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γ-ray and β-ray Spectrum Data for egs5 based on ICRP-107

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High Energy Accelerator Research Organization

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Contents

Japanese Parts **1**

1 はじめに **2**

2 ICRP 107 データ **2**

3 egs5 用データベース **2**
3.1 γ 線 2
3.2 β 線と内部転換電子 3

4 ICRP 107β 線データと他の β 線データとの比較 **4**

5 Sample user code **5**
5.1 `ucicrp107.f` 5

6 データベース及びユーザーコードのダウンロード **7**

English Parts **8**

1 Introduction **9**

2 ICRP 107 data **9**

3 Data base for egs5 **9**
3.1 γ-ray 9
3.2 β-ray and Internal conversion electrons 10

4 Comparison of the ICRP 107 β-ray data and other β-ray data **12**

5 Sample user code **12**
5.1 `ucicrp107.f` 12

6 Download database and user code **14**

Table **16**

Figure **31**

Appendix: Full listings of `ucicrp107.f` **38**

ICRP-107に基づく
egs5用γ線及びβ線スペクトルデータ

(Japanese Parts)

1 はじめに

線源の作り方で示されている様に、β 線源は γ 線源と異なりスペクトルは連続である。連続型の過程のサンプリングでは、一般には直接サンプリングは難しい。近似的な方法であるが、スペクトルの形が与えられている場合にどの様な場合にも適用できる方法は、横軸 (この場合は、エネルギー) を等間隔に区分し、その区間の積分値の全領域の積分値に対する割合を確率密度関数とし、乱数により対応するエネルギー区間をサンプリングし、エネルギー区間内では、一様分布として直線内挿によりエネルギーを決定する方法である。ICRU Report 56[1] のデータ及び BNL National Nuclear Data Center から公開されている「RADAR - The Decay Data」[2] を使った egs5 用の β 線スペクトルデータとその使い方については、KEK Report 2016-2[3] として出版されている。

一方、ICRP 107[4] には、「Nuclear Decay Data for Dosimetric Calculations」として、線量評価の必要なほとんどの核種のデータが出版されており、β 線スペクトルデータも含まれている。ICRP-107 には、その他に、γ 線のエネルギーと放出数及び内部転換電子のエネルギーと放出数が含まれている。

本レポートでは、ICRP Report 107 に収録されているデータを使って作成した egs5 用の γ 線データ、β 線スペクトルデータ及び内分転換電子データとその使い方を紹介する。

2 ICRP 107 データ

ICRP 107 には、97 元素の 1252 核種のデータが収録されている。

γ 線については、特性 X 線を含め寄与が 0.010%以上ものが掲載されている。

β 線のスペクトルデータは、崩壊当たりで対応するエネルギーで放出される β 線数が掲載されている。エネルギーは等間隔ではなく、放出量の多い低エネルギー部は細かく設定されている。

内部転換電子は、電子の運動エネルギーと放出当たりの放出数が掲載されている。

3 egs5 用データベース

3.1 γ 線

γ 線については、特性 X 線を含め収録されている光子データのうち、1 keV 以上のデータを採用し、核種毎に以下の構造を持つデータファイルを作成した。

1. 1 行目　核種の説明 20 文字
2. 2 行目　放出 γ 線数 (`ngnum`)
3. 3 から 3+`ngnum` 行目　γ 線エネルギー (MeV)、崩壊当たりの放出数

^{134}`Cs` の場合の例を以下に示す。

```
ICRP 107 Cs-134 gamma
   9
4.754E-01,  1.49E-02
5.632E-01,  8.35E-02
5.693E-01,  1.54E-01
6.047E-01,  9.76E-01
7.959E-01,  8.55E-01
8.020E-01,  8.69E-02
1.039E+00,  9.88E-03
1.168E+00,  1.79E-02
1.365E+00,  3.01E-02
```

3.2 β線と内部転換電子

ICRP 107 の β 線スペクトルデータは、電子エネルギーとそのエネルギーでの崩壊当たりに放出される電子数で示されている。データポイントは、低エネルギー領域では細かく、エネルギーが高い領域では荒く設定されている。egs5 のようなモンテカルロ計算で使用するために、設定したエネルギー区間領域で積分した放出率をもとめ、確率密度関数として用いることした。β-線の最大エネルギーによって設定したエネルギービン幅（deltae:0.4 MeV 以下では。0.002 MeV, 0.4-1.0 MeV では 0.005 MeV, 1.0MeV から 2MeV では 0.01MeV、2MeV から 4MeV では 0.02MeV,4 MeV 以上では 0.04MeV）による等間隔とした。但し、最後の領域の上限エネルギーは、β-線の最大エネルギーとした。求めるエネルギービンの下限エネルギー及び上限エネルギーを含む ICRP 104 のエネルギー点を求め、台形近似で積分を行った。求めるエネルギー区間の複数のデータポイントがある場合には、個々のデータを用いて積分を行った。データポイント間に複数のエネルギー区分がある場合には、エネルギーポイント間は、線形であるとして、各エネルギー区分の上限及び下限エネルギーに対応した値を求め、その結果を用いて台形近似による積分を行った。

得られた結果の総和は、本来、総 β-線放出量と一致するべきであるが、若干の違いが出るので、ICRP 107 に示されている総放出量になるように規格化を行った。

内分転換電子は、γ 線と同じように離散的なデータなので、電子のエネルギー (MeV) と崩壊当たりの放出数をデータとして使用した。

以上の条件で、核種毎に以下の構造を持つデータファイルを作成した。

1. 1 行目　核種の説明 20 文字
2. 2 行目　電子 (-1) か陽電子 (1) の識別データ、崩壊当たりの放出数
3. 3 行目　放出 β 線数 (`nbnum`)
4. 4 から 4+`nbnum` 行目　β 線の下限エネルギー (MeV)、崩壊当たりの放出数
5. 5+`nbnum` 行目　放出 内部転換電子数 (`nicon`)
6. 6+`nbnum` から 6+`nbnum`+`nicon` 行目　内部転換電子エネルギー (MeV)、崩壊当たりの放出数

^{198}`Au` の場合の例を以下に示す。

```
ICRP 107 Au-198  beta -
 -1,   1.0
          70
   0.000000      ,     0.0
  0.2000000E-01 ,     0.35025E-01
  0.4000000E-01 ,     0.35230E-01
  0.6000000E-01 ,     0.35511E-01
  0.8000000E-01 ,     0.35701E-01
  0.1000000     ,     0.35785E-01
  0.1200000     ,     0.35785E-01
  0.1400000     ,     0.35701E-01
  0.1600000     ,     0.35526E-01
  0.1800000     ,     0.35271E-01
  0.2000000     ,     0.34951E-01
  0.2200000     ,     0.34551E-01
  0.2400000     ,     0.34092E-01
  0.2600000     ,     0.33572E-01
  0.2800000     ,     0.32993E-01
  0.3000000     ,     0.32363E-01
  0.3200000     ,     0.31674E-01
  0.3400000     ,     0.30899E-01
  0.3600000     ,     0.30070E-01
  0.3800000     ,     0.29176E-01
  0.4000000     ,     0.28217E-01
  0.4200000     ,     0.27198E-01
  0.4400000     ,     0.26118E-01
  0.4600000     ,     0.25026E-01
  0.4800000     ,     0.23856E-01
  0.5000000     ,     0.22673E-01
```

```
  0.5200000     ,     0.21454E-01
  0.5400000     ,     0.20198E-01
  0.5600000     ,     0.18938E-01
  0.5800000     ,     0.17651E-01
  0.6000000     ,     0.16359E-01
  0.6200000     ,     0.15070E-01
  0.6400000     ,     0.13784E-01
  0.6600000     ,     0.12504E-01
  0.6800000     ,     0.11260E-01
  0.7000000     ,     0.10023E-01
  0.7200000     ,     0.88327E-02
  0.7400000     ,     0.76897E-02
  0.7600000     ,     0.65646E-02
  0.7800000     ,     0.55474E-02
  0.8000000     ,     0.45482E-02
  0.8200000     ,     0.36466E-02
  0.8400000     ,     0.28425E-02
  0.8600000     ,     0.20694E-02
  0.8800000     ,     0.14826E-02
  0.9000000     ,     0.92691E-03
  0.9200000     ,     0.58437E-03
  0.9400000     ,     0.45498E-03
  0.9600000     ,     0.32559E-03
  0.9800000     ,     0.19620E-03
   1.000000     ,     0.66804E-04
   1.020000     ,     0.20365E-05
   1.040000     ,     0.18931E-05
   1.060000     ,     0.17497E-05
   1.080000     ,     0.16062E-05
   1.100000     ,     0.14628E-05
   1.120000     ,     0.13209E-05
   1.140000     ,     0.11805E-05
   1.160000     ,     0.10401E-05
   1.180000     ,     0.89978E-06
   1.200000     ,     0.75941E-06
   1.220000     ,     0.63534E-06
   1.240000     ,     0.52755E-06
   1.260000     ,     0.41976E-06
   1.280000     ,     0.31198E-06
   1.300000     ,     0.20419E-06
   1.320000     ,     0.12953E-06
   1.340000     ,     0.88010E-07
   1.360000     ,     0.46486E-07
   1.372390     ,     0.79680E-08
   5
3.284E-01,  2.89E-02
3.970E-01,  4.08E-03
3.975E-01,  4.31E-03
3.995E-01,  1.87E-03
4.090E-01,  2.56E-03
```

^{137}Cs は、β 線と内部転換電子の両方を放出する核種として用いられることが多いが、内分転換電子は 0.662 MeV の γ 線と同様に ^{137}Cs の子孫核種である ^{137m}Ba から放出されるものである。

egs5 用のデータとしては、表 1 - 14 に示す核種が含まれている。半減期の `s` は、秒、`M` は分、`H` は時間、`D` は日、`Y` は年単位であることを示している。γray No. は、γ 線数、βbin No. は、β 線データのビン数、`IC e No.` は内部転換電子数で、欄の数字が 0 の場合は、対応する粒子の放出が無いことを意味する。

4 ICRP 107β 線データと他の β 線データとの比較

ICRP 107 に収録されている β 線データと他の β 線データの比較は、収録データの基になっている JAERI 1347 レポート [5] で、他のデータベースとの比較、実験データ及び評価データの比較が行われている。

ICRU-56 と RADAR の双方にデータがある 32 核種について、ICRU-56 データ、RADAR データと作成した ICRP 107 に基づいたデータ間のの β 線スペクトルの比較を第 1-6 図に示す。ICRU-56 データと作成したデータの比較状況は、JAERI 1347 レポートの比較と同じであり、データ作成処理の妥当性を確認することができた。

5 Sample user code

5.1 ucicrp107.f

ucicrp107.f は、ucsource.f の枠組みで egs5 用の ICRP 107 データを使用したユーザーコードである。ucicrp107.f では、使用する核種を、キーボードから入力するようにしている。ICRP 107 データを含むディレクトリーは、egs5run を実行しているディレクトリーにあることを前提としている。入力する核種名は、第 1 表にある表記方法である。例えば、^{90}Sr の場合には、Sr-90 と入力する。

ICRP 107 データを使用することに関連した箇所は、以下の箇所である。

1. 変数の定義

```
      real*8
     * spg(MXEBIN),spe(MXEBIN),spic(MXEBIN),egamma(210),pgamma(210),
     * cgamma(210),ebeta(210),pbeta(210),cbeta(210),eicon(210),
     * picon(210),cicon(210)

      integer
     * i,icases,idin,ie,ifti,ifto,ii,j,k,n,ner,nbtype,ngnum,nbnum,
     * nicon,istype

      character*10 atom
      character*72 soinf
      character*72 filename
```

   ngum は、放出される γ-線数、egamma は、放出 γ-線のエネルギーで、pgamma は、崩壊当たりの放出率である。ebeta は、データベースの区分の上限運動エネルギー、pbeta は、データベースの区分ごとの崩壊当たりの放出数である。nbtype は、電子 (-1) と陽電子 (1) かを識別する変数、nbnum は、分点数である。nicom は、放出される内部転換電子数、eicon は、放出内分転換電子のエネルギーで、picon は、崩壊当たりの放出率である。

   また、atom は、使用する核種名、soinf は、データベースの 1 行目に書かれている線源情報、filename は、入力した核種名を使って作成するデータファイル名である。

2. 計算する線種の指定 γ-線か、β-線か、内部転換電子線かを選択する。

```
      write(6,*) ' Source type 0:gamma, 1:beta, 2:IC'
      read(5,*) istype
```

3. データファイルの open 使用する核種データを入力し、該当するデータファイルを open する。

```
      write(6,'(A)')
     *   ' Key in atomic name and mass number like Sr-90'

      read(5,*) atom

      do i=1,10
        if(atom(i:i).eq.' ') go to 10
      end do
10    ii=i-1

      if(istype.eq.0) then  ! gamma-ray
        filename='ICRP_107/gamma-ray/'//atom(1:ii)//'.data'
      else
        filename='ICRP_107/beta-ray/'//atom(1:ii)//'.data'
      end if

      open(2,file=filename,STATUS='old')
```

4. データの読み込みと累積分布関数の計算

```
! Read data fron ICRP_107 data-base
!     soinf is explanation of source
! Gamma-ray
      if(istype.eq.0) then   ! gamma
        nbtype=0
        read(2,'(A72)') soinf
        read(2,*) ngnum
        do i=1,ngnum
          read(2,*) egamma(i),pgamma(i)
        end do
!-------------------------------------
!     Calculate CDF from emission rates
!-------------------------------------
        tnum=0.D0
        do ie=1,ngnum
          tnum=tnum+pgamma(ie)
        end do

        cgamma(1)=pgamma(1)/tnum
        pgamma(1)=pgamma(1)/tnum
        do ie=2,ngnum
          pgamma(ie)=pgamma(ie)/tnum
          cgamma(ie)=cgamma(ie-1)+pgamma(ie)
        end do
! Beta-ray and internal conversion electron
      else
        read(2,'(A72)') soinf
        read(2,*)  nbtype
        read(2,*) nbnum
        do i=1,nbnum
          read(2,*) ebeta(i),pbeta(i)
        end do
        read(2,*) nicon
        if(nicon.ne.0) then
          do i=1,nicon
            read(2,*) eicon(i),picon(i)
          end do
        end if

        if(istype.eq.2.and.nicon.eq.0) then
          write(6,'(A)') ' No IC-electron emitted'
          stop
        end if
```

γ-線、β-線及び内部転換電子線毎に、読み込んだデータから、累積分布関数を算出する。

5. エネルギーのサンプリング

```
!       ------------------------
!       Determine source energy
!       ------------------------
        if(istype.eq.0) then    ! photon
          iqin=nbtype
          call randomset(rnnow)
          do ie=1,ngnum
            if(rnnow.le.cgamma(ie)) go to 1000
          end do
1000      ekein=egamma(ie)
          spg(ie)=spg(ie)+1.0
        elseif(istype.eq.1) then        ! beta-ray
          iqin=nbtype
          call randomset(rnnow)
          do ie=2,nbnum
            if(rnnow.le.cbeta(ie)) go to 60
          end do
60        ekein=ebeta(ie-1)+(rnnow-cbeta(ie-1))*
```

```
     *          (ebeta(ie)-ebeta(ie-1))/(cbeta(ie)-cbeta(ie-1))
           spe(ie)=spe(ie)+1.0
         else       ! IC
           call randomset(rnnow)
           nbtype=-1
           do ie=1,nicon
             if(rnnow.le.cicon(ie)) go to 1100
           end do
1100       ekein=eicon(ie)
           spic(ie)=spic(ie)+1.0
         end if
```

γ-線と内分転換電子線は、離散的な反応であるので、乱数を使い、粒子のエネルギーを決定する。β-線は、連続したスペクトルなので、乱数で、エネルギービンを決定し、ビン内ではいつ様な分布であるとしてエネルギーを決定する。

粒子のエネルギーサンプリングに直接関係するのは以上である。結果を入射粒子当たりとする場合には、ヒストリー全体での平均を求めればよい。一方、線源強度が $\mathrm{Bq/cm^2}$ 又は $\mathrm{Bq/cm^3}$ の場合で、単位放射能当たり ($\mathrm{Bq/cm^2}$ 又は $\mathrm{Bq/cm^3}$) の量を計算する場合には、入射粒子当たりの結果に崩壊当たりの粒子数 (`tnum, tnumb` 又は `tnumic` を掛ける必要がある。

Appendix に、`ucicrp107.f` を示す。

6 データベース及びユーザーコードのダウンロード

上記に紹介した egs5 用の ICRP 107 データベース及びそれぞれのサンプルユーザーコードは、`rcwww.kek.jp/research/egs/kek/egs5/beta_ray/` からダウンロードできる。

References

[1] “Dosimetry of External Beta Rays for Radiation Protection”, ICRU Report 56.

[2] <http://www.doseinfo-radar.com/RADARDecay.html> (2016.4.1 final confirmation)

[3] Y. Kirihara, H. Hirayama and Y. Namito, “β-ray Spectrum Data for egs5 based on ICRU-56 or RADAR”, KEK Internal 2016-2, High Energy Accelerator Reserach Organization (2016).

[4] “Nuclear Decay Data for Dosimetric Calculations”,ICRP Publication 107, Annals of ICRP, 38(2008).

[5] A. Endo, Y. Yamaguchi and K. F. Eckerman, “Nuclear Decay Data for Dosimetry Calculation Revised Data of ICRP Publication 38”, JAERI 1347, Japan Atomic Energy Research Institute (2004).

γ-ray and β-ray Spectrum Data for egs5 based on ICRP-107

(English Parts)

1 Introduction

The continuous spectrum of a β-source differs from that of a γ-source as mentioned in the "Lecture note of Practices on How to Write Source Routine".

Generally, applying the direct sampling method to continuous distribution is difficult. The approximation method applicable to any case is to use a probability distribution function for a segmented interval in β-ray energy if a spectrum is known. The energy interval can be sampled using the cumulative distribution function with a random number. The β-ray energy in each energy bin is sampled assuming a uniform distribution inside the energy bin.

The data on the β-ray spectrum obtained from the ICRU Report 56[1] or "RADAR - The Decay Data" [2] released by the BNL National Nuclear Data Center for egs5 and the guidelines on using this data are published as the KEK Report 2016-2[3].

