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4031 Development of BRACSS code for recalculating Q values by Monte Carlo method

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Abstract

The A_1/A_2 values of SSR-6 [1] are derived from Q values calculated based on the Q system. However it is known that the current values(SSG-26 [2]) cannot be reproduced sufficiently because some calculation conditions are not clear. Thus we have developed BRACSS code for recalculating the Q values and clarify unclear conditions of the Q system. BRACSS covers the whole radionuclides listed in ICRP Publ.38 [3] and Publ.107 [4]. (We have used the emission data in ICRP Publ.38 for recalculation.) In addition, BRACSS can calculate the exemption values and D values.

BRACSS has been verified in cooperation with an expert working group. Unclear conditions (cut-off energy, selection of radiation type, consideration of progenies, etc.) are examined to set suitable parameters through discussion of the group. As a result of recalculating for 387 nuclides listed in SSG-26, it is shown that BRACSS can reproduce the same or close values to the current ones for most nuclides. It proves that BRACSS can better simulate the Q system with our conditions.

Introduction

The purpose of this study is reproducing of Q values by BRACSS. Q values were calculated in accordance with SSG-26. If the conditions shown in SSG-26 was wrong, we have examined on its own.

BRACSS originally contains built-in dose coefficients for Q values of external exposure, which are calculated with a phantom model by MCNPX code. For Q_A and Q_E, a voxel phantom of human body(ICRP Publ.110 [5]) is used. An irradiation geometry are isotropic(Q_A) and submersion(Q_E) as written in Q system. As a matter of fact, the calculated dose coefficients for Q_A show good agreement with the ones from ICRP Publ.116 [6] published lately. For comparison purpose, BRACSS also contains the ones of every irradiation geometry from Publ.116, and older ones used in Q system. For Q_B and Q_D, a skin slab phantom is used to assess a skin dose. Q_C of internal exposure is calculated with DCAL code which uses old biokinetic models and specific effective energy, SEE (ICRP Publ.30, 66-68 [7-10]). Instead of DCAL, we have recently developed BRAID code for calculating an internal dose with the latest model and data.

1. Reproducing calculation of Q_A values

Q_A values have been calculated using the complete X and gamma emission spectra for the nuclides, as given in ICRP Publ.38. The energy dependent relationship between effective dose and exposure free in air is given in ICRP Publ. 51 [11] for ISO-irradiation. Q_A values of Cm-248, Cf-252, and Cf-254 were calculated with the neutron emission data in ICRP Publ.38. Q_A value of Cf-252 was calculated with the effective dose coefficients in ICRP Publ.74 [12] for ROT-irradiation. Q_A values of Cm-248 and Cf-254 were calculated with doubled values of the effective dose coefficients in ICRP Publ.51 for AP-irradiation.

1.1 Results by BRACSS

In BRACSS, the dose coefficient(ISO-irradiation) for Q_A was calculated by MCNPX code with male voxel phantom(ICRP Publ. 110). We calculated Q_A values with this dose coefficient(Figure 1.1).

