phi + y1 = y0 + v\cdot T,\\
Z &= R\cdot\cos\theta + z1 = z0 + w\cdot T
\end{aligned} \tag{4}
$$

where the coordinates (*X*, *Y*, *Z*) is the point of intersection, and *T* is distance between the present particle position and the intersecting surface of SPH, respectively.

By obtaining the value of *T*, the surface coordinates (*X*, *Y*, *Z*) can be calculated.

$$
\begin{aligned}
&(u^2+v^2+w^2)T^2\\
&+2((x0-x1)\,u+(y0-y1)\,v+(z0-z1)\,w)\,T\\
&+(x0-x1)^2+(y0-y1)^2+(z0-z1)^2-R^2=0
\end{aligned} \tag{5}
$$

The positive root of above equation (5) is the value of *T*.

3) RCC

RCC is specified by the vertex of the center of the base (*x1*, *y1*, *z1*), the height vector (*hx*, *hy*, *hz*), and the radius (R).

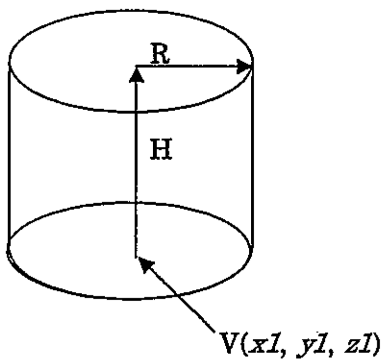


Fig. B3 RCC definition in PRESTA-CG

The intersecting point (*X*, *Y*, *Z*) of a particle vector with a surface of RCC can be presented as following equations:

(1) for both bases

Using the vector **N**, which is denoted from the center of the base (*x*1, *y*1, *z*1) to present particle position (*x*0, *y*0, *z*0), the height vector **H**, and the direction vector of flight **F** (*u, v, w*), the value of *T* can be obtained by the calculation of following inner product:

$$\frac{\mathbf{H}\cdot\mathbf{N}}{|\mathbf{H}|}=-\frac{\mathbf{H}\cdot\mathbf{F}}{|\mathbf{H}|\cdot|\mathbf{F}|}T \tag{6}$$

$$\frac{|\mathbf{H}|^2-\mathbf{H}\cdot\mathbf{N}}{|\mathbf{H}|}=-\frac{\mathbf{H}\cdot\mathbf{F}}{|\mathbf{H}|\cdot|\mathbf{F}|}T \tag{7}$$

If the value of *T* is positive, the square of the radius from the center of the base to the intersecting point at the base is denoted using the vector **M** ($x0+u\cdot T-x1$, $y0+v\cdot T-y1$, $z0+w\cdot T-z1$) and the height vector **H**:

$$r^2=|\mathbf{M}|^2-\left(\frac{\mathbf{M}\cdot\mathbf{H}}{|\mathbf{H}|}\right)^2 \tag{8}$$

$$\text{if } r^2 \leqq R^2, \tag{9}$$

the value of *T* is that we would like to obtain.

(2) For the curved surface of cylinder

If the flight direction and the height vector is not parallel, the intersecting point with the curved surface is obtained by the following equations:

Conditional formula:

$$\left(\frac{\mathbf{H}\cdot\mathbf{F}}{|\mathbf{H}|\cdot|\mathbf{F}|}\right)^2\neq 1 \tag{10}$$

The value of *T* is obtained by solving below the equation.

$$\left(\mathbf{F}\cdot\mathbf{F} - \frac{(\mathbf{H}\cdot\mathbf{F})^2}{\mathbf{H}\cdot\mathbf{H}}\right)T^2 + 2\left(\mathbf{N}\cdot\mathbf{F} - \frac{(\mathbf{H}\cdot\mathbf{F})(\mathbf{H}\cdot\mathbf{N})}{\mathbf{H}\cdot\mathbf{H}}\right)T + \mathbf{N}\cdot\mathbf{N} - \frac{(\mathbf{H}\cdot\mathbf{N})(\mathbf{H}\cdot\mathbf{N})}{\mathbf{H}\cdot\mathbf{H}} - R^2 = 0 \quad (11)$$

From equation (11), if the value of T is positive, and the height of the intersecting point is between the two bases, that is the solution we would like to obtain.

4) TRC

TRC is specified by the vertex of the center of the base (*x1, y1, z1*), the height vector (*hx, hy, hz*), and two scalar denoting the radii of the lower (*R1*) and upper (*R2*) bases.

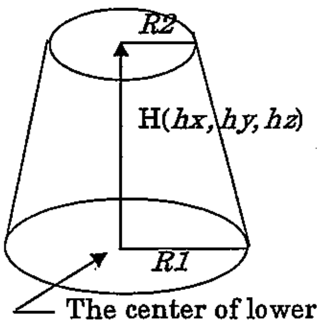


Fig. B4 TRC definition in PRESTA-CG

The coordinates (*X, Y, Z*) of the intersecting point of the particle with TRC is obtained following equations.

(1) For the upper and lower bases

Using the vector N, which is denoted from the center of the lower base (*x1, y1, z1*) to present particle position (*x0, y0, z0*), the height vector H, and the direction vector of flight **F** (*u, v, w*), the value of *T* can be obtained by the calculation of following inner product in the same manner with the case of RCC:

$$\frac{\mathbf{H}\cdot\mathbf{N}}{|\mathbf{H}|} = -\frac{\mathbf{H}\cdot\mathbf{F}}{|\mathbf{H}|\cdot|\mathbf{F}|}T \quad (12)$$

$$\frac{|\mathbf{H}|^2 - \mathbf{H}\cdot\mathbf{N}}{|\mathbf{H}|} = -\frac{\mathbf{H}\cdot\mathbf{F}}{|\mathbf{H}|\cdot|\mathbf{F}|}T \tag{13}$$

Here we calculate the root T.