In ICRP 107[4], on the other hand, the data from most radionuclides that are in need of dose assessment have been published as "Nuclear Decay Data for Dosimetric Calculations". These data include, the β-ray spectrum data, data on energy and emission number of γ-rays and internal conversion electrons data.

In this report, γ-ray data, β-ray spectrum data and the internal conversion electron data created for egs5 using the ICRP Report are presented, with he method of using them in egs5.

2 ICRP 107 data

The ICRP 107 is a database of 1252 nuclides of 97 elements.

In the case of γ-rays, data on γ-rays with an emission rate per decay of 0.010 % or more including the characteristic X rays.

The spectral data for β-rays contain is the number of β-rays emitted along with the corresponding energy per decay. The energy is not equally spaced, and the low energy part with high emission is finely set.

The internal conversion electrons data contains the kinetic energy of the electrons and the number of emissions per decay.

3 Data base for egs5

3.1 γ-ray

In the case of γ-rays, the photons of kinetic energy larger than 1 keV, including the characteristic X-rays, are selected and a data file is created with the following structure for each nuclide:

1. Line 1: Explanation of nuclide in 20 characters
2. Line 2 : Number of γ-rays emitted per decay (`ngnum`)
3. Lines from 3 to 3+`ngnum`: Energy of γ-ray and emission rate per decay

`An example of the datafile of` ^{134}`Cs` created based on these conditions has been given below:

```
ICRP 107 Cs-134 gamma
   9
4.754E-01,  1.49E-02
5.632E-01,  8.35E-02
5.693E-01,  1.54E-01
6.047E-01,  9.76E-01
7.959E-01,  8.55E-01
8.020E-01,  8.69E-02
1.039E+00,  9.88E-03
1.168E+00,  1.79E-02
1.365E+00,  3.01E-02
```

3.2 β-ray and Internal conversion electrons

The ICRP 107 β-ray spectrum data contains the data on electron energy and the number of electrons emitted per decay at the corresponding energy. The data points are fine in the low energy region and rough in the high energy region. To use these data in a Monte Carlo calculation such as egs5, we calculated the emission rate integrated over the set energy interval region and used it as a probability density function. The energy bin width (deltae) is set depending on the maximum energy of the β-ray (deltae: 0.002 MeV below 0.4 MeV, 0.005 MeV for 0.4 - 1.0 MeV, 0.01 MeV for 1.0 - 2 MeV, 0.02 MeV for 2 - 4 MeV, 0.04 MeV above 4 MeV). If multiple data points needed to be determined in the energy interval, the integration was performed using the individual data. If there are multiple energy divisions between the data points, it was assumed that the energy points were linear, and the values corresponding to the upper and lower limit energy of each energy division were determined; then, integration by trapezoidal approximation was performed using the results. The sum of the results obtained should be consistent with the total β-ray emission; in case of discrepancies, the results are standardized as the total emission shown in the ICRP 107.

Because the data on both internal conversion electrons and γ-rays are discrete, the energy of electrons (MeV) and the number of emissions per decay were used as the data.

Based on these conditions, a data file having the following structure was created for each nuclide:

1. Line 1: Explanation of nuclide in 20 characters
2. Line 2: Identification data of electron (-1) or positron (1) and the number of emissions per decay
3. Line 3: Emission β-ray number (`nbnum`)
4. Lines from 4 to 4+`nbnum`: Lower limit energy (MeV) of β-rays and the number of emissions per decay
5. Line 5+`nbnum`: Emission number of internal conversion electrons (`nicon`)
6. Lines from 6+`nbnum` to 6+`nbnum+nicon`: Internal conversion electron energy (MeV) and the number of emissions per decay

`An example of the datafile of` ^{198}`Au` created based on these conditions has been given below:

```
ICRP 107 Au-198  beta -
 -1,   1.0
          70
   0.000000     ,     0.0
  0.2000000E-01 ,     0.35025E-01
  0.4000000E-01 ,     0.35230E-01
  0.6000000E-01 ,     0.35511E-01
  0.8000000E-01 ,     0.35701E-01
  0.1000000     ,     0.35785E-01
  0.1200000     ,     0.35785E-01
  0.1400000     ,     0.35701E-01
  0.1600000     ,     0.35526E-01
  0.1800000     ,     0.35271E-01
  0.2000000     ,     0.34951E-01
  0.2200000     ,     0.34551E-01
  0.2400000     ,     0.34092E-01
  0.2600000     ,     0.33572E-01
  0.2800000     ,     0.32993E-01
  0.3000000     ,     0.32363E-01
  0.3200000     ,     0.31674E-01
  0.3400000     ,     0.30899E-01
  0.3600000     ,     0.30070E-01
```

```
  0.3800000     ,     0.29176E-01
  0.4000000     ,     0.28217E-01
  0.4200000     ,     0.27198E-01
  0.4400000     ,     0.26118E-01
  0.4600000     ,     0.25026E-01
  0.4800000     ,     0.23856E-01
  0.5000000     ,     0.22673E-01
  0.5200000     ,     0.21454E-01
  0.5400000     ,     0.20198E-01
  0.5600000     ,     0.18938E-01
  0.5800000     ,     0.17651E-01
  0.6000000     ,     0.16359E-01
  0.6200000     ,     0.15070E-01
  0.6400000     ,     0.13784E-01
  0.6600000     ,     0.12504E-01
  0.6800000     ,     0.11260E-01
  0.7000000     ,     0.10023E-01
  0.7200000     ,     0.88327E-02
  0.7400000     ,     0.76897E-02
  0.7600000     ,     0.65646E-02
  0.7800000     ,     0.55474E-02
  0.8000000     ,     0.45482E-02
  0.8200000     ,     0.36466E-02
  0.8400000     ,     0.28425E-02
  0.8600000     ,     0.20694E-02
  0.8800000     ,     0.14826E-02
  0.9000000     ,     0.92691E-03
  0.9200000     ,     0.58437E-03
  0.9400000     ,     0.45498E-03
  0.9600000     ,     0.32559E-03
  0.9800000     ,     0.19620E-03
   1.000000     ,     0.66804E-04
   1.020000     ,     0.20365E-05
   1.040000     ,     0.18931E-05
   1.060000     ,     0.17497E-05
   1.080000     ,     0.16062E-05
   1.100000     ,     0.14628E-05
   1.120000     ,     0.13209E-05
   1.140000     ,     0.11805E-05
   1.160000     ,     0.10401E-05
   1.180000     ,     0.89978E-06
   1.200000     ,     0.75941E-06
   1.220000     ,     0.63534E-06
   1.240000     ,     0.52755E-06
   1.260000     ,     0.41976E-06
   1.280000     ,     0.31198E-06
   1.300000     ,     0.20419E-06
   1.320000     ,     0.12953E-06
   1.340000     ,     0.88010E-07
   1.360000     ,     0.46486E-07
   1.372390     ,     0.79680E-08
   5
3.284E-01,  2.89E-02
3.970E-01,  4.08E-03
3.975E-01,  4.31E-03
3.995E-01,  1.87E-03
4.090E-01,  2.56E-03
```

^{137}Cs is often used as a nuclide emitting both β-ray and internal conversion electrons; however, internal conversion electrons are emitted from ^{137m}Ba, which is a progeny nuclide of ^{137}Cs as well as 0.662 MeV γ-ray.

The nuclides shown in Table 1 - 14 were included as the data for egs5. Half-life `S` indicates seconds, `M` indicates minutes, `H` indicates hours, `D` indicates days and `Y` indicates years. Similarly, γ-ray No. denotes the γ-ray number, β bin No. denotes the β-ray data bin number, `IC e No.` denotes the internal conversion electron number. In case the column number is 0, it indicates that there is no release of corresponding particles.

4 Comparison of the ICRP 107 β-ray data and other β-ray data

A comparison of the β-ray data contained in the ICRP 107 with other data is presented in JAERI 1347[5], which is the basis of the data recorded in the ICRP 107. Comparison with other databases, experimental data and evaluation data is given in JAERI 1347.

A comparison of the β-ray spectra among the ICRU-56 data, RADAR data and the data based on ICRP 107 is shown in Figure 1-6 for 32 nuclides, along with the data in both ICRU-56 and RADAR. The comparison between the ICRU-56 data and the data created was the same as that of the JAERI 1347 report, and the validity of data creation process was confirmed.

5 Sample user code

5.1 `ucicrp107.f`

`ucicrp107.f` is user code using the ICRP 107 data for egs5.

In `ucicrp107.f`, the nuclide to be used is input from the keyboard. The directory containing the ICRP 107 data is assumed to be present in the directory where `egs5run` is running. The nuclide name to be input is given in Table 1. For example, in the case of ^{90}Sr, enter `Sr-90`.

The relevant parts of the ICRP 107 data are given below::

1. Definition of variables

```
  real*8
* spg(MXEBIN),spe(MXEBIN),spic(MXEBIN),egamma(210),pgamma(210),
* cgamma(210),ebeta(210),pbeta(210),cbeta(210),eicon(210),
* picon(210),cicon(210)

 integer
* i,icases,idin,ie,ifti,ifto,ii,j,k,n,ner,nbtype,ngnum,nbnum,
* nicon,istype

 character*10 atom
 character*72 soinf
 character*72 filename
```

   `ngum` is the γ-ray number emitted, `egamma` is the energy of the emitted γ-ray, `pgamma` is the emission rate per decay. `ebeta` is the upper limit kinetic energy of division of the database, and `pbeta` is the number of emissions per collapse per division of the database. `nbtype` is a variable identifying electron (-1) and positron (1), and `nbnum` is the number of data points. `nicom` is the number of internal conversion electrons emitted, `eicon` is the energy of internal conversion electrons, and `picon` is the emission rate per decay.

   Further, `atom` is the nuclide name to be used, `soinf` is the source information written in the first line of the database, and `filename` is the data file name from the nuclide name entered.

2. Specification of particle type to calculate Select γ-ray, β-ray or internal conversion electron.

```
write(6,*) ' Source type 0:gamma, 1:beta, 2:IC'
read(5,*) istype
```

3. Data file open Enter nuclide data to be used and open the corresponding data file.

```
 write(6,'(A)')
*   ' Key in atomic name and mass number like Sr-90'
```

```
      read(5,*) atom

      do i=1,10
        if(atom(i:i).eq.' ') go to 10
      end do
10    ii=i-1

      if(istype.eq.0) then  ! gamma-ray
        filename='ICRP_107/gamma-ray/'//atom(1:ii)//'.data'
      else
        filename='ICRP_107/beta-ray/'//atom(1:ii)//'.data'
      end if

      open(2,file=filename,STATUS='old')
```

4. Read data and calculate cumulative distribution function

```
! Read data from ICRP_107 data-base
!     soinf is explanation of source
! Gamma-ray
      if(istype.eq.0) then   ! gamma
        nbtype=0
        read(2,'(A72)') soinf
        read(2,*) ngnum
        do i=1,ngnum
          read(2,*) egamma(i),pgamma(i)
        end do
!-------------------------------------
!     Calculate CDF from emission rates
!-------------------------------------
        tnum=0.D0
        do ie=1,ngnum
          tnum=tnum+pgamma(ie)
        end do

        cgamma(1)=pgamma(1)/tnum
        pgamma(1)=pgamma(1)/tnum
        do ie=2,ngnum
          pgamma(ie)=pgamma(ie)/tnum
          cgamma(ie)=cgamma(ie-1)+pgamma(ie)
        end do
! Beta-ray and internal conversion electron
      else
        read(2,'(A72)') soinf
        read(2,*)  nbtype
        read(2,*) nbnum
        do i=1,nbnum
          read(2,*) ebeta(i),pbeta(i)
        end do
        read(2,*) nicon
        if(nicon.ne.0) then
          do i=1,nicon
            read(2,*) eicon(i),picon(i)
          end do
        end if

        if(istype.eq.2.and.nicon.eq.0) then
          write(6,'(A)') ' No IC-electron emitted'
          stop
        end if
```

Calculate the cumulative distribution function from the data read for each γ-ray, β-ray and internal conversion electron.

5. Energy sampling

```
!       ------------------------
!       Determine source energy
!       ------------------------
        if(istype.eq.0) then    ! photon
          iqin=nbtype
          call randomset(rnnow)
          do ie=1,ngnum
            if(rnnow.le.cgamma(ie)) go to 1000
          end do
1000      ekein=egamma(ie)
          spg(ie)=spg(ie)+1.0
        elseif(istype.eq.1) then        ! beta-ray
          iqin=nbtype
          call randomset(rnnow)
          do ie=2,nbnum
            if(rnnow.le.cbeta(ie)) go to 60
          end do
60        ekein=ebeta(ie-1)+(rnnow-cbeta(ie-1))*
     *          (ebeta(ie)-ebeta(ie-1))/(cbeta(ie)-cbeta(ie-1))
          spe(ie)=spe(ie)+1.0
        else       ! IC
          call randomset(rnnow)
          nbtype=-1
          do ie=1,nicon
            if(rnnow.le.cicon(ie)) go to 1100
          end do
1100      ekein=eicon(ie)
          spic(ie)=spic(ie)+1.0
        end if
```

Because both the Since γ-ray and internal conversion electron are discrete reactions, we use random numbers to determine the energy of the particles. Because the β-ray is a continuous spectrum, the energy bins are determined by random numbers, and the energy is determined to be a uniform distribution within the bins.

This is directly related to the energy sampling of particles.

The average over the entire history can be obtained if the result is calculated per incident particle. On the other hand, when the source intensity is Bq/cm^2 or Bq/cm^3 and the amount of (Bq/cm^2 or Bq/cm^3) per unit activity is to be calculated, the result per incident particle needs to be multiplied by the number of particles per decay (`tnum, tnumb` or `tnumic`).

Appendix shows `ucicrp107.f`.

6 Download database and user code

The ICRP 107 database for egs5 introduced above and the sample user code for each can be downloaded from `rcwww.kek.jp/research/egs/kek/egs5/beta_ray/`.

References

[1] "Dosimetry of External Beta Rays for Radiation Protection", ICRU Report 56.

[2] <http://www.doseinfo-radar.com/RADARDecay.html> (2016.4.1 final confirmation)

[3] Y. Kirihara, H. Hirayama and Y. Namito, "β-ray Spectrum Data for egs5 based on ICRU-56 or RADAR", KEK Internal 2016-2, High Energy Accelerator Research Organization (2016).

[4] "Nuclear Decay Data for Dosimetric Calculations",ICRP Publication 107, Annals of ICRP, 38(2008).

[5] A. Endo, Y. Yamaguchi and K. F. Eckerman, "Nuclear Decay Data for Dosimetry Calculation Revised Data of ICRP Publication 38", JAERI 1347, Japan Atomic Energy Research Institute (2004).

Tables

Table 1: Nuclide included for egs5 based on ICRP 107 (1)

Element Ac	223	224	225	226	227	228	230	231	232	233
Half life	2.10M	2.78H	10.0D	29.37H	21.772Y	6.15H	122S	7.5M	119S	145S
γ-ray No.	59	22	49	24	40	61	120	39	33	7
β-bin No.	0	0	0	57(-)	10(-)	105(-)	143(-)	95(-)	186(-)	122(-)
IC e No.	61	28	57	14	11	16	6	52	31	7
Element Ag	99	100	101	102	102m	103	104	104m	105	105m
Half life	124S	2.24M	11.1M	12.9M	7.7M	65.7M	69.2M	33.5M	41.29D	7.23M
γ-ray No.	107	15	67	36	31	65	60	53	32	32
β-bin No.	105(+)	137(+)	147(+)	170(+)	104(+)	85(+)	98(+)	137(+)	0	72(+)
IC e No.	5	2	2	4	1	6	10	1	29	4
Element Ag	106	106m	108	108m	109m	110	110m	111	111m	112
Half life	23.96M	8.28 D	2.37 M	418 Y	39.6 S	24.6 S	249.76 D	7.45 D	64.8 S	3.130 H
γ-ray No.	8	40	11	6	9	12	15	6	20	44
β-bin No.	99(+)	0	84(-)	0	0	146(-)	146(-)	53(-)	87(-)	199(-)
IC e No.	0	42	0	24	6	0	17	0	7	0
Element Ag	113	113m	114	115	116	117				
Half life	5.37 H	68.7 S	4.6 S	20.0 M	2.68 M	73.6 S				
γ-ray No.	30	33	40	115	64	87				
β-bin No.	102(-)	89(-)	128(-1)	156(-1)	143(-)	105(-)				
IC e No.	0	27	1	1	5	11				
Element Al	26	28	29							
Half life	7.17E+5Y	2.2414M	6.56M							
γ-ray No.	11	17	6							
β-bin No.	60(+)	145(-)	122(-)							
IC e No.	12	4	0							
Element Am	237	238	239	240	241	242	242m	243	244	244m
Half life	73.0M	98M	11.9H	50.8H	432.2Y	16.02H	141Y	7.37E+3Y	10.1H	26M
γ-ray No.	44	48	26	15	20	32	28	15	12	22
β-bin No.	0	63(+)	0	0	0	68(-)	0	0	79(-)	77(-)
IC e No.	85	56	48	19	29	8	7	28	22	6
Element Am	245	246	246m	247						
Half life	2.05H	39M	25.0M	23.0M						
γ-ray No.	22	20	42	18						
β-bin No.	91(-)	61(-)	122(-)	82(-)						
IC e No.	10	30	15	7						
Element Ar	37	39	41	42	43	44				
Half life	35.04D	269Y	109.61M	32.9Y	5.37M	11.87M				
γ-ray No.	4	0	1	0	84	21				
β-bin No.	0	58(-)	126(-)	61(-)	116(-)	149(-)				
IC e No.	0	0	0	0	0	0				
Element As	68	69	70	71	72	73	74	76	77	78
Half life	151.6S	15.23M	52.6M	65.28H	26.0H	80.30D	17.77D	1.0778D	38.83H	90.7M
γ-ray No.	42	45	49	31	29	6	6	21	8	55
β-bin No.	153(+)	151(+)	154(+)	83(+)	168(+)	0	79(+-)	150(-)	70(-)	107(-)
IC e No.	1	1	0	5	2	11	1	0	0	0
Element As	79									
Half life	9.01M									
γ-ray No.	10									
β-bin No.	116(+)									
IC e No.	0									
Element At	204	205	206	207	208	209	210	211	215	216
Half life	9.2M	26.2M	30.6M	1.80H	1.63H	5.41H	8.1H	7.214H	1.00E-4S	3.00E-4S
γ-ray No.	65	95	69	83	56	41	28	20	5	19
β-bin No.	192(+)	176(+)	180(+)	115(+)	123(+)	58(+)	76(+)	0	0	0
IC e No.	79	15	31	39	42	43	39	2	5	18
Element At	217	218	220							
Half life	3.23E-2S	1.5S	3.71M							
γ-ray No.	10	0	21							
β-bin No.	0	146(-)	176(-)							
IC e No.	9	0	14							