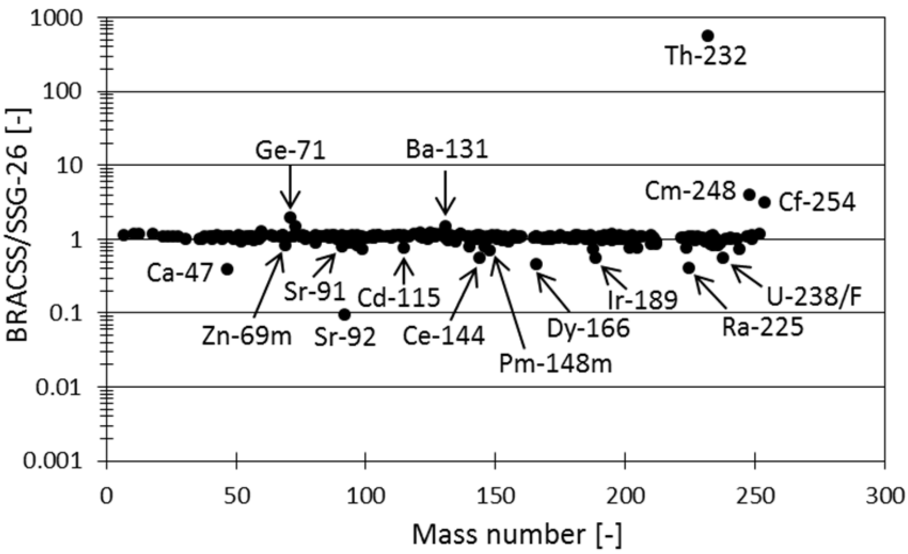

Figure 1.1 Q_A values by BRACSS

1.2 Consideration

We have found out that the nuclides(Ca-47,Zn-69m, Sr-91,Sr-92,Zr-95,Zr-97, Mo-99,Cd-115,Ba-131,Te-132,I-135,Ba-140,Gd-146, Pm-148m,Pt-188,Re-189, Hg-195m,Bi-212,Pb-212, Ra-224,Ra-225) were consistent with the results of SEAL (calculation tool) [13] were reasonable. Some of these nuclides(Ca-47,Zn-69m,Sr-91,Zr-95,Zr-97,Mo-99,Cd-115,Te-132,I-135,Ba-140,Gd-146,Pm-148m,Pt-188,Re-189,Ra-225) with considering transient equilibrium were close to current values. Therefore, actually some nuclides may have been calculated with transient equilibrium. However, it have been described that progenies to be taken into account in secular equilibrium in SSR-6. It have been described that Dy-166 to be taken into account in progeny in SSR-6. However, actually Q_A

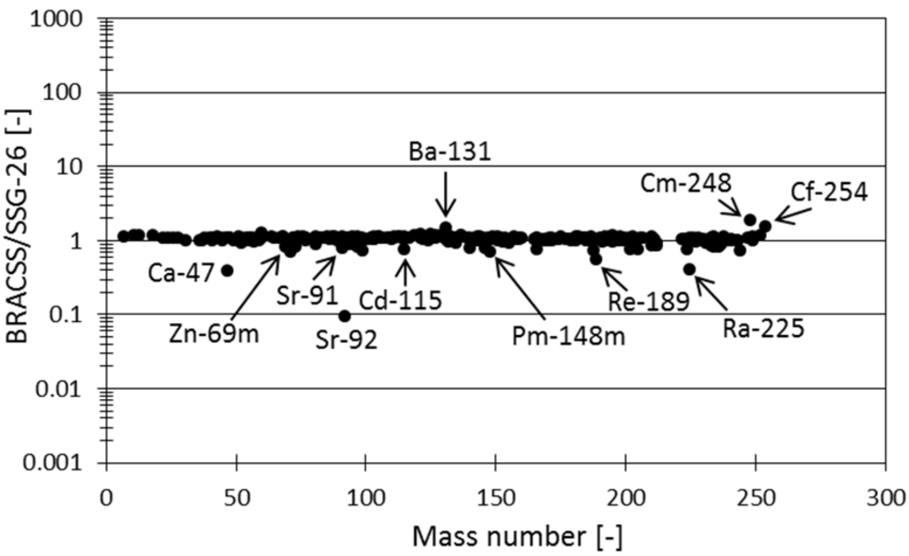

Figure 1.2 Q_A values by BRACSS after consideration

value of Dy-166 was consistent with current value without considering it. For Cm-248 and Cf-254 in BRACSS, the neutron coefficient for ISO-irradiation with voxel phantom was used. In SSG-26, the Q_A have been calculated using doubled values of effective dose coefficient of neutron for the AP-irradiation in ICRP Publ.51. When we calculated Q_A values by BRACSS with this coefficient, The Q_A values were close to current values. Most of the photons of Ge-71 and U-238/F are low energies. Q_A values fluctuate large under the influence of the cut-off energy. Therefore, it was found out that in good agreement with the conditions of the current cut-off energy(about 0.01MeV). Ce-144 was consistent with current value be calculated using the actual branching ratio without using it of SSG-26.