If the value of T is positive, the square of the radius from the center of the base to the intersecting point at the base is denoted using the vector **M** ($x0 + u\cdot T - x1$, $y0 + v\cdot T - y1, z0 + w\cdot T - z1$) and the height vector **H**:

$$r^2 = |\mathbf{M}|^2 - \left(\frac{\mathbf{M}\cdot\mathbf{H}}{|\mathbf{H}|}\right)^2 \tag{14}$$

$$\text{if} \quad r^2 \leqq R1^2, \tag{15}$$

$$\text{or} \quad r^2 \leqq R2^2, \tag{16}$$

the value of T is that we would like to obtain.

(2) For the curved surface of TRC

$$\left(|\mathbf{H}|^2\cdot|\mathbf{F}|^2 - \left(1 + \frac{(R2 - R1)^2}{|\mathbf{H}|^2}\right)(\mathbf{F}\cdot\mathbf{H})^2\right)T^2$$
$$+ 2\left(|\mathbf{H}|^2\cdot(\mathbf{N}\cdot\mathbf{F}) - (\mathbf{F}\cdot\mathbf{H})\left((\mathbf{N}\cdot\mathbf{H}) + (R2 - R1)\left(R1 + (\mathbf{N}\cdot\mathbf{H})\frac{(R2 - R1)}{|\mathbf{H}|^2}\right)\right)\right)T$$
$$+|\mathbf{H}|^2\left(|\mathbf{N}|^2 - \left(R1 + (\mathbf{N}\cdot\mathbf{H})\frac{(R2 - R1)}{|\mathbf{H}|^2}\right)^2\right) - (\mathbf{N}\cdot\mathbf{H})^2 = 0 \tag{17}$$

From equation (17), if the value of T is positive, and the height of the intersecting point is between the two bases, that is the solution we would like to obtain.

5) TOR

TOR is specified by the center ($x1, y1, z1$) of the torus, the radii of the torus and the torus tube.

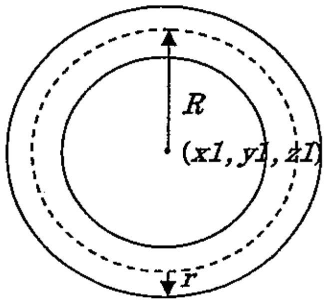


Fig. B5 TOR definition in PRESTA-CG

In the case of torus perpendicular with z-axis, the intersecting point (*X*, *Y*, *Z*) is denoted as the following equations.

$$\begin{aligned} X &= (R + r \cdot \cos\phi)\cos\theta + x1 = x0 + u \cdot T \\ Y &= (R + r \cdot \cos\phi)\sin\theta + y1 = y0 + v \cdot T \\ Z &= r \cdot \sin\phi + z1 = z0 + w \cdot T \end{aligned} \tag{18}$$

where T is the distance of the intersecting point of the torus with the present particle position.

By obtaining the value of *T*, it can be calculate the coordinates (*X*, *Y*, *Z*) of the intersecting point.

$$\begin{aligned} & T^4 + 4\,(u \cdot X' + v \cdot Y' + w \cdot Z')\,T^3 \\ & + \left\{4\,(u \cdot X' + v \cdot Y' + w \cdot Z')^2 + 2\left(X'^2 + Y'^2 + Z'^2 - r^2 - R^2\right) + 4\,R^2 \cdot w^2\right\}T^2 \\ & + \left\{4\,(u \cdot X' + v \cdot Y' + w \cdot Z')\left(X'^2 + Y'^2 + Z'^2 - r^2 - R^2\right) + 8\,R^2 \cdot w \cdot Z'\right\}T \\ & + \left(X'^2 + Y'^2 + Z'^2 - r^2 - R^2\right)^2 - 4\,R^2 \cdot r^2 + 4\,R^2 \cdot Z'^2 = 0 \end{aligned} \tag{19}$$

where $X' = x0 - x1$, $Y' = y0 - y1$, and $Z' = z0 - z1$, respectively.

The positive root of the equation (19) is the solution.

2. Procedure to calculate the distance between the particle position and the zone

boundary

It will be carried out the calculation of the distance of the zone boundary with the particle position in following manner.

(1) For the all bodies which constitute the zone where there is the particle at present, obtain the distance of the particle position with each body surface by the above procedure.

(2) Move the particle at small distance in the flight direction.

(3) Check the zone where moved particle is included.

(4) Compare the zone with the previous zone.

(5) If the new zone is different with the previous zone, obtain the smallest distance between the particle position and each body boundary.

(6) Carry out the procedure from (2) to (5) on the value obtained by the method of (1).

Appendix C Mathematical View of Closest Distance Calculation in PRESTA-CG

1. Treatment of HOWNEAR in PRESTA-CG

We have written a subroutine HWNEAR to calculate closest distance between the present particle position and each primitive body. Here, we will show mathematical considerations using at the subroutine HWNEAR in PRESTA-CG.

At first, we calculate shortest distance between the particle position and the body surface as the following manner.

1) RPP

For an RPP, a point of faces/edges/vertices can be shortest distance with the particle position (x0, y0, z0). That relation is shown in Table C1.