Table 2: Nuclide included for egs5 based on ICRP 107 (2)

Element	Au	186	187	190	191	192	193	193m	194	195	195m
Half life		10.7M	8.4M	42.8M	3.18H	4.94H	17.65H	3.9S	38.02H	186.098D	30.5S
γ-ray No.		62	283	130	80	83	61	12	84	23	12
β-bin No.		124(+)	136(+)	172(+)	88(+)	126(+)	0	0	75(+)	0	0
IC e No.		10	281	19	69	16	67	25	43	17	23

Element	Au	196	196m	198	198m	199	200	200m	201	202
Half life		6.183D	9.6H	2.69517D	2.27D	3.139D	48.4M	18.7H	26M	28.8S
γ-ray No.		15	21	5	14	13	19	14	23	14
β-bin No.		70(-)	0	70(-)	0	92(-)	113(-)	58(-)	65(-)	149(-)
IC e No.		17	34	5	37	13	2	34	3	0

Element	Ba	124	126	127	128	129	129m	131	131m	133	133m
Half life		11.0M	100M	12.7M	2.43D	2.23H	2.16H	11.50D	14.6M	10.52Y	38.9H
γ-ray No.		115	85	50	17	32	78	28	10	15	11
β-bin No.		83(+)	67(+)	123(+)	0	72(+)	101(+)	0	0	0	0
IC e No.		21	54	7	9	8	40	33	12	28	10

Element	Ba	135m	137m	139	140	141	142
Half life		28.7H	2.552M	83.06M	12.752D	18.27M	10.6M
γ-ray No.		9	3	10	9	103	43
β-bin No.		0	0	117(-)	52(-)	163(-)	99(-1)
IC e No.		6	6	2	11	5	7

Element	Be	7	10
Half life		53.22D	1.51E+6Y
γ-ray No.		1	0
β-bin No.		0	57(-)
IC e No.		2	0

Element	Bi	197	200	201	202	203	204	205	206	207	208
Half life		9.3M	36.4M	108M	1.72H	11.76H	11.22H	15.31D	6.243D	32.9Y	3.68E+5Y
γ-ray No.		140	30	95	92	72	60	56	32	9	4
β-bin No.		156(+)	149(+)	111(+)	141(+)	113(+)	69(+)	86(+)	75(+)	82(+)	0
IC e No.		210	40	37	54	42	71	79	52	13	5

Element	Bi	210	210m	211	212m	213	214	215	216
Half life		5.013D	3.04E+6Y	2.14M	7.0M	45.59M	19.9M	7.6M	2.17M
γ-ray No.		9	12	6	0	12	41	26	9
β-bin No.		60(-)	0	59(-)	78(-)	73(-)	165(-)	97(-)	179(-)
IC e No.		0	12	6	0	3	6	5	12

Element	Bk	245	246	247	248	249	250	251
Half life		4.94D	1.80D	1.38E+3Y	23.7H	330D	3.212H	55.6M
γ-ray No.		28	23	13	24	13	8	28
β-bin No.		0	0	0	88(-)	63(-)	90(-)	56(-)
IC e No.		13	26	10	9	0	15	25

Element	Br	72	73	74	74m	75	76	76m	77	77m	78
Half life		78.6S	3.4M	25.4M	96.7M	96.7M	16.2H	1.31S	57.036H	4.28M	6.46M
γ-ray No.		36	32	84	102	36	72	11	28	6	14
β-bin No.		178(+)	179(+)	133(+)	133(+)	102(+)	199(+)	137(+)	173(+)	0	129(+)
IC e No.		6	4	1	0	1	1	11	22	6	1

Element	Br	80	80m	82	82m	83	84	84m	85
Half life		17.68M	4.4205H	35.30H	6.13M	2.40H	31.80M	6.0M	2.90M
γ-ray No.		12	9	14	30	5	32	6	43
β-bin No.		102(-)	0	117(-)	158(-)	98(-)	118(-)	112(-)	176(-)
IC e No.		0	11	4	6	0	0	3	0

Element	C	10	11	14
Half life		19.255S	20.39M	5.70E+3Y
γ-ray No.		3	1	0
β-bin No.		97(+)	98(+)	80(-)
IC e No.		4	0	0

Element	Ca	41	45	47	49
Half life		1.02E+5Y	162.67D	4.536D	8.718M
γ-ray No.		16	5	4	6
β-bin No.		0	53(-)	101(-)	153(-)
IC e No.		0	0	0	0

Table 3: Nuclide included for egs5 based on ICRP 107 (3)

Element Cd	101	102	103	104	105	107	109	111	113	113m
Half life	1.36M	5.5M	7.3M	57.7M	55.5M	6.50H	461.4D	48.50M	7.7E+15Y	14.1Y
γ-ray No.	105	32	228	11	100	17	9	6	0	9
β-bin No.	110(+)	55(+)	157(+)	0	86(+)	152(+)	0	0	161(-)	60(-)
IC e No.	13	48	15	14	0	6	6	11	0	0

Element Cd	115	115m	117	117m	118	119	119m
Half life	53.46H	44.6D	2.49H	3.36H	50.3M	2.69M	2.20M
γ-ray No.	7	6	64	41	0	81	176
β-bin No.	57(-)	83(-)	112(-)	135(-)	53(-)	125(-)	163(-)
IC e No.	0	0	4	2	0	10	9

Element Ce	130	131	132	133	133m	134	135	137	137m	139
Half life	22.9M	10.2M	3.51H	97M	4.9H	3.16D	17.7H	9.0H	34.4H	137.641D
γ-ray No.	89	90	37	11	96	21	52	27	18	8
β-bin No.	54(+)	152(+)	0	100(+)	102(+)	0	75(+)	96(+)	0	0
IC e No.	44	13	51	9	25	15	53	6	6	6

Element Ce	141	143	144	145
Half life	32.508D	33.039H	284.91D	3.01M
γ-ray No.	7	19	14	92
β-bin No.	161(-)	75(-)	65(-)	125(-)
IC e No.	5	5	7	18

Element Cf	244	246	247	248	249	250	251	252	253	254
Half life	19.4M	35.7H	3.11H	334D	351Y	13.08Y	900Y	2.645Y	17.81D	60.5D
γ-ray No.	18	20	33	19	13	20	37	19	29	18
β-bin No.	0	0	0	0	0	0	0	0	0	0
IC e No.	5	10	23	9	50	9	19	9	4	5

Element Cf	255
Half life	85M
γ-ray No.	0
β-bin No.	73(-)
IC e No.	0

Element Cl	34	34m	36	38	39	40
Half life	1.5264S	32.00M	3.01E+5Y	37.24M	55.6M	1.35M
γ-ray No.	15	7	15	2	8	65
β-bin No.	113(+)	125(+)	72(-)	124(-)	174(-)	188(-)
IC e No.	0	1	0	0	0	0

Element Cm	238	239	240	241	242	243	244	245	246	247
Half life	2.4H	2.9H	27D	32.8D	162.8D	29.1Y	18.10Y	8.5E+3Y	4.76E+3Y	1.56E+7Y
γ-ray No.	22	19	20	30	20	26	18	29	18	7
β-bin No.	0	61(+)	0	0	0	0	0	0	0	0
IC e No.	4	16	8	44	6	42	6	27	5	18

Element Cm	248	249	250	251
Half life	3.48E+5Y	64.15M	8300Y	16.8M
γ-ray No.	20	20	18	20
β-bin No.	0	91(-)	20(-)	72(-)
IC e No.	8	5	5	11

Element Co	54	55	56	57	58	60	60m	61	62	62m
Half life	1.48M	17.53H	77.23D	271.74D	70.86D	5.2713Y	10.467M	1.650H	1.50M	13.91M
γ-ray No.	4	14	21	8	4	2	8	4	13	12
β-bin No.	113(+)	76(+)	74(+)	0	66(+)	76(-)	79(-)	64(-)	134(-)	152(-)
IC e No.	1	0	1	8	1	2	4	2	0	0

Element Cr	48	49	51	55	56
Half life	21.56H	42.3M	27.7025D	3.497M	5.94M
γ-ray No.	4	4	5	7	6
β-bin No.	110(+)	82(+)	0	132(-)	77(-)
IC e No.	4	3	2	0	5

Element Cs	121	121m	123	124	125	126	127	128	129	130
Half life	155S	122S	5.88M	30.8S	45M	1.64M	6.25H	3.640M	32.06H	29.21M
γ-ray No.	71	106	70	18	41	27	31	17	20	24
β-bin No.	111(+)	107(+)	161(+)	124(+)	105(+)	126(+)	54(+)	147(+)	88(+)	99(+-)
IC e No.	13	23	21	0	3	1	18	1	26	0

Table 4: Nuclide included for egs5 based on ICRP 107 (4)

Element	Cs	130m	131	132	134	134m	135	135m	136	137	138
Half life		3.46M	9.689D	6.479D	2.0648Y	2.903H	2.3E+6Y	53M	13.16D	30.1671Y	33.41M
γ-ray No.		24	11	14	9	15	0	2	11	3	26
β-bin No.		0	0	83(+-)	74(-)	0	136(-)	0	70(-)	60(-)	199(-)
IC e No.		33	0	9	7	12	0	9	23	0	1

Element	Cs	138m	139	140
Half life		2.91M	9.27M	63.7S
γ-ray No.		22	171	242
β-bin No.		170(-)	107(-)	157(-)
IC e No.		21	0	1

Element	Cu	57	59	60	61	62	64	66	67	69
Half life		0.1963S	81.5S	23.7M	3.333H	9.673M	12.700H	5.120M	61.83H	2.85M
γ-ray No.		5	28	25	16	3	4	2	8	31
β-bin No.		195(+)	190(+)	190(+)	62(+)	148(+)	67(+-)	134(-)	58(-)	136(-)
IC e No.		0	0	0	0	0	0	0	7	0

Element	Dy	148	149	150	151	152	153	154	155	157	159
Half life		3.3M	4.20M	7.17M	17.9M	2.38H	6.4H	3.0E+6Y	9.9H	8.14H	144.4D
γ-ray No.		39	132	16	109	9	118	0	98	14	16
β-bin No.		53(+)	134(+)	189(+)	93(+)	0	59(+)	0	55(+)	0	0
IC e No.		34	104	6	27	6	33	0	44	20	6

Element	Dy	165	165m	166	167	168
Half life		2.334H	1.257M	81.6H	6.20M	8.7M
γ-ray No.		34	42	21	38	21
β-bin No.		66(-)	53(-)	99(-)	106(-)	67(-)
IC e No.		3	14	13	30	26

Element	Er	154	156	159	161	163	165	167m	169	171	172
Half life		3.73M	19.5M	36M	3.21H	75.0M	10.36H	2.269S	9.40D	7.516H	49.3H
γ-ray No.		28	30	125	105	19	15	9	8	24	17
β-bin No.		100(+)	0	79(+)	77(+)	95(+)	0	0	177(-)	76(-)	91(-)
IC e No.		5	26	29	35	0	0	6	2	19	24

Element	Er	173
Half life		1.434M
γ-ray No.		20
β-bin No.		116(-)
IC e No.		40

Element	Es	249	250	250m	251	253	254	254m	255	256
Half life		102.2M	8.6H	2.22H	33H	20.47D	275.7D	39.3H	39.8D	25.4M
γ-ray No.		34	31	39	29	45	40	11	0	20
β-bin No.		87(+)	0	63(+)	0	0	0	58(-)	59(-)	86(-)
IC e No.		66	94	36	27	57	26	18	0	4

Element	Eu	142	142m	143	144	145	146	147	148	149	150
Half life		2.34S	1.223M	2.59M	10.2S	5.93D	4.61D	24.1D	54.5D	93.1D	36.9Y
γ-ray No.		19	37	63	10	27	76	34	60	23	57
β-bin No.		168(+)	120(+)	108(+)	135(+)	83(+)	75(+)	72(+)	85(+)	0	95(+)
IC e No.		2	12	3	0	17	21	25	56	13	33

Element	Eu	150m	152	152m	154	154m	155	156	157	158	159
Half life		12.8H	13.537Y	9.3116H	8.593Y	46.0M	4.7611Y	15.19D	15.18H	45.9M	18.1M
γ-ray No.		22	40	19	29	19	15	51	57	78	66
β-bin No.		66(-+)	75(-+)	95(-)	94(-)	0	128(-)	124(-)	66(-)	172(-)	124(-)
IC e No.		1	19	5	11	38	24	7	13	6	8

Element	F	17	18
Half life		64.49S	109.77M
γ-ray No.		2	1
β-bin No.		88(+)	65(+)
IC e No.		2	0

Element	Fe	52	53	53m	55	59	60	61	62
Half life		8.275H	8.51M	2.526M	2.737Y	44.495D	1.5E+6Y	5.98M	68S
γ-ray No.		4	10	6	5	4	0	48	1
β-bin No.		82(+)	138(+)	0	0	80(-)	60(-)	149(-)	103(-)
IC e No.		1	1	10	0	0	0	2	1

Table 5: Nuclide included for egs5 based on ICRP 107 (5)

Element Fm	251	252	253	254	255	256	257			
Half life	5.30H	25.39H	3.00D	3.240H	20.07H	157.6M	100.5D			
γ-ray No.	48	19	44	19	37	18	28			
β-bin No.	90(+)	0	0	0	0	0	0			
IC e No.	42	10	17	10	37	5	31			
Element Fr	212	219	220	221	222	223	224	227		
Half life	20.0M	2.0E-2S	27.4S	4.9M	14.2M	22.00M	3.33M	2.47M		
γ-ray No.	28	14	60	17	62	57	94	146		
β-bin No.	131(+)	0	62(-)	0	103(-)	59(-)	143(-)	121(-)		
IC e No.	38	26	57	23	7	16	9	84		
Element Ga	64	65	66	67	68	70	72	73	74	
Half life	2.627M	15.2M	9.49H	3.2612D	67.71M	21.14M	14.10H	4.86H	8.12M	
γ-ray No.	45	22	28	13	4	3	32	18	119	
β-bin No.	155(+)	110(+)	105(+)	0	96(+)	84(-)	160(-)	78(-)	121(-)	
IC e No.	0	4	0	10	0	0	1	9	1	
Element Gd	142	143m	144	145	145m	146	147	148	149	150
Half life	70.2S	110.0S	4.47M	23.0M	85S	48.27D	38.1H	74.6Y	9.28D	1.79E+6Y
γ-ray No.	78	71	72	65	18	14	66	0	31	0
β-bin No.	168(+)	120(+)	143(+)	162(+)	104(+)	0	60(+)	0	150(+)	0
IC e No.	10	19	8	3	20	15	39	0	23	0
Element Gd	151	152	153	159	162					
Half life	124D	1.08E+14Y	240.4D	18.479H	8.4M					
γ-ray No.	25	0	15	17	11					
β-bin No.	0	0	0	99(-)	54(-)					
IC e No.	19	0	22	4	14					
Element Ge	66	67	68	69	71	75	77	78		
Half life	2.26H	18.9M	270.95D	39.05H	11.43D	82.78M	11.30H	88M		
γ-ray No.	44	29	5	21	5	7	75	2		
β-bin No.	53(+)	153(+)	0	62(+)	0	60(-)	127(-)	127(-)		
IC e No.	13	1	0	0	0	0	3	1		
Element H	3									
Half life	12.32Y									
γ-ray No.	0									
β-bin No.	11(-)									
IC e No.	0									
Element Hf	167	169	170	172	173	174	175	177	178	179
Half life	2.05M	3.24M	16.01H	1.87Y	23.6H	2.0E+15Y	70D	51.4M	31Y	25.05D
γ-ray No.	16	20	51	72	29	0	14	43	18	19
β-bin No.	152(+)	93(+)	0	0	91(+)	0	0	0	0	0
IC e No.	7	23	88	48	38	0	18	70	64	63
Element Hf	180	181	182	182m	183	184				
Half life	5.5H	42.39D	9E+6Y	61.5M	1.067H	4.12H				
γ-ray No.	10	11	8	40	23	16				
β-bin No.	108(-)	53(-)	53(-)	91(-)	79(-)	57(-)				
IC e No.	33	23	18	68	9	20				
Element Hg	190	191m	192	193	193m	194	195	195m	197	197m
Half life	20.0M	50.8M	4.85H	3.80H	11.8H	440Y	10.53H	41.6H	64.94H	23.8H
γ-ray No.	32	87	33	40	91	22	33	48	22	26
β-bin No.	101(+)	105(+)	0	66(+)	60(+)	0	56(+)	83(+)	0	0
IC e No.	67	59	56	41	50	0	24	30	7	19
Element Hg	199	203	205	206	207					
Half life	42.66M	46.612D	5.2M	8.15M	2.9M					
γ-ray No.	13	6	30	10	33					
β-bin No.	0	100(-)	78(-)	67(-)	175(-)					
IC e No.	12	6	5	4	31					
Element Ho	150	153	153m	154	154m	155	156	157	159	160
Half life	76.8S	2.01M	9.3M	11.76M	3.10M	48M	56M	12.6M	33.05M	25.6M
γ-ray No.	9	153	40	55	39	108	71	65	58	36
β-bin No.	160(+)	143(+)	155(+)	111(+)	163(+)	105(+)	189(+)	77(+)	83(+)	57(+)
IC e No.	5	38	26	5	58	17	6	33	61	35

Table 6: Nuclide included for egs5 based on ICRP 107 (6)

