EVALUATION OF S-VALUES FOR BETA PARTICLES WITH MONTE CARLO CODE GATE V6.2 FOR UNIT DENSITY SPHERES OF VARIOUS SIZES

by

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ABSTRACT

EVALUATION OF S-VALUES FOR UNIT DENSITY SPHERE MODEL WITH MONTE CARLO CODE GATE V6.2

The aim of this project is to test the performance of Monte Carlo Code GATE V6.2 in dosimetric applications for small structures.

In this thesis, S-values for small structures, unit density spheres in various radii, are evaluated with Monte Carlo Code GATE V6.2.

First simulations of unit density spheres with uniform distributions of different radionuclides for various radii are done with Monte Carlo Code GATE V6.2. The S- values are calculated from the dose deposited data. The efficiency of Monte Carlo Code GATE V6.2 is tested by comparing the obtained values and reference values that were evaluated with computer program MIRDose.

ÖZET

S-DEĞERLERİNİN BİRİM KÜRE MODELİ KULLANILARAK MONTE CARLO GATE V6.2 KODUYLA HESAPLANMASI

Bu çalışmanın amacı, küçük yapıların dozimetrik uygulamaları yoluyla Monte Carlo GATE V6.2 kodunun performansının test edilmesidir.

Bu çalışmada çeşitli yarıçaplardaki birim küre modeliyle simüle edilmiş küçük yapıların S-Değerleri Monte Carlo GATE V6.2 kodu ile hesaplanmıştır.

İlk olarak Monte Carlo GATE V6.2 kodu ile herbir radyonüklid için ayrı olarak, farklı yarıçaplara sahip, düzgün aktivite dağılımı olan birim küreler simüle edilmiştir. Elde edilen doz verilerinden S-Değerleri hesaplanmıştır. Monte Carlo GATE V6.2 kodunun verimi, referans MIRDose doz emilim oranlarıyla hesaplanan S-Değerlerinin karşılaştırılmasıyla test edilmiştir.

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LIST OF SYMBOLS/ABBREVIATIONS

AF	Absorbed Fraction
Bq	Becquerel
DTC	Differentiated Thyroid Carcinoma
GATE	GEANT4 Application in Tomographic Emission
Gy	Gray
HCC	Hepatocellular Carcinoma
LET	Linear Energy Transfer
mAbs	Monoclonal antibodies
MC	Monte Carlo
RBE	Relative Biological Effectiveness
SAF	Specific Absorbed Fraction
SIRT	Selective Internal Radiation Therapy
TR	Targeted radiotherapy
UDSM	Unit Density Sphere Model
99mTc-MAA	99mTc-macroaggregated-albumin

1. INTRODUCTION

Monte Carlo based codes such as EGSnrc [1], PTRAN, MCNP [2] are widely preferred in dosimetric calculations. An open source and user friendly MC package, Monte Carlo Code Gate V6.2 is also beneficial for not only medical imaging applications but also dosimetric applications too. Including many detector types for different simulation geometries is a reason for this code to be preferred [3]. Gate 6.1.0 introduces a specific detector type, actors, for dosimetric scoring with many features [4]. The subject of this dissertation is testing the efficiency of Monte Carlo Code Gate V6.2 in dosimetric applications using Unit Density Sphere Model (from now on UDSM). The reason of working on UDSM is to estimate the S-values for small structures, representing the small tumours or organs in body, filled with different emitter types of electron-emitting radionuclides. A special detector, DoseActor, in Gate V6.2 is used to obtain the deposited dose values in spheres with various radii. To test the efficiency of the code, the data acquired is compared with the recommended values. UDSM simulation with Gate V6.2 is also essential for testing accuracy of UDSM for dosimetric applications in small structures [5]. There are many studies about UDSM and dosimetric applications in Gate.

Jeffry A. Siegel and M.G. Stabin, 1993, in their work entitled- Absorbed Fractions for Electrons and Beta Particles in Spheres of Various Sizes- dependency of absorbed fractions to unit density sphere size for electron and Beta particle emitter radionuclides was studied.

M.G. Stabin and M.W. Konijnenberg, 1999, in their work with title - Re-Evaluation of Absorbed Fractions for Photons and Electrons in Spheres of Various Sizes- AF for discrete photon and electron energies were calculated. The values acquired in this thesis were compared with the recommended values in this work.

D. Visvikis et al., 2006, in their work with title- Use of the GATE Monte Carlo Package for Dosimetry Applications- dose values were calculated through CT and PET FDG studies and modelled radiotherapy, bracytherapy experiments.

2. DOSIMETRY IN NUCLEAR MEDICINE

Dosimetry is the measurement or the estimation of absorbed dose as a result of ionizing radiation achieved from external (outside the body) or internal (inside the body) radiation exposure [6]. Radiation dose from external emitters, such as X-ray machines, can be measured but radiation dose from internal emitters can only be calculated [7] for this reason by two different committies, **Medical Internal Radiation Dose (from now on MIRD) Committee of The Society of Nuclear Medicine** and **The International Commission on Radiological Protection (from now on ICRP)** developed dosimetry schemas that are different in terminology but same in fundamental quantities.

The International Commission on Radiological Protection (ICRP) is established in 1928 as an independent and international organisation. This commission aims to protect both human and environment from the damaging effects of ionizing radiation [8]. ICRP published 129 reports including all aspects of ionizing radiation, since 1928, for this aim. The commity is still ongoing publishing reports [9].

Medical Internal Radiation Dose (MIRD) Committee of The Society of Nuclear Medicine, is established in 1965 [10]. 'The MIRD Committee develops standard methods, models, assumptions, and mathematical schema for assessing internal radiation doses from administered radiopharmaceuticals'. Calculation of assessed dose is systematically simplified by the MIRD approach for many radionuclides in terms of both software tools for experiments and clinical application. MIRD published 22 pamphlets to disseminate data of MIRD approach and still updating the pamphlets [11].

In MIRD Pamphlet No: 21 a generalized dosimetry schema is offered for standardization of both MIRD and ICRP terminology [12].

2.1. APPLICATIONS OF INTERNAL DOSIMETRY

Radioisotopes, such as ^{131}I, ^{90}Y, ^{18}F, ^{177}Lu, are used in nuclear medicine for diagnostic and therapeutic reasons. The usage of radioisotopes requires risk - benefit analyse [13]. Much absorbed dose in tumor and less absorbed dose in normal tissues are the main target of both internal and external dosimetry.

2.1.1. ^{131}I Therapy

Treatment of patients with differentiated thyroid carcinoma (from now on DTC) by radioiodine (^{131}I) therapy is an effective and safe method that is proven. After thyroidectomy radioiodine therapy is used to ablate the remnant thyroid tissue. The radioiodine is administered intravenously. The activity of ^{131}I at the first therapy is between 1.1-3.7GBq. In subsequent therapies or metastatic cases higher ^{131}I activity can be administered.

By the help of exogenous hormone therapies the iodine retention in the target tissue is adjusted and also serious complications in other organs - blood marrow and lungs - are avoided. Calculation of absorbed dose in blood is based on MIRD formalism. Scintigraphic imaging is used to quantify the activity of ^{131}I in the remnant thyroid tissue and in the whole body [14].

Reduced doses of ^{131}I can be used in therapy for palliative purposes [15].

2.1.2. ^{90}Y Therapy

Hepatocellular carcinoma (from now on HCC) is the third common cancer-related cause of death worldwide [16, 17]. Selective internal radiation therapy (from now on SIRT) with ^{90}Y-microspheres has many advantages such as less side effects, high selectivity relative to external radiotherapy, short-time hospital care [18].

First to identify the vessel pattern of the liver, hepatic angiogram is performed. Vessels supporting non-target organs are blocked to prevent healthy organs from ^{90}Y microspheres though ionizing radiation. ^{99m}Tc-MAA injected to hepatic artery to identify the distribution of ^{99m}Tc that is simulating distribution ^{90}Y-microspheres [19]. SPECT/CT projections are acquired. ^{90}Y-microspheres are administered through hepatic artery to the tumor. The residual activity in the liver is measured by gamma camera acquisitions [18].

^{90}Y- Ibritumomab Tiuxetan radioimmunotherapy is used to treat non-Hodgkin lymphoma [20].

2.2. RADIONUCLIDES IN NUCLEAR MEDICINE

Radiopharmaceuticals are used in diagnostic imaging and therapy. As a result of improvements in monoclonal antibodies (mAbs) -tissue specific biomolecules- targeted radiotherapy (from now on TR) had gained more importance. TR has the advantage of target selectivity that is essential in treatment of disseminated tumors and small metastases.

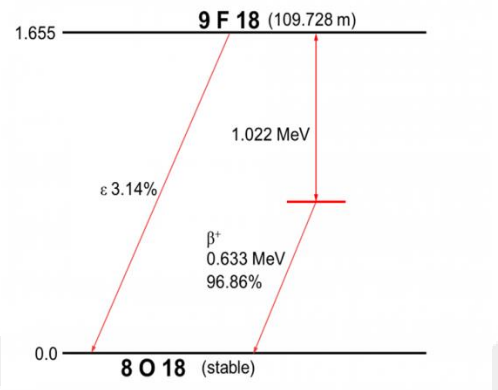
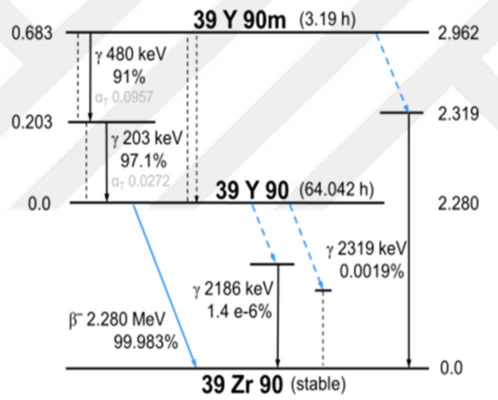
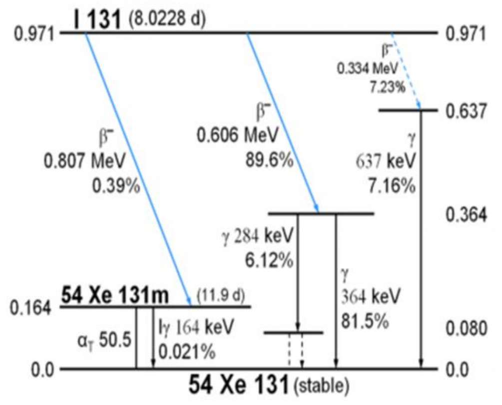
TR is based on the deposition of ionizing radiation from radionuclides that are attached to molecules used in cell metabolism. In cancerous cells, because of their high metabolism, targeted receptors or antigens are over-expressed. Natural molecules or analogues that exist in physiological pathways of cell metabolism are used in biological targeting.

Selection of radionuclide is important in TR. The administered radiation dose should be sufficient to overcome cancerous cell repair and proliferation while letting healthy tissue deliver minimum dose. In TR dose rate and absorbed radiation doses are very important in prediction of radiation doses. For fast growing tumors radionuclides with short half-lives are efficient such as ^{103}Pd. Radionuclides with long half-lives are essential for slow-growing tumors such as ^{125}I. ^{90}Y with high beta energy (2.3MeV) and long path length (5-10mm) can be preferred for treatment of large tumors while ^{131}I (0.8MeV and 1-2mm) is preferred for micro- metastases and small organs like thyroid.

Cell-specific targeting , microscopic lesions, tiny cancer cell clusters can be treated with α-particles due to their short range-high LET radiation (highest RBE).

For fine structures such as chromatin in cell nucleus, radionuclides emitting low energy (Auger electrons, 40 keV) is preferred such as ^{125}I [20]

Table 2.1. Radionuclide decay schemes and decay equations [21]

Radionuclide	Decay Scheme	Decay Equation
^{18}F		$^{18}_{9}F \xrightarrow{yields} {}^{18}_{8}O + {}^{0}_{+1}e$
^{90}Y		$^{90}_{39}Y \xrightarrow{yields} {}^{90}_{40}Zr + {}^{0}_{-1}e$
^{131}I		$^{131}_{53}I \xrightarrow{yields} {}^{131}_{54}Xe + {}^{0}_{+1}e$

2.3. BASIC CONCEPTS OF MIRD METHOD

2.3.1. Absorbed Dose Rate

The amount of energy absorbed per unit time per unit mass of material is knowns as **Absorbed Dose Rate** [7].

$$\dot{D} = \frac{kA\sum_i n_i E_i \phi_i}{m} \tag{2.1}$$

Here;

$\dot{D}$: Absorbed dose rate in terms of rad/h,

k: Proportionality constant yielding the dose rate in the desired units

A: Amount of activity

n_i: Number of radiations with energy E_i emitted per nuclear transition.

E_i: Energy per radiation (MeV)

ϕ_i: Absorbed Fraction

m: tissue mass [22].

2.3.2. Absorbed Fraction

Absorbed fraction is the fraction of energy that is absorbed in target region (r_T), emitted from a source region (r_S), ϕ ($r_T \leftarrow r_S$), that is represented with lowercase Greek letter ϕ.

$$absorbed\ fraction = \frac{energy\ absorbed\ in\ a\ target}{energy\ emitted\ from\ a\ source} \tag{2.2}$$

The source region can also be the target region (self-dose) [7].

AF includes emission type, energy, characteristics and geometry of both target and source organs. β and α particles are mainly absorbed in source tissue, while photons deposit energy in both source and target tissues [23]. Figure 2.1 shows AF values for photons, electrons, α-particles and how they effect source and target organ.

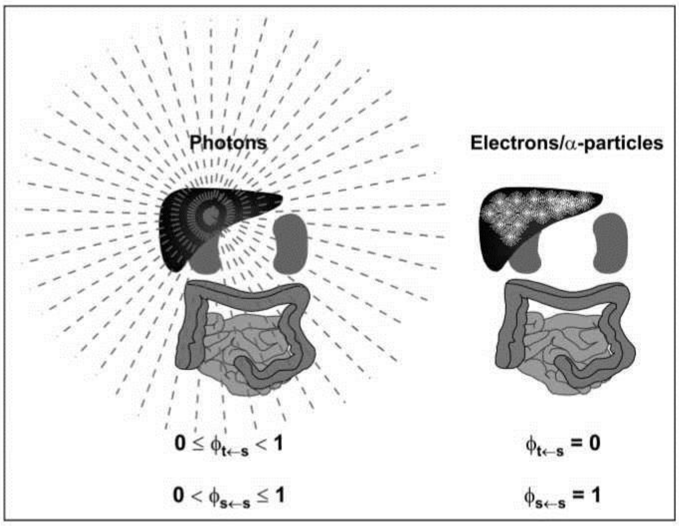


Figure 2.1. Tissue absorption properties of photons and particles [23]

Following formula was used to calculate AF;

$$\phi = 4\pi\rho \int_0^{\infty} x^2\, \psi(x)\Phi(x)dx \tag{2.3}$$

Here;

ϕ: Absorbed Fraction of energy in the source region

ρ: Medium density

x: Distance from the point source

ψ (x): Geometric reduction factor for a given geometry at distance x.

Φ(x): Specific absorbed fraction of energy at distance x [5].

AF is calculated by Monte Carlo method generally [23].

2.3.3. Specific Absorbed Fraction

Specific absorbed fraction is the absorbed fraction per unit mass of target organ.

It is represented with uppercase Greek letter Φ ($r_T \leftarrow r_S$) [7].

$$\Phi (r_T \leftarrow r_S) = \phi (r_T \leftarrow r_S) / m \tag{2.4}$$

2.3.4. Absorbed Dose

Absorbed dose in a target organ is given as following;

$$D = \frac{k\tilde{A} \sum_i n_i E_i \phi_i}{m} \tag{2.5}$$

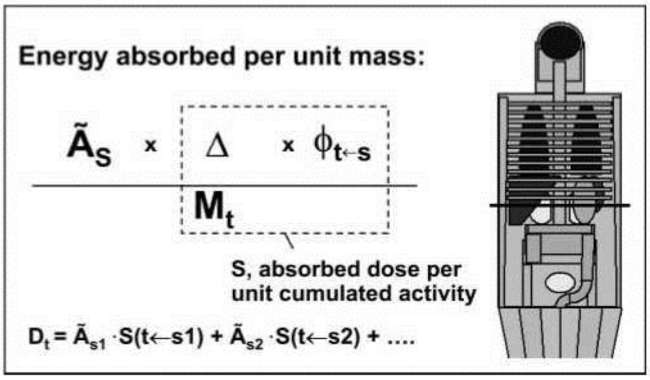


Figure 2.2. MIRD schema illustrated for definition of S values [23].

Here;

D: absorbed dose in a target organ (rad or Gy)

$\tilde{A}$: Time integrated activity in a source organ (μCi-h or MBq-s)

k: Proportionality constant yielding the dose rate in the desired units

n_i: Number of radiations with energy E_i emitted per nuclear transition.

E_i: Energy per radiation. (MeV)

ϕ_i: Absorbed Fraction

m: Target tissue mass [22].

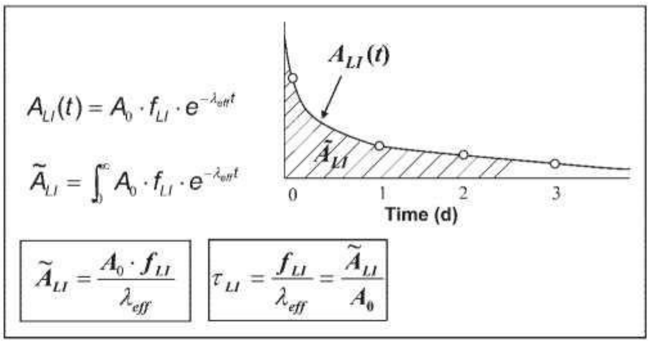


Figure 2.3. Time activity curve for liver [23].

$$\tilde{A}=\int_0^{\infty} A(t)\, dt \qquad (2.6)$$

$$\frac{\tilde{A}}{A} = \tau \qquad (2.7)$$

Here:

$\int_0^{\infty} A(t)\, dt$: Integral of activity over time

τ: Time integrated activity coefficient.[7,12]

2.3.5. S Factor

The following equation is constant for specific radionuclides and source organ-target organ combinations. The values are called as S Factors by the MIRD committee and tabulated for many radionuclides and source-target combinations [7].

$$S = \frac{\sum_i n_i E_i \phi_i}{m} \tag{2.8}$$

3. MONTE CARLO CODES IN DOSIMETRY

3.1. MONTE CARLO SIMULATIONS

Dosimetry is one of the application areas of Monte Carlo (MC) simulations. Different codes of MC such as MCNP, EGSnrc, PTRAN, XVMC, GATE are widely used today. In dosimetry, MC codes are used to evaluate the MIRD formalism data and patient specific dosimetry calculations [3, 24]. The data evaluated by MC codes are in good agreement with values acquired by MIRD methodology and published in MIRD pamphlets [25]. MC simulations are the most suitable method for patient - specific dosimetry because of involving tissue physical properties and being capable of using CT and SPECT images [7]. Dosimetry with MC codes is based on voxel S values (from now on VSV) because of imaging modalities, PET and SPECT. VSV supports absorbed dose calculations for non-uniform distribution of activity in the target tissue or organ [26]. Patient specific dosimetric calculations also include UDSM that is studied by MC codes and results are more realistic than published data in MIRD pamphlet 8 [25].

MC Code GATE V6.2

- facilitates 3D sources easily,
- is user friendly
- is open source. [3, 13].

In this thesis Monte Carlo Code GATE V6.2 is used.

3.2. GEANT4

GEANT4, developed in CERN, is an opensource software package that simulates the passage of particles through matter accurately. It is composed of tools that include all aspects of simulation process. GEANT4 is written in C++. The simulation toolkit include:

- the geometry of the system,
- the materials involved,

- the fundamental particles of interest,
- the generation of primary events,
- the tracking of particles through materials and electromagnetic fields,
- the physics processes governing particle interactions,
- the response of sensitive detector components,
- the generation of event data,
- the storage of events and tracks,
- the visualization of the detector and particle trajectories, and
- the capture and analysis of simulation data at different levels of detail and refinement.