The progeny of Th-232 is not considered in SSR-6. In spite of the half-lives of Th-232 is 1.405E+10[y], the half-lives of the progeny of Th-232 is short significantly compared to it. Thus, the calculations of SSG-26 can be presumed to have considered secular equilibrium (Th-232(1.405E+10[y]) ⇒ Ra-228(5.75[y])⇒Ac-228(6.15[h])⇒Th-228(1.9116[y])⇒・・・). The effects of Th-232 and Ra-228 on the Q_A values are small enough, and thus the Q_A values of these 3 nuclides are determined mostly by the effect of Ac-228 only(Table 1.1). Therefore, Q_A value calculation of Th-232 considering the progeny of Ra-228 and Ac-228 as secular equilibrium, resulted in reproducing current values.

Table 1.1 Calculation results of Q_A values for Th-232 and its progenies [TBq]

Nuclide	Progeny nuclides (SSR-6)	SSG-26	BRACSS
Th-232		1.2E+00	6.7E+02
Ra-228	Ac-228	1.2E+00	1.2E+00
Ac-228		1.2E+00	1.2E+00
Th-228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208	7.6E-01	8.3E-01

2. Reproducing calculation of Q_B values

Q_B is calculated by using the complete beta spectra for the radionuclides of ICRP Publ.38. The spectral data for the nuclide of interest are used with data from Refs [14-16] on the skin dose rate per unit activity of a monoenergetic electron emitter. The self-shielding of the package was taken to be a smooth function of the maximum energy of the beta spectrum

2.1 Results by BRACSS

In BRACSS, the skin equivalent dose coefficient for Q_B was calculated by MCNPX code with skin slab phantom. We calculated Q_B values with this dose coefficient(Figure 2.1). Cut-off energy is 0.3MeV as well as SSG-26. We considered beta particles, internal conversion electrons and auger electrons.

2.2 Consideration

We have found out that the nuclides(Al-26, Ca-47, Dy-166, Pb-212, Ra-225, Sr-92) were consistent with SEAL were reasonable. There were some nuclides (Bi-205,Bi-207,Cs-136,Eu-148,Hf-172,Ho-166m,Lu-172,Pb-201,Pt-188) that were consistent with current values without consideration of internal conversion electrons and auger electrons. There were some nuclides (Fe-60,Hf-172,Hg-194,Pt-188) that Q_B values were consistent with current values without considering progenies. (It described that these nuclides are considering their progenies in SSR-6.) Some of nuclides were close to current values, when cut-off energy changed into about 0.6 MeV(Figure 2.2).

Therefore, we found out that in the calculation of SSG-26, the calculation conditions(cut-off energy, selection of radiation type, consideration of progenies) were different for each nuclide.