Element | Ho	161	162	162m	163	164	164m	166	166m	167	168
Half life	2.48H	15.0M	67.0M	4570Y	29M	38.0M	26.80H	1.20E+3Y	3.1H	2.99M
γ-ray No.	26	25	36	3	23	21	20	34	24	88
β-bin No.	0	57(+)	97(+)	0	98(-)	0	94(-)	67(-)	52(-)	135(-)
IC e No.	26	8	36	0	12	18	6	31	32	20

Element | Ho	168m	170
Half life	132S	2.76M
γ-ray No.	33	48
β-bin No.	0	168(-)
IC e No.	6	55

Element | I	118	118m	119	120	120m	121	122	123	124	125
Half life	13.7M	8.5M	19.1M	81.6M	53M	2.12H	3.63M	13.27H	4.1760D	59.400D
γ-ray No.	51	57	37	118	39	40	14	18	32	10
β-bin No.	145(+)	104(+)	108(+)	116(+)	148(+)	53(+)	162(+)	0	108(+)	0
IC e No.	0	15	3	1	3	8	0	7	2	6
Element | I	126	128	129	130	130m	131	132	132m	133	134
Half life	12.93D	24.99M	1.57E+7Y	12.36H	8.84M	8.02070D	2.295H	1.387H	20.8H	52.5M
γ-ray No.	11	9	11	17	40	11	45	13	18	49
β-bin No.	64(-+)	107(-)	79(-)	89(-)	124(-)	82(-)	108(-)	76(-)	78(-)	118(-)
IC e No.	3	0	6	5	9	5	3	17	1	3

Element | I	134m	135
Half life	3.60M	6.57H
γ-ray No.	17	31
β-bin No.	122(-)	108(-)
IC e No.	26	1

Element | In	103	105	106	106m	107	108	108m	109	109m	110
Half life	60S	5.07M	6.2M	5.2M	32.4M	58.0M	39.6M	4.2H	1.34M	4.9H
γ-ray No.	152	150	35	34	125	78	38	58	2	38
β-bin No.	123(+)	186(+)	123(+)	124(+)	111(+)	81(+)	178(+)	81(+)	0	58(+)
IC e No.	8	13	10	2	4	9	1	18	6	32
Element | In	110m	111	111m	112	112m	113m	114	114m	115	115m
Half life	69.1M	2.8047D	7.7M	14.97M	20.56M	1.6579H	71.9S	49.51D	4.41E+14Y	4.486H
γ-ray No.	34	7	3	12	9	5	8	9	0	6
β-bin No.	115(+)	0	0	80(-+)	0	0	101(-)	0	101(-)	85(-)
IC e No.	1	12	6	0	6	6	0	6	0	6
Element | In	116m	117	117m	118	118m	119	119m	121	121m	
Half life	54.41M	43.2M	116.2M	5.0S	4.364M	2.4M	18.0M	23.1S	3.88M	
γ-ray No.	11	4	10	8	60	4	17	9	23	
β-bin No.	58(-)	59(-)	90(-)	112(-)	114(-)	80(-)	135(-)	123(-)	185(-)	
IC e No.	4	5	7	0	10	5	4	6	6	
Element | Ir	180	182	183	184	185	186	186m	187	188	189
Half life	1.5M	15M	58M	3.09H	14.4H	16.64H	1.92H	10.5H	41.5H	13.2D
γ-ray No.	60	65	92	125	78	111	69	71	76	37
β-bin No.	125(+)	112(+)	118(+)	163(+)	70(+)	120(+)	135(+)	97(+)	83(+)	0
IC e No.	35	11	24	23	46	28	23	69	41	48
Element | Ir	190	190m	191	192	192m	193	194	194m	195	195m
Half life	11.78D	3.087H	4.94S	73.827D	1.45M	10.53D	19.28H	171D	2.5H	3.8H
γ-ray No.	47	26	16	17	16	22	36	13	22	71
β-bin No.	0	0	0	69(-)	77(-)	0	111(-)	98(-)	57(-)	96(-)
IC e No.	70	25	11	27	5	5	1	41	14	47

Element | Ir	196	196m
Half life	52S	1.40H
γ-ray No.	11	24
β-bin No.	162(-)	97(-)
IC e No.	4	29

Element | K	38	40	42	43	44	45	46
Half life	7.636M	1.251E+9Y	12.360H	22.3H	22.13M	17.3M	105S
γ-ray No.	3	16	5	10	36	23	16
β-bin No.	124(+)	67(-+)	178(-)	92(-)	143(-)	107(-)	161(-)
IC e No.	0	4	0	0	0	0	0

Table 7: Nuclide included for egs5 based on ICRP 107 (7)

Element Kr	74	75	76	77	79	81	81m	83m	85	85m
Half life	11.50M	4.29M	14.8H	74.4M	35.04H	2.29E+5Y	13.10S	1.83H	10.756Y	4.480H
γ-ray No.	45	46	55	11	29	9	4	12	1	5
β-bin No.	98(+)	185(+)	0	104(+)	62(+)	0	0	0	70(-)	86(-)
IC e No.	11	8	29	2	10	1	6	11	0	7

Element Kr	87	88	89
Half life	76.3M	2.84H	3.15M
γ-ray No.	24	35	320
β-bin No.	196(-)	147(-)	126(-)
IC e No.	0	2	4

Element La	128	129	130	131	132	132m	133	134	135	136
Half life	5.18M	11.6M	8.7M	59M	4.8H	24.3M	3.912H	6.45M	19.5H	9.87M
γ-ray No.	93	71	59	57	59	22	50	18	20	26
β-bin No.	126(+)	136(+)	109(+)	96(+)	186(+)	89(+)	52(+)	136(+)	90(+)	93(+)
IC e No.	13	4	2	15	1	27	8	0	3	1

Element La	137	138	140	141	142	143
Half life	6.0E+4Y	1.02E+11Y	1.6781D	3.92H	91.1M	14.2M
γ-ray No.	11	4	13	15	98	74
β-bin No.	0	129(-)	190(-)	127(-)	114(-)	172(-)
IC e No.	0	2	4	0	1	0

Element Lu	165	167	169	169m	170	171	171m	172	172m	173
Half life	10.74M	51.5M	34.06H	160S	2.012D	8.24D	79S	6.70D	3.7M	1.37Y
γ-ray No.	101	90	74	24	89	32	33	67	16	25
β-bin No.	142(+)	103(+)	55(+)	0	123(+)	64(+)	0	63(+)	0	0
IC e No.	18	28	56	5	14	43	6	48	5	25
Element Lu	174	174m	176	176m	177	177m	178	178m	179	180
Half life	3.31Y	142D	3.85E+10Y	3.635H	6.647D	160.4D	28.4M	23.1M	4.59H	5.7M
γ-ray No.	17	27	11	17	14	49	37	11	19	40
β-bin No.	178(+)	0	61(-)	67(-)	101(-)	78(-)	106(-)	55(-)	72(-)	141(-)
IC e No.	7	25	18	6	8	81	5	29	1	46

Element Lu	181
Half life	3.5M
γ-ray No.	36
β-bin No.	130(-)
IC e No.	59

Element Mg	27	28
Half life	9.458M	20.915H
γ-ray No.	3	7
β-bin No.	90(-)	87(-)
IC e No.	0	2

Element Mn	50	51	52	52m	53	54	56	57	58
Half life	1.75M	46.2M	5.591D	21.1M	3.7E+6Y	312.12D	2.5789H	85.4S	65.2S
γ-ray No.	12	2	8	4	23	1	7	23	38
β-bin No.	185(+)	111(+)	59(+)	133(+)	0	71(-+)	144(-)	135(-)	108(-)
IC e No.	2	0	3	0	0	2	0	4	1
Element Mo	89	90	91	91m	93	93m	99	101	102
Half life	2.11M	5.56H	15.49M	64.6S	4.0E+3Y	6.85H	65.94H	14.61M	11.3M
γ-ray No.	13	25	6	12	8	4	11	106	9
β-bin No.	117(+)	56(+)	172(+)	200(+)	0	0	123(-)	132(-)	52(-)
IC e No.	0	16	0	7	0	12	3	7	1

Element N	13	16
Half life	9.965M	7.13S
γ-ray No.	1	4
β-bin No.	61(+)	262(-)
IC e No.	0	1

Element Na	22	24
Half life	2.6019Y	14.9590H
γ-ray No.	2	2
β-bin No.	93(+)	105(-)
IC e No.	4	0

Table 8: Nuclide included for egs5 based on ICRP 107 (8)

Element | Nb	87	88	88m	89	89m	90	91	91m	92	92m
Half life	3.75M	14.5M	7.78M	2.03H	66M	14.60H	680Y	60.86D	3.47E+7Y	10.15D
γ-ray No.	7	20	87	41	5	21	9	11	4	5
β-bin No.	192(+)	111(+)	139(+)	161(+)	133(+)	76(+)	48(+)	69(+)	0	57(+)
IC e No.	8	5	6	0	1	11	0	6	8	4
Element | Nb	93	94	94m	95	95m	96	97	98	99	99m
Half life	16.13Y	2.03E+4Y	6.263M	34.991D	3.61D	23.35H	72.1M	51.3M	15.0S	2.6M
γ-ray No.	10	2	18	1	9	22	5	61	9	147
β-bin No.	0	96(-1)	62(-)	94(-)	60(-)	76(-)	65(-)	159(-)	172(-)	102(-)
IC e No.	6	2	7	2	7	4	1	4	9	7
Element | Nd	134	135	136	137	138	139	139m	140	141	141m
Half life	8.5M	12.4M	50.65M	38.5M	5.04H	29.7M	5.50H	3.37D	2.49H	62.0S
γ-ray No.	39	45	53	107	25	32	53	12	20	2
β-bin No.	88(+)	186(+)	55(+)	127(+)	0	91(+)	97(+)	0	82(+)	89(+)
IC e No.	60	11	21	12	19	3	33	0	2	6
Element | Nd	144	147	149	151	152					
Half life	2.29E+15Y	10.98D	1.728H	12.44M	11.4M					
γ-ray No.	0	20	61	72	25					
β-bin No.	0	91(-)	80(-)	124(-)	57(-)					
IC e No.	0	7	12	3	10					
Element | Ne	19	24								
Half life	17.22S	3.38M								
γ-ray No.	6	6								
β-bin No.	112(+)	101(-)								
IC e No.	10	8								
Element | Ni	56	57	59	63	65	66				
Half life	6.075D	35.60H	1.01E+5Y	100.1Y	2.51719H	54.6H				
γ-ray No.	6	6	6	0	9	0				
β-bin No.	57(+)	88(+)	27(+)	35(-)	108(-)	127(-)				
IC e No.	11	1	0	0	0	0				
Element | Np	232	233	234	235	236	236m	237	238	239	240
Half life	14.7M	36.2M	4.4D	396.1D	1.54E+5Y	22.5H	2.144E+6Y	2.117D	2.3565D	61.9M
γ-ray No.	32	39	30	32	31	26	47	14	28	39
β-bin No.	88(+)	0	80(+)	0	168(-)	55(-)	0	64(-)	73(-)	96(-)
IC e No.	51	23	40	8	30	11	41	14	42	33
Element | Np	240m	241	242(2.2m)	242(5.5m)						
Half life	7.22M	13.9M	2.2M	5.5M						
γ-ray No.	43	31	42	12						
β-bin No.	112(-)	66(-)	136(-)	82(-)						
IC e No.	7	10	3	24						
Element | O	14	15	19							
Half life	70.606S	122.24S	26.464S							
γ-ray No.	4	1	6							
β-bin No.	105(+)	88(+)	122(-)							
IC e No.	6	0	0							
Element | Os	180	181	182	183	183m	185	186	189	190m	191
Half life	21.5M	105M	22.10H	13.0H	9.9H	93.6D	2.0E+15Y	5.8H	9.9M	15.4D
γ-ray No.	28	90	28	43	34	13	0	14	6	15
β-bin No.	87(+)	77(+)	0	72(+)	87(+)	0	0	0	0	73(-)
IC e No.	40	35	41	27	42	26	0	5	28	11
Element | Os	191m	193	194	196						
Half life	13.10H	30.11H	6.0Y	34.9M						
γ-ray No.	23	39	22	18						
β-bin No.	0	59(-)	50(-)	59(-)						
IC e No.	5	13	5	5						
Element | P	30	32	33							
Half life	2.498M	14.263D	25.34D							
γ-ray No.	2	0	0							
β-bin No.	162(+)	87(-)	126(-)							
IC e No.	0	0	0							

Table 9: Nuclide included for egs5 based on ICRP 107 (9)

Element Pa	227	228	229	230	231	232	233	234	234m	235
Half life	38.3M	22H	1.50D	17.4D	3.276E+4Y	1.31D	26.967D	6.70H	1.17M	24.5M
γ-ray No.	53	61	28	36	44	24	24	81	58	1
β-bin No.	0	55(+)	0	0	0	68(-)	59(-)	64(-)	115(-)	72(-)
IC e No.	46	52	11	44	63	31	37	40	1	2

Element Pa	236	237
Half life	9.1M	8.7M
γ-ray No.	65	22
β-bin No.	146(-)	114(-)
IC e No.	11	20

Element Pb	194	195m	196	197	197m	198	199	200	201	201m
Half life	12.0M	15M	37M	8M	43M	2.4H	90M	21.5H	9.33H	61S
γ-ray No.	76	56	24	45	73	26	90	29	46	8
β-bin No.	81(+)	139(+)	94(+)	130(+)	116(+)	0	91(+)	0	92(+)	0
IC e No.	46	36	47	37	41	50	40	38	49	6

Element Pb	202	202m	203	204m	205	209	210	211	212	214
Half life	5.25E+4Y	3.53H	51.873H	67.2M	1.53E+7Y	3.253H	22.20Y	36.1M	10.64H	26.8M
γ-ray No.	15	12	13	4	15	0	21	21	14	23
β-bin No.	0	0	0	0	0	66(-)	33(-)	70(-)	59(-)	53(-)
IC e No.	0	40	9	18	0	0	5	3	9	18

Element Pd	96	97	98	99	100	101	103	107	109	109m
Half life	122S	3.10M	17.7M	21.4M	3.63D	8.47H	16.991D	6.5E+6Y	13.7012H	4.69M
γ-ray No.	24	68	20	94	16	35	10	0	20	9
β-bin No.	76(+)	177(+)	75(+)	119(+)	0	79(+)	0	19(-)	53(-)	0
IC e No.	18	6	15	3	25	12	0	0	6	6

Element Pd	111	112	114
Half life	23.4M	21.03H	2.42M
γ-ray No.	66	7	10
β-bin No.	109(-)	55(-)	74(-)
IC e No.	0	5	6

Element Pm	136	137m	139	140	140m	141	142	143	144	145
Half life	107S	2.4M	4.15M	9.2S	5.95M	20.90M	40.5S	265D	363D	17.7Y
γ-ray No.	19	105	63	18	37	33	8	7	10	16
β-bin No.	152(+)	104(+)	175(+)	128(+)	163(+)	135(+)	190(+)	0	0	0
IC e No.	12	40	6	0	10	0	0	6	19	11

Element Pm	146	147	148	148m	149	150	151	152	152m	153
Half life	5.53Y	2.6234Y	5.368D	41.29D	53.08H	2.68H	28.40H	4.12M	7.52M	5.25M
γ-ray No.	9	10	10	15	21	55	78	73	75	70
β-bin No.	81(-)	114(-)	125(-)	52(-)	55(-)	174(-)	61(-)	176(-)	165(-)	96(-)
IC e No.	7	0	1	20	1	2	17	4	23	47

Element Pm	154	154m
Half life	1.73M	2.68M
γ-ray No.	135	124
β-bin No.	199(-)	192(-)
IC e No.	19	39

Element Po	203	204	205	206	207	208	209	210	211	212
Half life	36.7M	3.53H	1.66H	8.8D	5.80H	2.898Y	102Y	138.376D	0.516S	2.99E-7S
γ-ray No.	85	43	76	38	33	15	13	1	3	0
β-bin No.	162(+)	0	127(+)	0	59(+)	0	0	0	0	0
IC e No.	42	58	57	46	52	28	13	6	13	0

Element Po	212m	213	214	215	216	218
Half life	45.1S	4.2E-6S	643E-4S	1.781E-3S	0.145S	3.10M
γ-ray No.	3	2	2	3	1	0
β-bin No.	0	0	0	0	0	131(-)
IC e No.	12	5	11	6	6	0

Element Pr	134	134	135	136	137	138	138m	139	140	142
Half life	11M	17M	24M	13.1M	1.28H	1.45M	2.12H	4.41H	3.39M	19.12H
γ-ray No.	41	32	54	77	61	10	18	21	6	2
β-bin No.	108(+)	124(+)	135(+)	179(+)	85(+)	172(+)	83(+)	57(+)	120(+)	110(-)
IC e No.	5	1	5	2	1	0	10	0	1	0

Element Pr	142m	143	144	144m	145	146	147	148	148m
Half life	14.6M	13.57D	17.28M	7.2M	5.984H	24.15M	13.4M	2.29M	2.01M
γ-ray No.	4	1	4	22	36	78	95	58	10
β-bin No.	0	95(-)	151(-)	79(-)	92(-)	107(-)	133(-)	124(-)	106(-)
IC e No.	2	0	0	6	0	1	14	5	8

Table 10: Nuclide included for egs5 based on ICRP 107 (10)

Element Pt	184	186	187	188	189	190	191	193	193m	195m
Half life	17.3M	2.08H	2.35H	10.2D	10.87H	6.50E+11Y	2.802D	50Y	4.33D	4.02D
γ-ray No.	71	38	70	25	90	0	34	20	25	26
β-bin No.	53(+)	0	101(+)	0	95(+)	0	0	0	0	0
IC e No.	59	105	72	34	65	0	55	0	9	23

Element Pt	197	197m	199	200	202
Half life	19.8915H	95.41M	30.80M	12.5H	44H
γ-ray No.	19	20	30	48	0
β-bin No.	73(-)	72(-)	87(-)	68(-)	91(-)
IC e No.	8	14	9	28	0