GEANT4 is dependent on physics models that handle the interaction of particle with matter in a very wide energy range. GEANT4 incorporates many data and expertise that have been drawn around the world about particle interactions with matter [27].

3.3. GATE

Gate (Geant4 application For Emission Tomography) is an open source of Monte Carlo simulation program developed by the OpenGATE collaboration since 2001, released in 2004. GATE is a simulation platform improved for modelling planar scintigraphy, Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET). In addition to this not only modelling X-ray computed tomography and radiation therapy experiments feature but also dose calculation, simulation speeding up and optical physics modelling features are implemented to new version of GATE; GATE V6 [28].

GATE does not require C++ programming skills since it has a scripting mechanism that is referred as macro language. All commands are based on scripts. To build up a simulation in GATE, commands should be entered interactively or in the form of macro files that are containing an ordered batch of commands. Each command has one or two parameters to perform a particular function. GATE commands follows a tree structure with respect to the function they represent.

When GATE is run a prompt, **Idle>**, appears in the terminal. In this mode commands can be entered interactively. All functions, parameters, properties of GATE can be accessed with command lines. All components of a simulation can be parameterized by using command lines.

Storing commands is useful for a successful simulation. Macros are ASCII files that contain scripted GATE commands. Files contain both GATE commands and comments. Comments are explanations about the program details that start with character '#'. In macros, commands should be in right order to build up a simulation and store data output [29].

3.3.1. Architecture of a Simulation in GATE

A simulation is divided into 7 steps:

- Verbosity and visualization
- Geometry
- Digitizer
- Physics
- Sources
- Outputs
- Experiment

Commands should be arranged to follow the steps given above in simulation macros. Detailed dosimetry and radiotherapy simulation steps are as follows:

- Define beam geometry (Not included in internal dosimetry applications.)
- Define phantom geometry (Spheres in various sizes made of water and muscle material are phantoms, materials are defined in GATE material database)
- Specify the output (DoseActor in UDSM application.)
- Set up physics process (Standard energy physics modules in GATE are used)
- Initialize the simulation
- Define the sources (^{90}Y, ^{18}F, ^{131}I energy spectrums are defined to GATE and uniformly distributed in spheres.)
- Start the simulation
- /gate/application/setTotalNumberOfPrimaries[particle_number]

- /gate/application/start [29].

3.3.2. Practice of Simulation Architecture for Dosimetry

In GATE, The World is the system-defined volume where the all simulation takes place and data acquired. For that reason it should be large enough to include all volumes of the simulation.

```
# World
/gate/world/geometry/setXLength 25.0 cm
/gate/world/geometry/setYLength 25.0 cm
/gate/world/geometry/setZLength 25.0 cm
```

- The material of the World is determined by following command as ‘water’

```
/gate/world/setMaterial Water
```

- World is going to be visualised in wireframe form.

```
/gate/world/vis/ forceWireframe
```

- Geometric and content properties of daughter volume- Global Box- is introduced to the simulation.

```
# Global Box
/gate/world/daughters/name            USM
/gate/world/daughters/insert          sphere
/gate/USM/geometry/setRmin            0 cm
/gate/USM/geometry/setRmax            0.133650 cm
/gate/USM/placement/setTranslation  0. 0. 0. cm
/gate/USM/setMaterial Water
/gate/USM/vis/setVisible 1
/gate/USM/vis/setColor yellow
/gate/USM/vis/forceWireframe
```

- Physics of the simulation is introduced with limitations as ‘cuts’. With a command, a macros file including physics commands implemented to the simulations.

```
#=====================================================
# PHYSICS
#=====================================================
/gate/geometry/setIonisationPotential Water 75 eV
/gate/geometry/setIonisationPotential Air 85.7 eV

/control/execute physicA.mac

#=====================================================
# CUTS
#=====================================================
/gate/physics/Gamma/SetCutInRegion     world 0.1 mm
/gate/physics/Electron/SetCutInRegion   world 0.1 mm
/gate/physics/Positron/SetCutInRegion   world 0.1 mm

/gate/physics/Gamma/SetCutInRegion     USM 0.01 mm
/gate/physics/Electron/SetCutInRegion   USM 0.01 mm
/gate/physics/Positron/SetCutInRegion   USM 0.01 mm

/gate/physics/processes/ElectronIonisation/setStepFunction e+ 0.1 0.0005 mm
/gate/physics/processes/ElectronIonisation/setStepFunction e- 0.1 0.0005 mm
```

- Data is acquired by DoseActor tool. Data output is recorded as HDR and IMG files.

```
#=====================================================
# OUTPUT: ACTOR CONCEPT
#=====================================================
/gate/actor/addActor SimulationStatisticActor USMStat
/gate/actor/USMStat/save  ../OUTPUT/Y90Stat.txt

/gate/actor/addActor                          DoseActor  doseDistribution
/gate/actor/doseDistribution/save              ../OUTPUTI131/OUTPUT0.13/I131.root
/gate/actor/doseDistribution/save              ../DOUTPUT/Y90.hdr
/gate/actor/doseDistribution/attachTo                USM
```

```
/gate/actor/doseDistribution/stepHitType          random
/gate/actor/doseDistribution/setPosition          0 0 0 cm
/gate/actor/doseDistribution/setResolution        10 10 10
/gate/actor/doseDistribution/saveEveryNSeconds     10
/gate/actor/doseDistribution/enableEdep           true
/gate/actor/doseDistribution/enableUncertaintyEdep true
/gate/actor/doseDistribution/enableDose           true
/gate/actor/doseDistribution/enableUncertaintyDose true
/gate/actor/doseDistribution/enableNumberOfHits    true

#========================================================
# INITIALISATION
#========================================================
/gate/run/initialize
```

- With a command, a macro file including source commands implemented to the simulations.

```
#========================================================
# SOURCE
#========================================================
/control/execute SourceF18.mac
```

- GATE is based on Monte Carlo methodology. Number generator module is implemented to the simulation with following commands.

```
#========================================================
# RANDOM
#========================================================
# JamesRandom MersenneTwister
/gate/random/setEngineName MersenneTwister
/gate/random/setEngineSeed 1021
```

- Activation of the source is defined with the following command.

```
#========================================================
```

```
# START BEAMS
#=========================================================
/gate/application/setTotalNumberOfPrimaries 10000000

/gate/application/start
```

4. MATERIAL AND METHOD

GATE V 6.2 includes DoseActor tool for internal dosimetry applications. In this thesis unit density sphere model is used to assess GATE V 6.2 efficiency.

Spheres with various radii and sizes are simulated. All the spheres and their around are filled with water and muscle tissue separately. ^{131}I, ^{90}Y, ^{18}F decay data are introduced to the GATE V6.2. Related decay data are acquired from MIRD RADTABS program. All decay data spectrum graphics that is introduced to simulation are given below.

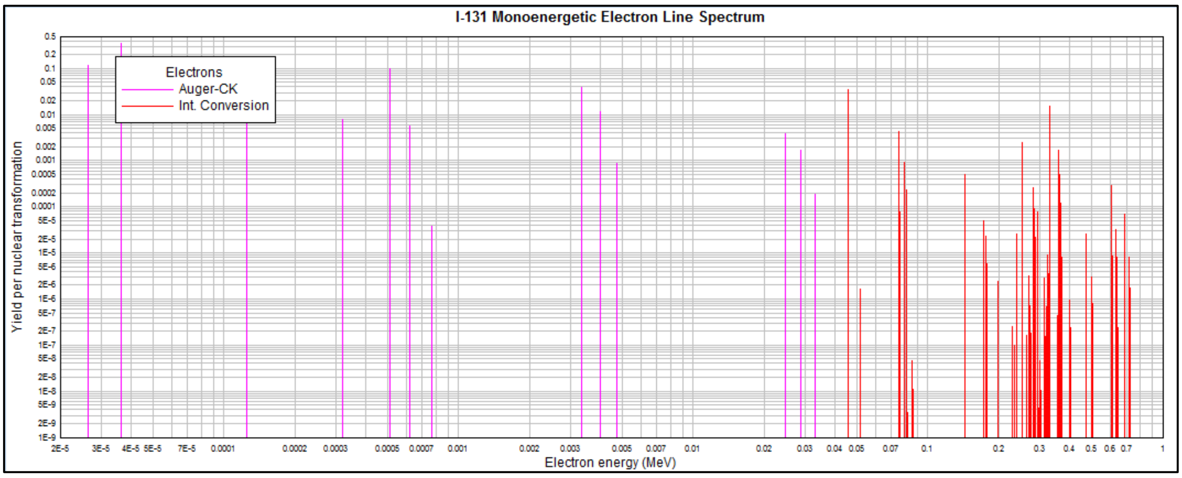


Figure 4.1. I-131 Monoenergetic Electron Line Spectrum

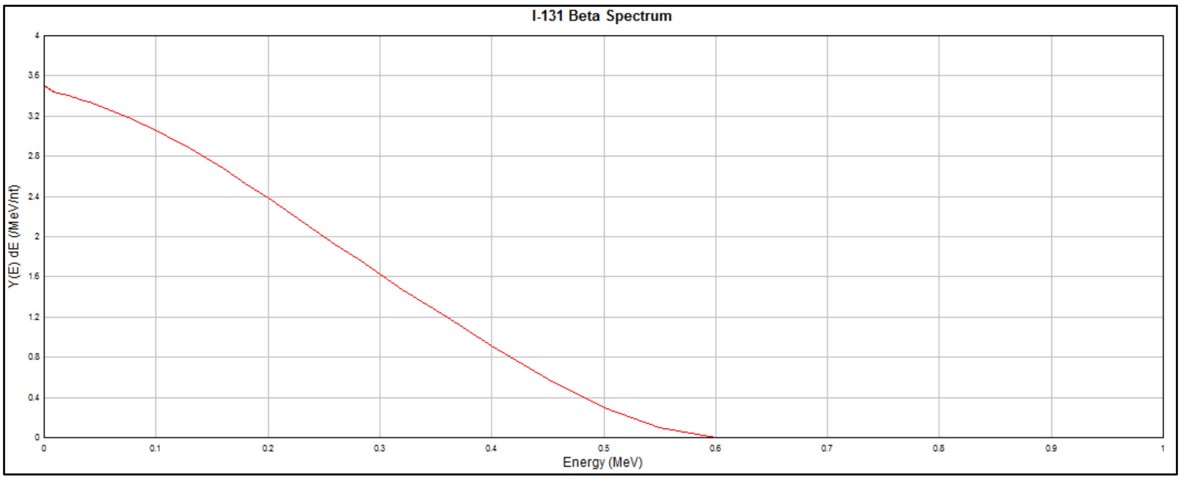


Figure 4.2. I-131 Beta Spectrum

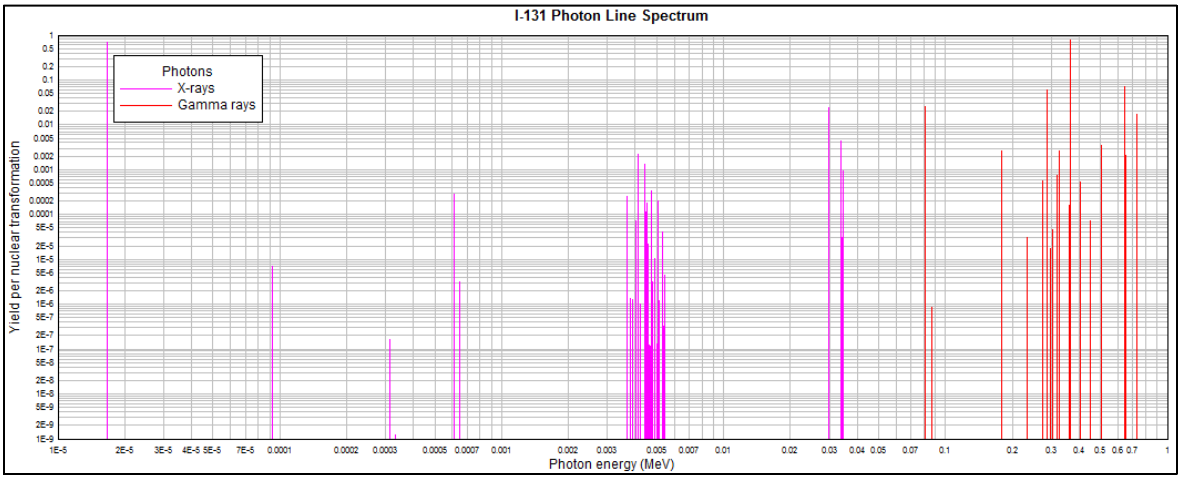


Figure 4.3. I-131 Photon Line Spectrum

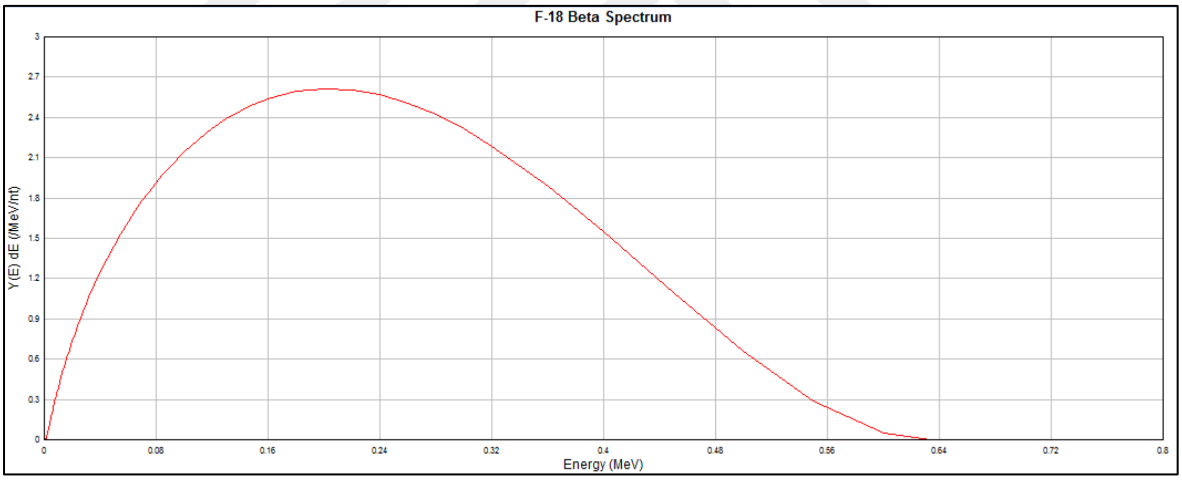


Figure 4.4. F-18 Beta Spectrum

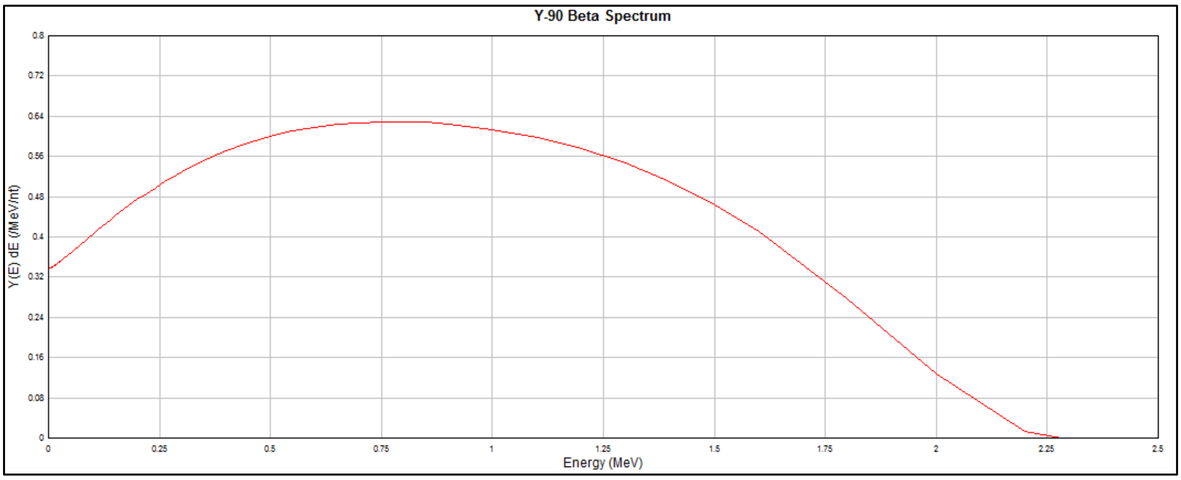


Figure 4.5. Y-90 Beta Spectrum

^{131}I, ^{90}Y, ^{18}F activities are distributed uniformly and separately into the spheres. Activity is chosen as 10.000.000 Bq (Becquerel) to lessen the uncertainty. Higher activity should have caused longer processing time as a result 10.000.000 Bq activity was taken as optimum activity. Table 4.1 shows how uncertainty changes depending different activities. Table 4.2 shows simulation statistics data for two different activities 20 MBq and 10 MBq respectively. Even the uncertainty data is smaller in 20MBq activity simulation, simulation time takes two times longer than the 10 MBq activity simulation.

Table 4.1. Activity – Uncertainty relation

Radionuclide	**Activity (Bq)**	**Uncertainty at the Center of the Middle Layer (per cent)**	**Uncertainty of the Whole Middle Layer (per cent)**
90Y	1.000.000	1.3	1.5
90Y	5.000.000	0.6	0.7
90Y	10.000.000	0.4	0.5
90Y	20.000.000	0.3	0.3

Table 4.2. Statistical Data for Simulations with Different Activities

Statistical Data of 20MBq Activity	**Statistical Data of 10MBq Activity**
# NumberOfRun = 1	# NumberOfRun = 1
# NumberOfEvents = 20000000	# NumberOfEvents = 10000000
# NumberOfTracks = 66338742	# NumberOfTracks = 33176305
# NumberOfSteps = 1705105994	# NumberOfSteps = 852769208
# NumberOfGeometricalSteps = 11109654	# NumberOfGeometricalSteps = 5556694
# NumberOfPhysicalSteps = 1693996340	# NumberOfPhysicalSteps = 847212514
# ElapsedTime = 11095.3	# ElapsedTime = 5447.91
# StartDate = Wed Dec 23 11:59:20 2015	# StartDate = Wed Dec 23 15:16:59 2015
# EndDate = Wed Dec 23 15:04:15 2015	# EndDate = Wed Dec 23 16:47:47 2015
# CurrentSimulationTime = 1e+09	# CurrentSimulationTime = 1e+09

Unit density spheres' radii and mass properties are shown in Table 4.2 that are filled with water.

Table 4.3. Sphere Properties for Water (d=1 g/cm^3)

Mass (g)	**Radius (cm)**	**Mass (g)**	**Radius (cm)**
0.01	0.133650	40	2.121569
0.1	0.287941	60	2.428590
0.5	0.492373	80	2.673009
1	0.620350	100	2.879412
2	0.781593	300	4.152831
4	0.984745	400	4.570781
6	1.127252	500	4.923725
8	1.240701	600	5.232239
10	1.336505	1000	6.203505
20	1.683890		

Figure 4.6. shows visualization of GATE simulation, unit density sphere filled with activity and interactions (red coloured), paths followed by particles (green coloured).

