Comparison of RADLST and Geant4 results for the estimation of decay energy

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1. Introduction

The Program RADLST[1] (Radiation Listing) is designed to calculate the nuclear and atomic radiations associated with the radioactive decay of nuclei using the Evaluated Nuclear Structure Data File[2] (ENSDF) format data. RADLST produces listings containing the energies, intensities, and dose rates for various nuclear radiations such as α, β, γ, conversion electrons, and X-rays, etc. For the evaluation of the result of RADLST, Geant4[3] simulation code has been used. RADLST computes radiations from ENSDF format input with its own auxiliary files which contain atomic data. Although calculation is performed on the basis of physics, some assumptions and numerical methods are used to avoid complexity. On the other hand, Geant4 simulates each particle's behavior with Monte Carlo method based on selected physics model.

2. Methods and Results

2.1 Radioactive nuclei

For this study, we selected 5 different nuclei to check effect from dissimilar conditions(Table I). In order to compare the results from different decay mode, actinide nuclei and beta emitters are investigated.

Table I: Radioactive nuclei selected for this study

Nuclide	Decay mode	Half-life
^{238}Pu	α : 100.00 % SF : 1.9E-7 %	87.7 y
^{244}Cm	α : 100.00 % SF : 1.4E-4 %	18.1 y
^{90}Sr	β^- : 100.00 %	28.90 y
^{137}Cs	β^- : 100.00 %	30.08 y
^{154}Eu	β^- : 99.98 % ε : 0.02 %	8.601 y

2.2 RADLST program

RADLST is one of the analysis programs for ENSDF. This program is able to convert the information of ENSDF to several forms for the purpose of various fields such as nuclear medicine, health physics, nuclear power and so on. Because ENSDF does not contain the data about neutrino, X-ray, Auger electron and recoil ion, RADLST performs supplementary calculation based on the energy conservation. In the calculation of beta decay, huge amount of computation should be performed coincidentally and thus some numerical calculation methods, for instance Romberg integration, are used.

2.3 Geant4 Simulation

In this work, Geant4 version 9.4p04 (Fig. 1.) has been used to compare the radiation energy from radioactive nuclei with RADLST. All geometry and physics models are simplified. It is because the purpose of this study is the estimation of the emission energy which arises from decay and thus interactions should be excluded.

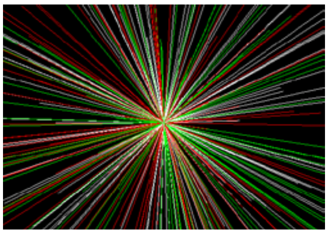

Fig. 1. Geant4 simulation process of nuclear decay.

As the decay process, just single decay and subsequent gamma transitions are allowed(Fig. 2). The output data is separated depending on the emission type – electron, neutrino, alpha, gamma and recoil ion.

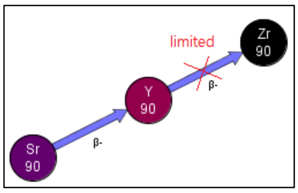

Fig. 2. Decay path of ^{90}Sr. Only first decay and following gamma transition are allowed. Once parent nuclei decay to daughter nuclei, further decays are prohibited.

2.4 Results

Average energy and energy distributions are compared according to the emission type. As the Figure 3 shows, Geant4 tracks all particles so that detailed energy spectrum is available whereas we could obtain discrete information from RADLST. Discrete electrons near 0 keV which are not appear in Geant4 simulation are originated from the Auger effect. RADLST takes into account Auger effect and corresponding X-rays while Geant4 code in this simulation does not contain that effect. Instead of plotting continuous beta particles, RADLST shows beta endpoint energy as default. Unlike Geant4, electrons generated from beta decay and discrete electrons are separated.