Table C1 Shortest Distance for RPP

Particle position		z0 < Zmin	Zmin ≦ z0 ≦ Zmax	Zmax < z0
x0 < Xmin	y0 < Ymin	vertex	edge	vertex
	Ymin ≦ y0 ≦ Ymax	edge	face	edge
	Ymax < y0	vertex	edge	vertex
Xmin ≦ x0 ≦ Xmax	y0 < Ymin	edge	face	edge
	Ymin ≦ y0 ≦ Ymax	face	nearest face among 6 faces	face
	Ymax < y0	edge	face	edge
Xmax < x0	y0 < Ymin	vertex	edge	vertex
	Ymin ≦ y0 ≦ Ymax	edge	face	edge

	Ymax<y0	vertex	edge	vertex

where (Xmin, Ymin, Zmin) and (Xmax, Ymax, Zmax) are smallest and largest coordinates of the vertices of RPP, respectively.

2) SPH

In the case of SPH, the shortest distance (L) of the particle with the surface of SPH is on the line from the present particle position (x0, y0, z0) to the center of SPH (x1, y1, z1).

$$L = | SQRT((x0-x1)^2 + (y0-y1)^2 + (z0-z1)^2) - R |$$

where R is the radius of SPH.

3) RCC

For an RCC, a point on the upper and lower bases / side can be shortest distance with the particle position (x0, y0, z0). The shortest distance for each case is shown in Table C2.

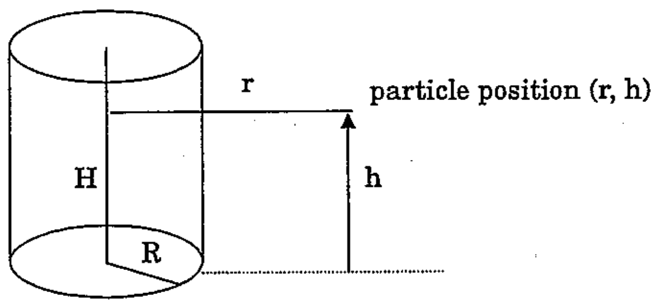


Table C2　　Shortest Distance for RCC

Particle position	r≦R	R<r
h<0	Lower base	Edge of lower base
0≦h≦H	Minimal value of	

	bases and curved surface	Curved surface
H<h	Upper base	Edge of upper base

4) TRC

The shortest distance in the case of TRC is shown in Table C3.

Table C3 Shortest Distance for TRC

Particle position	Shortest distance
Below the lower base and smaller than the side circle of the lower base	On the lower base
Below the lower base and larger than the side circle of the lower	On the curved surface or edge of the lower base
Between both bases, and smaller than the circle of the lower base ——————> smaller than the circle of the upper base ——————>	On the curved surface or the lower base or the upper base
above the upper base and smaller than the side circle of the upper base	On the upper base
above the upper base and larger than the side circle of the upper base	On the curved surface or the edge of the upper base

5) TOR

In the case of TOR, the shortest distance (L) between tube wall of the torus and the particle position is on the shortest line intersecting the center of the tube with the present particle position (x0, y0, z0) and the extended line. Here, the coordinates of the center of torus is denoted (x1, y1, z1).

If the direction of the torus is along z-axis, L is presented as follows:

$$L = | SQRT((SQRT((x0-x1)^2+(y0-y1)^2)-R)^2+(z0-z1)^2)-r |$$

where R, and r are the radii of the torus, and the torus tube, respectively.

2. Procedure to calculate shortest distance between the particle position and the zone boundary

The minimum value is adopted in shortest distance for each body which constitutes the zone where there is the particle at present.

Appendix D Input specification of PRESTA-CG (SYSIN data)

If first column is *, that line is treated as comments.

Card 1 Title Information [Format (A72)]

TITLEI Problem Title

Switches of Calculation Condition

Card 2 Control Switch (1) [Free Format]

IECUTF ECUT option

0: Default (= 0.521 MeV for All Region)

1: User Defined for Each Region

IPCUTF PCUT option

0: Default (=0.001 MeV for All Region)

1: User Defined for Each Region

IDBGFG Check option of Calculation

0: print all

1: partially (ECNSV1, NTALLY: off)

2: off

Media and Geometry

Card 3 [Free Format]

NMED Total Number of Materials (Max. $NMED)

Card 4 Name of Material [column 1 to 24]

For example,

AIR

WATER

...

((MEDARR(I, J), I = 1, 24), J=1, NMED)

* The name is assigned by PEGS4 data in which the user made for the EGS4 calculation. The zone number is corresponded with the name of material at Card 7.

Card 5 CG Description (Body data) [Free Format]

Define the simple shapes (bodies) for calculation by the CG (combinatorial geometry) description. One set of these cards is required for each body, or the END card to terminate the calculation.

The method of describing each of the body types is discussed in App. A. The description of each body must begin a new line of input, and the first parameter on that line must be the appropriate three character code for the body type. Table A1 lists the additional input parameters required for each body type in their proper sequence. The user is free to distribute these parameters. A line beginning with the character END signals that the description of all of the problem bodies is complete.

Card 6 — CG Information (Zone Data) — [Free Format]

Geometrical specification of the input zones begins immediately after the line containing the END parameter for the body data. The method of describing the input zones in terms of the input bodies is discussed in other works [7-9, 14]. Body numbers are determined by the input number in which the bodies are read in Card 4. The description of each input zone must begin on a new line of input, and the first parameter on that line must be a character string beginning with the letter Z. The user is free to distribute the parameters necessary for describing an input zone. A line beginning with the character END signals that the description of all of the problem input zones is complete.