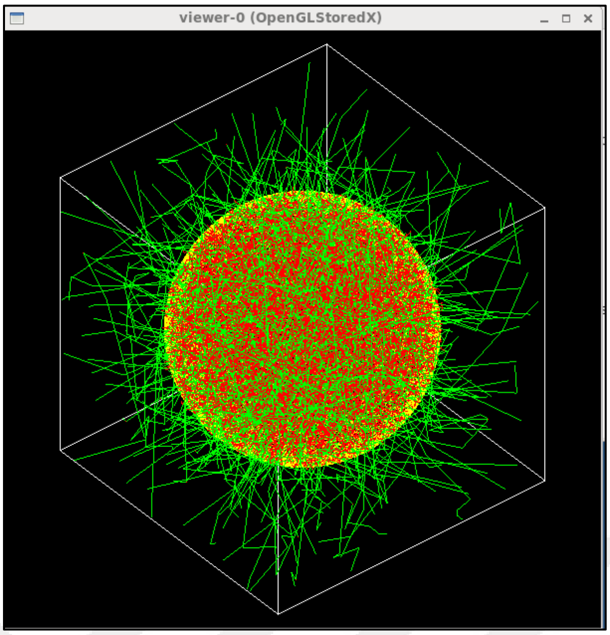


Figure 4.6. Activation distributed in Unit Density Sphere

10X10X10 DoseActors are attached to the unit density spheres. DoseActors can be attached to a rectangular prism shaped voxel volumes. This corresponds 10 layers in all planes XY- YZ – XZ and a total of 1000 DoseActors. Indicated DoseActor number is also chosen to lessen the uncertainty.

Output files are saved in hdr and img format. Output files are visualized and data are acquired by imageJ program.

Fifth layer of the dose output is taken to acquire most accurate data. Data is acquired in two ways. First whole layer is taken, second only the center of the layer is taken for dose information. In figure 4.2. hdr image of fifth layer is shown.Yellow circle indicates the area where the output data is taken for whole layer. DoseActor output data are in terms of Gy.

Calculation of absorbed dose is made as follows;

- Dose left by a particle is calculated. Gy/Particle

- The result is multiplied by the abundance of the related radionuclide which is 1 for ^{90}Y, 3.58758 for ^{131}I, 0.9673 for ^{18}F.
- Unit conversion is made Gy/Bq-s to mGy/MBq-s

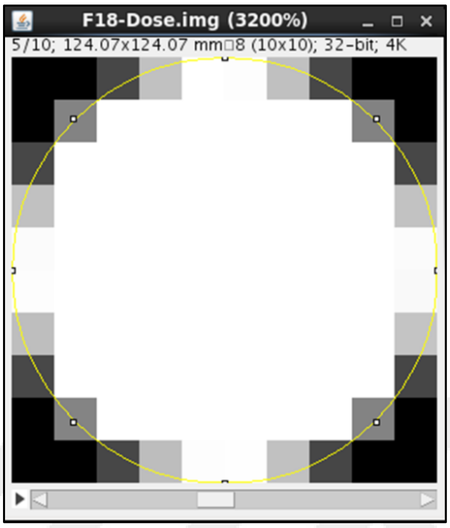


Figure 4.7. DoseActor data appearance

Data that are acquired from the simulation is compared with the reference data from Radiation Dose Assessment Resource (from now RADAR)[30]. RADAR is an accessible site for all forms of internal nuclear medicine dosimetry data.

4.1. ^{90}Y RESULTS

Table 4.3 last column shows S-values calculated for the data acquired (3. column) from the center of the layer for ^{90}Y activity.

Table 4.4. Results of the center of the layer (^{90}Y)

r (cm)	Mass (g)	Gy	Gy/particle	Gy/Bq-s	mGy/MBq-s
0.13365	0.01	4.400E-02	4.400E-09	4.40E-09	4.40E+00
0.287941	0.1	9.000E-03	9.000E-10	9.00E-10	9.00E-01
0.492373	0.5	3.000E-03	3.000E-10	3.00E-10	3.00E-01
0.62035	1	1.000E-03	1.000E-10	1.00E-10	1.00E-01
0.781593	2	7.356E-04	7.356E-11	7.36E-11	7.36E-02
0.984745	4	3.708E-04	3.708E-11	3.71E-11	3.71E-02
1.127252	6	2.471E-04	2.471E-11	2.47E-11	2.47E-02
1.240701	8	1.865E-04	1.865E-11	1.87E-11	1.87E-02
1.336505	10	1.492E-04	1.492E-11	1.49E-11	1.49E-02
1.68389	20	7.427E-05	7.427E-12	7.43E-12	7.43E-03
2.121569	40	3.723E-05	3.723E-12	3.72E-12	3.72E-03
2.42859	60	2.487E-05	2.487E-12	2.49E-12	2.49E-03
2.673009	80	1.865E-05	1.865E-12	1.87E-12	1.87E-03
2.879412	100	1.483E-05	1.483E-12	1.48E-12	1.48E-03
4.152831	300	4.962E-06	4.962E-13	4.96E-13	4.96E-04
4.570781	400	3.726E-06	3.726E-13	3.73E-13	3.73E-04
4.923725	500	2.972E-06	2.972E-13	2.97E-13	2.97E-04
5.232239	600	2.491E-06	2.491E-13	2.49E-13	2.49E-04
6.203505	1000	1.481E-06	1.481E-13	1.48E-13	1.48E-04

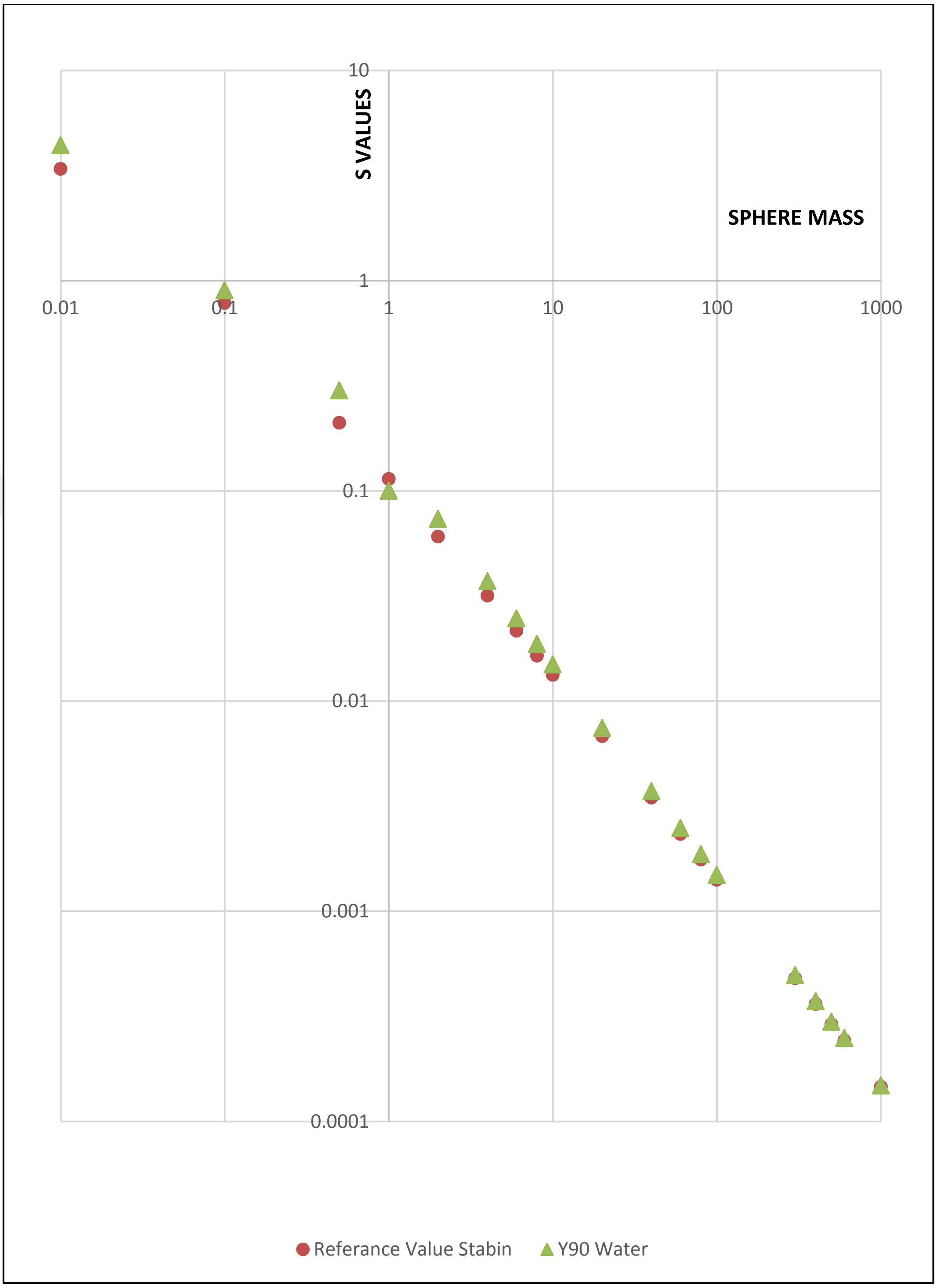


Figure 4.8. Reference values and calculated results for ^{90}Y (center of layer)

In Figure 4.3, x-axis belongs to sphere mass values, y-axis belongs to S-values indicated at the last column of Table 4.3. The graph shows reference and calculated values' correlation.

S-values calculated for the data acquired from the whole fifth layer for 90Y activity are shown in Table 4.4. in the last column (3. column).

Table 4.5. Results of the whole layer (^{90}Y)

r (cm)	Mass (g)	Gy	Gy/particle	Gy/Bq-s	mGy/MBq-s
0.13365	0.01	3.900E-02	3.900E-09	3.90E-09	3.90E+00
0.287941	0.1	8.000E-03	8.000E-10	8.00E-10	8.00E-01
0.492373	0.5	2.000E-03	2.000E-10	2.00E-10	2.00E-01
0.62035	1	1.000E-03	1.000E-10	1.00E-10	1.00E-01
0.781593	2	6.633E-04	6.633E-11	6.63E-11	6.63E-02
0.984745	4	3.480E-04	3.480E-11	3.48E-11	3.48E-02
1.127252	6	2.364E-04	2.364E-11	2.36E-11	2.36E-02
1.240701	8	1.793E-04	1.793E-11	1.79E-11	1.79E-02
1.336505	10	1.442E-04	1.442E-11	1.44E-11	1.44E-02
1.68389	20	7.325E-05	7.325E-12	7.33E-12	7.33E-03
2.121569	40	3.700E-05	3.700E-12	3.70E-12	3.70E-03
2.42859	60	2.470E-05	2.470E-12	2.47E-12	2.47E-03
2.673009	80	1.854E-05	1.854E-12	1.85E-12	1.85E-03
2.879412	100	1.484E-05	1.484E-12	1.48E-12	1.48E-03
4.152831	300	4.964E-06	4.964E-13	4.96E-13	4.96E-04
4.570781	400	3.722E-06	3.722E-13	3.72E-13	3.72E-04
4.923725	500	2.978E-06	2.978E-13	2.98E-13	2.98E-04
5.232239	600	2.480E-06	2.480E-13	2.48E-13	2.48E-04
6.203505	1000	1.489E-06	1.489E-13	1.49E-13	1.49E-04

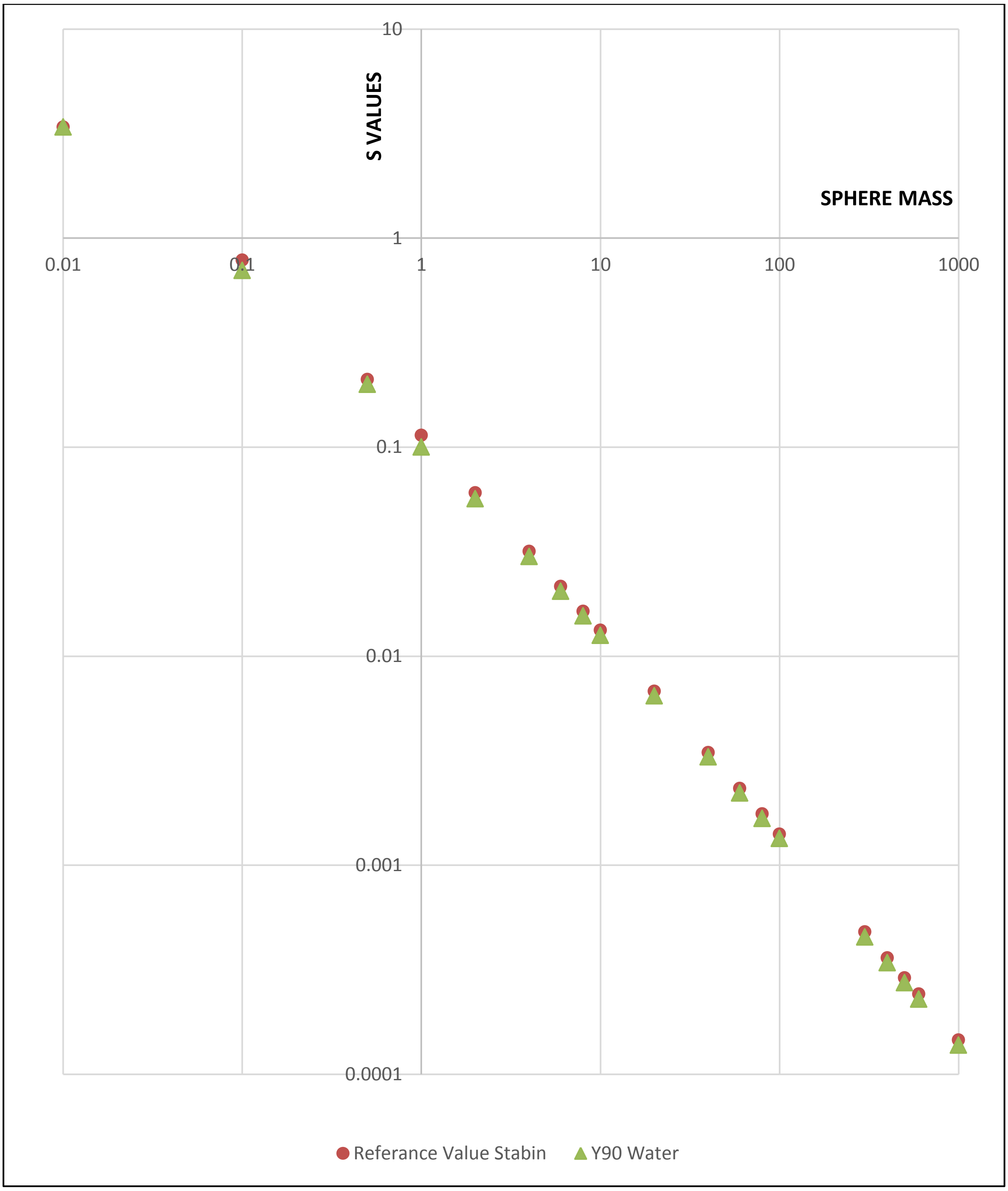


Figure 4.9. Reference values and calculated results for ^{90}Y (whole layer)

In Figure 4.4, x-axis belongs to sphere mass values, y-axis belongs to S-values indicated at the last column of Table 4.4. The graph shows reference and calculated values' correlation.

4.2. ^{18}F RESULTS

Table 4.5 last column shows S-values calculated for the data acquired (3. column) from the center of fifth layer for ^{18}F activity.

Table 4.6. Results of the center of the layer (^{18}F)

r (cm)	Mass (g)	Gy	Gy/particle	Gy/Bq-s	mGy/MBq-s
0.13365	0.01	3.900E-02	3.9E-09	3.77E-09	3.77E+00
0.287941	0.1	4.000E-03	4E-10	3.87E-10	3.87E-01
0.492373	0.5	8.414E-04	8.41E-11	8.14E-11	8.14E-02
0.62035	1	4.262E-04	4.26E-11	4.12E-11	4.12E-02
0.781593	2	2.202E-04	2.2E-11	2.13E-11	2.13E-02
0.984745	4	1.130E-04	1.13E-11	1.09E-11	1.09E-02
1.127252	6	7.621E-05	7.62E-12	7.37E-12	7.37E-03
1.240701	8	5.790E-05	5.79E-12	5.60E-12	5.60E-03
1.336505	10	4.665E-05	4.67E-12	4.51E-12	4.51E-03
1.68389	20	2.434E-05	2.43E-12	2.35E-12	2.35E-03
2.121569	40	1.269E-05	1.27E-12	1.23E-12	1.23E-03
2.42859	60	8.720E-06	8.72E-13	8.43E-13	8.43E-04
2.673009	80	6.757E-06	6.76E-13	6.54E-13	6.54E-04
2.879412	100	5.495E-06	5.5E-13	5.32E-13	5.32E-04
4.152831	300	2.061E-06	2.06E-13	1.99E-13	1.99E-04
4.570781	400	1.599E-06	1.6E-13	1.55E-13	1.55E-04
4.923725	500	1.327E-06	1.33E-13	1.28E-13	1.28E-04
5.232239	600	1.115E-06	1.12E-13	1.08E-13	1.08E-04
6.203505	1000	7.210E-07	7.21E-14	6.97E-14	6.97E-05

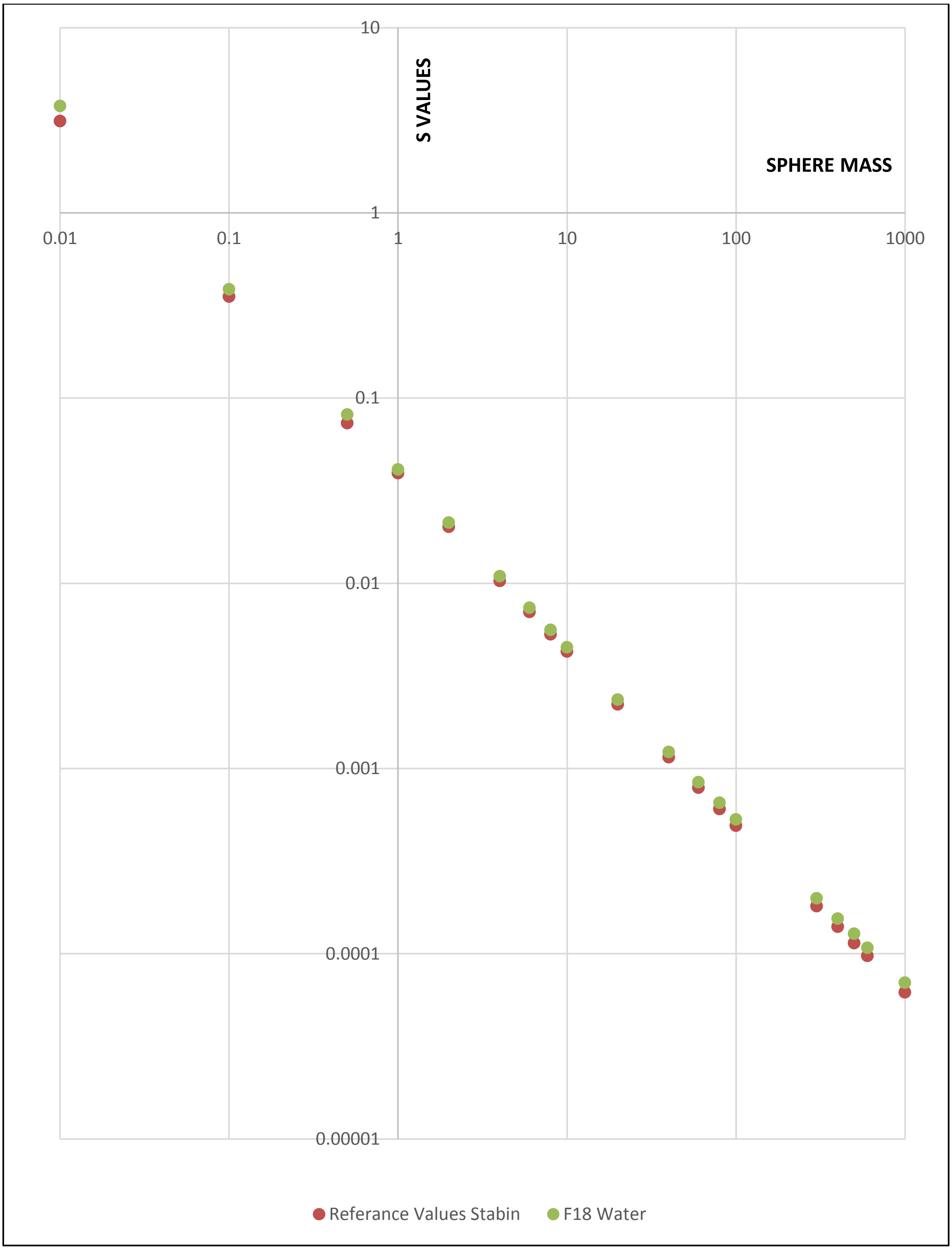


Figure 4.10. Reference values and calculated results for ^{18}F (center of layer)

In Figure 4.5, x-axis belongs to sphere mass values, y-axis belongs to S-values indicated at the last column of Table 4.5. The graph shows reference and calculated values' correlation.