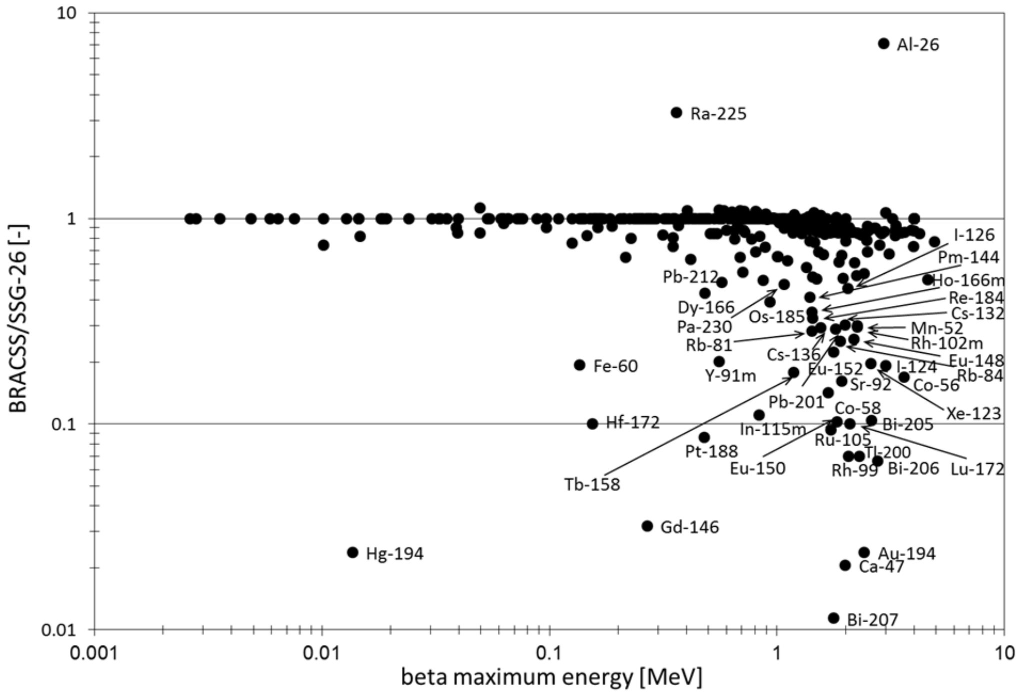

Figure 2.1 Q_B values by BRACSS

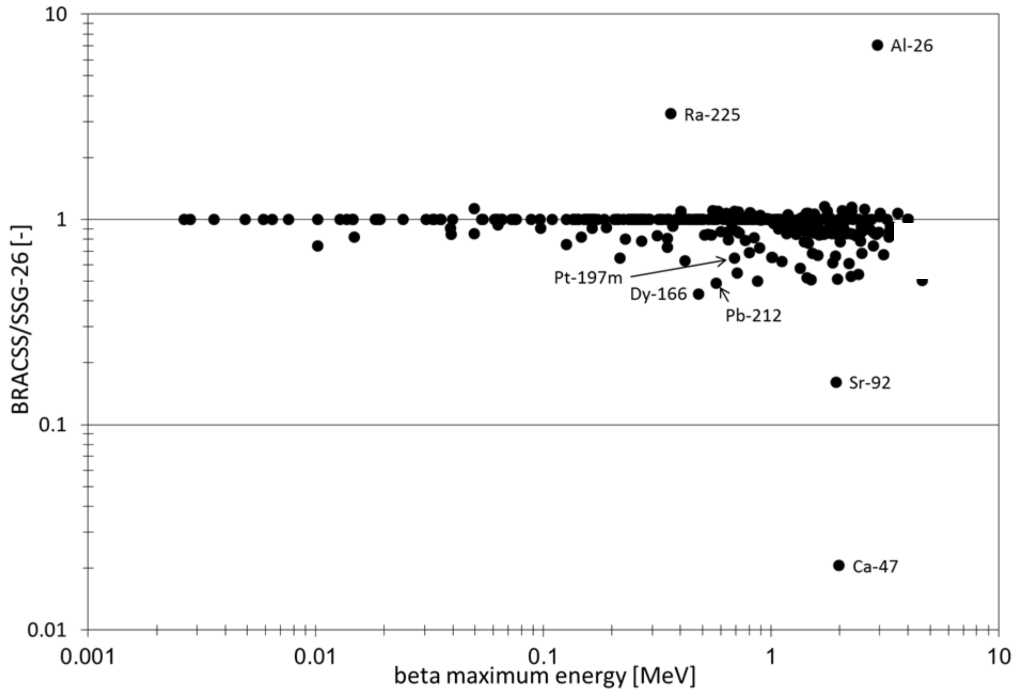

Figure 2.2 Q_B values by BRACSS after consideration

3. Reproducing calculation of Q_C values

Q_C values of SSG-26 were calculated with effective dose coefficients for inhalation of the nuclide [Sv/Bq] in BSS [17].

3.1 Results by BRACSS

In BRACSS, we calculated Q_C values with the effective dose coefficients for inhalation which calculated by DCAL code(Figure 3.1). Most nuclides were consistent with current values except Th-231.