Card 7 — Material Data — [Free format]

Input the material number for each zone. Material numbers are determined by the order in which Card 4 data are read in.

Card 8 — Cut off Energy of Electrons — [Free Format]

Input ECUT data (unit: MeV), if IECUTF is not equal to 0.

Card 9 — Cut off Energy of Photons — [Free Format]

Input PCUT data (unit: MeV), if IPCUTF is not equal to 0.

Source Cards

Card 10 — [Free Format]

IQII — Set the source particle
- 1: positrons
- 0: photons
- -1: electrons

IBETFG — reading method of particle energy
- -1: read from the data file (nucgamma.dat)

0: mono-energy particles (read the below card)

positive: spectral data (assigned emission rate for each energy group)

EINN Kinetic energy of emitted particle (Unit: MeV)

(If IBETFG=0)

NCASPB Emitted particle number for each batch

NBATCH Batch number

ISFG Source shape

0: Point source

1: Circler surface source (along with Z-surface)

2: Rectangular surface source (along with X-surface)

3: Cylindrical volume source

JWATCH Control switch to draw the particle trajectories

If JWATCH is 4, data files (user.f18、user.f15) drawing trajectories are made.

Card 11

Assign spectral data of source particles.

1) If IBETFG is −1,

Input the nuclide name (within 8 letters) made in the file (nucgamma.dat), if the source particles are photons.

2) If IBETFG is positive, input energy boundaries and relative intensities.

[Free Format]

EBANDL, EBANDH, SPECTI: Lower energy (MeV), Higher energy (MeV), Intensity (Relative value)

Card 12 Source position [Free Format]

0) If ISFG=0 (Point source),

XSOR: X-coordinate (cm)

YSOR: Y-coordinate (cm)

ZSOR: Z-coordinate (cm)

1) If ISFG=1 (Circler surface source)

XSOR: X-coordinate of the circle center (cm)

YSOR: Y-coordinate of the circle center (cm)

ZSOR: Z-coordinate of the circle center (cm)

RRSOR: Radius of the circle (cm)

2) If ISFG=2 (Rectangular surface source),

XSOR: position of X-coordinate (cm)

YSOR: minimum value of Y-coordinate (cm)

YSOR1: maximum value of Y-coordinate (cm)

ZSOR: minimum value of Z-coordinate (cm)

ZSOR1: maximum value of Z-coordinate (cm)

3) If ISFG=3 (Cylindrical volume source),

XSOR: the center position (X-coordinate) of the base circle (cm)

YSOR: the center position (Y-coordinate) of the base circle (cm)

ZSOR: the center position (Z-coordinate) of the base circle (cm)

RRSOR: radius of the cylinder (cm)

HSOR: height of the cylinder (cm)[Z direction]

<u>Card 13</u> Emitted Direction [Free Format]

UII: X-direction cosine

VII: Y-direction cosine

WII: Z-direction cosine

If UII, VII, and WII are set 0, the radiation is emitted isotropic.

<u>Calculated Results</u>

<u>Card 14</u> Calculation of Energy Deposition (1) [Free Format]

ICKCNT the number of calculating energy deposition.

<u>Card 15</u> Calculation of Energy Deposition (2) [Free Format]

If ICKCNT>0,

DELTAE energy bin (MeV). Set the calculation of energy deposition.

<u>Card 16</u> Zone Number of the Calculation [Free Format]

If ICKCNT>0,

ICHKMD Set the zone number calculating energy deposition.

If ICHKMD set negative number, the number means material number calculating energy deposition.

Appendix E Sample Input / Output of PRESTA-CG

Page 1

```
   victoreen 550-3 chamber
*   PRINT  :  0=ALL ,1=EXCEPT ECNSV1 & NTALLY ,2=EXCEPT 1 & SPECTRUM
*     ECUT  PCUT   PRINT
       1      1     2
*  MATERIAL COUNT
     2
*  MATERIAL NAME
AIR
ACRYLE
****************
*** GEOMETRY ***
****************
  RCC   1  0.00      0.00      0.00      0.00      0.00      17.00
           0.235
  RCC   2  0.00      0.00      2.81      0.00      0.00      11.98
           2.67
  RCC   3  0.00      0.00      2.81      0.00      0.00      11.98
           2.81
  SPH   4  0.00      0.00      2.81      2.67
  SPH   5  0.00      0.00      2.81      2.81
  SPH   6  0.00      0.00     14.79      2.67
  SPH   7  0.00      0.00     14.79      2.81
  SPH   8  0.00      0.00      8.80    100.0
  SPH   9  0.00      0.00      8.80    200.0
  END
*****************
*** ZONE DATA ***
*****************
* COLLECTING ELECTRODE
  Z01         +1
* GAS(AIR)
  Z02         +2     -1 OR  +4     -1 OR  +6     -1
* ACRYLIC
  Z03         +3     -2 OR  +5     -4     -2 OR  +7     -6     -2
* AIR
  Z04         +8     -3     -5     -7
* ESCAPE
  Z05         +9     -8
  END
****************
* MET          *
****************
      2     1     2     1     0
*
*ECUT
  0.521 0.521 0.521 0.521 0.521
*PCUT
  0.001 0.001 0.001 0.001 0.001
*      IQII     IBETFG       EINN     NCASPB     NBATCH       ISFG      JWATCH
          0          0      0.800     100000         10          2           0
*ISFG=2 surface x
*     X      Y0      Y1     Z0       Z1
  -4.0  -2.81   2.81    0.0     17.6
*  UI    VI    WI
  1.0  0.0  0.0
*ICKCNT
  1
*DELTAE
  0.01
*ICHKMD
  2
```