Table 4.6 last column shows S-values calculated for the data acquired (3. column) from the whole fifth layer for ^{18}F activity.

Table 4.7. Results of the whole layer (^{18}F)

r (cm)	Mass (g)	Gy	Gy/particle	Gy/Bq-s	mGy/MBq-s
0.13365	0.01	3.500E-02	3.5E-09	3.39E-09	3.39E+00
0.287941	0.1	4.000E-03	4E-10	3.87E-10	3.87E-01
0.492373	0.5	8.367E-04	8.37E-11	8.09E-11	8.09E-02
0.62035	1	4.249E-04	4.25E-11	4.11E-11	4.11E-02
0.781593	2	2.165E-04	2.17E-11	2.09E-11	2.09E-02
0.984745	4	1.105E-04	1.11E-11	1.07E-11	1.07E-02
1.127252	6	7.479E-05	7.48E-12	7.23E-12	7.23E-03
1.240701	8	5.679E-05	5.68E-12	5.49E-12	5.49E-03
1.336505	10	4.589E-05	4.59E-12	4.44E-12	4.44E-03
1.68389	20	2.375E-05	2.38E-12	2.30E-12	2.30E-03
2.121569	40	1.238E-05	1.24E-12	1.20E-12	1.20E-03
2.42859	60	8.500E-06	8.5E-13	8.22E-13	8.22E-04
2.673009	80	6.522E-06	6.52E-13	6.31E-13	6.31E-04
2.879412	100	5.306E-06	5.31E-13	5.13E-13	5.13E-04
4.152831	300	1.968E-06	1.97E-13	1.90E-13	1.90E-04
4.570781	400	1.521E-06	1.52E-13	1.47E-13	1.47E-04
4.923725	500	1.253E-06	1.25E-13	1.21E-13	1.21E-04
5.232239	600	1.067E-06	1.07E-13	1.03E-13	1.03E-04
6.203505	1000	6.830E-07	6.83E-14	6.61E-14	6.61E-05

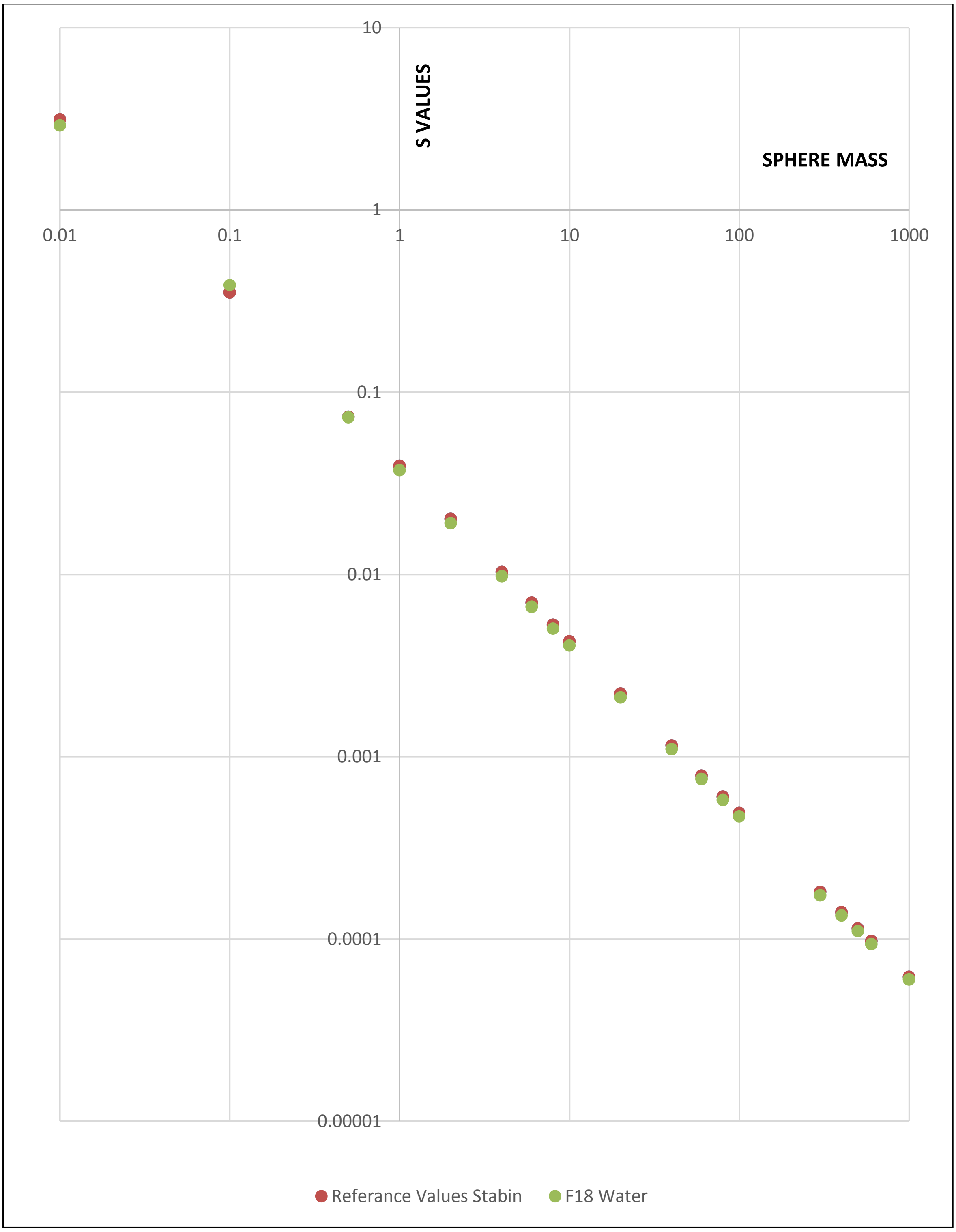


Figure 4.11. Reference values and calculated results for ^{18}F (whole layer)

In Figure 4.6, x-axis belongs to sphere mass values, y-axis belongs to S-values indicated at the last column of Table 4.6. The graph shows reference and calculated values' correlation.

4.3. ^{131}I RESULTS

Table 4.7. last column shows S-values calculated for the data acquired (3. column) from the center of fifth layer for ^{131}I activity.

Table 4.8. Results of the center of the layer (^{131}I)

r (cm)	Mass (g)	Gy	Gy/particle	Gy/Bq-s	mGy/MBq-s
0.13365	0.01	8.000E-03	8E-10	2.87E-09	2.870064
0.287941	0.1	8.650E-04	8.65E-11	3.10E-10	0.310326
0.492373	0.5	1.767E-04	1.767E-11	6.34E-11	0.063393
0.62035	1	8.847E-05	8.847E-12	3.17E-11	0.031739
0.781593	2	4.484E-05	4.484E-12	1.61E-11	0.016087
0.984745	4	2.279E-05	2.279E-12	8.18E-12	0.008176
1.127252	6	1.528E-05	1.528E-12	5.48E-12	0.005482
1.240701	8	1.150E-05	1.15E-12	4.13E-12	0.004126
1.336505	10	9.259E-06	9.259E-13	3.32E-12	0.003322
1.68389	20	4.728E-06	4.728E-13	1.70E-12	0.001696
2.121569	40	2.420E-06	2.42E-13	8.68E-13	0.000868
2.42859	60	1.635E-06	1.635E-13	5.87E-13	0.000587
2.673009	80	1.245E-06	1.245E-13	4.47E-13	0.000447
2.879412	100	1.013E-06	1.013E-13	3.63E-13	0.000363
4.152831	300	3.608E-07	3.608E-14	1.29E-13	0.000129
4.570781	400	2.770E-07	2.77E-14	9.94E-14	0.000099
4.923725	500	2.252E-07	2.252E-14	8.08E-14	0.000081
5.232239	600	1.919E-07	1.919E-14	6.88E-14	0.000069
6.203505	1000	1.200E-07	1.2E-14	4.31E-14	0.000043

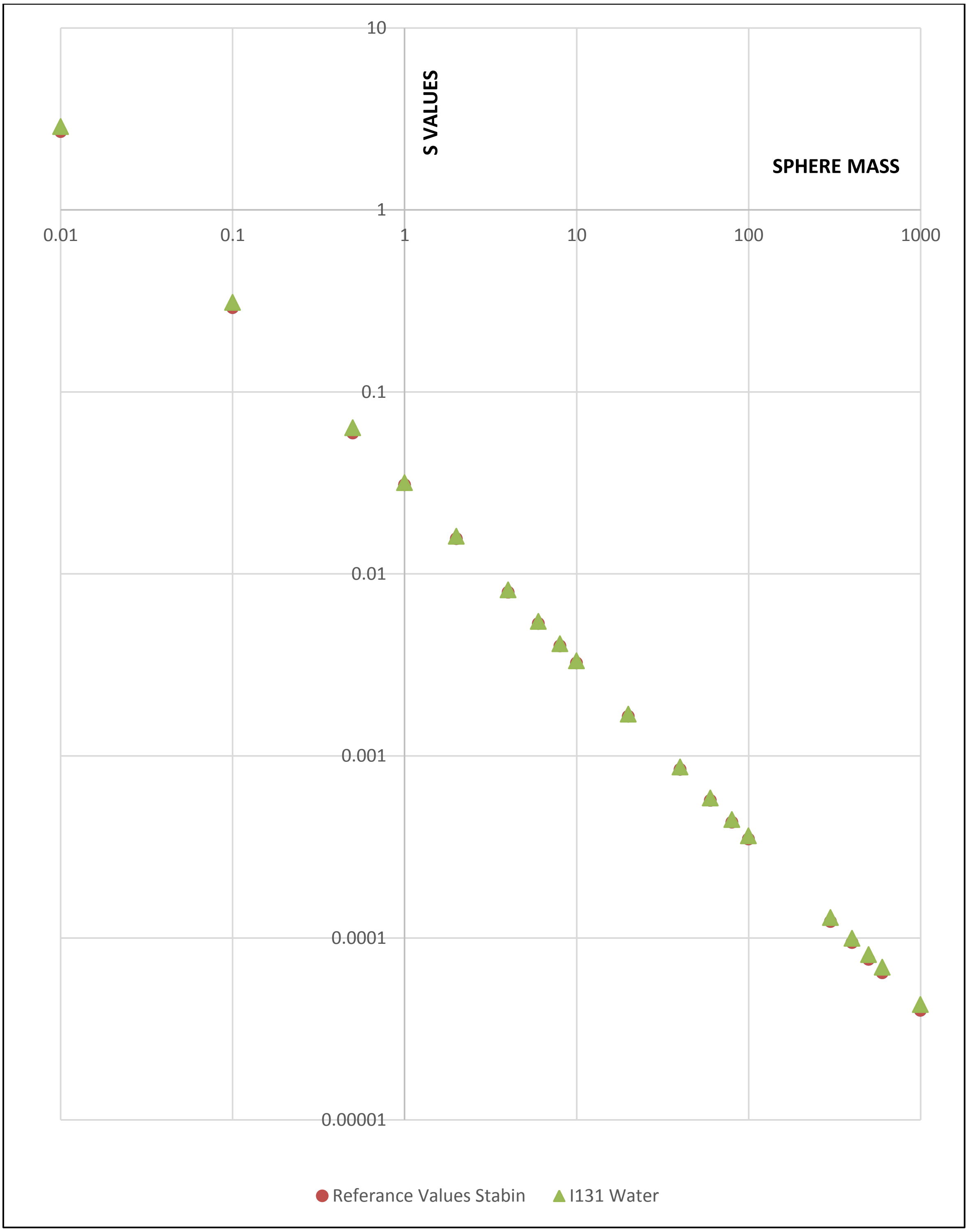


Figure 4.12. Reference values and calculated results for ^{131}I (center of layer)

In Figure 4.7, x-axis belongs to sphere mass values, y-axis belongs to S-values indicated at the last column of Table 4.7. The graph shows reference and calculated values' correlation.

Table 4.8 last column shows S-values calculated for the data acquired (3. column) from the whole fifth layer for ^{131}I activity.

Table 4.9. Results of the whole layer (^{131}I)

r (cm)	Mass (g)	Gy	Gy/particle	Gy/Bq-s	mGy/MBq-s
0.13365	0.01	8.000E-03	8E-10	2.87E-09	2.870064
0.287941	0.1	8.608E-04	8.608E-11	3.09E-10	0.308819
0.492373	0.5	1.757E-04	1.757E-11	6.30E-11	0.063034
0.62035	1	8.849E-05	8.849E-12	3.17E-11	0.031746
0.781593	2	4.471E-05	4.471E-12	1.60E-11	0.016040
0.984745	4	2.261E-05	2.261E-12	8.11E-12	0.008112
1.127252	6	1.516E-05	1.516E-12	5.44E-12	0.005439
1.240701	8	1.146E-05	1.146E-12	4.11E-12	0.004111
1.336505	10	9.214E-06	9.214E-13	3.31E-12	0.003306
1.68389	20	4.686E-06	4.686E-13	1.68E-12	0.001681
2.121569	40	2.403E-06	2.403E-13	8.62E-13	0.000862
2.42859	60	1.619E-06	1.619E-13	5.81E-13	0.000581
2.673009	80	1.235E-06	1.235E-13	4.43E-13	0.000443
2.879412	100	9.979E-07	9.979E-14	3.58E-13	0.000358
4.152831	300	3.520E-07	3.52E-14	1.26E-13	0.000126
4.570781	400	2.702E-07	2.702E-14	9.69E-14	0.000097
4.923725	500	2.202E-07	2.202E-14	7.90E-14	0.000079
5.232239	600	1.855E-07	1.855E-14	6.65E-14	0.000067
6.203505	1000	1.156E-07	1.156E-14	4.15E-14	0.000041

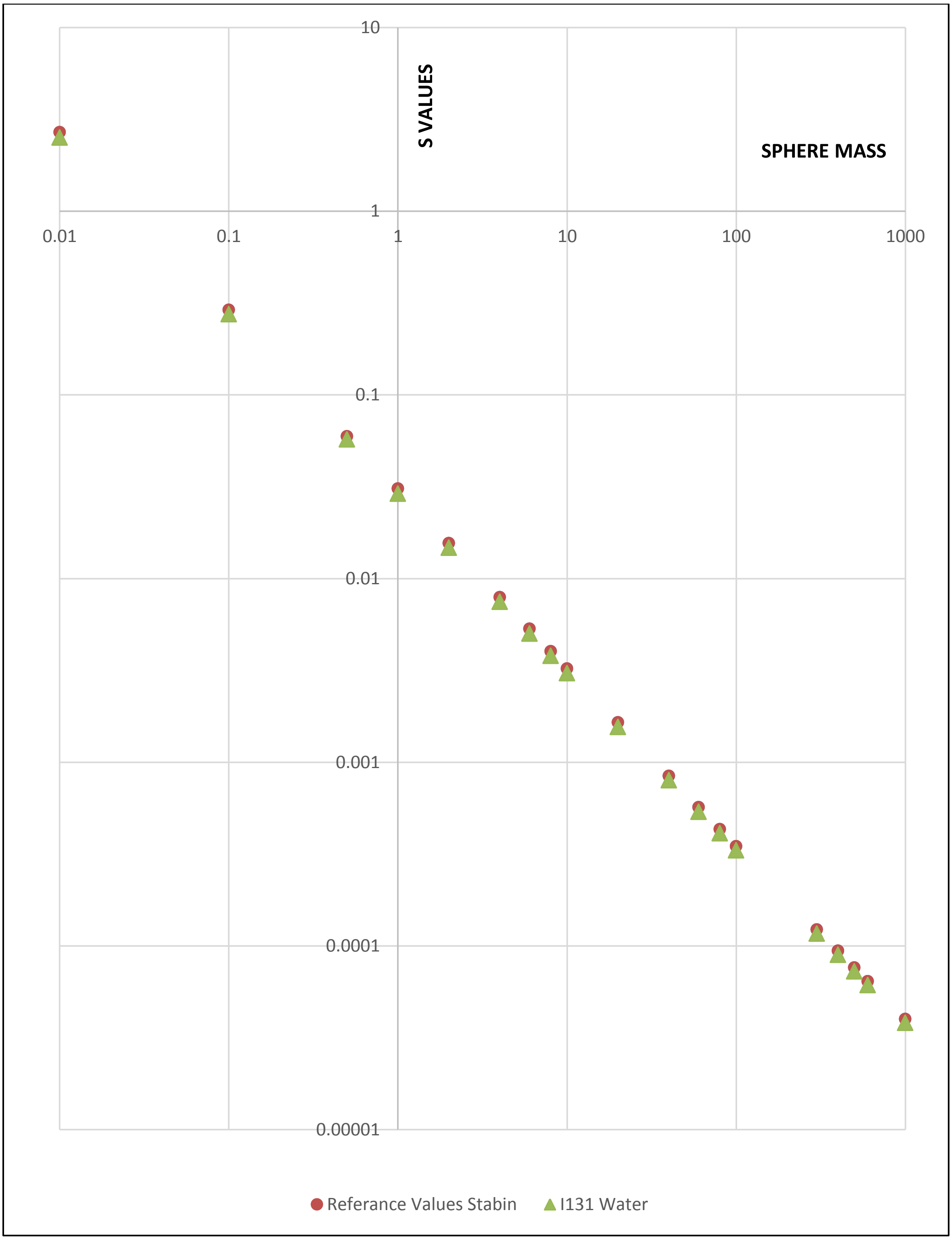


Figure 4.13. Reference values and calculated results for ^{131}I (whole layer)

In Figure 4.8, x-axis belongs to sphere mass values, y-axis belongs to S-values indicated at the last column of Table 4.8. The graph shows reference and calculated values' correlation.

5. RESULTS AND DISCUSSION

Data and calculations of S values belonging to ^{131}I are shown in Table 4.7 for the center of the layer and in Table 4.8 for the whole layer. For both data acquisitions the uncertainty is between 1.3 % - 1.5 % that is very acceptable. Figure 4.7 and Figure 4.8 are the graphs belonging reference S values and S values that are calculated from the center of the layer and whole layer respectively. In table 5.1 relative error of calculated S values are shown. ^{131}I is a moderate β^- emitter with a mean energy of 192 keV and has a short range in water (2.3 mm) [31]. This causes dose to be absorbed mostly in the source volume. As a result S value calculation from the absorbed dose data that is acquired from the center of the layer is more accurate than the data acquired from the whole layer.

Data and calculations of S values belonging to ^{90}Y are shown in Table 4.3 for the center of the layer and in Table 4.4 for the whole layer. For both data acquisitions the uncertainty is between 0.4 % - 0.8 % that is very acceptable. Figure 4.3 and Figure 4.4 are the graphs belonging reference S values and S values that are calculated from the center of the layer and whole layer respectively. In table 5.1 relative error of calculated S values are shown. ^{90}Y is a high β^- emitter with a mean energy of 932.9 keV and long range in water (11.3 mm) [31]. As a result S value calculation from the absorbed dose data that is acquired from the center of the layer becomes more accurate when the sphere mass is above 300 g. For smaller masses whole layer values are more accurate as a result of dose absorption at the outside of the unit sphere.