Element Pu	232	234	235	236	237	238	239	240	241	242
Half life	33.7M	8.8H	25.3M	2.858Y	45.2D	87.7Y	2.411E+4Y	6564Y	14.35Y	3.75E+5Y
γ-ray No.	21	23	32	18	26	18	33	18	30	18
β-bin No.	0	0	0	0	0	0	0	0	12(-)	0
IC e No.	0	4	13	8	19	8	12	8	0	6

Element Pu	243	244	245	246
Half life	4.956H	8.00E+7Y	10.5H	10.84D
γ-ray No.	25	17	79	24
β-bin No.	60(-)	0	59(-)	187(-)
IC e No.	18	5	28	31

Element Ra	219	220	221	222	223	224	225	226	227	228
Half life	10 MS	1.79E-2S	28S	38.0S	11.43D	3.66D	14.9D	1600Y	42.2M	5.75Y
γ-ray No.	24	3	34	7	37	11	15	12	59	15
β-bin No.	0	0	0	0	0	0	178(-)	0	66(-)	21(-)
IC e No.	24	6	28	6	44	6	5	6	29	13

Element Ra	230
Half life	93M
γ-ray No.	52
β-bin No.	72(-)
IC e No.	37

Element Rb	77	78	78m	79	80	81	81m	82	82m	83
Half life	3.77M	17.66M	5.74M	22.9M	33.4S	4.576H	30.5M	1.273M	6.472H	86.2D
γ-ray No.	73	103	74	35	5	29	46	4	25	9
β-bin No.	110(+)	157(+)	132(+)	133(+)	119(+)	62(+)	67(+)	170(+)	135(+)	0
IC e No.	1	0	3	7	0	1	7	0	5	11

Element Rb	84	84m	86	86m	87	88	89	90	90m
Half life	32.77D	20.26M	18.642D	1.017M	4.923E10Y	17.78M	15.15M	158S	258S
γ-ray No.	6	5	1	2	0	17	20	89	99
β-bin No.	84(+-)	0	90(-)	0	143(-)	134(-)	114(-)	166(-)	148(-)
IC e No.	1	14	0	6	0	0	0	1	3

Element Re	178	179	180	181	182	182m	183	184	184m	186
Half life	13.2M	19.5M	2.44M	19.9H	64.0H	12.7H	70.0D	38.0D	169 D	3.7183D
γ-ray No.	116	52	40	95	53	50	36	19	37	23
β-bin No.	184(+)	64(+)	135(+)	178(+)	0	88(+)	0	181(+)	0	55(-)
IC e No.	13	46	9	54	74	34	56	21	48	6

Element Re	186m	187	188	188m	189	190	190m
Half life	2.00E+5 Y	4.12E+10Y	17.0040H	18.59M	24.3H	3.1M	3.2H
γ-ray No.	22	0	34	21	44	27	77
β-bin No.	0	3(-)	108(-)	0	52(-)	89(-)	142(-)
IC e No.	19	0	5	24	12	14	28

Element Rh	94	95	95m	96	96m	97	97m	98	99	99m
Half life	70.6S	5.02M	1.96M	9.90M	1.51M	30.7M	46.2M	8.7M	16.1D	4.7H
γ-ray No.	21	72	16	113	35	72	79	14	37	40
β-bin No.	181(+)	159(+)	194(+)	163(+)	116(+)	105(+)	129(+)	171(+)	56(+)	54(+)
IC e No.	4	3	7	7	8	1	8	0	14	13
Element Rh	100	100m	101	101m	102	102m	103m	104	104m	105
Half life	20.8H	4.6M	3.3Y	4.34D	207D	3.742Y	56.114M	42.3S	4.34M	35.36H
γ-ray No.	35	39	10	12	20	17	14	19	27	4
β-bin No.	76(+)	132(+)	0	0	67(+-)	169(+)	0	124(-)	64(-)	58(-)
IC e No.	6	30	12	12	1	37	6	0	21	2

Table 11: Nuclide included for egs5 based on ICRP 107 (11)

Element | Rh	106	106m	107	108	109
Half life	29.80S	131M	21.7M	16.8S	80S
γ-ray No.	18	37	22	5	39
β-bin No.	179(-)	89(-)	77(-)	114(-)	131(-)
IC e No.	0	6	1	2	19

Element | Rn	207	209	210	211	212	215	216	217	218	219
Half life	9.25M	28.5M	2.4H	14.6H	23.9M	2.30 US	4.5E-5S	5.40E-4S	3.5E-2S	3.96S
γ-ray No.	125	66	51	25	1	0	0	0	1	12
β-bin No.	164(+)	126(+)	0	77(+)	0	0	0	0	0	0
IC e No.	73	29	68	64	6	0	0	0	6	21

Element | Ru	220	222	223	92	94	95	97	103	105	106
Half life	55.6S	3.8235D	24.3M	3.65M	51.8M	1.643H	2.9D	39.26D	4.44H	373.59D
γ-ray No.	2	2	89	61	7	59	13	6	36	0
β-bin No.	0	0	96(-)	141(+)	64(+)	62(+)	0	78(-)	97(-)	21(-)
IC e No.	6	6	15	24	7	6	11	4	8	0

Element | Ru	107	108
Half life	3.75M	4.55M
γ-ray No.	115	12
β-bin No.	148(-)	69(-)
IC e No.	4	21

Element | S	35	37	38
Half life	87.51D	5.05M	170.3M
γ-ray No.	0	6	4
β-bin No.	85(-)	123(-)	148(-)
IC e No.	0	0	0

Element | Sb	111	113	114	115	116	116m	117	118	118m	119
Half life	75S	6.67M	3.49M	32.1M	15.8M	60.3M	2.80H	3.6M	5.00H	38.19H
γ-ray No.	28	68	34	18	12	15	18	10	11	11
β-bin No.	102(+)	142(+)	187(+)	77(+)	121(+)	59(+)	59(+)	133(+)	156(+)	0
IC e No.	11	7	0	2	1	18	6	0	17	5

Element | Sb	120	120m	122	122m	124	124m	124m	125	126	126m
Half life	15.89M	5.76D	2.7238D	4.191M	60.20D	93S	20.2M	2.75856Y	12.35D	19.15M
γ-ray No.	8	8	4	20	19	4	11	18	25	8
β-bin No.	84(+)	0	100(-+)	0	117(-)	0	0	64(-)	96(-)	97(-)
IC e No.	0	16	1	17	1	8	5	13	7	4

Element | Sb	127	128	128m	129	130	130m	131	133
Half life	3.85D	9.01H	10.4M	4.40H	39.5M	6.3M	23.03M	2.5M
γ-ray No.	31	46	15	55	59	42	70	97
β-bin No.	76(-)	104(-)	131(-)	115(-)	147(-)	173(-)	152(-)	147(-)
IC e No.	5	5	3	3	8	15	3	10

Element | Sc	42	43	44	44m	46	47	48	49	50
Half life	62.0S	3.891H	3.97H	58.61H	83.79D	3.3492D	43.67H	57.2M	102.5S
γ-ray No.	7	2	4	4	2	1	5	2	13
β-bin No.	143(+)	61(+)	75(+)	0	75(-)	62(-)	68(-)	101(-)	135(-)
IC e No.	1	0	0	4	1	1	0	0	1

Element | Se	70	71	72	73	73m	75	77m	79	79m	81
Half life	41.1M	4.74M	8.40D	7.15H	39.8M	119.779D	17.36S	2.95E+5Y	3.92M	18.45M
γ-ray No.	33	87	5	9	31	12	5	0	11	11
β-bin No.	61(+)	189(+)	0	84(+)	89(+)	0	0	77(-)	125(-)	81(-)
IC e No.	8	3	6	4	7	26	6	0	6	0

Element | Se	81m	83	83m	84
Half life	57.28M	22.3M	70.1S	3.1M
γ-ray No.	8	83	35	1
β-bin No.	59(-)	167(-)	196(-)	94(-)
IC e No.	6	2	1	1

Element | Si	31	32
Half life	157.3M	132Y
γ-ray No.	5	0
β-bin No.	76(-)	114(-)
IC e No.	4	0

Table 12: Nuclide included for egs5 based on ICRP 107 (12)

Element | Sm	139	140	141	141m	142	143	143m	145	146	147
Half life	2.57M	14.82M	10.2M	22.6M	72.49M	8.75M	66S	340D	1.03E+8Y	1.060E11Y
γ-ray No.	86	94	33	43	14	32	10	13	0	0
β-bin No.	193(+)	88(+)	159(+)	157(+)	59(+)	123(+)	112(+)	0	0	0
IC e No.	25	16	2	8	0	2	8	6	0	0

Element | Sm	148	151	153	155	156	157
Half life	7E+15Y	90Y	46.50H	22.3M	9.4H	8.03M
γ-ray No.	0	18	24	24	19	70
β-bin No.	0	40(-)	82(-)	83(-)	74(-)	138(-)
IC e No.	0	2	9	3	19	17

Element | Sn	106	108	109	110	111	113	113m	117m	119m	121
Half life	1.92M	10.30M	18.0M	4.11H	35.3M	115.09D	21.4M	13.76D	293.1D	27.03H
γ-ray No.	22	24	112	6	29	9	15	8	15	0
β-bin No.	84(+)	78(+)	88(+)	0	73(+)	0	0	0	0	196(-)
IC e No.	43	27	10	5	0	2	6	9	11	0

Element | Sn	121m	123	123m	125	125m	126	127	127m	128	129
Half life	43.9Y	129.2D	40.06M	9.64D	9.52M	2.30E+5Y	2.10H	4.13M	59.07M	2.23M
γ-ray No.	13	4	6	26	27	14	83	4	14	31
β-bin No.	181(-)	72(-)	72(-1)	120(-)	104(-)	127(-)	162(-)	137(-)	64(-)	171(-)
IC e No.	8	0	3	0	3	24	2	2	17	2

Element | Sn	130	130m
Half life	3.72M	1.7M
γ-ray No.	39	100
β-bin No.	74(-)	102(-)
IC e No.	26	16

Element | Sr	79	80	81	82	83	85	85m	87m	89	90
Half life	2.25M	106.3M	22.3M	25.36D	32.41H	64.84D	67.63M	2.815H	50.53D	28.79Y
γ-ray No.	19	11	47	8	64	4	5	3	0	0
β-bin No.	109(+)	86(+)	147(+)	0	64(+)	0	67(+)	0	76(-)	56(-)
IC e No.	9	7	3	0	8	4	18	6	0	0

Element | Sr	91	92	93	94
Half life	9.63H	2.66H	7.423M	75.3S
γ-ray No.	23	7	163	15
β-bin No.	137(-)	98(-)	105(-)	177(-)
IC e No.	0	1	10	1

Element | Ta	170	172	173	174	175	176	177	178	178m	179
Half life	6.76M	36.8M	3.14H	1.14H	10.5H	8.09H	56.56H	9.31M	2.36H	1.82Y
γ-ray No.	34	91	104	126	84	107	31	31	13	19
β-bin No.	126(+)	187(+)	97(+)	151(+)	100(+)	111(+)	0	93(+)	0	0
IC e No.	14	17	26	13	39	43	7	8	32	0

Element | Ta	180	182	182m	183	184	185	186
Half life	8.152H	114.43D	15.84M	5.1D	8.7H	49.4M	10.5M
γ-ray No.	19	33	16	37	36	29	85
β-bin No.	72(-)	87(-)	0	67(-)	74(-)	92(-)	190(-)
IC e No.	12	37	25	55	31	22	12

Element | Tb	146	147	147m	148	148m	149	149m	150	150m	151
Half life	23S	1.64H	1.87M	60M	2.20M	4.118H	4.16M	3.48H	5.8M	17.609H
γ-ray No.	11	18	30	74	68	87	19	140	28	77
β-bin No.	143(+)	123(+)	183(+)	120(+)	151(+)	124(+)	94(+)	183(+)	78(+)	73(+)
IC e No.	2	7	6	1	38	24	12	2	67	36

Element | Tb	151m	152	152m	153	154	155	156	156m	156m	157
Half life	25S	17.5H	4.2M	2.34D	21.5H	5.32D	5.35D	24.4H	5.3H	71Y
γ-ray No.	18	139	74	80	112	43	45	3	17	20
β-bin No.	65(+)	150(+)	88(+)	56(+)	128(+)	0	0	0	0	0
IC e No.	21	13	95	38	20	62	32	7	6	0

Element | Tb	158	160	161	162	163	164	165
Half life	180Y	72.3D	6.906D	7.60M	19.5M	3.0M	2.11M
γ-ray No.	18	23	28	44	62	197	26
β-bin No.	85(-)	89(-)	61(-)	88(-)	70(-)	184(-)	144(-)
IC e No.	20	10	17	24	15	57	9

Element | Tc	91	91m	92	93	93m	94	94m	95	95m	96
Half life	3.14M	3.3M	4.25M	2.75H	43.5M	293M	52.0M	20.0H	61D	4.28D
γ-ray No.	108	10	25	12	21	13	20	9	12	12
β-bin No.	131(+)	119(+)	104(+)	83(+)	130(+)	83(+)	123(+)	0	72(+)	0
IC e No.	0	1	11	2	6	11	1	6	21	16

Table 13: Nuclide included for egs5 based on ICRP 107 (13)

Element | Tc	96m	97	97m	98	99	99m	101	102	102m	104
Half life	51.5M	2.6E+6Y	90.1D	4.2E+6Y	2.111E+5Y	6.015H	14.2M	5.28S	4.35M	18.3M
γ-ray No.	28	8	9	2	7	4	21	12	35	122
β-bin No.	180(+)	0	0	201(-)	148(-)	89(-)	67(-)	174(-)	115(-)	133(-)
IC e No.	6	0	6	3	0	13	1	0	9	1

Element | Tc	105
Half life	7.6M
γ-ray No.	122
β-bin No.	183(-)
IC e No.	21

Element | Te	113	114	115	115m	116	117	118	119	119m	121
Half life	1.7M	15.2M	5.8M	6.7M	2.49H	62M	6.00D	16.05H	4.70D	19.16D
γ-ray No.	43	130	61	35	28	24	8	17	29	7
β-bin No.	128(+)	81(+)	197(+)	150(+)	88(+)	91(+)	0	64(+)	65(+)	0
IC e No.	2	26	11	8	10	1	0	8	20	16
Element | Te	121m	123	123m	125	127	127m	129	129m	131	131m
Half life	154D	6.00E+14Y	119.25D	57.40D	9.35H	109D	69.6M	33.6D	25.0M	30H
γ-ray No.	14	16	7	12	7	21	20	19	33	53
β-bin No.	0	0	0	0	71(-)	74(-)	75(-)	82(-)	106(-)	122(-)
IC e No.	14	0	11	12	0	8	5	6	3	20

Element | Te	132	133	133m	134
Half life	3.204D	12.5M	55.4M	41.8M
γ-ray No.	10	98	112	24
β-bin No.	122(-)	133(-)	165(-)	68(-)
IC e No.	15	2	14	18

Element | Th	223	224	226	227	228	229	230	231	232	233
Half life	0.60S	1.05S	30.57M	18.68D	1.9116Y	7.34E+3Y	7.538E+4Y	25.52H	1.405E10Y	22.3M
γ-ray No.	59	14	20	39	20	46	21	39	17	94
β-bin No.	0	0	0	0	0	0	0	196(-)	0	64(-)
IC e No.	82	9	10	80	8	69	8	29	7	11

Element | Th	234	235	236
Half life	24.10D	7.1M	37.5M
γ-ray No.	22	28	30
β-bin No.	99(-)	97(-)	57(-)
IC e No.	20	16	11

Element | Ti	44	45	51	52
Half life	60.0Y	184.8M	5.76M	1.7M
γ-ray No.	4	3	3	6
β-bin No.	0	54(+)	109(-)	93(-)
IC e No.	5	0	1	4

Element | Tl	190	190m	194	194m	195	196	197	198	198m	199
Half life	2.6M	3.7M	33.0M	32.8M	1.16H	1.84H	2.84H	5.3H	1.87H	7.42H
γ-ray No.	28	70	13	49	98	55	55	89	39	35
β-bin No.	152(+)	109(+)	110(+)	144(+)	91(+)	167(-)	60(+)	123(+)	69(+)	94(+)
IC e No.	15	64	6	43	40	16	52	61	44	40
Element | Tl	200	201	202	204	206	206m	207	208	209	210
Half life	26.1H	72.912H	12.23D	3.78Y	4.200M	3.74M	4.77M	3.053M	2.161M	1.30M
γ-ray No.	45	21	11	18	16	24	3	7	7	24
β-bin No.	73(+)	0	0	78(-)	78(-)	0	73(-)	91(-)	99(-)	111(-)
IC e No.	47	22	7	0	1	69	0	12	10	14
Element | Tm	161	162	163	164	165	166	167	168	170	171
Half life	30.2M	21.70M	1.810H	2.0M	30.06H	7.70H	9.25D	93.1D	128.6D	1.92Y
γ-ray No.	98	91	84	75	80	63	15	25	15	16
β-bin No.	113(+)	192(+)	72(+)	154(+)	138(+)	99(+)	0	59(-+)	98(-)	50(-)
IC e No.	36	7	38	6	64	32	11	33	5	6

Element | Tm	172	173	174	175	176
Half life	63.6H	8.24H	5.4M	15.2M	1.85M
γ-ray No.	31	6	47	56	94
β-bin No.	95(-)	66(-)	61(-)	96(-)	194(-)
IC e No.	7	10	35	12	48

Table 14: Nuclide included for egs5 based on ICRP 107 (14)

Element U	227	228	230	231	232	233	234	235	235m	236
Half life	1.1M	9.1M	20.8D	4.2D	68.9Y	1.592E+5Y	2.455E+5Y	7.04E+8Y	26M	2.342E+7Y
γ-ray No.	38	19	22	33	22	53	20	22	1	19
β-bin No.	0	0	0	0	0	0	0	0	0	0
IC e No.	33	11	8	19	9	32	9	69	1	8

Element U	237	238	239	240	242
Half life	6.75D	4.468E+9Y	23.45M	14.1H	16.8M
γ-ray No.	29	18	35	38	20
β-bin No.	93(-)	0	65(-)	191(-)	62(-)
IC e No.	30	8	7	13	6