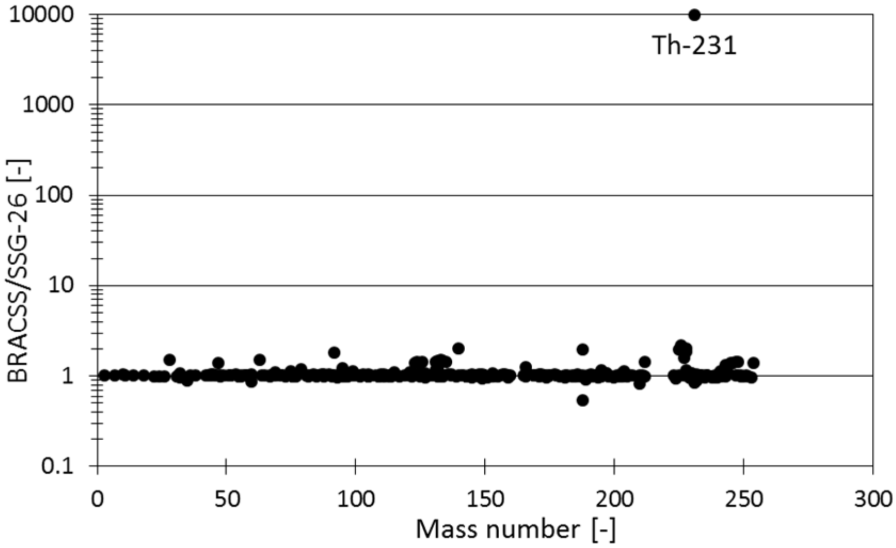

Figure 3.1 Q_C values by BRACSS

3.2 Consideration

The effective dose coefficient for inhalation of Th-231 is different from DCAL, BSS, ICRP Publ.68 and SSG-26 (Table 3.1). Only the coefficient of SSG-26 is very large. The other nuclides were consistent with them. The coefficients of SSG-26 are referred to BSS. Q_C value of Th-231 by BRACSS was consistent with SEAL. Therefore, there may have been a mistake to quote from the coefficient of BSS to SSG-26. Or there may have been a special consideration, but they are not described in SSG-26.

The coefficients of mercury(Hg-194,Hg-195m,Hg-197,Hg-197m,Hg-203) are different from BSS and SSG-26(The maximum ratio of SSG-26 to BSS is about 20). The coefficients of mercury is close to one's of ICRP Publ.68 ANNEXE C(vapour) rather than BSS(1μmAMAD). Therefore the coefficients of mercury of SSG-26 are able to guess one's of ICRP Publ.68 ANNEXE C(vapour) has been used.

Table 3.1 Effective dose coefficients for inhalation [Sv/Bq]

Nuclide	DCAL code	BSS(SS-115)	ICRP Publ.68	SSG-26
Th-231	3.19E-10	3.20E-10	4.00E-10	3.10E-06

4. Reproducing calculation of Q_D values

Q_D values have been calculated using the beta spectra and discrete electron emissions for the nuclides, as tabulated by the ICRP Publ. [3,11]. The emission data for the nuclide of interest were used with data from Cross et al. [18] on the skin dose rate for monoenergetic electrons emitted from the surface of the skin.

4.1 Results by BRACSS

In BRACSS, the dose coefficient for Q_D was calculated by MCNPX code with skin slab phantom. We calculated Q_D values with this dose coefficient(Figure 4.1). Cut-off Energy is 0.06MeV as well as

SSG-26. We considered beta particles, internal conversion electrons and auger electrons.

4.2 Consideration

We have found out that the nuclides(Yb-175, Pa-230) were consistent with SEAL were reasonable. Q_D value of Yb-175 was close to current value, when cut-off energy changed into about 0.38MeV.

Most of nuclides(Sn-119m,Pm-145, Tm-171, Lu-174, Os-191m,Hg-197) were close to current values, when cut-off energy changed into about 0.7 MeV.

Pb-202 emit auger electrons that are lower than cut-off energy. Therefore, it is impossible that Q_D value of Pb-202 in SSG-26 is derived. We calculated Q_D value of Pb-202 with considering a daughter nuclide (Tl-202(half-lives:12.23[d])). (It's not described that Pb-202 is considering its progeny(Tl-202) in SSR-6.) (Figure 4.2) Then the Q_D value of Pb-202 was consistent with current value.