Data and calculations of S values belonging to ^{18}F are shown in Table 4.5 for the center of the layer and in Table 4.6 for the whole layer. For both data acquisitions the uncertainty is between 0.6 % - 0.7 % and that is very acceptable. Figure 4.5 and Figure 4.6 are the graphs belonging reference S values and S values that are calculated from the center of the layer and whole layer respectively. In table 5.1 relative error of calculated S values are shown. ^{18}F is a high β^+ emitter with a mean energy of 249,8 keV [31]. As a result of positron annihilation whole layer values are more accurate than layer center values for all radii and all sphere masses.

For the circumstances given above results are highly correlated with the reference results [25].

Table 5.1. Relative error of the S values

Mass (g)	Relative Error					
	Center of the Layer	Whole Layer	Center of the Layer	Whole Layer	Center of the Layer	Whole Layer
	^{18}F		^{90}Y		^{131}I	
0.01	20.53	8.16	29.41	14.71	6.69	6.69
0.1	9.61	9.61	14.80	2.04	7.01	6.49
0.5	11.03	10.41	42.18	5.21	6.72	6.12
1	4.64	4.32	12.28	12.28	2.74	2.72
2	5.45	3.67	21.39	9.46	3.12	2.82
4	6.12	3.77	16.97	9.78	3.10	2.29
6	5.31	3.35	14.40	9.44	2.66	1.85
8	5.67	3.65	13.72	9.33	2.63	2.27
10	5.19	3.47	12.18	8.42	2.52	2.02
20	6.05	3.48	9.22	7.72	2.80	1.89
40	6.74	4.13	7.60	6.94	3.11	2.39
60	7.04	4.34	6.74	6.01	3.09	2.08
80	8.21	4.45	5.97	5.34	3.39	2.56
100	8.25	4.53	5.25	5.18	4.13	2.58
300	10.14	5.17	3.42	3.38	5.24	2.67
400	10.48	5.09	3.21	3.10	5.61	3.01
500	12.60	6.32	3.04	2.84	5.89	3.54
600	10.85	6.07	2.93	2.48	7.07	3.50
1000	12.67	6.73	1.99	1.44	7.63	3.68

6. CONCLUSION

MIRD schema introduces specific absorbed fraction factor to represent fraction of energy absorbed in a specific organ while for this aim ICRP schema also introduces radiation weighting factors and tissue weighting factors [7, 12]. For internal electron emitters the absorbed fraction was thought to be in unity because of weak penetration ability of electrons [7, 32]. UDSM is a model with tissue like properties that is proposed to simulate spherical structures in human body with an uniform activity distribution [7]. This model works for calculation of absorbed fractions for different radionuclides with different types of radiation.

UDSM absorbed dose results are accurate when compared to the reference values especially for bigger sphere masses. As the structure of sphere (tumor or cancer cell clusters) gets smaller, radionuclide properties becomes significant for dose calculations. Since the administered dose depends tumor structure and radionuclide properties, dose from electrons can’t be in unity for UDSM.

Monte Carlo Code GATE V6.2 is an efficient code for assessment of internal dosimetry applications. Simulation results are highly correlated with reference values.

7. FUTURE WORK

Monte Carlo Code GATE V6.2 simulation includes physical half-life of radioactive nuclides. In real human tissue not only physical half-life but also biological half-life of radionuclide is essential for internal dose calculations. The higher version of GATE that is including biological half-life is being planned to use for more efficient simulations.

Patient specific dose assessment is essential in internal dosimetry. For this purpose instead of UDSM, voxel S-values are planned to use for patient specific dose calculations. By this way the simulation is expected to include patient tissue differences.

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APPENDIX A: UDSM SIMULATION MAIN FILE

```
#=====================================================
# VISUALISATION AND VERBOSITY
#=====================================================
/control/execute visu.mac
/control/execute verbose.mac
#=====================================================
# PHANTOM
#=====================================================
/gate/geometry/setMaterialDatabase GateMaterials.db

# World
/gate/world/geometry/setXLength 5.0 cm
/gate/world/geometry/setYLength 5.0 cm
/gate/world/geometry/setZLength 5.0 cm
/gate/world/setMaterial Water
/gate/world/vis/setVisible 1
/gate/world/vis/setColor white
/gate/world/vis/forceWireframe

# Global Box
/gate/world/daughters/name            USM
/gate/world/daughters/insert          sphere
/gate/USM/geometry/setRmin            0 cm
/gate/USM/geometry/setRmax            1.336505 cm
/gate/USM/placement/setTranslation  0. 0. 0. cm
/gate/USM/setMaterial Water
/gate/USM/vis/setVisible 1
/gate/USM/vis/setColor blue
/gate/USM/vis/forceWireframe
```

```
#==================================================
# PHYSICS
#==================================================
/gate/geometry/setIonisationPotential Water 75 eV
/gate/geometry/setIonisationPotential Muscle 75 eV
/gate/geometry/setIonisationPotential Air 85.7 eV
/control/execute physicA.mac
#
# CUTS
#
/gate/physics/Gamma/SetCutInRegion      world 0.1 mm
/gate/physics/Electron/SetCutInRegion   world 0.1 mm
/gate/physics/Positron/SetCutInRegion   world 0.1 mm
/gate/physics/Gamma/SetCutInRegion      USM 0.01 mm
/gate/physics/Electron/SetCutInRegion   USM 0.01 mm
/gate/physics/Positron/SetCutInRegion   USM 0.01 mm
/gate/physics/processes/ElectronIonisation/setStepFunction e+ 0.1 0.0005 mm
/gate/physics/processes/ElectronIonisation/setStepFunction e- 0.1 0.0005 mm
#==================================================
# OUTPUT: ACTOR CONCEPT
#==================================================
/gate/actor/addActor SimulationStatisticActor USMStat
/gate/actor/USMStat/save  ../OUTPUTF18WW/OUTPUT1.34/F18Stat.txt
/gate/actor/addActor                    DoseActor  doseDistribution
/gate/actor/doseDistribution/save             ../OUTPUTF18WW/OUTPUT1.34/F18.hdr
/gate/actor/doseDistribution/attachTo             USM
/gate/actor/doseDistribution/stepHitType        random
/gate/actor/doseDistribution/setPosition        0 0 0 cm
/gate/actor/doseDistribution/setResolution       10 10 10
/gate/actor/doseDistribution/saveEveryNSeconds     10
/gate/actor/doseDistribution/enableEdep           true
/gate/actor/doseDistribution/enableUncertaintyEdep true
/gate/actor/doseDistribution/enableDose           true
```

```
/gate/actor/doseDistribution/enableUncertaintyDose true
/gate/actor/doseDistribution/enableNumberOfHits    true
#=====================================================
# INITIALISATION
#=====================================================
/gate/run/initialize
#=====================================================
# SOURCE
#=====================================================
/control/execute SourceF18.mac
#/control/execute Source1I131.mac
#/control/execute SourceY90.mac
#=====================================================
# RANDOM
#=====================================================
# JamesRandom MersenneTwister
/gate/random/setEngineName MersenneTwister
/gate/random/setEngineSeed 1021
#=====================================================
# START BEAMS
#=====================================================
/gate/application/setTotalNumberOfPrimaries 10000000
/gate/application/start
#exit
```

APPENDIX B: UDSM SIMULATION - PHYSICS FILE

```
#=====================================================================
# Electromagnetic processes : physics list standard option 3 (issue de egammaStandardPhys.mac)
#=====================================================================
/gate/physics/addProcess PhotoElectric
/gate/physics/processes/PhotoElectric/setModel StandardModel
/gate/physics/addProcess Compton
/gate/physics/processes/Compton/setModel StandardModel
/gate/physics/addProcess RayleighScattering
/gate/physics/processes/RayleighScattering/setModel PenelopeModel
/gate/physics/addProcess ElectronIonisation
/gate/physics/processes/ElectronIonisation/setModel StandardModel e-
/gate/physics/processes/ElectronIonisation/setModel StandardModel e+
/gate/physics/addProcess Bremsstrahlung e-
/gate/physics/addProcess Bremsstrahlung e+
/gate/physics/processes/Bremsstrahlung/setModel StandardModel e-
/gate/physics/processes/Bremsstrahlung/setModel StandardModel e+
/gate/physics/addProcess PositronAnnihilation e+
/gate/physics/addProcess eMultipleScattering e+
/gate/physics/addProcess eMultipleScattering e-
#=====================================================================
# Additional processes not included in the list option 3
#=====================================================================
#pair production
#/gate/physics/addProcess GammaConversion
#/gate/physics/processes/GammaConversion/setModel StandardModel
#=====================================================================
# customized CUTS
#=====================================================================
#1/1 of dosel size
```

/gate/physics/displayCuts
/gate/physics/setEMin 0.1 keV
/gate/physics/setEMax 10 GeV
/gate/physics/setDEDXBinning 220 $ pouvoir d'arret
/gate/physics/setLambdaBinning 220 $ mean free path
/gate/physics/processes/eMultipleScattering/setGeometricalStepLimiterType e+ distanceToBoundary
#/gate/physics/processes/Bremsstrahlung/addFilter angleFilter secondaries
#/gate/physics/processes/Bremsstrahlung/secondaries/angleFilter/setAngle 20
#/gate/physics/processes/Bremsstrahlung/secondaries/angleFilter/setDirection 1 0 0
#==
#additional features
#==
/gate/physics/processes/eMultipleScattering/setGeometricalStepLimiterType e- distanceToBoundary
/gate/physics/processes/eMultipleScattering/setGeometricalStepLimiterType e+ distanceToBoundary

APPENDIX C: VERBOSITY AND VISUALISATION FILES

```
/gate/verbose Physic    1
/gate/verbose Cuts      1
/gate/verbose SD        0
/gate/verbose Actions   0
/gate/verbose Actor     0
/gate/verbose Step      0
/gate/verbose Error     1
/gate/verbose Warning   1
/gate/verbose Output    0
/gate/verbose Beam      0
/gate/verbose Volume    0
/gate/verbose Image     0
/gate/verbose Geometry  2

/vis/open OGLSX
/vis/viewer/set/viewpointThetaPhi
/vis/viewer/zoom 1
/vis/viewer/set/style surface
/vis/drawVolume
#/vis/viewer/flush
/tracking/verbose 0
/tracking/storeTrajectory 1
/vis/scene/add/trajectories
/vis/scene/endOfEventAction accumulate
## the following line
/vis/viewer/set/auxiliaryEdge 1
/vis/geometry/set/forceWireframe
/vis/viewer/set/lineSegmentsPerCircle 200
#/vis/viewer/set/style surface
#/vis/viewer/flush
```

```
#/vis/viewer/set/hiddenEdge 1
## the following lines store ALL trajectories (do not use with too many events !)
/vis/scene/add/trajectories
/vis/scene/add/hits
/tracking/storeTrajectory 1
/vis/scene/endOfEventAction accumulate
/vis/scene/notifyHandlers
/vis/scene/list
```

APPENDIX D: SOURCE FILE

```
/gate/source/addSource EM
/gate/source/EM/gps/type Volume
/gate/source/EM/gps/shape Sphere
/gate/source/EM/gps/radius 0.133650 cm
/gate/source/EM/gps/centre 0. 0. 0. cm
/gate/source/EM/gps/particle gamma
/gate/source/EM/gps/angtype iso
/gate/source/EM/setIntensity 1.8255
/gate/source/EM/gps/energytype User
/gate/source/EM/gps/histname energy

/gate/source/EM/gps/histpoint    0.0000166175    0
/gate/source/EM/gps/histpoint    0.0000166175    0.762736
/gate/source/EM/gps/histpoint    0.0000166175    0
/gate/source/EM/gps/histpoint    0.0000922478    0
/gate/source/EM/gps/histpoint    0.0000922478    0.00000757745
/gate/source/EM/gps/histpoint    0.0000922478    0
/gate/source/EM/gps/histpoint    0.000313    0
/gate/source/EM/gps/histpoint    0.000313    0.000000181712
/gate/source/EM/gps/histpoint    0.000313    0
/gate/source/EM/gps/histpoint    0.0003292    0
/gate/source/EM/gps/histpoint    0.0003292    0.00000000136135
/gate/source/EM/gps/histpoint    0.0003292    0
/gate/source/EM/gps/histpoint    0.000608259    0
/gate/source/EM/gps/histpoint    0.000608259    0.000309105
/gate/source/EM/gps/histpoint    0.000608259    0
/gate/source/EM/gps/histpoint    0.000642201    0
/gate/source/EM/gps/histpoint    0.000642201    0.00000341928
/gate/source/EM/gps/histpoint    0.000642201    0
/gate/source/EM/gps/histpoint    0.00365269    0
```

/gate/source/EM/gps/histpoint	0.00365269	0.000270989
/gate/source/EM/gps/histpoint	0.00365269	0
/gate/source/EM/gps/histpoint	0.00378523	0
/gate/source/EM/gps/histpoint	0.00378523	0.00000149608
/gate/source/EM/gps/histpoint	0.00378523	0
/gate/source/EM/gps/histpoint	0.00384813	0
/gate/source/EM/gps/histpoint	0.00384813	0.00000139288
/gate/source/EM/gps/histpoint	0.00384813	0
/gate/source/EM/gps/histpoint	0.00398191	0
/gate/source/EM/gps/histpoint	0.00398191	0.0000778852
/gate/source/EM/gps/histpoint	0.00398191	0
/gate/source/EM/gps/histpoint	0.00408379	0
/gate/source/EM/gps/histpoint	0.00408379	0.000276832
/gate/source/EM/gps/histpoint	0.00408379	0
/gate/source/EM/gps/histpoint	0.00409719	0
/gate/source/EM/gps/histpoint	0.00409719	0.00245351
/gate/source/EM/gps/histpoint	0.00409719	0
/gate/source/EM/gps/histpoint	0.00417734	0
/gate/source/EM/gps/histpoint	0.00417734	0.00000112585
/gate/source/EM/gps/histpoint	0.00417734	0
/gate/source/EM/gps/histpoint	0.004413	0
/gate/source/EM/gps/histpoint	0.004413	0.00144796
/gate/source/EM/gps/histpoint	0.004413	0
/gate/source/EM/gps/histpoint	0.00442743	0
/gate/source/EM/gps/histpoint	0.00442743	0.000127153
/gate/source/EM/gps/histpoint	0.00442743	0
/gate/source/EM/gps/histpoint	0.00449034	0
/gate/source/EM/gps/histpoint	0.00449034	0.00020036
/gate/source/EM/gps/histpoint	0.00449034	0
/gate/source/EM/gps/histpoint	0.00456633	0
/gate/source/EM/gps/histpoint	0.00456633	0.0000238744
/gate/source/EM/gps/histpoint	0.00456633	0
/gate/source/EM/gps/histpoint	0.00461402	0

/gate/source/EM/gps/histpoint	0.00461402	0.000000131668
/gate/source/EM/gps/histpoint	0.00461402	0
/gate/source/EM/gps/histpoint	0.00462673	0
/gate/source/EM/gps/histpoint	0.00462673	0.000000126338
/gate/source/EM/gps/histpoint	0.00462673	0
/gate/source/EM/gps/histpoint	0.00470486	0
/gate/source/EM/gps/histpoint	0.00470486	0.0000402593
/gate/source/EM/gps/histpoint	0.00470486	0
/gate/source/EM/gps/histpoint	0.00470692	0
/gate/source/EM/gps/histpoint	0.00470692	0.000359019
/gate/source/EM/gps/histpoint	0.00470692	0
/gate/source/EM/gps/histpoint	0.00472599	0
/gate/source/EM/gps/histpoint	0.00472599	0.00000189442
/gate/source/EM/gps/histpoint	0.00472599	0
/gate/source/EM/gps/histpoint	0.00473937	0
/gate/source/EM/gps/histpoint	0.00473937	0.00000282808
/gate/source/EM/gps/histpoint	0.00473937	0
/gate/source/EM/gps/histpoint	0.00475109	0
/gate/source/EM/gps/histpoint	0.00475109	0.00000336137
/gate/source/EM/gps/histpoint	0.00475109	0
/gate/source/EM/gps/histpoint	0.00476235	0
/gate/source/EM/gps/histpoint	0.00476235	0.0000000148915
/gate/source/EM/gps/histpoint	0.00476235	0
/gate/source/EM/gps/histpoint	0.00476373	0
/gate/source/EM/gps/histpoint	0.00476373	0.0000000137496
/gate/source/EM/gps/histpoint	0.00476373	0
/gate/source/EM/gps/histpoint	0.00489553	0
/gate/source/EM/gps/histpoint	0.00489553	0.000011112
/gate/source/EM/gps/histpoint	0.00489553	0
/gate/source/EM/gps/histpoint	0.00495593	0
/gate/source/EM/gps/histpoint	0.00495593	0.000000139229
/gate/source/EM/gps/histpoint	0.00495593	0
/gate/source/EM/gps/histpoint	0.00503405	0

/gate/source/EM/gps/histpoint	0.00503405	0.000216155
/gate/source/EM/gps/histpoint	0.00503405	0
/gate/source/EM/gps/histpoint	0.00508031	0
/gate/source/EM/gps/histpoint	0.00508031	0.00000133369
/gate/source/EM/gps/histpoint	0.00508031	0
/gate/source/EM/gps/histpoint	0.00509294	0
/gate/source/EM/gps/histpoint	0.00509294	0.0000000152095
/gate/source/EM/gps/histpoint	0.00509294	0
/gate/source/EM/gps/histpoint	0.00525621	0
/gate/source/EM/gps/histpoint	0.00525621	0.0000274089
/gate/source/EM/gps/histpoint	0.00525621	0
/gate/source/EM/gps/histpoint	0.00526892	0
/gate/source/EM/gps/histpoint	0.00526892	0.0000443189
/gate/source/EM/gps/histpoint	0.00526892	0
/gate/source/EM/gps/histpoint	0.00534706	0
/gate/source/EM/gps/histpoint	0.00534706	0.000000230419
/gate/source/EM/gps/histpoint	0.00534706	0
/gate/source/EM/gps/histpoint	0.00534913	0
/gate/source/EM/gps/histpoint	0.00534913	0.000000349998
/gate/source/EM/gps/histpoint	0.00534913	0
/gate/source/EM/gps/histpoint	0.00540454	0
/gate/source/EM/gps/histpoint	0.00540454	0.00000311539
/gate/source/EM/gps/histpoint	0.00540454	0
/gate/source/EM/gps/histpoint	0.00540593	0
/gate/source/EM/gps/histpoint	0.00540593	0.00000483836
/gate/source/EM/gps/histpoint	0.00540593	0
/gate/source/EM/gps/histpoint	0.0294521	0
/gate/source/EM/gps/histpoint	0.0294521	0.0140078
/gate/source/EM/gps/histpoint	0.0294521	0
/gate/source/EM/gps/histpoint	0.0297812	0
/gate/source/EM/gps/histpoint	0.0297812	0.0259418
/gate/source/EM/gps/histpoint	0.0297812	0
/gate/source/EM/gps/histpoint	0.0335665	0