Page 1

1 START OF EXECUTABLE CODE ===> TYMNOW=   0.0000

```
<<<<<    victoreen 550-3 chamber                                                                           >>>>>
<<<<< *   PRINT  :  0=ALL ,1=EXCEPT ECNSV1 & NTALLY ,2=EXCEPT 1 & SPECTRUM                                 >>>>>
<<<<< *     ECUT  PCUT   PRINT                                                                             >>>>>
<<<<<        1       1     2                                                                               >>>>>
<<<<< *  MATERIAL COUNT                                                                                    >>>>>
<<<<<       2                                                                                              >>>>>
<<<<< *  MATERIAL NAME                                                                                     >>>>>
<<<<< AIR                                                                                                  >>>>>
<<<<< ACRYLE                                                                                               >>>>>
<<<<< ****************                                                                                     >>>>>
<<<<< *** GEOMETRY ***                                                                                     >>>>>
<<<<< ****************                                                                                     >>>>>
<<<<<   RCC   1  0.00        0.00        0.00        0.00        0.00       17.00                          >>>>>
<<<<<            0.235                                                                                     >>>>>
<<<<<   RCC   2  0.00        0.00        2.81        0.00        0.00       11.98                          >>>>>
<<<<<            2.67                                                                                      >>>>>
<<<<<   RCC   3  0.00        0.00        2.81        0.00        0.00       11.98                          >>>>>
<<<<<            2.81                                                                                      >>>>>
<<<<<   SPH   4  0.00        0.00        2.81        2.67                                                  >>>>>
<<<<<   SPH   5  0.00        0.00        2.81        2.81                                                  >>>>>
<<<<<   SPH   6  0.00        0.00       14.79        2.67                                                  >>>>>
<<<<<   SPH   7  0.00        0.00       14.79        2.81                                                  >>>>>
<<<<<   SPH   8  0.00        0.00        8.80      100.0                                                   >>>>>
<<<<<   SPH   9  0.00        0.00        8.80      200.0                                                   >>>>>
<<<<<   END                                                                                                >>>>>
<<<<< *****************                                                                                    >>>>>
<<<<< *** ZONE DATA ***                                                                                    >>>>>
<<<<< *****************                                                                                    >>>>>
<<<<< * COLLECTING ELECTRODE                                                                               >>>>>
<<<<<   Z01            +1                                                                                  >>>>>
<<<<< * GAS(AIR)                                                                                           >>>>>
<<<<<   Z02            +2      -1 OR  +4      -1 OR  +6      -1                                            >>>>>
<<<<< * ACRYLIC                                                                                            >>>>>
<<<<<   Z03            +3      -2 OR  +5      -4      -2 OR  +7      -6      -2                            >>>>>
<<<<< * AIR                                                                                                >>>>>
<<<<<   Z04            +8      -3      -5      -7                                                          >>>>>
<<<<< * ESCAPE                                                                                             >>>>>
<<<<<   Z05            +9      -8                                                                          >>>>>
<<<<<   END                                                                                                >>>>>
<<<<< ****************                                                                                     >>>>>
<<<<< * MET          *                                                                                     >>>>>
<<<<< ****************                                                                                     >>>>>
<<<<<         2      1      2      1      0                                                                >>>>>
<<<<< *                                                                                                    >>>>>
<<<<< *ECUT                                                                                                >>>>>
<<<<<    0.521 0.521 0.521 0.521 0.521                                                                     >>>>>
<<<<< *PCUT                                                                                                >>>>>
<<<<<    0.001 0.001 0.001 0.001 0.001                                                                     >>>>>
<<<<< *      IQII      IBETFG       EINN     NCASPB     NBATCH       ISFG       JWATCH                     >>>>>
<<<<<           0           0      0.800     100000         10          2            0                     >>>>>
<<<<< *ISFG=2 surface x                                                                                    >>>>>
<<<<< *     X      Y0      Y1     Z0       Z1                                                              >>>>>
<<<<<   -4.0  -2.81   2.81    0.0     17.6                                                                 >>>>>
<<<<< *  UI    VI    WI                                                                                    >>>>>
<<<<<   1.0  0.0  0.0                                                                                      >>>>>
<<<<< *ICKCNT                                                                                              >>>>>
<<<<<   1                                                                                                  >>>>>
<<<<< *DELTAE                                                                                              >>>>>
<<<<<   0.01                                                                                               >>>>>
<<<<< *ICHKMD                                                                                              >>>>>
<<<<<    2                                                                                                 >>>>>
<<<<<                                                                                                      >>>>>
```

```
Page 2

1   victoreen 550-3 chamber

 ********************************************
 *****     PRESTA ON                    *****
 *****                                  *****
 ***** IECUTF= 1                        *****
 *****     USER SET ECUT ENERGY         *****
 *****                                  *****
 ***** IPCUTF= 1                        *****
 *****     USER SET PCUT ENERGY         *****
 *****                                  *****
 ***** IDBGFG= 2                        *****
 *****     DEBUG FLAG OFF               *****
 *****                                  *****
 *****     RAYLEIGH SCATTERING ON       *****
 *****     INCOHERENT SCATTERING ON     *****
 *****     COMPTON PROFILE ON           *****
 *****     LINEAR POLARIZATION OFF      *****
 ***** INCIDENT POLARIZATION= 0.00000E+00 **
 *****     ELECTRON IMPACT OFF          *****
 *****     CHANGE RHO OFF               *****
 *****                                  *****
 ********************************************
 ***** NMED  = 2 : NUMBER OF MEDIA        *****
 *****  1    AIR                        *****
 *****  2    ACRYLE                     *****
 ********************************************
   RCC    1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.7000E+01  2.3500E-0
1
   RCC    2  0.0000E+00  0.0000E+00  2.8100E+00  0.0000E+00  0.0000E+00  1.1980E+01  2.6700E+0
0
   RCC    3  0.0000E+00  0.0000E+00  2.8100E+00  0.0000E+00  0.0000E+00  1.1980E+01  2.8100E+0
0
   SPH    4  0.0000E+00  0.0000E+00  2.8100E+00  2.6700E+00
   SPH    5  0.0000E+00  0.0000E+00  2.8100E+00  2.8100E+00
   SPH    6  0.0000E+00  0.0000E+00  1.4790E+01  2.6700E+00
   SPH    7  0.0000E+00  0.0000E+00  1.4790E+01  2.8100E+00
   SPH    8  0.0000E+00  0.0000E+00  8.8000E+00  1.0000E+02
   SPH    9  0.0000E+00  0.0000E+00  8.8000E+00  2.0000E+02
   END
   Z01            1
   Z02            2       -1 OR    4       -1 OR    6       -1
   Z03            3       -2 OR    5       -4       -2 OR    7       -6       -2
   Z04            8       -3      -5       -7
   Z05            9       -8
   END
 ********************************************
 *****     K-EGDE FLAG ON               *****
 ********************************************
 ************************************
 ***  OPTION DATA TABLE           ***
 ************************************
  No.  MED    ECUT     PCUT IEDGFL IAUGER IRAYLR INCOHR IPROFR LPOLAR IMPACR        RHOR
    1    2   0.521    0.001      1      0      1      1      1      0      0 0.00000E+00
    2    1   0.521    0.001      1      0      1      1      1      0      0 0.00000E+00
    3    2   0.521    0.001      1      0      1      1      1      0      0 0.00000E+00
    4    1   0.521    0.001      1      0      1      1      1      0      0 0.00000E+00
    5    0   0.521    0.001      0      0      0      0      0      0      0 0.00000E+00
 RAYLEIGH OPTION REQUESTED FOR MEDIUM NUMBER  1

 RAYLEIGH OPTION REQUESTED FOR MEDIUM NUMBER  2

 INCOHERENT OPTION REQUESTED FOR MEDIUM NUMBER  1

 INCOHERENT OPTION REQUESTED FOR MEDIUM NUMBER  2
```