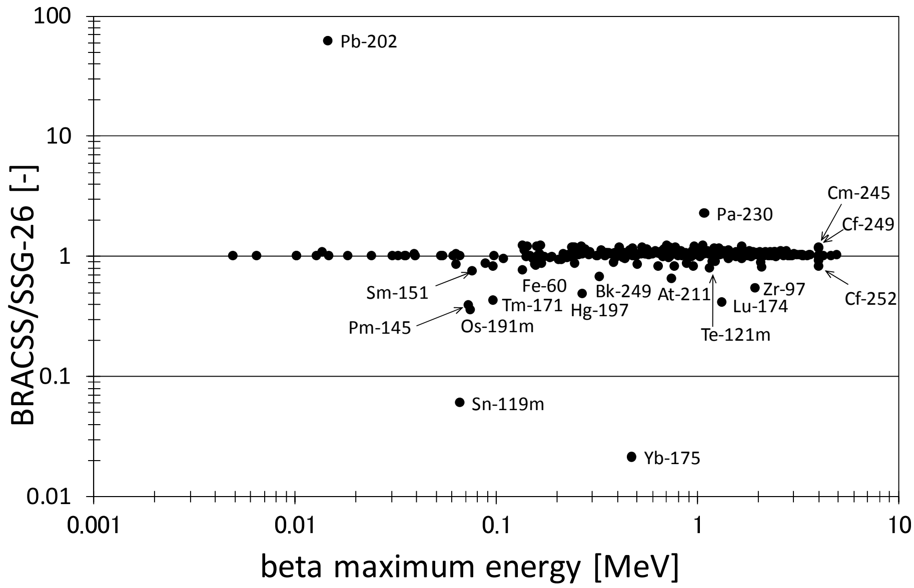

Figure 4.1 Q_D values by BRACSS

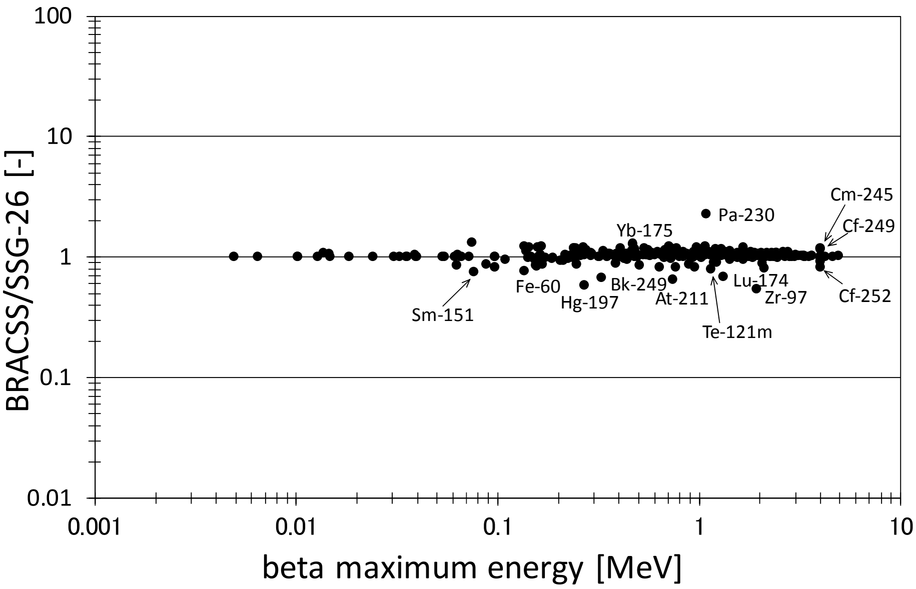

Figure 4.2 Q_D values by BRACSS after consideration

Therefore, we found out that in the calculation of the SSG-26, the calculation conditions(cut-off energy, consideration of progenies) were different for each nuclide.

5. Reproducing calculation of Q_E values

Q_E in SSG-26 have been calculated using effective(or equivalent skin) dose coefficient for submersion in a semi-infinite cloud, from USEPA Federal Guidance Report No. 12 [19].

5.1 Results by BRACSS

In BRACSS, the dose coefficient for Q_E was calculated by MCNPX code with male voxel phantom (ICRP Publ.110). We calculated Q_E values with this dose coefficient(Figure 5.1).