/gate/source/EM/gps/histpoint	0.0335665	0.00243522
/gate/source/EM/gps/histpoint	0.0335665	0
/gate/source/EM/gps/histpoint	0.0336295	0
/gate/source/EM/gps/histpoint	0.0336295	0.00472116
/gate/source/EM/gps/histpoint	0.0336295	0
/gate/source/EM/gps/histpoint	0.0338651	0
/gate/source/EM/gps/histpoint	0.0338651	0.0000240211
/gate/source/EM/gps/histpoint	0.0338651	0
/gate/source/EM/gps/histpoint	0.0338785	0
/gate/source/EM/gps/histpoint	0.0338785	0.0000328048
/gate/source/EM/gps/histpoint	0.0338785	0
/gate/source/EM/gps/histpoint	0.0343952	0
/gate/source/EM/gps/histpoint	0.0343952	0.000510579
/gate/source/EM/gps/histpoint	0.0343952	0
/gate/source/EM/gps/histpoint	0.034408	0
/gate/source/EM/gps/histpoint	0.034408	0.000995801
/gate/source/EM/gps/histpoint	0.034408	0
/gate/source/EM/gps/histpoint	0.0344862	0
/gate/source/EM/gps/histpoint	0.0344862	0.00000447782
/gate/source/EM/gps/histpoint	0.0344862	0
/gate/source/EM/gps/histpoint	0.0344882	0
/gate/source/EM/gps/histpoint	0.0344882	0.00000610349
/gate/source/EM/gps/histpoint	0.0344882	0
/gate/source/EM/gps/histpoint	0.0345436	0
/gate/source/EM/gps/histpoint	0.0345436	0.0000523268
/gate/source/EM/gps/histpoint	0.0345436	0
/gate/source/EM/gps/histpoint	0.034545	0
/gate/source/EM/gps/histpoint	0.034545	0.0000989453
/gate/source/EM/gps/histpoint	0.034545	0
/gate/source/EM/gps/histpoint	0.080185	0
/gate/source/EM/gps/histpoint	0.080185	0.0262257
/gate/source/EM/gps/histpoint	0.080185	0
/gate/source/EM/gps/histpoint	0.0859	0

```
/gate/source/EM/gps/histpoint 0.0859 0.0000008987
/gate/source/EM/gps/histpoint 0.0859 0
/gate/source/EM/gps/histpoint 0.177214 0
/gate/source/EM/gps/histpoint 0.177214 0.0026961
/gate/source/EM/gps/histpoint 0.177214 0
/gate/source/EM/gps/histpoint 0.23218 0
/gate/source/EM/gps/histpoint 0.23218 0.000031863
/gate/source/EM/gps/histpoint 0.23218 0
/gate/source/EM/gps/histpoint 0.272498 0
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/gate/source/EM/gps/histpoint 0.2958 0
/gate/source/EM/gps/histpoint 0.3024 0
/gate/source/EM/gps/histpoint 0.3024 0.000047386
/gate/source/EM/gps/histpoint 0.3024 0
/gate/source/EM/gps/histpoint 0.318088 0
/gate/source/EM/gps/histpoint 0.318088 0.00077615
/gate/source/EM/gps/histpoint 0.318088 0
/gate/source/EM/gps/histpoint 0.324651 0
/gate/source/EM/gps/histpoint 0.324651 0.00021242
/gate/source/EM/gps/histpoint 0.324651 0
/gate/source/EM/gps/histpoint 0.325789 0
/gate/source/EM/gps/histpoint 0.325789 0.00273695
/gate/source/EM/gps/histpoint 0.325789 0
/gate/source/EM/gps/histpoint 0.3584 0
/gate/source/EM/gps/histpoint 0.3584 0.0001634
/gate/source/EM/gps/histpoint 0.3584 0
/gate/source/EM/gps/histpoint 0.364489 0
```

```
/gate/source/EM/gps/histpoint   0.364489   0.817
/gate/source/EM/gps/histpoint   0.364489   0
/gate/source/EM/gps/histpoint   0.404814   0
/gate/source/EM/gps/histpoint   0.404814   0.00054739
/gate/source/EM/gps/histpoint   0.404814   0
/gate/source/EM/gps/histpoint   0.4496   0
/gate/source/EM/gps/histpoint   0.4496   0.00007353
/gate/source/EM/gps/histpoint   0.4496   0
/gate/source/EM/gps/histpoint   0.503004   0
/gate/source/EM/gps/histpoint   0.503004   0.00360297
/gate/source/EM/gps/histpoint   0.503004   0
/gate/source/EM/gps/histpoint   0.636989   0
/gate/source/EM/gps/histpoint   0.636989   0.0717326
/gate/source/EM/gps/histpoint   0.636989   0
/gate/source/EM/gps/histpoint   0.642719   0
/gate/source/EM/gps/histpoint   0.642719   0.00217322
/gate/source/EM/gps/histpoint   0.642719   0
/gate/source/EM/gps/histpoint   0.722911   0
/gate/source/EM/gps/histpoint   0.722911   0.0177289
/gate/source/EM/gps/histpoint   0.722911   0

#====================================================
# MONOENERGETIC EMISSIONS
#====================================================
/gate/source/addSource MonoE
/gate/source/MonoE/gps/type Volume
/gate/source/MonoE/gps/shape Sphere
/gate/source/MonoE/gps/radius 0.133650 cm
/gate/source/MonoE/gps/centre 0. 0. 0. cm
/gate/source/MonoE/gps/particle e-
/gate/source/MonoE/gps/angtype iso
/gate/source/MonoE/setIntensity 0.762080
/gate/source/MonoE/gps/energytype User
```

```
/gate/source/MonoE/gps/histname energy
/gate/source/MonoE/gps/histpoint    0.0000261504    0
/gate/source/MonoE/gps/histpoint    0.0000261504    0.118727
/gate/source/MonoE/gps/histpoint    0.0000261504    0
/gate/source/MonoE/gps/histpoint    0.0000362367    0
/gate/source/MonoE/gps/histpoint    0.0000362367    0.36283
/gate/source/MonoE/gps/histpoint    0.0000362367    0
/gate/source/MonoE/gps/histpoint    0.000123806    0
/gate/source/MonoE/gps/histpoint    0.000123806    0.0445522
/gate/source/MonoE/gps/histpoint    0.000123806    0
/gate/source/MonoE/gps/histpoint    0.000317976    0
/gate/source/MonoE/gps/histpoint    0.000317976    0.00828747
/gate/source/MonoE/gps/histpoint    0.000317976    0
/gate/source/MonoE/gps/histpoint    0.000505029    0
/gate/source/MonoE/gps/histpoint    0.000505029    0.0996618
/gate/source/MonoE/gps/histpoint    0.000505029    0
/gate/source/MonoE/gps/histpoint    0.00061706    0
/gate/source/MonoE/gps/histpoint    0.00061706    0.00570048
/gate/source/MonoE/gps/histpoint    0.00061706    0
/gate/source/MonoE/gps/histpoint    0.000766872    0
/gate/source/MonoE/gps/histpoint    0.000766872    0.0000383051
/gate/source/MonoE/gps/histpoint    0.000766872    0
/gate/source/MonoE/gps/histpoint    0.00332402    0
/gate/source/MonoE/gps/histpoint    0.00332402    0.0392981
/gate/source/MonoE/gps/histpoint    0.00332402    0
/gate/source/MonoE/gps/histpoint    0.00400104    0
/gate/source/MonoE/gps/histpoint    0.00400104    0.0116568
/gate/source/MonoE/gps/histpoint    0.00400104    0
/gate/source/MonoE/gps/histpoint    0.00470489    0
/gate/source/MonoE/gps/histpoint    0.00470489    0.000885238
/gate/source/MonoE/gps/histpoint    0.00470489    0
/gate/source/MonoE/gps/histpoint    0.0244715    0
/gate/source/MonoE/gps/histpoint    0.0244715    0.00393828
```

```
/gate/source/MonoE/gps/histpoint    0.0244715    0
/gate/source/MonoE/gps/histpoint    0.0286854    0
/gate/source/MonoE/gps/histpoint    0.0286854    0.0017619
/gate/source/MonoE/gps/histpoint    0.0286854    0
/gate/source/MonoE/gps/histpoint    0.0329032    0
/gate/source/MonoE/gps/histpoint    0.0329032    0.000189387
/gate/source/MonoE/gps/histpoint    0.0329032    0
/gate/source/MonoE/gps/histpoint    0.045629    0
/gate/source/MonoE/gps/histpoint    0.045629    0.0355294
/gate/source/MonoE/gps/histpoint    0.045629    0
/gate/source/MonoE/gps/histpoint    0.051344    0
/gate/source/MonoE/gps/histpoint    0.051344    0.00000169406
/gate/source/MonoE/gps/histpoint    0.051344    0
/gate/source/MonoE/gps/histpoint    0.0747681    0
/gate/source/MonoE/gps/histpoint    0.0747681    0.00433327
/gate/source/MonoE/gps/histpoint    0.0747681    0
/gate/source/MonoE/gps/histpoint    0.0750811    0
/gate/source/MonoE/gps/histpoint    0.0750811    0.000324126
/gate/source/MonoE/gps/histpoint    0.0750811    0
/gate/source/MonoE/gps/histpoint    0.0754103    0
/gate/source/MonoE/gps/histpoint    0.0754103    0.0000800774
/gate/source/MonoE/gps/histpoint    0.0754103    0
/gate/source/MonoE/gps/histpoint    0.0792584    0
/gate/source/MonoE/gps/histpoint    0.0792584    0.000964331
/gate/source/MonoE/gps/histpoint    0.0792584    0
/gate/source/MonoE/gps/histpoint    0.080185    0
/gate/source/MonoE/gps/histpoint    0.080185    0.000243166
/gate/source/MonoE/gps/histpoint    0.080185    0
/gate/source/MonoE/gps/histpoint    0.0804831    0
/gate/source/MonoE/gps/histpoint    0.0804831    0.00000020694
/gate/source/MonoE/gps/histpoint    0.0804831    0
/gate/source/MonoE/gps/histpoint    0.0807961    0
/gate/source/MonoE/gps/histpoint    0.0807961    0.0000000151348
```

/gate/source/MonoE/gps/histpoint 0.0807961 0
/gate/source/MonoE/gps/histpoint 0.0811253 0
/gate/source/MonoE/gps/histpoint 0.0811253 0.00000000357359
/gate/source/MonoE/gps/histpoint 0.0811253 0
/gate/source/MonoE/gps/histpoint 0.0849734 0
/gate/source/MonoE/gps/histpoint 0.0849734 0.0000000458713
/gate/source/MonoE/gps/histpoint 0.0849734 0
/gate/source/MonoE/gps/histpoint 0.0859 0
/gate/source/MonoE/gps/histpoint 0.0859 0.0000000115644
/gate/source/MonoE/gps/histpoint 0.0859 0
/gate/source/MonoE/gps/histpoint 0.142658 0
/gate/source/MonoE/gps/histpoint 0.142658 0.000504316
/gate/source/MonoE/gps/histpoint 0.142658 0
/gate/source/MonoE/gps/histpoint 0.171797 0
/gate/source/MonoE/gps/histpoint 0.171797 0.0000511055
/gate/source/MonoE/gps/histpoint 0.171797 0
/gate/source/MonoE/gps/histpoint 0.17211 0
/gate/source/MonoE/gps/histpoint 0.17211 0.0000325651
/gate/source/MonoE/gps/histpoint 0.17211 0
/gate/source/MonoE/gps/histpoint 0.172439 0
/gate/source/MonoE/gps/histpoint 0.172439 0.0000316404
/gate/source/MonoE/gps/histpoint 0.172439 0
/gate/source/MonoE/gps/histpoint 0.176287 0
/gate/source/MonoE/gps/histpoint 0.176287 0.0000242841
/gate/source/MonoE/gps/histpoint 0.176287 0
/gate/source/MonoE/gps/histpoint 0.177214 0
/gate/source/MonoE/gps/histpoint 0.177214 0.00000583044
/gate/source/MonoE/gps/histpoint 0.177214 0
/gate/source/MonoE/gps/histpoint 0.197624 0
/gate/source/MonoE/gps/histpoint 0.197624 0.00000249227
/gate/source/MonoE/gps/histpoint 0.197624 0
/gate/source/MonoE/gps/histpoint 0.226763 0
/gate/source/MonoE/gps/histpoint 0.226763 0.000000260584

```
/gate/source/MonoE/gps/histpoint    0.226763    0
/gate/source/MonoE/gps/histpoint    0.227076    0
/gate/source/MonoE/gps/histpoint    0.227076    0.000000120457
/gate/source/MonoE/gps/histpoint    0.227076    0
/gate/source/MonoE/gps/histpoint    0.227405    0
/gate/source/MonoE/gps/histpoint    0.227405    0.000000107744
/gate/source/MonoE/gps/histpoint    0.227405    0
/gate/source/MonoE/gps/histpoint    0.231253    0
/gate/source/MonoE/gps/histpoint    0.231253    0.000000102231
/gate/source/MonoE/gps/histpoint    0.231253    0
/gate/source/MonoE/gps/histpoint    0.23218    0
/gate/source/MonoE/gps/histpoint    0.23218    0.0000000247575
/gate/source/MonoE/gps/histpoint    0.23218    0
/gate/source/MonoE/gps/histpoint    0.237942    0
/gate/source/MonoE/gps/histpoint    0.237942    0.0000266446
/gate/source/MonoE/gps/histpoint    0.237942    0
/gate/source/MonoE/gps/histpoint    0.249749    0
/gate/source/MonoE/gps/histpoint    0.249749    0.00250626
/gate/source/MonoE/gps/histpoint    0.249749    0
/gate/source/MonoE/gps/histpoint    0.261244    0
/gate/source/MonoE/gps/histpoint    0.261244    0.000000168516
/gate/source/MonoE/gps/histpoint    0.261244    0
/gate/source/MonoE/gps/histpoint    0.267081    0
/gate/source/MonoE/gps/histpoint    0.267081    0.00000317546
/gate/source/MonoE/gps/histpoint    0.267081    0
/gate/source/MonoE/gps/histpoint    0.267394    0
/gate/source/MonoE/gps/histpoint    0.267394    0.000000294161
/gate/source/MonoE/gps/histpoint    0.267394    0
/gate/source/MonoE/gps/histpoint    0.267723    0
/gate/source/MonoE/gps/histpoint    0.267723    0.000000153783
/gate/source/MonoE/gps/histpoint    0.267723    0
/gate/source/MonoE/gps/histpoint    0.267844    0
```

/gate/source/MonoE/gps/histpoint	0.267844	0.000000419505
/gate/source/MonoE/gps/histpoint	0.267844	0
/gate/source/MonoE/gps/histpoint	0.271571	0
/gate/source/MonoE/gps/histpoint	0.271571	0.000000739866
/gate/source/MonoE/gps/histpoint	0.271571	0
/gate/source/MonoE/gps/histpoint	0.272498	0
/gate/source/MonoE/gps/histpoint	0.272498	0.000000185549
/gate/source/MonoE/gps/histpoint	0.272498	0
/gate/source/MonoE/gps/histpoint	0.278888	0
/gate/source/MonoE/gps/histpoint	0.278888	0.000269124
/gate/source/MonoE/gps/histpoint	0.278888	0
/gate/source/MonoE/gps/histpoint	0.279201	0
/gate/source/MonoE/gps/histpoint	0.279201	0.0000956999
/gate/source/MonoE/gps/histpoint	0.279201	0
/gate/source/MonoE/gps/histpoint	0.27953	0
/gate/source/MonoE/gps/histpoint	0.27953	0.0000800738
/gate/source/MonoE/gps/histpoint	0.27953	0
/gate/source/MonoE/gps/histpoint	0.283378	0
/gate/source/MonoE/gps/histpoint	0.283378	0.0000925514
/gate/source/MonoE/gps/histpoint	0.283378	0
/gate/source/MonoE/gps/histpoint	0.283532	0
/gate/source/MonoE/gps/histpoint	0.283532	0.0000238652
/gate/source/MonoE/gps/histpoint	0.283532	0
/gate/source/MonoE/gps/histpoint	0.284305	0
/gate/source/MonoE/gps/histpoint	0.284305	0.0000225804
/gate/source/MonoE/gps/histpoint	0.284305	0
/gate/source/MonoE/gps/histpoint	0.290095	0
/gate/source/MonoE/gps/histpoint	0.290095	0.00000601731
/gate/source/MonoE/gps/histpoint	0.290095	0
/gate/source/MonoE/gps/histpoint	0.290383	0
/gate/source/MonoE/gps/histpoint	0.290383	0.0000000185656
/gate/source/MonoE/gps/histpoint	0.290383	0

```
/gate/source/MonoE/gps/histpoint    0.290696    0
/gate/source/MonoE/gps/histpoint    0.290696    0.00000000119886
/gate/source/MonoE/gps/histpoint    0.290696    0
/gate/source/MonoE/gps/histpoint    0.291025    0
/gate/source/MonoE/gps/histpoint    0.291025    0.00000000153649
/gate/source/MonoE/gps/histpoint    0.291025    0
/gate/source/MonoE/gps/histpoint    0.291233    0
/gate/source/MonoE/gps/histpoint    0.291233    0.0000788794
/gate/source/MonoE/gps/histpoint    0.291233    0
/gate/source/MonoE/gps/histpoint    0.294873    0
/gate/source/MonoE/gps/histpoint    0.294873    0.00000000430447
/gate/source/MonoE/gps/histpoint    0.294873    0
/gate/source/MonoE/gps/histpoint    0.2958    0
/gate/source/MonoE/gps/histpoint    0.2958    0.00000000107673
/gate/source/MonoE/gps/histpoint    0.2958    0
/gate/source/MonoE/gps/histpoint    0.296983    0
/gate/source/MonoE/gps/histpoint    0.296983    0.0000000462843
/gate/source/MonoE/gps/histpoint    0.296983    0
/gate/source/MonoE/gps/histpoint    0.297296    0
/gate/source/MonoE/gps/histpoint    0.297296    0.00000000294193
/gate/source/MonoE/gps/histpoint    0.297296    0
/gate/source/MonoE/gps/histpoint    0.297625    0
/gate/source/MonoE/gps/histpoint    0.297625    0.00000000376926
/gate/source/MonoE/gps/histpoint    0.297625    0
/gate/source/MonoE/gps/histpoint    0.301473    0
/gate/source/MonoE/gps/histpoint    0.301473    0.0000000107081
/gate/source/MonoE/gps/histpoint    0.301473    0
/gate/source/MonoE/gps/histpoint    0.3024    0
/gate/source/MonoE/gps/histpoint    0.3024    0.00000000267899
/gate/source/MonoE/gps/histpoint    0.3024    0
/gate/source/MonoE/gps/histpoint    0.312671    0
/gate/source/MonoE/gps/histpoint    0.312671    0.00000287975
/gate/source/MonoE/gps/histpoint    0.312671    0
```

/gate/source/MonoE/gps/histpoint	0.312984	0
/gate/source/MonoE/gps/histpoint	0.312984	0.000000160366
/gate/source/MonoE/gps/histpoint	0.312984	0
/gate/source/MonoE/gps/histpoint	0.313313	0
/gate/source/MonoE/gps/histpoint	0.313313	0.0000000441088
/gate/source/MonoE/gps/histpoint	0.313313	0
/gate/source/MonoE/gps/histpoint	0.317161	0
/gate/source/MonoE/gps/histpoint	0.317161	0.000000627313
/gate/source/MonoE/gps/histpoint	0.317161	0
/gate/source/MonoE/gps/histpoint	0.318088	0
/gate/source/MonoE/gps/histpoint	0.318088	0.000000157987
/gate/source/MonoE/gps/histpoint	0.318088	0
/gate/source/MonoE/gps/histpoint	0.319234	0
/gate/source/MonoE/gps/histpoint	0.319234	0.000000700407
/gate/source/MonoE/gps/histpoint	0.319234	0
/gate/source/MonoE/gps/histpoint	0.319547	0
/gate/source/MonoE/gps/histpoint	0.319547	0.0000000972868
/gate/source/MonoE/gps/histpoint	0.319547	0
/gate/source/MonoE/gps/histpoint	0.319876	0
/gate/source/MonoE/gps/histpoint	0.319876	0.0000000645437
/gate/source/MonoE/gps/histpoint	0.319876	0
/gate/source/MonoE/gps/histpoint	0.320372	0
/gate/source/MonoE/gps/histpoint	0.320372	0.00000948168
/gate/source/MonoE/gps/histpoint	0.320372	0
/gate/source/MonoE/gps/histpoint	0.320685	0
/gate/source/MonoE/gps/histpoint	0.320685	0.000000598001
/gate/source/MonoE/gps/histpoint	0.320685	0
/gate/source/MonoE/gps/histpoint	0.321014	0
/gate/source/MonoE/gps/histpoint	0.321014	0.000000212597
/gate/source/MonoE/gps/histpoint	0.321014	0
/gate/source/MonoE/gps/histpoint	0.323724	0
/gate/source/MonoE/gps/histpoint	0.323724	0.000000176836