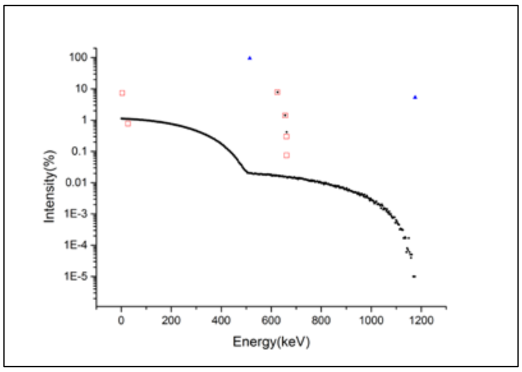

Fig. 3. Energy distribution of electrons from the beta decay of ^{137}Cs. Black points reflect electrons which are calculated from Geant4. Red squares and blue triangle means discrete electrons and beta endpoint energy respectively calculated from RADLST.

Table II shows average energy emitted by several radiation types per decay in unit of keV. The results from RADLST and Geant4 in Table II show little differences except electromagnetic radiation of ^{238}Pu and recoil ion energy.

Table II: Average emission energy per decay (keV) calculated by RADLST and Geant4

	^{238}Pu		^{244}Cm	
	RADLST	Geant4	RADLST	Geant4
alpha	5486.387	5478.255	5796.403	5800.521
e^-	8.474	8.335	5.919	6.369
EM	1.418	0.025	0.017	0.011
ion	92.387	93.995	95.211	96.834
total	5588.666	5580.610	5897.550	5903.735
	^{137}Cs		^{154}Eu	
	RADLST	Geant4	RADLST	Geant4
e^-	247.895	232.613	272.431	269.147
neutrino	361.894	378.980	448.128	445.783
EM	565.419	560.576	1241.871	1237.853
ion	0.003	0.002	0.007	0.002
total	1175.212	1172.171	1963.437	1952.785
	^{90}Sr			
	RADLST	Geant4		
e^-	195.800	174.066		
neutrino	350.196	371.937		
ion	0.001	0.002		
total	545.998	546.006		

The difference in ^{238}Pu electromagnetic radiation result from whether X-ray is considered or not. If X-ray part is removed, the result of RADLST become 0.024 and this value is very close to that of Geant4, 0.025. The differences of recoil ion energy stem from 2 reasons. The first reason is that Geant4 calculates continuous recoil ion energy from 3-body process whereas RADLST simplifies the process and calculates it with average beta energy only. The other reason is that the nuclear recoil associated with the emission of electromagnetic quanta is not considered in this simulation code while RADLST does. Since the absolute values of average recoil ion energy are minute except alpha emitter, these distinctions are ignorable.

As we can see from Figure 4 which plots ratio of result from Geant4 to that of RADLST, if we take into account the absence of X-ray and recoil of nucleus made by gamma energy in this Geant4 simulation code, the average energy of all electromagnetic radiation calculated from RADLST becomes quite similar to that of Geant4 as well as average energy of all light particles. Although heavy particle energy of some nuclei looks like mismatched seriously, there are little difference in the absolute value. Furthermore, heavy particle average energy is almost same in the case of alpha emitter for which the energy carried by recoil ion is significant. Therefore, overall performance of RADLST is quite reasonable.

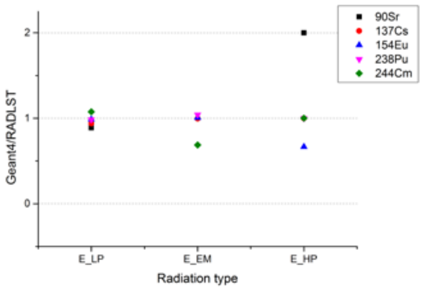

Fig. 4. Comparison of the results of RADLST and Geant4 according to the radiation type. The result of Geant4 is divided by that of RADLST. Accurate values are located near 1. Average energy of electromagnetic radiation and heavy particle had been corrected.

* E_LP: average energy of all light particles
* E_EM: average energy of all electromagnetic radiation
* E_HP: average energy of all heavy particles

3. Conclusions

It is possible to calculate the radiation energy of radioactive nuclei with RADLST. Although this program could not provide detailed information, users can obtain summarized report immediately. Moreover, ENSDF format is accepted to RADLST as input and thus the newest data is available for computation. In spite of its simplicity and assumptions, RADLST shows reliable results which are similar to those of Geant4.

REFERENCES

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