Page 3

```
 COMPTON PROFILE OPTION REQUESTED FOR MEDIUM NUMBER  1

 COMPTON PROFILE OPTION REQUESTED FOR MEDIUM NUMBER  2

 ELECTRON IMPACT IONIZATION DATA AVAILABLE FOR MEDIUM  2 BUT OPTION NOT REQUESTED.

 ELECTRON IMPACT IONIZATION DATA AVAILABLE FOR MEDIUM  1 BUT OPTION NOT REQUESTED.

 EGS SUCCESSFULLY 'HATCHED' FOR     2 MEDIA.
1****************************************
 QUANTITIES ASSOCIATED WITH EACH MEDIA:


 AIR
      RHO=  0.1204600E-02 G/CM**3      RLC=    30399.20       CM
      AE=  0.5210000      MEV      UE=    10.51100       MEV
      AP=  0.1000000E-02 MEV      UP=    10.00000       MEV

 ACRYLE
      RHO=    1.190000       G/CM**3      RLC=    34.07870       CM
      AE=  0.5210000      MEV      UE=    10.51100       MEV
      AP=  0.1000000E-02 MEV      UP=    10.00000       MEV
 **************************************************

 INFORMATION OF MEDIUM AND CUT-OFFFOR EACH REGION


 MEDIUM(  1)=ACRYLE                    ECUT=.52100      MEV, PCUT=.10000E-02 MEV , IRAYLR=  1
 MEDIUM(  2)=AIR                       ECUT=.52100      MEV, PCUT=.10000E-02 MEV , IRAYLR=  1
 MEDIUM(  3)=ACRYLE                    ECUT=.52100      MEV, PCUT=.10000E-02 MEV , IRAYLR=  1
 MEDIUM(  4)=AIR                       ECUT=.52100      MEV, PCUT=.10000E-02 MEV , IRAYLR=  1
 MEDIUM(  5)=VACUUM                    ECUT=.52100      MEV, PCUT=.10000E-02 MEV , IRAYLR=  0
 **************************************************
 *********************************************
 ***** IQII= 0                          *****
 *****   SOURCE : GAMMA RAY             *****
 *****                                  *****
 ***** IBETFG=     0                    *****
 *****   MONO ENERGY                    *****
 *****                                  *****
 ** INPUT KINETIC ENERGY= 8.000E-01(MeV) **
 *  NUMBER OF INPUT PARTICLE AT BATCH=    100000
 *  NUMBER OF BATCH=          10
 *****                                   *****
 **** ISFG=  2 IS MODEL OF SOURCE ****
 ****         0    : POINT SOURCE          ****
 ****         1    : Z PLANE SURFACE ( R )  ****
 ****         2    : X PLANE SURFACE SOURCE ****
 ****         3    : VOLUME SOURCE OF RZ    ****
 *****                                   *****
 ***** JWATCH= 0:IF 4 THEN WRITE PLOT DATA
 *********************************************
 ****  X PLANE SURFACE SOURCE ****
 X=     -4.000
 Y= FROM      -2.810 TO       2.810
 Z= FROM       0.000 TO      17.600
 ***** SOURCE DIRECTION      *****
 ***  UI= 1.000E+00 VI= 0.000E+00 WI= 0.000E+00
 DEPOSITION AREA DATA
 NO.=     1, REGION NO.    =     2

0*** PRESTA INPUTS ***
 IPLC,IBCA,ILCA,IOLDTM,BLCMIN:
```