/gate/source/MonoE/gps/histpoint	0.323724	0
/gate/source/MonoE/gps/histpoint	0.323844	0
/gate/source/MonoE/gps/histpoint	0.323844	0.00000370357
/gate/source/MonoE/gps/histpoint	0.323844	0
/gate/source/MonoE/gps/histpoint	0.324651	0
/gate/source/MonoE/gps/histpoint	0.324651	0.0000000440167
/gate/source/MonoE/gps/histpoint	0.324651	0
/gate/source/MonoE/gps/histpoint	0.324862	0
/gate/source/MonoE/gps/histpoint	0.324862	0.0000020952
/gate/source/MonoE/gps/histpoint	0.324862	0
/gate/source/MonoE/gps/histpoint	0.325789	0
/gate/source/MonoE/gps/histpoint	0.325789	0.000000526988
/gate/source/MonoE/gps/histpoint	0.325789	0
/gate/source/MonoE/gps/histpoint	0.329933	0
/gate/source/MonoE/gps/histpoint	0.329933	0.0156323
/gate/source/MonoE/gps/histpoint	0.329933	0
/gate/source/MonoE/gps/histpoint	0.352983	0
/gate/source/MonoE/gps/histpoint	0.352983	0.00000044627
/gate/source/MonoE/gps/histpoint	0.352983	0
/gate/source/MonoE/gps/histpoint	0.353296	0
/gate/source/MonoE/gps/histpoint	0.353296	0.0000000227194
/gate/source/MonoE/gps/histpoint	0.353296	0
/gate/source/MonoE/gps/histpoint	0.353625	0
/gate/source/MonoE/gps/histpoint	0.353625	0.00000000560284
/gate/source/MonoE/gps/histpoint	0.353625	0
/gate/source/MonoE/gps/histpoint	0.357473	0
/gate/source/MonoE/gps/histpoint	0.357473	0.0000000964875
/gate/source/MonoE/gps/histpoint	0.357473	0
/gate/source/MonoE/gps/histpoint	0.3584	0
/gate/source/MonoE/gps/histpoint	0.3584	0.0000000243119
/gate/source/MonoE/gps/histpoint	0.3584	0
/gate/source/MonoE/gps/histpoint	0.359072	0
/gate/source/MonoE/gps/histpoint	0.359072	0.00173458

```
/gate/source/MonoE/gps/histpoint    0.359072    0
/gate/source/MonoE/gps/histpoint    0.359385    0
/gate/source/MonoE/gps/histpoint    0.359385    0.000422151
/gate/source/MonoE/gps/histpoint    0.359385    0
/gate/source/MonoE/gps/histpoint    0.359714    0
/gate/source/MonoE/gps/histpoint    0.359714    0.00032261
/gate/source/MonoE/gps/histpoint    0.359714    0
/gate/source/MonoE/gps/histpoint    0.363562    0
/gate/source/MonoE/gps/histpoint    0.363562    0.000512402
/gate/source/MonoE/gps/histpoint    0.363562    0
/gate/source/MonoE/gps/histpoint    0.364489    0
/gate/source/MonoE/gps/histpoint    0.364489    0.000126141
/gate/source/MonoE/gps/histpoint    0.364489    0
/gate/source/MonoE/gps/histpoint    0.370258    0
/gate/source/MonoE/gps/histpoint    0.370258    0.00000836041
/gate/source/MonoE/gps/histpoint    0.370258    0
/gate/source/MonoE/gps/histpoint    0.399397    0
/gate/source/MonoE/gps/histpoint    0.399397    0.00000097062
/gate/source/MonoE/gps/histpoint    0.399397    0
/gate/source/MonoE/gps/histpoint    0.39971    0
/gate/source/MonoE/gps/histpoint    0.39971    0.000000122577
/gate/source/MonoE/gps/histpoint    0.39971    0
/gate/source/MonoE/gps/histpoint    0.400039    0
/gate/source/MonoE/gps/histpoint    0.400039    0.0000000784401
/gate/source/MonoE/gps/histpoint    0.400039    0
/gate/source/MonoE/gps/histpoint    0.403887    0
/gate/source/MonoE/gps/histpoint    0.403887    0.000000240032
/gate/source/MonoE/gps/histpoint    0.403887    0
/gate/source/MonoE/gps/histpoint    0.404814    0
/gate/source/MonoE/gps/histpoint    0.404814    0.0000000598244
/gate/source/MonoE/gps/histpoint    0.404814    0
/gate/source/MonoE/gps/histpoint    0.468448    0
/gate/source/MonoE/gps/histpoint    0.468448    0.0000270708
```

```
/gate/source/MonoE/gps/histpoint   0.468448   0
/gate/source/MonoE/gps/histpoint   0.497587   0
/gate/source/MonoE/gps/histpoint   0.497587   0.00000305659
/gate/source/MonoE/gps/histpoint   0.497587   0
/gate/source/MonoE/gps/histpoint   0.4979   0
/gate/source/MonoE/gps/histpoint   0.4979   0.000000523609
/gate/source/MonoE/gps/histpoint   0.4979   0
/gate/source/MonoE/gps/histpoint   0.498229   0
/gate/source/MonoE/gps/histpoint   0.498229   0.000000368477
/gate/source/MonoE/gps/histpoint   0.498229   0
/gate/source/MonoE/gps/histpoint   0.502077   0
/gate/source/MonoE/gps/histpoint   0.502077   0.000000811899
/gate/source/MonoE/gps/histpoint   0.502077   0
/gate/source/MonoE/gps/histpoint   0.503004   0
/gate/source/MonoE/gps/histpoint   0.503004   0.000000201101
/gate/source/MonoE/gps/histpoint   0.503004   0
/gate/source/MonoE/gps/histpoint   0.602433   0
/gate/source/MonoE/gps/histpoint   0.602433   0.000289762
/gate/source/MonoE/gps/histpoint   0.602433   0
/gate/source/MonoE/gps/histpoint   0.608163   0
/gate/source/MonoE/gps/histpoint   0.608163   0.0000085823
/gate/source/MonoE/gps/histpoint   0.608163   0
/gate/source/MonoE/gps/histpoint   0.631572   0
/gate/source/MonoE/gps/histpoint   0.631572   0.0000331138
/gate/source/MonoE/gps/histpoint   0.631572   0
/gate/source/MonoE/gps/histpoint   0.631885   0
/gate/source/MonoE/gps/histpoint   0.631885   0.00000414683
/gate/source/MonoE/gps/histpoint   0.631885   0
/gate/source/MonoE/gps/histpoint   0.632214   0
/gate/source/MonoE/gps/histpoint   0.632214   0.00000276177
/gate/source/MonoE/gps/histpoint   0.632214   0
```

```
/gate/source/addSource EM
/gate/source/EM/gps/type Volume
/gate/source/EM/gps/shape Sphere
/gate/source/EM/gps/radius 0.133650 cm
/gate/source/EM/gps/centre 0. 0. 0. cm
/gate/source/EM/gps/particle gamma
/gate/source/EM/gps/angtype iso
/gate/source/EM/setIntensity 1.8255
/gate/source/EM/gps/energytype User
/gate/source/EM/gps/histname energy

/gate/source/EM/gps/histpoint    0.0000166175    0
/gate/source/EM/gps/histpoint    0.0000166175    0.762736
/gate/source/EM/gps/histpoint    0.0000166175    0
/gate/source/EM/gps/histpoint    0.0000922478    0
/gate/source/EM/gps/histpoint    0.0000922478    0.00000757745
/gate/source/EM/gps/histpoint    0.0000922478    0
/gate/source/EM/gps/histpoint    0.000313    0
/gate/source/EM/gps/histpoint    0.000313    0.000000181712
/gate/source/EM/gps/histpoint    0.000313    0
/gate/source/EM/gps/histpoint    0.0003292    0
/gate/source/EM/gps/histpoint    0.0003292    0.00000000136135
/gate/source/EM/gps/histpoint    0.0003292    0
/gate/source/EM/gps/histpoint    0.000608259    0
/gate/source/EM/gps/histpoint    0.000608259    0.000309105
/gate/source/EM/gps/histpoint    0.000608259    0
/gate/source/EM/gps/histpoint    0.000642201    0
/gate/source/EM/gps/histpoint    0.000642201    0.00000341928
/gate/source/EM/gps/histpoint    0.000642201    0
/gate/source/EM/gps/histpoint    0.00365269    0
/gate/source/EM/gps/histpoint    0.00365269    0.000270989
/gate/source/EM/gps/histpoint    0.00365269    0
```

/gate/source/EM/gps/histpoint	0.00378523	0
/gate/source/EM/gps/histpoint	0.00378523	0.00000149608
/gate/source/EM/gps/histpoint	0.00378523	0
/gate/source/EM/gps/histpoint	0.00384813	0
/gate/source/EM/gps/histpoint	0.00384813	0.00000139288
/gate/source/EM/gps/histpoint	0.00384813	0
/gate/source/EM/gps/histpoint	0.00398191	0
/gate/source/EM/gps/histpoint	0.00398191	0.0000778852
/gate/source/EM/gps/histpoint	0.00398191	0
/gate/source/EM/gps/histpoint	0.00408379	0
/gate/source/EM/gps/histpoint	0.00408379	0.000276832
/gate/source/EM/gps/histpoint	0.00408379	0
/gate/source/EM/gps/histpoint	0.00409719	0
/gate/source/EM/gps/histpoint	0.00409719	0.00245351
/gate/source/EM/gps/histpoint	0.00409719	0
/gate/source/EM/gps/histpoint	0.00417734	0
/gate/source/EM/gps/histpoint	0.00417734	0.00000112585
/gate/source/EM/gps/histpoint	0.00417734	0
/gate/source/EM/gps/histpoint	0.004413	0
/gate/source/EM/gps/histpoint	0.004413	0.00144796
/gate/source/EM/gps/histpoint	0.004413	0
/gate/source/EM/gps/histpoint	0.00442743	0
/gate/source/EM/gps/histpoint	0.00442743	0.000127153
/gate/source/EM/gps/histpoint	0.00442743	0
/gate/source/EM/gps/histpoint	0.00449034	0
/gate/source/EM/gps/histpoint	0.00449034	0.00020036
/gate/source/EM/gps/histpoint	0.00449034	0
/gate/source/EM/gps/histpoint	0.00456633	0
/gate/source/EM/gps/histpoint	0.00456633	0.0000238744
/gate/source/EM/gps/histpoint	0.00456633	0
/gate/source/EM/gps/histpoint	0.00461402	0
/gate/source/EM/gps/histpoint	0.00461402	0.000000131668

/gate/source/EM/gps/histpoint	0.00461402	0
/gate/source/EM/gps/histpoint	0.00462673	0
/gate/source/EM/gps/histpoint	0.00462673	0.000000126338
/gate/source/EM/gps/histpoint	0.00462673	0
/gate/source/EM/gps/histpoint	0.00470486	0
/gate/source/EM/gps/histpoint	0.00470486	0.0000402593
/gate/source/EM/gps/histpoint	0.00470486	0
/gate/source/EM/gps/histpoint	0.00470692	0
/gate/source/EM/gps/histpoint	0.00470692	0.000359019
/gate/source/EM/gps/histpoint	0.00470692	0
/gate/source/EM/gps/histpoint	0.00472599	0
/gate/source/EM/gps/histpoint	0.00472599	0.00000189442
/gate/source/EM/gps/histpoint	0.00472599	0
/gate/source/EM/gps/histpoint	0.00473937	0
/gate/source/EM/gps/histpoint	0.00473937	0.00000282808
/gate/source/EM/gps/histpoint	0.00473937	0
/gate/source/EM/gps/histpoint	0.00475109	0
/gate/source/EM/gps/histpoint	0.00475109	0.00000336137
/gate/source/EM/gps/histpoint	0.00475109	0
/gate/source/EM/gps/histpoint	0.00476235	0
/gate/source/EM/gps/histpoint	0.00476235	0.0000000148915
/gate/source/EM/gps/histpoint	0.00476235	0
/gate/source/EM/gps/histpoint	0.00476373	0
/gate/source/EM/gps/histpoint	0.00476373	0.0000000137496
/gate/source/EM/gps/histpoint	0.00476373	0
/gate/source/EM/gps/histpoint	0.00489553	0
/gate/source/EM/gps/histpoint	0.00489553	0.000011112
/gate/source/EM/gps/histpoint	0.00489553	0
/gate/source/EM/gps/histpoint	0.00495593	0
/gate/source/EM/gps/histpoint	0.00495593	0.000000139229
/gate/source/EM/gps/histpoint	0.00495593	0
/gate/source/EM/gps/histpoint	0.00503405	0
/gate/source/EM/gps/histpoint	0.00503405	0.000216155

/gate/source/EM/gps/histpoint	0.00503405	0
/gate/source/EM/gps/histpoint	0.00508031	0
/gate/source/EM/gps/histpoint	0.00508031	0.00000133369
/gate/source/EM/gps/histpoint	0.00508031	0
/gate/source/EM/gps/histpoint	0.00509294	0
/gate/source/EM/gps/histpoint	0.00509294	0.0000000152095
/gate/source/EM/gps/histpoint	0.00509294	0
/gate/source/EM/gps/histpoint	0.00525621	0
/gate/source/EM/gps/histpoint	0.00525621	0.0000274089
/gate/source/EM/gps/histpoint	0.00525621	0
/gate/source/EM/gps/histpoint	0.00526892	0
/gate/source/EM/gps/histpoint	0.00526892	0.0000443189
/gate/source/EM/gps/histpoint	0.00526892	0
/gate/source/EM/gps/histpoint	0.00534706	0
/gate/source/EM/gps/histpoint	0.00534706	0.000000230419
/gate/source/EM/gps/histpoint	0.00534706	0
/gate/source/EM/gps/histpoint	0.00534913	0
/gate/source/EM/gps/histpoint	0.00534913	0.000000349998
/gate/source/EM/gps/histpoint	0.00534913	0
/gate/source/EM/gps/histpoint	0.00540454	0
/gate/source/EM/gps/histpoint	0.00540454	0.00000311539
/gate/source/EM/gps/histpoint	0.00540454	0
/gate/source/EM/gps/histpoint	0.00540593	0
/gate/source/EM/gps/histpoint	0.00540593	0.00000483836
/gate/source/EM/gps/histpoint	0.00540593	0
/gate/source/EM/gps/histpoint	0.0294521	0
/gate/source/EM/gps/histpoint	0.0294521	0.0140078
/gate/source/EM/gps/histpoint	0.0294521	0
/gate/source/EM/gps/histpoint	0.0297812	0
/gate/source/EM/gps/histpoint	0.0297812	0.0259418
/gate/source/EM/gps/histpoint	0.0297812	0
/gate/source/EM/gps/histpoint	0.0335665	0

```
/gate/source/EM/gps/histpoint    0.0335665    0.00243522
/gate/source/EM/gps/histpoint    0.0335665    0
/gate/source/EM/gps/histpoint    0.0336295    0
/gate/source/EM/gps/histpoint    0.0336295    0.00472116
/gate/source/EM/gps/histpoint    0.0336295    0
/gate/source/EM/gps/histpoint    0.0338651    0
/gate/source/EM/gps/histpoint    0.0338651    0.0000240211
/gate/source/EM/gps/histpoint    0.0338651    0
/gate/source/EM/gps/histpoint    0.0338785    0
/gate/source/EM/gps/histpoint    0.0338785    0.0000328048
/gate/source/EM/gps/histpoint    0.0338785    0
/gate/source/EM/gps/histpoint    0.0343952    0
/gate/source/EM/gps/histpoint    0.0343952    0.000510579
/gate/source/EM/gps/histpoint    0.0343952    0
/gate/source/EM/gps/histpoint    0.034408    0
/gate/source/EM/gps/histpoint    0.034408    0.000995801
/gate/source/EM/gps/histpoint    0.034408    0
/gate/source/EM/gps/histpoint    0.0344862    0
/gate/source/EM/gps/histpoint    0.0344862    0.00000447782
/gate/source/EM/gps/histpoint    0.0344862    0
/gate/source/EM/gps/histpoint    0.0344882    0
/gate/source/EM/gps/histpoint    0.0344882    0.00000610349
/gate/source/EM/gps/histpoint    0.0344882    0
/gate/source/EM/gps/histpoint    0.0345436    0
/gate/source/EM/gps/histpoint    0.0345436    0.0000523268
/gate/source/EM/gps/histpoint    0.0345436    0
/gate/source/EM/gps/histpoint    0.034545    0
/gate/source/EM/gps/histpoint    0.034545    0.0000989453
/gate/source/EM/gps/histpoint    0.034545    0
/gate/source/EM/gps/histpoint    0.080185    0
/gate/source/EM/gps/histpoint    0.080185    0.0262257
/gate/source/EM/gps/histpoint    0.080185    0
/gate/source/EM/gps/histpoint    0.0859    0
```

```
/gate/source/EM/gps/histpoint 0.0859 0.0000008987
/gate/source/EM/gps/histpoint 0.0859 0
/gate/source/EM/gps/histpoint 0.177214 0
/gate/source/EM/gps/histpoint 0.177214 0.0026961
/gate/source/EM/gps/histpoint 0.177214 0
/gate/source/EM/gps/histpoint 0.23218 0
/gate/source/EM/gps/histpoint 0.23218 0.000031863
/gate/source/EM/gps/histpoint 0.23218 0
/gate/source/EM/gps/histpoint 0.272498 0
/gate/source/EM/gps/histpoint 0.272498 0.000577619
/gate/source/EM/gps/histpoint 0.272498 0
/gate/source/EM/gps/histpoint 0.284305 0
/gate/source/EM/gps/histpoint 0.284305 0.0613567
/gate/source/EM/gps/histpoint 0.284305 0
/gate/source/EM/gps/histpoint 0.2958 0
/gate/source/EM/gps/histpoint 0.2958 0.000017974
/gate/source/EM/gps/histpoint 0.2958 0
/gate/source/EM/gps/histpoint 0.3024 0
/gate/source/EM/gps/histpoint 0.3024 0.000047386
/gate/source/EM/gps/histpoint 0.3024 0
/gate/source/EM/gps/histpoint 0.318088 0
/gate/source/EM/gps/histpoint 0.318088 0.00077615
/gate/source/EM/gps/histpoint 0.318088 0
/gate/source/EM/gps/histpoint 0.324651 0
/gate/source/EM/gps/histpoint 0.324651 0.00021242
/gate/source/EM/gps/histpoint 0.324651 0
/gate/source/EM/gps/histpoint 0.325789 0
/gate/source/EM/gps/histpoint 0.325789 0.00273695
/gate/source/EM/gps/histpoint 0.325789 0
/gate/source/EM/gps/histpoint 0.3584 0
/gate/source/EM/gps/histpoint 0.3584 0.0001634
/gate/source/EM/gps/histpoint 0.3584 0
/gate/source/EM/gps/histpoint 0.364489 0
```

```
/gate/source/EM/gps/histpoint    0.364489    0.817
/gate/source/EM/gps/histpoint    0.364489    0
/gate/source/EM/gps/histpoint    0.404814    0
/gate/source/EM/gps/histpoint    0.404814    0.00054739
/gate/source/EM/gps/histpoint    0.404814    0
/gate/source/EM/gps/histpoint    0.4496    0
/gate/source/EM/gps/histpoint    0.4496    0.00007353
/gate/source/EM/gps/histpoint    0.4496    0
/gate/source/EM/gps/histpoint    0.503004    0
/gate/source/EM/gps/histpoint    0.503004    0.00360297
/gate/source/EM/gps/histpoint    0.503004    0
/gate/source/EM/gps/histpoint    0.636989    0
/gate/source/EM/gps/histpoint    0.636989    0.0717326
/gate/source/EM/gps/histpoint    0.636989    0
/gate/source/EM/gps/histpoint    0.642719    0
/gate/source/EM/gps/histpoint    0.642719    0.00217322
/gate/source/EM/gps/histpoint    0.642719    0
/gate/source/EM/gps/histpoint    0.722911    0
/gate/source/EM/gps/histpoint    0.722911    0.0177289
/gate/source/EM/gps/histpoint    0.722911    0

#=====================================================
# MONOENERGETIC EMISSIONS
#=====================================================
/gate/source/addSource MonoE
/gate/source/MonoE/gps/type Volume
/gate/source/MonoE/gps/shape Sphere
/gate/source/MonoE/gps/radius 0.133650 cm
/gate/source/MonoE/gps/centre 0. 0. 0. cm
/gate/source/MonoE/gps/particle e-
/gate/source/MonoE/gps/angtype iso
/gate/source/MonoE/setIntensity 0.762080
/gate/source/MonoE/gps/energytype User
```

```
/gate/source/MonoE/gps/histname energy

/gate/source/MonoE/gps/histpoint    0.0000261504    0
/gate/source/MonoE/gps/histpoint    0.0000261504    0.118727
/gate/source/MonoE/gps/histpoint    0.0000261504    0
/gate/source/MonoE/gps/histpoint    0.0000362367    0
/gate/source/MonoE/gps/histpoint    0.0000362367    0.36283
/gate/source/MonoE/gps/histpoint    0.0000362367    0
/gate/source/MonoE/gps/histpoint    0.000123806    0
/gate/source/MonoE/gps/histpoint    0.000123806    0.0445522
/gate/source/MonoE/gps/histpoint    0.000123806    0
/gate/source/MonoE/gps/histpoint    0.000317976    0
/gate/source/MonoE/gps/histpoint    0.000317976    0.00828747
/gate/source/MonoE/gps/histpoint    0.000317976    0
/gate/source/MonoE/gps/histpoint    0.000505029    0
/gate/source/MonoE/gps/histpoint    0.000505029    0.0996618
/gate/source/MonoE/gps/histpoint    0.000505029    0
/gate/source/MonoE/gps/histpoint    0.00061706    0
/gate/source/MonoE/gps/histpoint    0.00061706    0.00570048
/gate/source/MonoE/gps/histpoint    0.00061706    0
/gate/source/MonoE/gps/histpoint    0.000766872    0
/gate/source/MonoE/gps/histpoint    0.000766872    0.0000383051
/gate/source/MonoE/gps/histpoint    0.000766872    0
/gate/source/MonoE/gps/histpoint    0.00332402    0
/gate/source/MonoE/gps/histpoint    0.00332402    0.0392981
/gate/source/MonoE/gps/histpoint    0.00332402    0
/gate/source/MonoE/gps/histpoint    0.00400104    0
/gate/source/MonoE/gps/histpoint    0.00400104    0.0116568
/gate/source/MonoE/gps/histpoint    0.00400104    0
/gate/source/MonoE/gps/histpoint    0.00470489    0
/gate/source/MonoE/gps/histpoint    0.00470489    0.000885238
/gate/source/MonoE/gps/histpoint    0.00470489    0
/gate/source/MonoE/gps/histpoint    0.0244715    0
```

```
/gate/source/MonoE/gps/histpoint    0.0244715    0.00393828
/gate/source/MonoE/gps/histpoint    0.0244715    0
/gate/source/MonoE/gps/histpoint    0.0286854    0
/gate/source/MonoE/gps/histpoint    0.0286854    0.0017619
/gate/source/MonoE/gps/histpoint    0.0286854    0
/gate/source/MonoE/gps/histpoint    0.0329032    0
/gate/source/MonoE/gps/histpoint    0.0329032    0.000189387
/gate/source/MonoE/gps/histpoint    0.0329032    0
/gate/source/MonoE/gps/histpoint    0.045629    0
/gate/source/MonoE/gps/histpoint    0.045629    0.0355294
/gate/source/MonoE/gps/histpoint    0.045629    0
/gate/source/MonoE/gps/histpoint    0.051344    0
/gate/source/MonoE/gps/histpoint    0.051344    0.00000169406
/gate/source/MonoE/gps/histpoint    0.051344    0
/gate/source/MonoE/gps/histpoint    0.0747681    0
/gate/source/MonoE/gps/histpoint    0.0747681    0.00433327
/gate/source/MonoE/gps/histpoint    0.0747681    0
/gate/source/MonoE/gps/histpoint    0.0750811    0
/gate/source/MonoE/gps/histpoint    0.0750811    0.000324126
/gate/source/MonoE/gps/histpoint    0.0750811    0
/gate/source/MonoE/gps/histpoint    0.0754103    0
/gate/source/MonoE/gps/histpoint    0.0754103    0.0000800774
/gate/source/MonoE/gps/histpoint    0.0754103    0
/gate/source/MonoE/gps/histpoint    0.0792584    0
/gate/source/MonoE/gps/histpoint    0.0792584    0.000964331
/gate/source/MonoE/gps/histpoint    0.0792584    0
/gate/source/MonoE/gps/histpoint    0.080185    0
/gate/source/MonoE/gps/histpoint    0.080185    0.000243166
/gate/source/MonoE/gps/histpoint    0.080185    0
/gate/source/MonoE/gps/histpoint    0.0804831    0
/gate/source/MonoE/gps/histpoint    0.0804831    0.00000020694
/gate/source/MonoE/gps/histpoint    0.0804831    0
/gate/source/MonoE/gps/histpoint    0.0807961    0
```