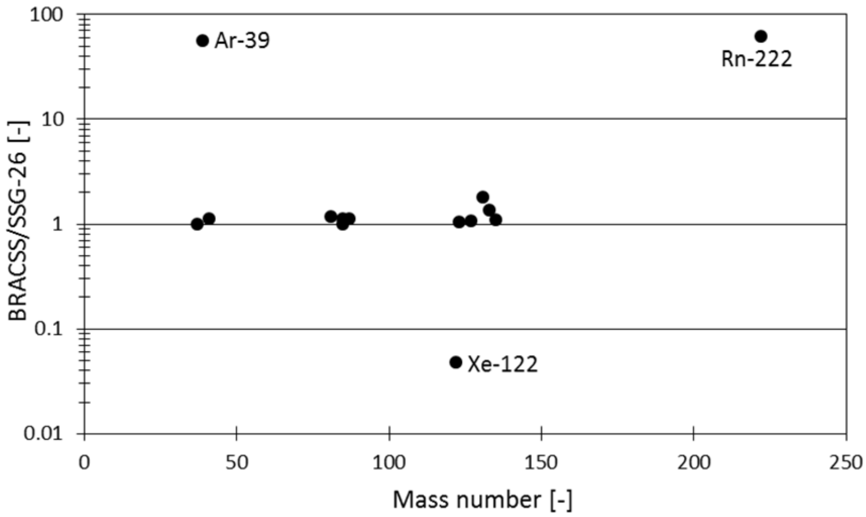

Figure 5.1　Q_E values by BRACSS

5.2 Consideration

It described that Xe-122 and Rn-222 are considering their progenies (Xe-122:I-122 / Rn-222:Po-218,Pb-214, At-218,Bi-214,Po-214) in SSR-6. Q_E values of Xe-122 and Rn-222 by BRACSS without considering their progenies were consistent with current values.

Only Ar-39 was not consistent with current value. It does not have progeny, and have only beta spectrum. Q_E values of Kr-85 etc. having beta spectrum which energy range close to Ar-39 were consistent with current values.

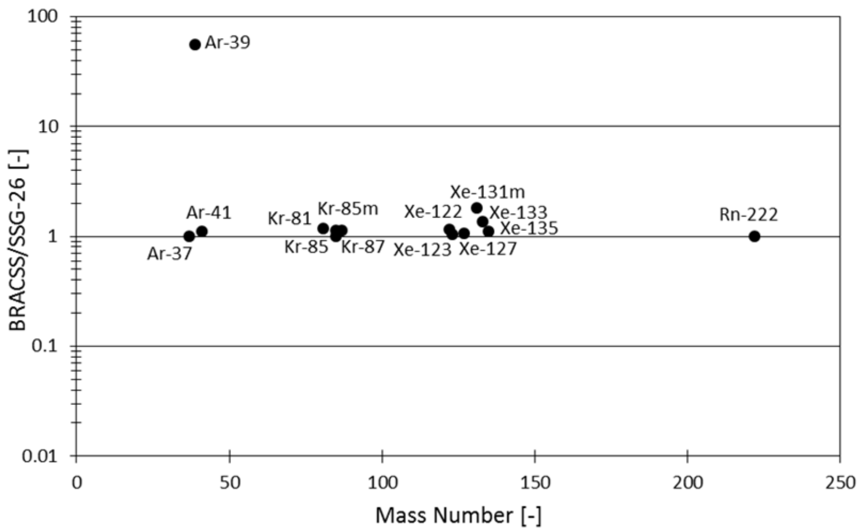

Figure 5.2　Q_E values by BRACSS for Xe-122 and Rn-222 without progeny

Therefore the dose coefficient for Q_E values in BRACSS is reasonable. It is presumed that only evaluation of Ar-39 was different or it had evaluation mistake.

Conclusions

Reproducing calculation of the Q system by BRACSS was generally well reproduce current values(SSG-26). And, it was confirmed that performance to calculate the Q value of BRACSS is reasonable. Most nuclides could reproduce current value using the calculated conditions described in SSG-26. However, it was found out that some of nuclides had been derived in a different calculation conditions from SSG-26. From these experiences, at the time of revision of A_1/A_2 values, it is important to describe the exact calculation conditions to SSG-26.

Future issues of the A_1/A_2 values should include reference dose, exposure pathways, irradiation geometry, consideration of progeny and transportation period, which are reasonable for accident instances. We are planning to implement model and data(emission data, dose coefficients, etc.) for examining these issues.

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