Page 4

```
 INITIAL:              0           0           0           0   0.000
 FINAL:                0           0           0           0   3.185
0----------------------------------------------------------------------

 PRESTA CALCULATED MINIMUM STEP SIZES FOR MAXIMUM ENERGY ELECTRONS

                      MEDIUM NO.          t,prime,min for E=Emax
                          1                     2.34      cm
                          2                     0.237E-02 cm
 ----------------------------------------------------------------------

          6  3 11  3  0  4  0
         13  8 15 11 11 14  0
          6 15  0  2  3 11  0
          5 14  2 14  4  8  0
          7 15  7 10 12  2  0
1    1000000 CASES COMPLETED

 IXXST=    123456789
 IXXEND=           78

 AVAILABLE K.E.=     0.80000      MEV
 TOTKE=     0.80000E+06 MEV


PULSE HEIGHT DISTRIBUTION FOR      0.80000     MEV
DETECTOR NO.=      1  REGION NO.   =     2
 TOTAL DEP. ENERGY      = 9.440E+01 MEV
 TOTAL  INPUT ENERGY = 8.000E+05 MEV
 DEP. EFFICIENCY        =  0.000118
 YIELD DATA             =      1.000


 TOTAL CASE =      1000000 TOTAL COUNTS =        5855.
 YIELD DATA             =      1.000


 RESPONSE FUNCTION
 FOR A     0.800 MeV BEAM
  NO.        ENERGY   COUNTS UP-COUNTS     COUNTS/INCIDENT PARTICLES
    1     0.010000      2665.       3190.  2.665E-03
    2     0.020000      1912.       1278.  1.912E-03
    3     0.030000       505.        773.  5.050E-04
    4     0.040000       294.        479.  2.940E-04
    5     0.050000       183.        296.  1.830E-04
    6     0.060000       119.        177.  1.190E-04
    7     0.070000        80.         97.  8.000E-05
    8     0.080000        39.         58.  3.900E-05
    9     0.090000        28.         30.  2.800E-05
   10     0.100000        15.         15.  1.500E-05
   11     0.110000        10.          5.  1.000E-05
   12     0.120000         2.          3.  2.000E-06
   13     0.130000         1.          2.  1.000E-06
   14     0.140000         2.          0.  2.000E-06
   15     0.150000         0.          0.  0.000E+00
1    1000000 CASES OUT OF     1000000 REQUESTED COMPLETED IN        0.0000       SECONDS

 IXXST=    123456789
 IXXEND=           78

 AVAILABLE K.E.=     0.80000      MEV
 TOTKE=     0.80000E+06 MEV
```

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```
**********************************
*        TOTAL RESULT            *
**********************************

DETECTOR NO.=     1  REGION NO.  =    2
 TOTAL DEP. ENERGY    = 9.440E+01 MEV
 TOTAL  INPUT ENERGY = 8.000E+05 MEV
 DEPOSITION FACTOR    =  0.000118
 TOTAL CASE =     1000000 TOTAL COUNTS =       5855.00
```

NO.	ENERGY(MEV)	COUNTS	UP-COUNTS	COUNTS/INCIDENT PARTICLES
1	0.010000	2665.00	3190.00	2.665E-03
2	0.020000	1912.00	1278.00	1.912E-03
3	0.030000	505.00	773.00	5.050E-04
4	0.040000	294.00	479.00	2.940E-04
5	0.050000	183.00	296.00	1.830E-04
6	0.060000	119.00	177.00	1.190E-04
7	0.070000	80.00	97.00	8.000E-05
8	0.080000	39.00	58.00	3.900E-05
9	0.090000	28.00	30.00	2.800E-05
10	0.100000	15.00	15.00	1.500E-05
11	0.110000	10.00	5.00	1.000E-05
12	0.120000	2.00	3.00	2.000E-06
13	0.130000	1.00	2.00	1.000E-06
14	0.140000	2.00	0.00	2.000E-06
15	0.150000	0.00	0.00	0.000E+00

```
FINAL TIME LEFT ===> TYMNOW=     0.0000
```

Appendix F　Program list of PRESTA-CG

1. egs4comp.bat

```
rem The parameter %1 is the name of the user Tutorn.mor code.
rem - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
rem
echo USER/EGS4 CONFIGURATION AND HEIRARCHY FOR TUTOR CODES
echo ────────────────────────────────────────────
echo .
echo   egs4mac.mor  -  egs4 standard macros
echo + nrccmac.mor  -  nrcc macros
echo + machine.mac  -  EGS4/pc/lahey fortran macros
echo ────────────────────────────────────
echo + kek4mac.mor
echo + %1.mor    - user Tutor code - macros and source
echo + kek4.mor
echo ────────────────────────────────────
echo + prnter.mor   - printer controller source code
echo + egs4blok.mor - egs4 standard block data
echo + egs4.mor   - egs4 standard subroutines
echo .
echo ──────────────────
echo END OF USER/EGS4 CONFIGURATION FOR TUTOR CODE
echo .
@ECHO OFF