/gate/source/MonoE/gps/histpoint 0.0807961 0.0000000151348
/gate/source/MonoE/gps/histpoint 0.0807961 0
/gate/source/MonoE/gps/histpoint 0.0811253 0
/gate/source/MonoE/gps/histpoint 0.0811253 0.00000000357359
/gate/source/MonoE/gps/histpoint 0.0811253 0
/gate/source/MonoE/gps/histpoint 0.0849734 0
/gate/source/MonoE/gps/histpoint 0.0849734 0.0000000458713
/gate/source/MonoE/gps/histpoint 0.0849734 0
/gate/source/MonoE/gps/histpoint 0.0859 0
/gate/source/MonoE/gps/histpoint 0.0859 0.0000000115644
/gate/source/MonoE/gps/histpoint 0.0859 0
/gate/source/MonoE/gps/histpoint 0.142658 0
/gate/source/MonoE/gps/histpoint 0.142658 0.000504316
/gate/source/MonoE/gps/histpoint 0.142658 0
/gate/source/MonoE/gps/histpoint 0.171797 0
/gate/source/MonoE/gps/histpoint 0.171797 0.0000511055
/gate/source/MonoE/gps/histpoint 0.171797 0
/gate/source/MonoE/gps/histpoint 0.17211 0
/gate/source/MonoE/gps/histpoint 0.17211 0.0000325651
/gate/source/MonoE/gps/histpoint 0.17211 0
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#=====================================================
# BETAMINUS EMISSIONS
#=====================================================

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/gate/source/betaminus/gps/shape Sphere
/gate/source/betaminus/gps/radius 0.133650 cm
/gate/source/betaminus/gps/centre 0. 0. 0. cm
/gate/source/betaminus/gps/particle e-
/gate/source/betaminus/gps/angtype iso
/gate/source/betaminus/setIntensity 1.00000
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/gate/source/betaminus/gps/histpoint 0.00010 3.502E+00
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/gate/source/betaminus/gps/histpoint 0.00026 3.501E+00
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/gate/source/betaminus/gps/histpoint 0.00260 3.484E+00
/gate/source/betaminus/gps/histpoint 0.00280 3.483E+00
/gate/source/betaminus/gps/histpoint 0.00300 3.481E+00
/gate/source/betaminus/gps/histpoint 0.00320 3.480E+00
/gate/source/betaminus/gps/histpoint 0.00360 3.477E+00
/gate/source/betaminus/gps/histpoint 0.00400 3.474E+00
/gate/source/betaminus/gps/histpoint 0.00450 3.471E+00
/gate/source/betaminus/gps/histpoint 0.00500 3.467E+00
```

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/gate/source/betaminus/gps/histpoint 0.00550 3.463E+00
/gate/source/betaminus/gps/histpoint 0.00600 3.460E+00
/gate/source/betaminus/gps/histpoint 0.00650 3.456E+00
/gate/source/betaminus/gps/histpoint 0.00700 3.452E+00
/gate/source/betaminus/gps/histpoint 0.00750 3.449E+00
/gate/source/betaminus/gps/histpoint 0.00800 3.445E+00
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/gate/source/betaminus/gps/histpoint 0.00900 3.438E+00
/gate/source/betaminus/gps/histpoint 0.01000 3.437E+00
/gate/source/betaminus/gps/histpoint 0.01100 3.434E+00
/gate/source/betaminus/gps/histpoint 0.01200 3.432E+00
/gate/source/betaminus/gps/histpoint 0.01300 3.429E+00
/gate/source/betaminus/gps/histpoint 0.01400 3.426E+00
/gate/source/betaminus/gps/histpoint 0.01500 3.423E+00
/gate/source/betaminus/gps/histpoint 0.01600 3.420E+00
/gate/source/betaminus/gps/histpoint 0.01800 3.414E+00
/gate/source/betaminus/gps/histpoint 0.02000 3.408E+00
/gate/source/betaminus/gps/histpoint 0.02200 3.402E+00
/gate/source/betaminus/gps/histpoint 0.02400 3.395E+00
/gate/source/betaminus/gps/histpoint 0.02600 3.389E+00
/gate/source/betaminus/gps/histpoint 0.02800 3.382E+00
/gate/source/betaminus/gps/histpoint 0.03000 3.375E+00
/gate/source/betaminus/gps/histpoint 0.03200 3.368E+00
/gate/source/betaminus/gps/histpoint 0.03600 3.353E+00
/gate/source/betaminus/gps/histpoint 0.04000 3.338E+00
/gate/source/betaminus/gps/histpoint 0.04500 3.318E+00
/gate/source/betaminus/gps/histpoint 0.05000 3.298E+00
/gate/source/betaminus/gps/histpoint 0.05500 3.277E+00
/gate/source/betaminus/gps/histpoint 0.06000 3.255E+00
/gate/source/betaminus/gps/histpoint 0.06500 3.233E+00
/gate/source/betaminus/gps/histpoint 0.07000 3.209E+00
/gate/source/betaminus/gps/histpoint 0.07500 3.185E+00
/gate/source/betaminus/gps/histpoint 0.08000 3.161E+00
```

```
/gate/source/betaminus/gps/histpoint 0.08500 3.136E+00
/gate/source/betaminus/gps/histpoint 0.09000 3.110E+00
/gate/source/betaminus/gps/histpoint 0.10000 3.055E+00
/gate/source/betaminus/gps/histpoint 0.11000 2.999E+00
/gate/source/betaminus/gps/histpoint 0.12000 2.939E+00
/gate/source/betaminus/gps/histpoint 0.13000 2.877E+00
/gate/source/betaminus/gps/histpoint 0.14000 2.812E+00
/gate/source/betaminus/gps/histpoint 0.15000 2.745E+00
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/gate/source/betaminus/gps/histpoint 0.20000 2.384E+00
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/gate/source/betaminus/gps/histpoint 0.26000 1.928E+00
/gate/source/betaminus/gps/histpoint 0.28000 1.776E+00
/gate/source/betaminus/gps/histpoint 0.30000 1.625E+00
/gate/source/betaminus/gps/histpoint 0.32000 1.478E+00
/gate/source/betaminus/gps/histpoint 0.36000 1.194E+00
/gate/source/betaminus/gps/histpoint 0.40000 9.124E-01
/gate/source/betaminus/gps/histpoint 0.45000 5.805E-01
/gate/source/betaminus/gps/histpoint 0.50000 2.974E-01
/gate/source/betaminus/gps/histpoint 0.55000 9.410E-02
/gate/source/betaminus/gps/histpoint 0.60000 4.666E-03
#/gate/source/betaminus/gps/histpoint      0.65000 2.335E-03
#/gate/source/betaminus/gps/histpoint      0.70000 1.282E-03
#/gate/source/betaminus/gps/histpoint      0.75000 4.287E-04
#/gate/source/betaminus/gps/histpoint      0.80000 7.371E-06
#/gate/source/betaminus/gps/histpoint      0.80687 0.000E+00
/gate/source/betaminus/gps/arbint Spline
/gate/source/list
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/gate/source/MonoE/gps/histpoint	0.636063	0
/gate/source/MonoE/gps/histpoint	0.636063	0.00000818822
/gate/source/MonoE/gps/histpoint	0.636063	0
/gate/source/MonoE/gps/histpoint	0.636989	0
/gate/source/MonoE/gps/histpoint	0.636989	0.00000204042
/gate/source/MonoE/gps/histpoint	0.636989	0
/gate/source/MonoE/gps/histpoint	0.637302	0
/gate/source/MonoE/gps/histpoint	0.637302	0.000000981148
/gate/source/MonoE/gps/histpoint	0.637302	0
/gate/source/MonoE/gps/histpoint	0.637615	0
/gate/source/MonoE/gps/histpoint	0.637615	0.000000121408
/gate/source/MonoE/gps/histpoint	0.637615	0
/gate/source/MonoE/gps/histpoint	0.637944	0
/gate/source/MonoE/gps/histpoint	0.637944	0.0000000807245
/gate/source/MonoE/gps/histpoint	0.637944	0
/gate/source/MonoE/gps/histpoint	0.641792	0
/gate/source/MonoE/gps/histpoint	0.641792	0.000000242047
/gate/source/MonoE/gps/histpoint	0.641792	0
/gate/source/MonoE/gps/histpoint	0.642719	0
/gate/source/MonoE/gps/histpoint	0.642719	0.00000006033
/gate/source/MonoE/gps/histpoint	0.642719	0
/gate/source/MonoE/gps/histpoint	0.688355	0
/gate/source/MonoE/gps/histpoint	0.688355	0.0000706758
/gate/source/MonoE/gps/histpoint	0.688355	0
/gate/source/MonoE/gps/histpoint	0.717494	0
/gate/source/MonoE/gps/histpoint	0.717494	0.00000842644
/gate/source/MonoE/gps/histpoint	0.717494	0
/gate/source/MonoE/gps/histpoint	0.717807	0
/gate/source/MonoE/gps/histpoint	0.717807	0.000000335541
/gate/source/MonoE/gps/histpoint	0.717807	0
/gate/source/MonoE/gps/histpoint	0.718136	0
/gate/source/MonoE/gps/histpoint	0.718136	0.000000104036
/gate/source/MonoE/gps/histpoint	0.718136	0

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/gate/source/MonoE/gps/histpoint    0.721985    0
/gate/source/MonoE/gps/histpoint    0.721985    0.00000179196
/gate/source/MonoE/gps/histpoint    0.721985    0
/gate/source/MonoE/gps/histpoint    0.722911    0
/gate/source/MonoE/gps/histpoint    0.722911    0.000000453966
/gate/source/MonoE/gps/histpoint    0.722911    0

#=====================================================
# BETAMINUS EMISSIONS
#=====================================================

/gate/source/addSource betaminus
/gate/source/betaminus/gps/type Volume
/gate/source/betaminus/gps/shape Sphere
/gate/source/betaminus/gps/radius 0.133650 cm
/gate/source/betaminus/gps/centre 0. 0. 0. cm
/gate/source/betaminus/gps/particle e-
/gate/source/betaminus/gps/angtype iso
/gate/source/betaminus/setIntensity 1.00000
/gate/source/betaminus/gps/energytype Arb
/gate/source/betaminus/gps/histname arb

/gate/source/betaminus/gps/histpoint 0.00000 3.503E+00
/gate/source/betaminus/gps/histpoint 0.00010 3.502E+00
/gate/source/betaminus/gps/histpoint 0.00011 3.502E+00
/gate/source/betaminus/gps/histpoint 0.00012 3.502E+00
/gate/source/betaminus/gps/histpoint 0.00013 3.502E+00
/gate/source/betaminus/gps/histpoint 0.00014 3.502E+00
/gate/source/betaminus/gps/histpoint 0.00015 3.502E+00
/gate/source/betaminus/gps/histpoint 0.00016 3.502E+00
/gate/source/betaminus/gps/histpoint 0.00018 3.501E+00
/gate/source/betaminus/gps/histpoint 0.00020 3.501E+00
/gate/source/betaminus/gps/histpoint 0.00022 3.501E+00
```

/gate/source/betaminus/gps/histpoint 0.00024 3.501E+00
/gate/source/betaminus/gps/histpoint 0.00026 3.501E+00
/gate/source/betaminus/gps/histpoint 0.00028 3.501E+00
/gate/source/betaminus/gps/histpoint 0.00030 3.501E+00
/gate/source/betaminus/gps/histpoint 0.00032 3.500E+00
/gate/source/betaminus/gps/histpoint 0.00036 3.500E+00
/gate/source/betaminus/gps/histpoint 0.00040 3.500E+00
/gate/source/betaminus/gps/histpoint 0.00045 3.500E+00
/gate/source/betaminus/gps/histpoint 0.00050 3.499E+00
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/gate/source/betaminus/gps/histpoint 0.00060 3.498E+00
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/gate/source/betaminus/gps/histpoint 0.00100 3.496E+00
/gate/source/betaminus/gps/histpoint 0.00110 3.495E+00
/gate/source/betaminus/gps/histpoint 0.00120 3.494E+00
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/gate/source/betaminus/gps/histpoint 0.00280 3.483E+00
/gate/source/betaminus/gps/histpoint 0.00300 3.481E+00
/gate/source/betaminus/gps/histpoint 0.00320 3.480E+00
/gate/source/betaminus/gps/histpoint 0.00360 3.477E+00

/gate/source/betaminus/gps/histpoint 0.00400 3.474E+00
/gate/source/betaminus/gps/histpoint 0.00450 3.471E+00
/gate/source/betaminus/gps/histpoint 0.00500 3.467E+00
/gate/source/betaminus/gps/histpoint 0.00550 3.463E+00
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/gate/source/betaminus/gps/histpoint 0.00700 3.452E+00
/gate/source/betaminus/gps/histpoint 0.00750 3.449E+00
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/gate/source/betaminus/gps/histpoint 0.04000 3.338E+00
/gate/source/betaminus/gps/histpoint 0.04500 3.318E+00
/gate/source/betaminus/gps/histpoint 0.05000 3.298E+00
/gate/source/betaminus/gps/histpoint 0.05500 3.277E+00
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/gate/source/betaminus/gps/histpoint 0.07000 3.209E+00
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/gate/source/betaminus/gps/histpoint 0.16000 2.676E+00
/gate/source/betaminus/gps/histpoint 0.18000 2.532E+00
/gate/source/betaminus/gps/histpoint 0.20000 2.384E+00
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/gate/source/betaminus/gps/histpoint 0.26000 1.928E+00
/gate/source/betaminus/gps/histpoint 0.28000 1.776E+00
/gate/source/betaminus/gps/histpoint 0.30000 1.625E+00
/gate/source/betaminus/gps/histpoint 0.32000 1.478E+00
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/gate/source/betaminus/gps/histpoint 0.55000 9.410E-02
/gate/source/betaminus/gps/histpoint 0.60000 4.666E-03
#/gate/source/betaminus/gps/histpoint        0.65000 2.335E-03
#/gate/source/betaminus/gps/histpoint        0.70000 1.282E-03
#/gate/source/betaminus/gps/histpoint        0.75000 4.287E-04
#/gate/source/betaminus/gps/histpoint        0.80000 7.371E-06
/gate/source/betaminus/gps/arbint Spline
/gate/source/list
```