Element V	47	48	49	50	52	53
Half life	32.6M	15.9735D	330D	1.50E+17Y	3.743M	1.61M
γ-ray No.	5	6	23	2	5	7
β-bin No.	97(+)	102(+)	0	128(-)	129(-)	123(-)
IC e No.	0	0	0	2	0	0

Element W	177	178	179	179m	181	185	185m	187	188	190
Half life	132M	21.6D	37.05M	6.40M	121.2D	75.1D	1.597M	23.72H	69.78D	30.0M
γ-ray No.	73	21	20	21	20	14	39	18	13	15
β-bin No.	80(+)	0	0	0	0	88(-)	0	67(-)	176(-)	97(-)
IC e No.	47	0	6	9	3	0	54	10	3	11

Element Xe	120	121	122	123	125	127	127m	129m	131m	133
Half life	40M	40.1M	20.1H	2.08H	16.9H	36.4D	69.2S	8.88D	11.84D	5.243D
γ-ray No.	100	100	25	72	26	11	8	11	11	11
β-bin No.	58(+)	141(+)	0	77(+)	90(+)	0	0	0	0	175(-)
IC e No.	53	4	41	9	22	22	12	11	6	7

Element Xe	133m	135	135m	137	138
Half life	2.19D	9.14H	15.29M	3.818M	14.08M
γ-ray No.	9	10	4	83	41
β-bin No.	0	93(-)	86(-)	106(-)	138(-)
IC e No.	6	4	6	1	7

Element Y	81	83	83m	84m	85	85m	86	86m	87	87m
Half life	70.4S	7.08M	2.85M	39.5M	2.68H	4.86H	14.74H	48M	79.8H	13.37H
γ-ray No.	16	123	12	26	8	65	46	7	5	4
β-bin No.	114(+)	174(+)	164(+)	131(+)	101(+)	114(+)	159(+)	76(+)	92(+)	63(+)
IC e No.	17	4	13	0	1	1	1	12	3	6

Element Y	88	89	90	90m	91	91m	92	93	94	95
Half life	106.65D	15.663S	64.10H	3.19H	58.51D	49.71M	3.54H	10.18H	18.7M	10.3M
γ-ray No.	4	1	9	3	1	1	13	27	30	53
β-bin No.	78(+)	0	116(-)	66(-)	79(-)	0	183(-)	146(+)	124(-)	112(-)
IC e No.	4	6	0	9	0	6	0	0	0	0

Element Yb	162	163	164	165	166	167	169	175	177	178
Half life	18.87M	11.05M	75.8M	9.9M	56.7H	17.5M	32.026D	4.185D	1.911H	74M
γ-ray No.	55	120	46	106	16	33	23	11	26	6
β-bin No.	65(+)	122(+)	0	74(+)	0	66(+)	0	95(-)	71(-)	66(-)
IC e No.	27	11	24	21	6	48	57	7	6	5

Element Yb	179
Half life	8.0M
γ-ray No.	25
β-bin No.	104(-)
IC e No.	38

Element Zn	60	61	62	63	65	69	69m	71	71m	72
Half life	2.38M	89.1S	9.186H	38.47M	244.06D	56.4M	13.76H	2.45M	3.96H	46.5H
γ-ray No.	9	47	14	10	4	2	1	21	27	13
β-bin No.	155(+)	117(+)	62(+)	119(+)	166(+)	92(-)	79(-)	142(-)	102(-)	171(-)
IC e No.	3	0	5	0	2	0	5	0	0	12

Element Zr	85	86	87	88	89	89m	93	95	97
Half life	7.86M	16.5H	1.68H	83.4D	78.41H	4.161M	1.53E+6Y	64.032D	16.744H
γ-ray No.	37	10	23	5	8	3	0	2	27
β-bin No.	184(+)	91(+)	115(+)	0	92(+)	121(+)	47(-)	58(-)	97(-)
IC e No.	3	12	0	6	3	6	0	2	2

Figures

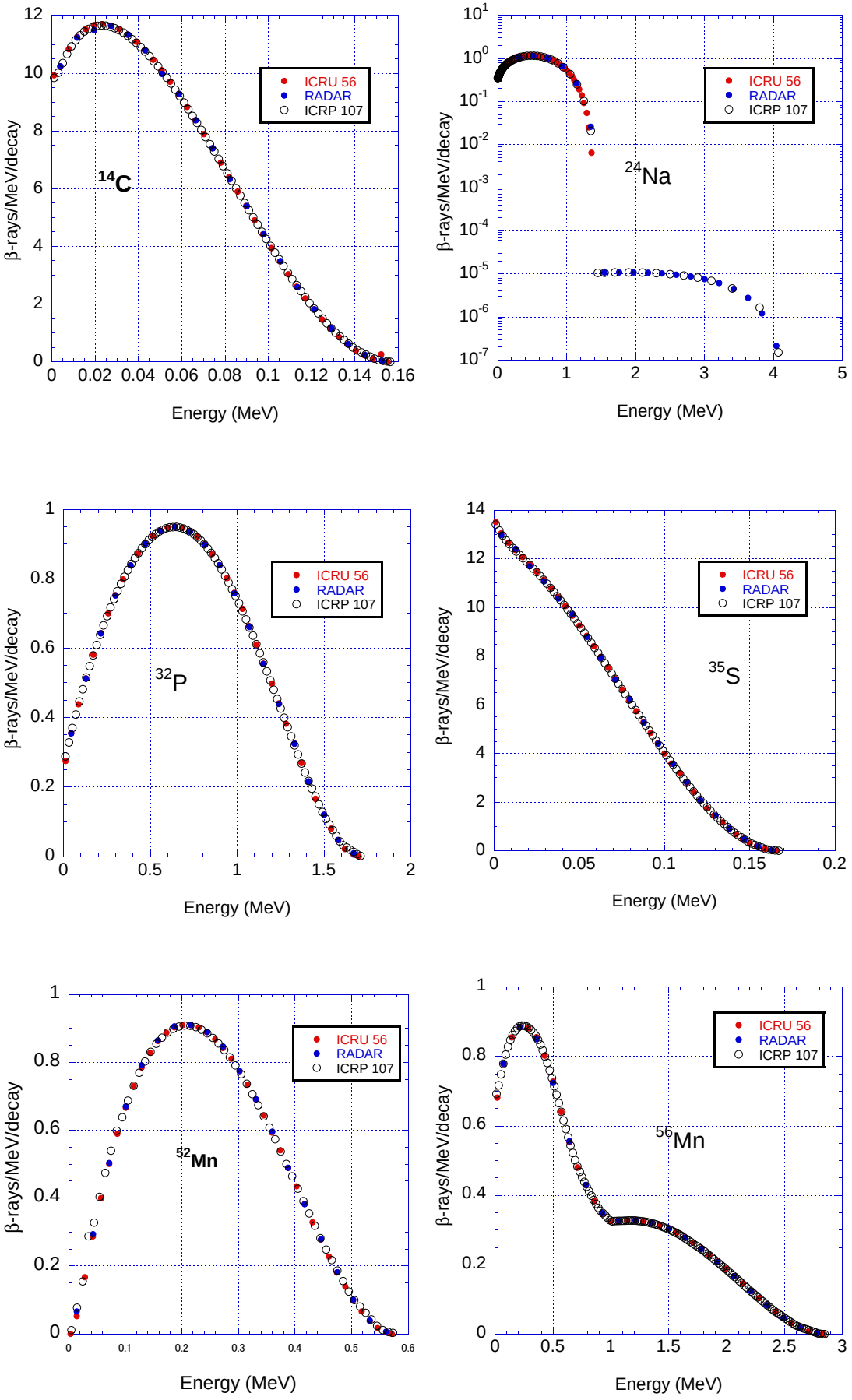

Figure 1: Comparison of β-ray spectrum between ICRU Report 56, RADAR and ICRP 107(1).

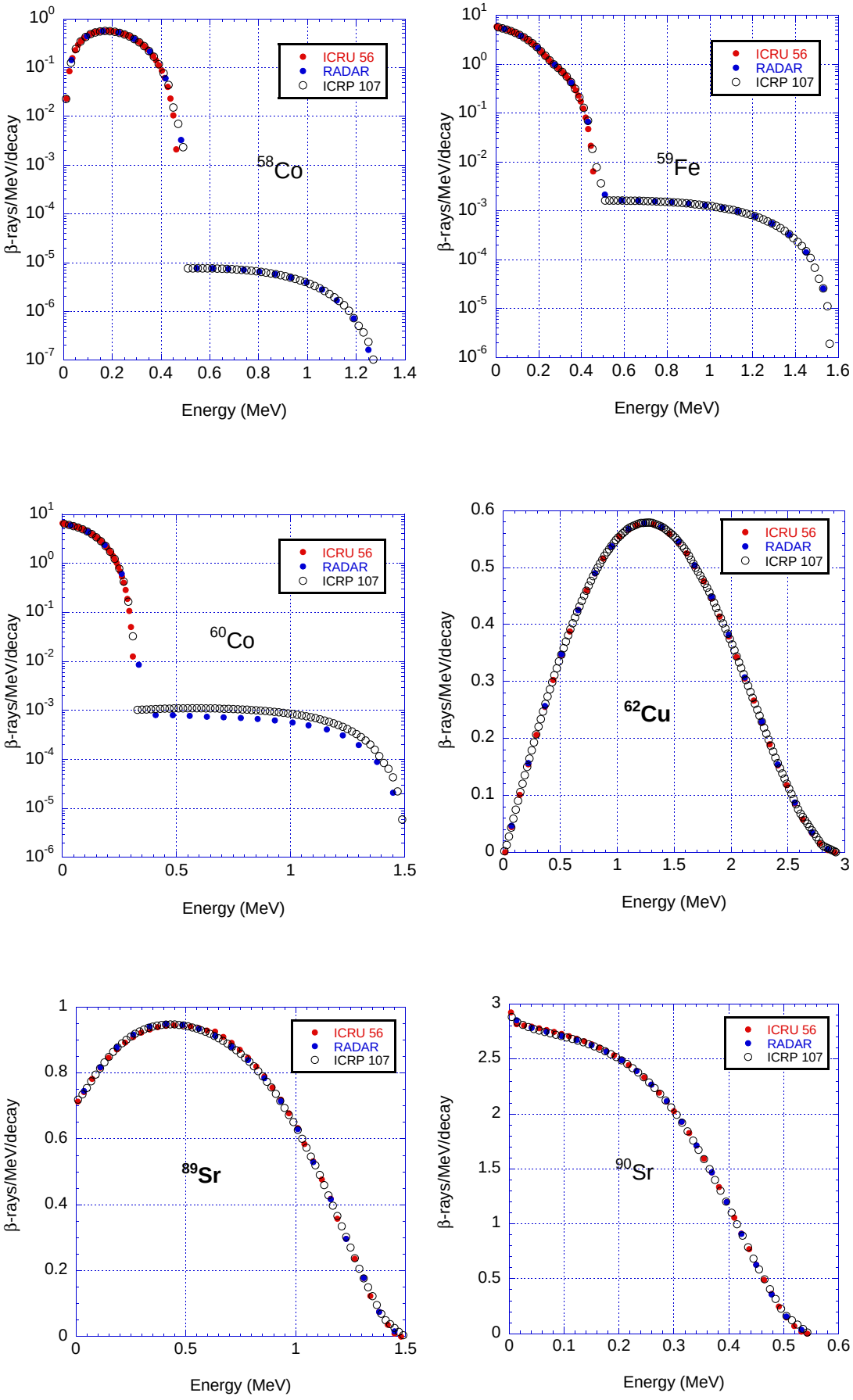

Figure 2: Comparison of β-ray spectrum between ICRU Report 56, RADAR and ICRP 107(2).

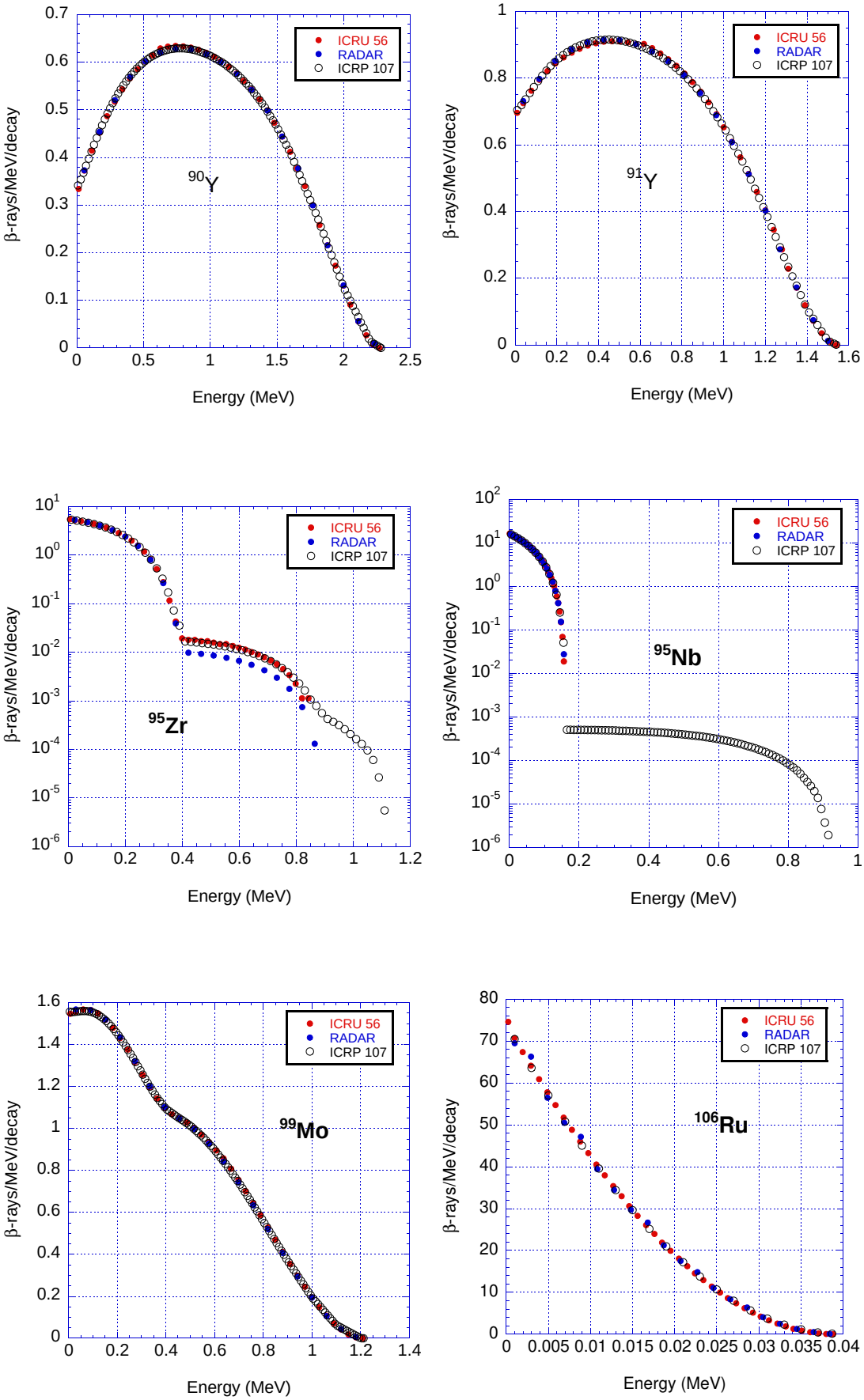

Figure 3: Comparison of β-ray spectrum between ICRU Report 56, RADAR and ICRP 107(3).

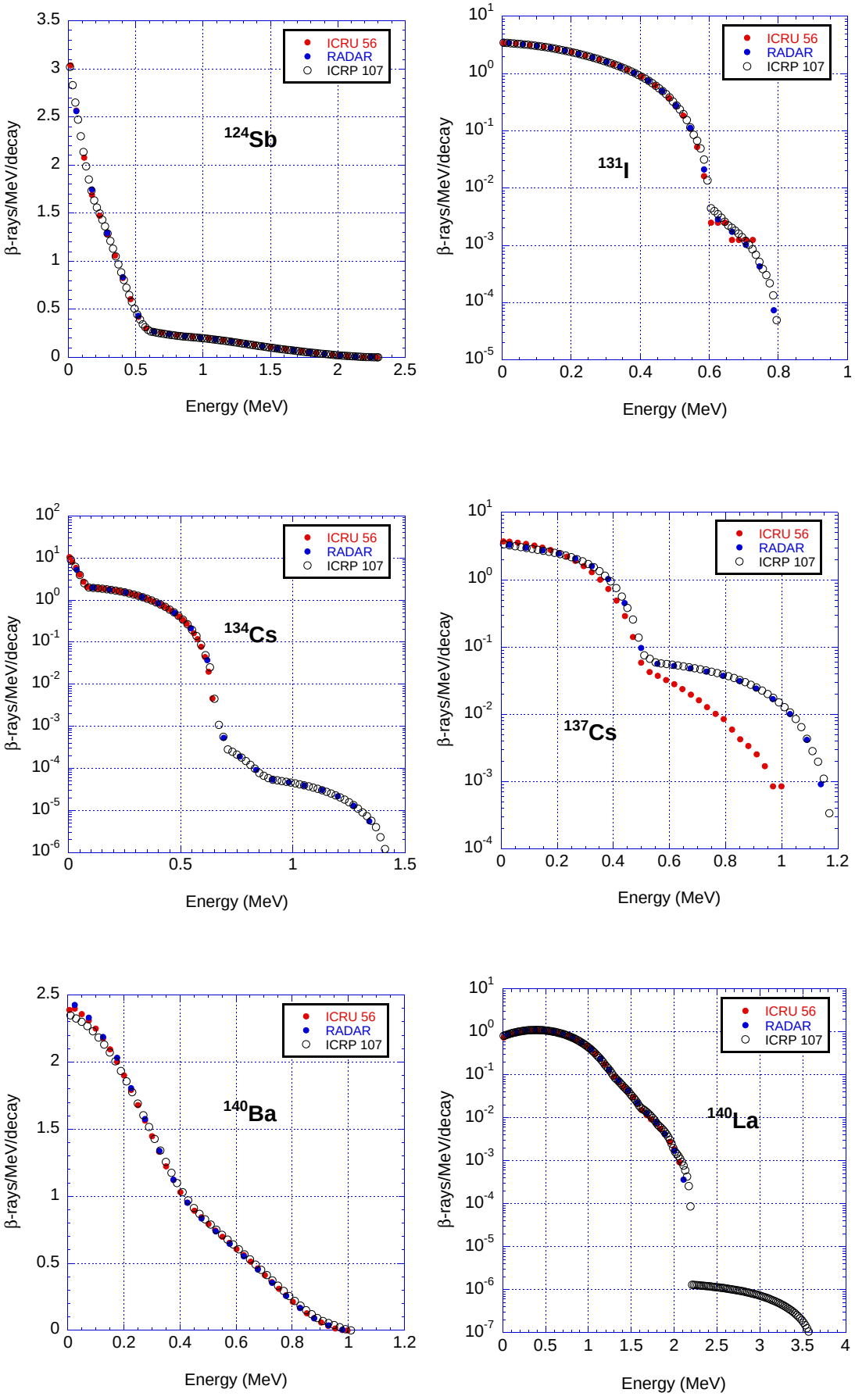

Figure 4: Comparison of β-ray spectrum between ICRU Report 56, RADAR and ICRP 107(4).