REM Usage: EGS4COMP
REM use PRESTA

DEL MORTJOB.*
DEL MORTJOB*.TMP
del egs4cg.exe

REM Produce MORTJOB.MOR.
COPY LISTING.ON+EGS4MAC.MOR+NRC4MACP.MOR+PRESTA.MOR+KEK4MACN.MOR MORTJOB1.TMP
COPY MORTJOB1.TMP+CGPMAC.MOR+USRMAC.MOR+CGPUSER.MOR+AUSHOW.MOR MORTJOB2.TMP
COPY MORTJOB2.TMP+CGPSUB.MOR+RMARIN.MOR+TOR.MOR+PICTSB.MOR MORTJOB3.TMP
COPY MORTJOB3.TMP+FREEGM.MOR MORTJOB4.TMP
COPY MORTJOB4.TMP    +PRNTER.MOR+NRCCAUXP.MOR MORTJOB5.TMP
COPY MORTJOB5.TMP+KEK4N.MOR+EGS4BLOK.MOR+EGS4n.MOR MORTJOB.MOR
DEL MORTJOB*.TMP

REM Convert from MORTJOB.MOR to MORTJOB.FOR.
copy C:¥egs4¥mortran3¥mortran3.dat  mortran3.dat
C:¥EGS4¥MORTRAN3¥MORTRAN3.EXE
```

```
REM Compile, link and execute MORTJOB.FOR.
REM Compile, link with Lahey Fortran 95
lf95 MORTJOB.for -nw -lst -o0 > A.A

REM Compile, link with Microsoft FORTRAN POWERSTATION
REM FL32 /Ox /W0 /G4 MORTJOB.for

ren MORTJOB.exe EGS4CG.EXE
```

2. files for PRESTA-CG

CGPMAC.MOR:	the CG macros
USRMAC.MOR:	the macros of user
CGPUSER.MOR:	Main part of user routine
AUSHOW.MOR:	describing subroutines AUSGAB and HOWFAR
CGPSUB.MOR:	subroutines on CG description
RMARIN.MOR:	the routine of random number
TOR.MOR:	the subroutine of torus
PICTSB.MOR:	the subroutine for drawing particle trajectories
FREEGM.MOR:	the subroutine of reading free format for CG

Appendix G The macros and related variables using in PRESTA-CG

1) $CALL-HOWNEAR-FOR-COMBINATORIAL-GEOMETRY({P1})

Calculate shortest distance between the present particle position and the zone boundary constituted the particle, and call the subroutine HWNEAR.

2) COMIN/GEOM/

Store the variables presenting CG configuration.

3) COMIN/TVALCG/

Store the variables keeping the distance of intersecting next surface with the present position.

4) $CHGTRCG

Assign the value of USTEP.

5) COMIN/ZONDTA/

Store the zone data of CG configuration.

6) $SEARCHZON

Search the zone number.

7) $MXRPP

Maximum number of RPP

8) COMIN/RPPDTA/

Store the data of RPP.

9) $RPPCG1

Calculate the distance of the intersecting surface of RPP with the particle position.

10) $RPPCGSH

Check the RPP including the particle or not.

11) $MXZON

Maximum number of calculable zones.

12) $MXBODY

Maximum number of calculable bodies.

13) $MXSPH

Maximum number of calculable SPHs.

14) COMIN/SPHDTA/

Store the data of SPH.

15) $SPHCG1

Calculate the distance of intersecting point of the SPH surface with the particle.

16) $SPHCGSH

Check the SPH including the particle or not.

17) $MXRCC

Maximum number of calculable RCCs.

18) COMIN/RCCDTA/

Store the data of RCC.

19) $RCCCG1

Calculate the distance of intersecting point of the RCC surface with the particle.

20) $RCCCGSH

Check the RCC including the particle or not.

21) $MXTRC

Maximum number of calculable TRCs.

22) COMIN/TRCDTA/

Store the data of TRC.

23) $TRCCG1

Calculate the distance of intersecting point of the TRC surface with the particle.

24) $TRCCGSH

Check the TRC including the particle or not.

25) $MXTOR

Maximum number of calculable TORs.

26) COMIN/TORDTA/

Store the data of TOR.

27) $TORCG1

Calculate the distance of intersecting point of the TOR surface with the particle.

28) $TORCGSH

Check the TOR including the particle or not.

29) subroutine HOWFAR

①Calculate the distance of intersecting point of the particle and the surface of body where there is the particle at present.

②Calculate the distance and next crossing zone number.

30) subroutine HWNEAR

Calculate shortest distance between the particle position and the surface of each body constituted the zone where there is the particle at present.

31) subroutine RPPCG1

Calculate the distance of the particle with the intersecting point of that with the RPP surface.

32) subroutine SPHCG1

Calculate the distance of the particle with the intersecting point of that with the SPH surface.

33) subroutine RCCCG1

Calculate the distance of the particle with the intersecting point of that with the RCC surface.

34) subroutine TRCCG1

Calculate the distance of the particle with the intersecting point of that with the TRC surface.

35) subroutine TORCG1

Calculate the distance of the particle with the intersecting point of that with the TOR surface.

36) subroutine SRZONE

Search the zone number including the particle.

37) subroutine FERRA

Calculate the intersecting point on the surface of TOR by the Ferrari's formula of the fourth equation.

38) subroutine QADRTI

Calculate the intersecting point on the surface of TOR by the formula of quadratic equation.

39) subroutine CARDA

Calculate the intersecting point on the surface of TOR by the Cardano's formula of the third equation.