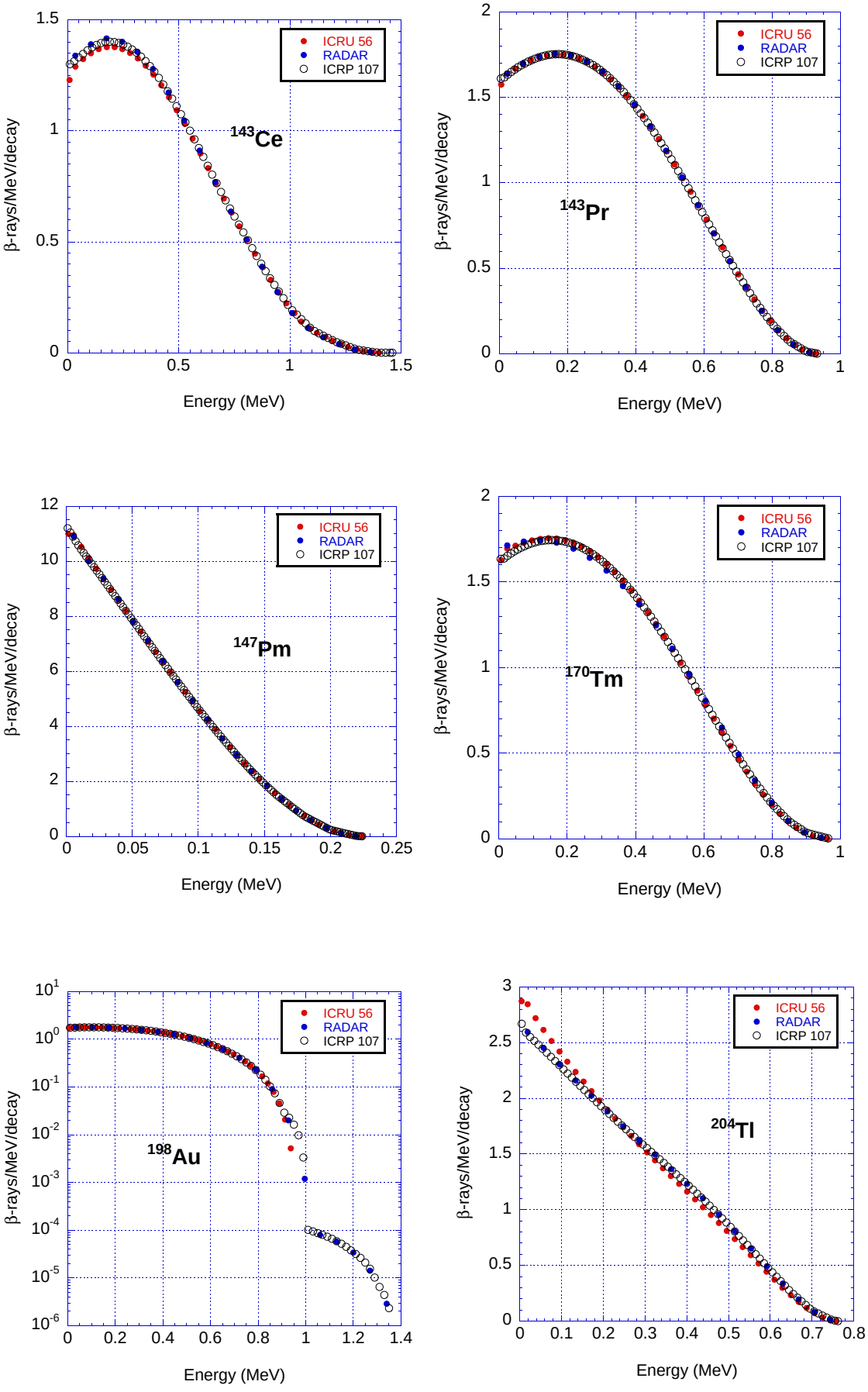

Figure 5: Comparison of β-ray spectrum between ICRU Report 56, RADAR and ICRP 107(5).

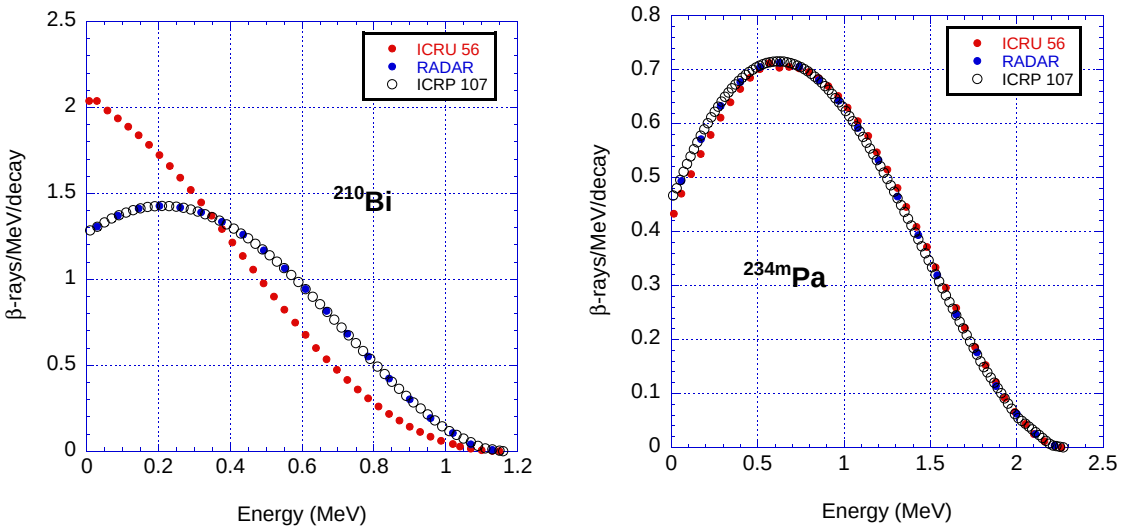

Figure 6: Comparison of β-ray spectrum between ICRU Report 56, RADAR and ICRP 107(6).

Appendix: Full listings of `ucicrp107.f`

```
!*****************************************************************
!****************************  KEK, High Energy Accelerator Research  *
!****************************  Organization                           *
!***** u c i c r p 1 0 7 *****                                       *
!****************************    EGS5.0 USER CODE -  12 May 2016      *
!* This is a general User Code based on the cg geometry scheme.       *
!*****************************************************************
!                                                                    *
!  PROGRAMMERS:  H. Hirayama                                         *
!                Applied Research Laboratory                         *
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!                                                                    *
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!                                                                    *
!                Y. Namito                                           *
!                Radiation Science Center                            *
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!                Fax:         +81-29-864-1993                        *
!                                                                    *
!*****************************************************************
!*****************************************************************
! The ucicrp107.f User Code requires a cg-input file only           *
! (e.g., ucradar.data).                                             *
! The following shows the geometry for usource.data.                *
! Input data for CG geometry must be written at the top of data-input  *
! file together with material assignment to each region.  Cg-data can  *
! be checked by CGview.                                             *
! This user code is sample user code to use ICRP 107 gamma-ray,     *
! beta-ray or internal conversion electron data.                    *
! Use Ranlux random number generator.                               *
!*****************************************************************
!                                                                    *
!             ----------------------                                 *
!             cg Geometry (ucsource)                                 *
!             ----------------------                                 *
!                                                                    *
!                                                                    *
!                    R                                               *
!                    ^                                               *
!                    |                                               *
!           +----+---+----+--------+------+---                       *
!           |    |   |                                              *
!           |    Outer| vacuum region                               *
!           +    +----+----+--------+------+--- r=6.0 cmm           *
!           |    |         Vacuum          |                        *
!           |    +----+--------+------+--- R=4.0 cm                 *
!           |    |    |   Vacuum          |                        *
!           +    +    +    +--------+      +--- R=2.0 cm           *
!           |    |    |    |        |      |                        *
!           |    |    |    | Vacuum |Vacuum|                        *
! 1.253 MeV |    |    |    |        |      |                        *
!      =========>+----+----+--------+------+--------> Z              *
!     photons  -5.0  0.0  3.0      5.0    7.0 cm                     *
!                                                                    *
!                                                                    *
!                                                                    *
!                                                                    *
!*****************************************************************
!23456789|123456789|123456789|123456789|123456789|123456789|123456789|12

!-----------------------------------------------------------------------
!------------------------------ main code ------------------------------
!-----------------------------------------------------------------------
!-----------------------------------------------------------------------
! Step 1: Initialization
!-----------------------------------------------------------------------
      implicit none

!     ------------
!     EGS5 COMMONs
!     ------------
      include 'include/egs5_h.f'                ! Main EGS "header" file
```

```
      include 'include/egs5_bounds.f'
      include 'include/egs5_brempr.f'
      include 'include/egs5_edge.f'
      include 'include/egs5_media.f'
      include 'include/egs5_misc.f'
      include 'include/egs5_thresh.f'
      include 'include/egs5_uphiot.f'
      include 'include/egs5_useful.f'
      include 'include/egs5_usersc.f'
      include 'include/egs5_userxt.f'
      include 'include/randomm.f'

!     ----------------------
!     Auxiliary-code COMMONs
!     ----------------------
      include 'auxcommons/aux_h.f'   ! Auxiliary-code "header" file

      include 'auxcommons/edata.f'
      include 'auxcommons/etaly1.f'
      include 'auxcommons/instuf.f'
      include 'auxcommons/lines.f'
      include 'auxcommons/nfac.f'
      include 'auxcommons/watch.f'

!     ------------------
!     cg related COMMONs
!     ------------------
      include 'auxcommons/geom_common.f' ! geom-common file
      integer irinn

      common/totals/                          ! Variables to score
     * maxpict
      integer maxpict

!**** real*8                                                 ! Arguments
      real*8 totke
      real*8 rnnow,etot

      real*8                                              ! Local variables
     * availke,tnum,tnumb,tnumic,wtin,wtsum,xi0,yi0,zi0,emax

       real*8
     * spg(MXEBIN),spe(MXEBIN),spic(MXEBIN),egamma(210),pgamma(210),
     * cgamma(210),ebeta(210),pbeta(210),cbeta(210),eicon(210),
     * picon(210),cicon(210)

      real
     * tarray(2),tt,tt0,tt1,cputime,etime

      integer
     * i,icases,idin,ie,ifti,ifto,ii,j,k,n,ner,nbtype,ngnum,nbnum,
     * nicon,istype

      character*10 atom
      character*72 soinf
      character*72 filename

      character*24 medarr(1)

!     ----------
!     Open files
!     ----------
!-----------------------------------------------------------------
!     Units 7-26 are used in pegs and closed.  It is better not
!     to use as output file. If they are used, they must be opened
!     after call pegs5. Unit for pict must be 39.
!-----------------------------------------------------------------
      write(6,*) ' Source type 0:gamma, 1:beta, 2:IC'
      read(5,*) istype

      write(6,'(A)')
     *   ' Key in atomic name and mass number like Sr-90'

      read(5,*) atom

      do i=1,10
        if(atom(i:i).eq.' ') go to 10
      end do
10    ii=i-1
```

```
      if(istype.eq.0) then  ! gamma-ray
        filename='ICRP_107/gamma-ray/'//atom(1:ii)//'.data'
      else
        filename='ICRP_107/beta-ray/'//atom(1:ii)//'.data'
      end if

      open(2,file=filename,STATUS='old')

      open(6,FILE='egs5job.out',STATUS='unknown')
      open(4,FILE='egs5job.inp',STATUS='old')
      open(39,FILE='egs5job.pic',STATUS='unknown')

!     ====================
      call counters_out(0)
!     ====================

!-----------------------------------------------------------------------
! Step 2: pegs5-call
!-----------------------------------------------------------------------
!     ==============
      call block_set                ! Initialize some general variables
!     ==============

!     ---------------------------------
!     Define media before calling PEGS5
!     ---------------------------------

      nmed=1
      medarr(1)='NAI                      '

      do j=1,nmed
        do i=1,24
          media(i,j)=medarr(j)(i:i)
        end do
      end do

      chard(1) = 1.0d0       !  optional, but recommended to invoke
                             !  automatic step-size control

      write(6,fmt="('chard =',5e12.5)") (chard(j),j=1,1)

!     ----------------------------------
!     Run KEK PEGS5 before calling HATCH
!     ----------------------------------
      write(6,'(A/)') 'PEGS5-call comes next'

!     ==========
      call pegs5
!     ==========

!-----------------------------------------------------------------------
! Step 3: Pre-hatch-call-initialization
!-----------------------------------------------------------------------
!-----------------------------------------------
!     Initialize cg related parameter
!-----------------------------------------------
      npreci=3     ! PICT data mode for CGView in free format

      ifti = 4     ! Input unit number for cg-data
      ifto = 39    ! Output unit number for PICT

      write(6,fmt="(' CG data')")
      call geomgt(ifti,6)  ! Read in CG data
      write(6,fmt="(' End of CG data',/)")

      if(npreci.eq.3) write(ifto,fmt="('CSTA-FREE-TIME')")
      if(npreci.eq.2) write(ifto,fmt="('CSTA-TIME')")

      rewind ifti
      call geomgt(ifti,ifto)! Dummy call to write geom info for ifto
      write(ifto,'(A)') 'CEND'

!-------------------------------
!     Get nreg from cg input data
!-------------------------------
      nreg=izonin

!   Read material for each refion from egs5job.data
      read(4,'(15I5)') (med(i),i=1,nreg)

!     ------------------------------------------------------------
```

```
!     Random number seeds.  Must be defined before call hatch
!     or defaults will be used.  inseed (1- 2^31)
!     ------------------------------------------------------
      luxlev = 1
      inseed=1
      write(6,'(/A,I12.5X,A)') ' inseed=',inseed,
     *   ' (seed for generating unique sequences of Ranlux)'

!     =============
      call rluxinit  ! Initialize the Ranlux random-number generator
!     =============

!-----------------------------------------------------------------------
! Step 4:  Determination-of-incident-particle-parameters
!-----------------------------------------------------------------------
! Read data fron ICRP_107 data-base
!     soinf is explanation of source
! Gamma-ray
      if(istype.eq.0) then   ! gamma
        nbtype=0
        read(2,'(A72)') soinf
        read(2,*) ngnum
        do i=1,ngnum
          read(2,*) egamma(i),pgamma(i)
        end do
!-------------------------------------
!     Calculate CDF from emission rates
!-------------------------------------
        tnum=0.D0
        do ie=1,ngnum
          tnum=tnum+pgamma(ie)
        end do

        cgamma(1)=pgamma(1)/tnum
        pgamma(1)=pgamma(1)/tnum
        do ie=2,ngnum
          pgamma(ie)=pgamma(ie)/tnum
          cgamma(ie)=cgamma(ie-1)+pgamma(ie)
        end do
! Beta-ray and internal conversion electron
      else
        read(2,'(A72)') soinf
        read(2,*)  nbtype
        read(2,*) nbnum
        do i=1,nbnum
          read(2,*) ebeta(i),pbeta(i)
        end do
        read(2,*) nicon
        if(nicon.ne.0) then
          do i=1,nicon
            read(2,*) eicon(i),picon(i)
          end do
        end if

        if(istype.eq.2.and.nicon.eq.0) then
          write(6,'(A)') ' No IC-electron emitted'
          stop
        end if

!-------------------------------------------------
!     Calculate CDF from spectrum or emission rates
!-------------------------------------------------
        tnumb=0.d0
        do ie=1,nbnum
          tnumb=tnumb+pbeta(ie)
        end do
        cbeta(1)=0.d0
        pbeta(1)=0.d0
        do ie=2,nbnum
          pbeta(ie)=pbeta(ie)/tnumb
          cbeta(ie)=cbeta(ie-1)+pbeta(ie)
        end do

        tnumic=0.d0
        if(nicon.ne.0) then
          do ie=1,nicon
            tnumic=tnumic+picon(ie)
          end do
          cicon(1)=picon(1)/tnumic
          picon(1)=picon(1)/tnumic
```

```
          if(nicon.ge.2) then
            do ie=2,nicon
              picon(ie)=picon(ie)/tnumic
              cicon(ie)=cicon(ie-1)+picon(ie)
            end do
          end if
        end if
      end if

      if(istype.eq.0) then   ! gamma
        ekein=egamma(ngnum) ! Maximum kinetic energy
      elseif(istype.eq.1) then   ! beta-ray
          ekein=ebeta(nbnum) ! Maximum kinetic energy
      else     ! IC electron
        ekein=eicon(nicon) ! Maximum kinetic energy
      end if

      xin=0.0             ! Source position
      yin=0.0
      zin=-5.0
      uin=0.0            ! Moving along z axis
      vin=0.0
      win=1.0
      irin=0             ! Starting region (0: Automatic search in CG)
      wtin=1.0           ! Weight = 1 since no variance reduction used

!-----------------------------------------------------------------------
! Step 5:   hatch-call
!-----------------------------------------------------------------------
      emaxe = 0.D0 ! dummy value to extract min(UE,UP+RM).

      write(6,'(/A)') '  Call hatch to get cross-section data'

!     ------------------------------
!     Open files (before HATCH call)
!     ------------------------------
      open(UNIT=KMPI,FILE='pgs5job.pegs5dat',STATUS='old')
      open(UNIT=KMPO,FILE='egs5job.dummy',STATUS='unknown')

      write(6,'(/A/)') ' HATCH-call comes next'

!     ==========
      call hatch
!     ==========

!     ------------------------------
!     Close files (after HATCH call)
!     ------------------------------
      close(UNIT=KMPI)
      close(UNIT=KMPO)

      write(39,fmt="('MSTA')")
      write(39,fmt="(i4)") nreg
      write(39,fmt="(15i4)") (med(i),i=1,nreg)
      write(39,fmt="('MEND')")

!-----------------------------------------------------------------------
! Step 6:  Initialization-for-howfar
!-----------------------------------------------------------------------
!-----------------------------------------------------------------------
! Step 7:  Initialization-for-ausgab
!-----------------------------------------------------------------------

      ncount = 0
      ilines = 0
      nwrite = 10
      nlines = 10
      idin = -1
      totke = 0.
      wtsum = 0.

!     =========================
      call ecnsv1(0,nreg,totke)
      call ntally(0,nreg)
!     =========================

!     Zero the variables
      if(istype.eq.0) then   ! gamma
        do j=1,ngnum
          spg(j)=0.D0
        end do
```

```
      elseif(istype.eq.1) then   ! beta
        do j=1,nbnum
          spe(j)=0.D0
        end do
      else                       ! IC electron
        do j=1,nbnum
          spe(j)=0.D0
        end do
      end if

!     Set histories and histories to write trajectories
      ncases=100000
!     Set maximum number for pict
      maxpict=500

      tt=etime(tarray)
      tt0=tarray(1)

!-----------------------------------------------------------------------
! Step 8:  Shower-call
!-----------------------------------------------------------------------
!     Write batch number
      write(39,fmt="('0    1')")
                                          ! -------------------------
      do i=1,ncases                       ! Start of batch -loop
                                          ! -------------------------

        wtin = 1.0

        wtsum = wtsum + wtin              ! Keep running sum of weights

!       ------------------------
!       Determine source energy
!       ------------------------
        if(istype.eq.0) then    ! photon
          iqin=nbtype
          call randomset(rnnow)
          do ie=1,ngnum
            if(rnnow.le.cgamma(ie)) go to 1000
          end do
1000      ekein=egamma(ie)
          spg(ie)=spg(ie)+1.0
        elseif(istype.eq.1) then        ! beta-ray
          iqin=nbtype
          call randomset(rnnow)
          do ie=2,nbnum
            if(rnnow.le.cbeta(ie)) go to 60
          end do
60        ekein=ebeta(ie-1)+(rnnow-cbeta(ie-1))*
     *          (ebeta(ie)-ebeta(ie-1))/(cbeta(ie)-cbeta(ie-1))
          spe(ie)=spe(ie)+1.0
        else       ! IC
          call randomset(rnnow)
          nbtype=-1
          do ie=1,nicon
            if(rnnow.le.cicon(ie)) go to 1100
          end do
1100      ekein=eicon(ie)
          spic(ie)=spic(ie)+1.0
        end if

        etot = ekein + iabs(iqin)*RM        ! Incident total energy (MeV)
        availke = etot + iqin*RM        ! Available K.E. (MeV) in system
        totke = totke + availke                 ! Keep running sum of KE

!       ---------------------------
!       Determine source  direction
!       ---------------------------

!       -------------------------
!       Determine source position
!       -------------------------

!       ----------------------------------
!       Get source region from cg input data
!       ----------------------------------

        if(irin.le.0.or.irin.gt.nreg) then
          call srzone(xin,yin,zin,iqin+2,0,irinn)
          if(irinn.le.0.or.irinn.ge.nreg) then
```

```
            write(6,fmt="(' Stopped in MAIN. irinn = ',i5)")irinn
            stop
          end if
          call rstnxt(iqin+2,0,irinn)
        else
          irinn=irin
        end if

!       ------------------------------------------------------------
!       Compare maximum energy of material data and incident energy
!       ------------------------------------------------------------
        if(etot+(1-iabs(iqin))*RM.gt.emaxe) then
          write(6,fmt="(' Stopped in MAIN.',
     1    ' (Incident kinetic energy + RM) > min(UE,UP+RM).')")
          stop
        end if

!       ------------------------------------------------------
!       Verify the normarization of source direction cosines
!       ------------------------------------------------------
        if(abs(uin*uin+vin*vin+win*win-1.0).gt.1.e-6) then
          write(6,fmt="(' Following source direction cosines are not',
     1    ' normarized.',3e12.5)")uin,vin,win
          stop
        end if

!       ============================================================
        call shower (iqin,etot,xin,yin,zin,uin,vin,win,irinn,wtin)
!       ============================================================

        ncount = ncount + 1         ! Count total number of actual cases

                                                ! ------------------
      end do                                    ! End of batch loop
                                                ! ------------------

      call plotxyz(99,0,0,0.D0,0.D0,0.D0,0.D0,0,0.D0,0.D0)

      write(39,fmt="('9')")          ! Set end of batch for CG View

      tt=etime(tarray)
      tt1=tarray(1)
      cputime=tt1-tt0
      write(6,'(A,G15.5)') ' Elapsed Time (sec)=',cputime

!-----------------------------------------------------------------------
! Step 9:  Output-of-results
!-----------------------------------------------------------------------

!     ------------------------------------------------------------
!     Source spectrum.  Incident particle spectrum to detector.
!     ------------------------------------------------------------
      write(6,'(/A,A72)') ' Result for ',soinf

      if(istype.eq.0) then    ! photon
        write(6,'(/A/30X,A/A,11X,A,11X,A)')' Sampled source spectrum',
     *      'particles/source',' Energy',' Gamma-ray',' pdf'

        do ie=1,ngnum

!       -------------------------
!       Gamma spectrum per source
!       -------------------------
          spg(ie)=spg(ie)/ncount
          write(6,'(G12.5,A,8X,G12.5,8X,G12.5)')
     *       egamma(ie),' MeV--',spg(ie),pgamma(ie)
        end do

      elseif(istype.eq.1) then    ! beta-ray
        write(6,'(/A/30X,A/A,11X,A,11X,A)')' Sampled source spectrum',
     *      'particles/source','Upper energy',' Beta-ray',' pdf'

        do ie=2,nbnum
!       -------------------------
!       Beta spectrum per source
!       -------------------------
          spe(ie)=spe(ie)/ncount
          write(6,'(G12.5,A,8X,G12.5,8X,G12.5)')
     *     ebeta(ie),' MeV--',spe(ie),pbeta(ie)
        end do
```

```
      else                          ! IC-electron
        write(6,'(/A/30X,A/A,11X,A,11X,A)')' Sampled source spectrum',
     *      'particles/source',' Energy',' IC-electron',' pdf'

        do ie=1,nicon

!     ----------------------------
!     Electron spectrum per source
!     ----------------------------
           spic(ie)=spic(ie)/ncount
           write(6,'(G12.5,A,8X,G12.5,8X,G12.5)')
     *        eicon(ie),' MeV--',spic(ie),picon(ie)
        end do

      end if

!     ====================
      call counters_out(1)
!     ====================

      stop

      end

!------------------------last line of main code------------------------

!------------------------------ausgab.f--------------------------------
! Version:   030831-1300
! Reference: SLAC-265 (p.19-20, Appendix 2)
!----------------------------------------------------------------------
!23456789|123456789|123456789|123456789|123456789|123456789|123456789|12

! ---------------------------------------------------------------------
! Required subroutine for use with the EGS5 Code System
! -----------------------------------------------
! A AUSGAB to: produce trajectory data for imode=0
!
! -----------------------------------------------

      subroutine ausgab(iarg)

      implicit none

      include 'include/egs5_h.f'                ! Main EGS "header" file

      include 'include/egs5_epcont.f'    ! COMMONs required by EGS5 code
      include 'include/egs5_misc.f'
      include 'include/egs5_stack.f'
      include 'include/egs5_useful.f'

      include 'auxcommons/aux_h.f'   ! Auxiliary-code "header" file

      include 'auxcommons/lines.f'        ! Auxiliary-code COMMONs

      common/totals/                          ! Variables to score
     * maxpict
      integer maxpict

      integer                                                ! Arguments
     * iarg

      real*8                                           ! Local variables
     * edepwt

      integer
     * ie,iql,irl

!     ------------------------
!     Set some local variables
!     ------------------------
      irl = ir(np)
      iql = iq(np)
      edepwt = edep*wt(np)

!     ----------------------------------
!     Output particle information for plot
!     ----------------------------------
      if (ncount.le.maxpict) then
        call plotxyz(iarg,np,iq(np),x(np),y(np),z(np),e(np),ir(np),
     *       wt(np),time(np))
```

```
      end if

      return

      end

!-------------------------last line of ausgab.f-----------------------
!------------------------------howfar.f--------------------------------
! Version:   070627-1600
! Reference: T. Torii and T. Sugita, "Development of PRESTA-CG
! Incorporating Combinatorial Geometry in EGS4/PRESTA", JNC TN1410 2002-201,
! Japan Nuclear Cycle Development Institute (2002).
! Improved version is provided by T. Sugita. 7/27/2004
!----------------------------------------------------------------------
!23456789|123456789|123456789|123456789|123456789|123456789|123456789|12

! ----------------------------------------------------------------------
! Required (geometry) subroutine for use with the EGS5 Code System
! ----------------------------------------------------------------------
! This is a CG-HOWFAR.
! ----------------------------------------------------------------------

      subroutine howfar
      implicit none
c
      include 'include/egs5_h.f'       ! Main EGS "header" file
      include 'include/egs5_epcont.f'  ! COMMONs required by EGS5 code
      include 'include/egs5_stack.f'
      include 'auxcommons/geom_common.f' ! geom-common file
c
c
      integer i,j,jjj,ir_np,nozone,jty,kno
      integer irnear,irnext,irlold,irlfg,itvlfg,ihitcg
      double precision xidd,yidd,zidd,x_np,y_np,z_np,u_np,v_np,w_np
      double precision tval,tval0,tval00,tval10,tvalmn,delhow
      double precision atvaltmp
      integer iq_np
c
      ir_np = ir(np)
      iq_np = iq(np) + 2
c
      if(ir_np.le.0) then
        write(6,*) 'Stopped in howfar with ir(np) <=0'
        stop
      end if
c
      if(ir_np.gt.izonin) then
        write(6,*) 'Stopped in howfar with ir(np) > izonin'
        stop
      end if
c
      if(ir_np.EQ.izonin) then
        idisc=1
        return
      end if
c
      tval=1.d+30
      itvalm=0
c
c     body check
      u_np=u(np)
      v_np=v(np)
      w_np=w(np)
      x_np=x(np)
      y_np=y(np)
      z_np=z(np)
c
      do i=1,nbbody(ir_np)
        nozone=ABS(nbzone(i,ir_np))
        jty=itblty(nozone)
        kno=itblno(nozone)
c     rpp check
        if(jty.eq.ityknd(1)) then
          if(kno.le.0.or.kno.gt.irppin) go to 190
          call rppcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     sph check
        elseif(jty.eq.ityknd(2)) then
          if(kno.le.0.or.kno.gt.isphin) go to 190
```

```
          call sphcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     rcc check
        elseif(jty.eq.ityknd(3)) then
          if(kno.le.0.or.kno.gt.irccin) go to 190
          call rcccg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     trc check
        elseif(jty.eq.ityknd(4)) then
          if(kno.le.0.or.kno.gt.itrcin) go to 190
          call trccg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     tor check
        elseif(jty.eq.ityknd(5)) then
          if(kno.le.0.or.kno.gt.itorin) go to 190
          call torcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     rec check
        elseif(jty.eq.ityknd(6)) then
          if(kno.le.0.or.kno.gt.irecin) go to 190
          call reccg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     ell check
        elseif(jty.eq.ityknd(7)) then
          if(kno.le.0.or.kno.gt.iellin) go to 190
          call ellcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     wed check
        elseif(jty.eq.ityknd(8)) then
          if(kno.le.0.or.kno.gt.iwedin) go to 190
          call wedcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     box check
        elseif(jty.eq.ityknd(9)) then
          if(kno.le.0.or.kno.gt.iboxin) go to 190
          call boxcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     arb check
        elseif(jty.eq.ityknd(10)) then
          if(kno.le.0.or.kno.gt.iarbin) go to 190
          call arbcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     hex check
        elseif(jty.eq.ityknd(11)) then
          if(kno.le.0.or.kno.gt.ihexin) go to 190
          call hexcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     haf check
        elseif(jty.eq.ityknd(12)) then
          if(kno.le.0.or.kno.gt.ihafin) go to 190
          call hafcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     tec check
        elseif(jty.eq.ityknd(13)) then
          if(kno.le.0.or.kno.gt.itecin) go to 190
          call teccg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c     gel check
        elseif(jty.eq.ityknd(14)) then
          if(kno.le.0.or.kno.gt.igelin) go to 190
          call gelcg1(kno,x_np,y_np,z_np,u_np,v_np,w_np)
c
c**** add new geometry in here
c
       end if
  190  continue
      end do
c
      irnear=ir_np
      if(itvalm.eq.0) then
        tval0=cgeps1
        xidd=x_np+tval0*u_np
        yidd=y_np+tval0*v_np
        zidd=z_np+tval0*w_np
  310   continue
          if(x_np.ne.xidd.or.y_np.ne.yidd.or.z_np.ne.zidd) goto 320
          tval0=tval0*10.d0
          xidd=x_np+tval0*u_np
          yidd=y_np+tval0*v_np
          zidd=z_np+tval0*w_np
          go to 310
  320   continue
c       write(*,*) 'srzone:1'
        call srzone(xidd,yidd,zidd,iq_np,ir_np,irnext)
c
        if(irnext.ne.ir_np) then
          tval=0.0d0
          irnear=irnext
        else
```

```
          tval00=0.0d0
          tval10=10.0d0*tval0
          irlold=ir_np
          irlfg=0
  330     continue
          if(irlfg.eq.1) go to 340
            tval00=tval00+tval10
            if(tval00.gt.1.0d+06) then
              write(6,9000) iq(np),ir(np),x(np),y(np),z(np),
     &                      u(np),v(np),w(np),tval00
 9000 format(' TVAL00 ERROR : iq,ir,x,y,z,u,v,w,tval=',
     &       2I3,1P7E12.5)
              stop
            end if
            xidd=x_np+tval00*u_np
            yidd=y_np+tval00*v_np
            zidd=z_np+tval00*w_np
            call srzold(xidd,yidd,zidd,irlold,irlfg)
            go to 330
  340     continue
c
          tval=tval00
          do j=1,10
            xidd=x_np+tval00*u_np
            yidd=y_np+tval00*v_np
            zidd=z_np+tval00*w_np
c           write(*,*) 'srzone:2'
            call srzone(xidd,yidd,zidd,iq_np,irlold,irnext)
            if(irnext.ne.irlold) then
              tval=tval00
              irnear=irnext
            end if
            tval00=tval00-tval0
          end do
          if(ir_np.eq.irnear) then
            write(0,*) 'ir(np),tval=',ir_np,tval
          end if
        end if
      else
        do j=1,itvalm-1
          do i=j+1,itvalm
            if(atval(i).lt.atval(j)) then
              atvaltmp=atval(i)
              atval(i)=atval(j)
              atval(j)=atvaltmp
            endif
          enddo
        enddo
        itvlfg=0
        tvalmn=tval
        do jjj=1,itvalm
          if(tvalmn.gt.atval(jjj)) then
            tvalmn=atval(jjj)
          end if
          delhow=cgeps2
          tval0=atval(jjj)+delhow
          xidd=x_np+tval0*u_np
          yidd=y_np+tval0*v_np
          zidd=z_np+tval0*w_np
  410     continue
          if(x_np.ne.xidd.or.y_np.ne.yidd.or.z_np.ne.zidd) go to 420
            delhow=delhow*10.d0
            tval0=atval(jjj)+delhow
            xidd=x_np+tval0*u_np
            yidd=y_np+tval0*v_np
            zidd=z_np+tval0*w_np
          go to 410
  420     continue
c         write(*,*) 'srzone:3'
          call srzone(xidd,yidd,zidd,iq_np,ir_np,irnext)
          if((irnext.ne.ir_np.or.atval(jjj).ge.1.).and.
     &        tval.gt.atval(jjj)) THEN
            tval=atval(jjj)
            irnear=irnext
            itvlfg=1
            goto 425
          end if
        end do
  425   continue
```

```
        if(itvlfg.eq.0) then
          tval0=cgmnst
          xidd=x_np+tval0*u_np
          yidd=y_np+tval0*v_np
          zidd=z_np+tval0*w_np
 430      continue
          if(x_np.ne.xidd.or.y_np.ne.yidd.or.z_np.ne.zidd) go to 440
            tval0=tval0*10.d0
            xidd=x_np+tval0*u_np
            yidd=y_np+tval0*v_np
            zidd=z_np+tval0*w_np
            go to 430
 440      continue
          if(tvalmn.gt.tval0) then
            tval=tvalmn
          else
            tval=tval0
          end if
        end if
      end if
      ihitcg=0
      if(tval.le.ustep) then
        ustep=tval
        ihitcg=1
      end if
      if(ihitcg.eq.1) THEN
        if(irnear.eq.0) THEN
          write(6,9200) iq(np),ir(np),x(np),y(np),z(np),
     &                  u(np),v(np),w(np),tval
 9200 format(' TVAL ERROR : iq,ir,x,y,z,u,v,w,tval=',2I3,1P7E12.5)
          idisc=1
          itverr=itverr+1
          if(itverr.ge.100) then
            stop
          end if
          return
        end if
        irnew=irnear
        if(irnew.ne.ir_np) then
          call rstnxt(iq_np,ir_np,irnew)
        endif
      end if
      return
      end
!--------------------last line of subroutine howfar----------------------
```