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Recalculating activity concentration limits for an exempt material and activity limits for an exempt consignment prescribed in the IAEA Regulations for the Safe Transport of Radioactive Material by the BRACSS code

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Abstract

International Atomic Energy Agency (IAEA) Transport Regulations SSR-6 [1] provides basic radionuclide values, as listed in Table 2, for classifying the packages to be used. This gives A_1 and A_2 activity concentration limits for exempt material (exemption concentrations) and activity limits for exempt consignments (exemption values) for each nuclide.

The exemption concentrations and exemption values in the SSR-6 are taken from the values given in the IAEA Basic Safety Standards (GSR Part 3 [2]), and the underlying scenarios can be found in the EC document RP-65 [3].

Inspired by recent needs to either reevaluate these values or add new nuclides, we have developed the basic numerical value radionuclide calculation system (BRACSS) to calculate such values. Herein, we report the recalculated exemption concentrations and values. Recalculated A_1 and A_2 values were previously reported in PATRAM2016 [4].

During the early stages of verifying the BRACSS code, our results for many nuclides did not represent those in SSR-6, even when using the conditions given in RP-65 [3]. The dose conversion coefficients for internal exposure, which we took from ICRP Publs. 68 [5] (for workers) and 72 [6] (for the public), were generally consistent with those used in RP-65's internal exposure scenario. The dose conversion coefficients for external exposures were also reproduced based on the conditions given in RP-65. When the conversion coefficients were not sufficiently precise, we calculated the external exposures using the MCNPX 2.6.0 code by assuming appropriate geometries [9][10]. It should be noted that BRACSS also includes a function to select either nuclear data given in ICRP Publs. 38 [7] or 107 [8] for future calculations related to radionuclides that may be transported.

To justify the above scenarios and geometries, we calculated exemption limits for 387 nuclides listed in SSR-6. For most nuclides, the calculated values are in good agreement with those in SSR-6, demonstrating the validity of the BRACSS calculations. Together with the previously reported A_1 and A_2 results, this confirms the accuracy of the BRACSS calculations.

Introduction

Table 2 of the IAEA Transport Regulations SSR-6 [1] provides basic radionuclide values for classifying the packages to be used. It lists the following values for each radionuclide.

A_1: Activity value for special forms of radioactive material
A_2: Activity value for radioactive material that is not in a special form
Activity concentration limit for exempt material
Activity limit for exempt consignments

The exemption concentrations and exemption values given in the SSR-6 are taken from the values given in the IAEA Basic Safety Standards (GSR Part 3 [2]), and the underlying scenarios can be found in EC document RP-65 [3]. Recently, however, there have been needs to either reevaluate these values or add un-listed nuclides. These basic values have been evaluated by the Working Group on Methods for Calculating A_1/A_2 Values (A_1/A_2 working group) under the IAEA's Transport Safety Standards Committee. Japan has been participating in the A_1/A_2 working group and has developed the basic numerical value radionuclide calculation system (BRACSS) for calculating the basic values. Recalculated A_1 and A_2 values produced by BRACSS have previously been reported in PATRAM2016 [4]. In this study, we discuss the recalculated values and related issues regarding the activity concentration limits for exempt material and the activity limits for exempt consignments.

Evaluation of the RP-65 and BRACSS values

The RP-65 [3] values were calculated as follows. After determining the given nuclide and nuclide type (solid, foil, liquid, gas, or capsule), the appropriate scenario was determined automatically. Then, the results were compared with the dose limit, and the activity concentration limit for exempt material and the activity limit for exempt consignments were output.

On the other hand, the BRACSS values are calculated as follows. First, we determine the kind of values to be calculated, the scenario, the nuclide, whether we consider progeny nuclides, the decay dataset (ICRP Publs. 38 [7] or 107 [8]), and the exposure scenario (external exposure, ICRP Publ. 107 [8], or internal exposure, ICRP Publs. 68 [5] or 72 [6]). Then, we compare the results with the dose limit and output the activity concentration limit for exempt material and the activity limit for exempt consignments.

Compared with RP-65 [3], BRACSS considers more options during the calculation process to measure effects of parameters on the final calculation result. Table 1 shows the scenarios used to evaluate the exemption concentrations and exemption values, which were calculated as follows.

1. Calculate the effective and skin equivalent doses for each exposure pathway per 1 Bq/g of radioactivity concentration or 1 Bq of radioactivity.
2. Add the effective dose and the skin equivalent dose for each exposure pathway group.
3. Calculate the exemption values for each exposure pathway group using the following equation: Exemption value (radioactivity or radioactivity concentration) = reference dose/sum of above dose values
4. Adopt the lowest of the three values calculated above for the exposure pathway groups.

Table 1. Scenarios used for the calculations[3]

Scenario		Critical Pathway for Activity Concentration	Critical Pathway for Exempt Activity
Work-place	Normal use	A1.1 External exposure from handling a source A1.2 External exposure from a 1m^3 source A1.3 External exposure from a gas bottle A1.4 Inhalation of dusts A1.5 Ingestion from contaminated hands	B1.1 External exposure from a point source B1.2 External exposure from handling a source
	Accidental	A1.1 External exposure from handling a source A1.2 External exposure from a 1m^3 source A1.3 External exposure from a gas bottle source A1.4 Inhalation of dusts A1.5 Ingestion from contaminated hands	Spillage B2.1 External exposure from contaminated hands B2.2 External exposure from contaminated face B2.3 External exposure from contaminated floor surface B2.4 Ingestion from hands B2.5 Inhalation of re-suspended activity B2.6 External exposure from aerosol or dust cloud
			Fire B2.7 Contamination of skin B2.8 Inhalation of dust or volatiles B2.9 External exposure from combustion products

Recalculation results

RP-65 [3] describes the scenarios and numerical values used to calculate the exemption concentrations, both overall and for each nuclide. In this study, we take these scenarios and numerical values, recalculate the concentrations using BRACSS, and compare them with the RP-65 values. Specifically, we divide the recalculated value for each nuclide by the RP-65 values. If the recalculated and RP-65 values match, this will give a value of 1, while values less than or greater than 1 indicate that the recalculated value is an underestimate or overestimate, respectively. The results of this comparison are shown in Figure 1 (exemption concentrations) and Figure 2 (exemption values).

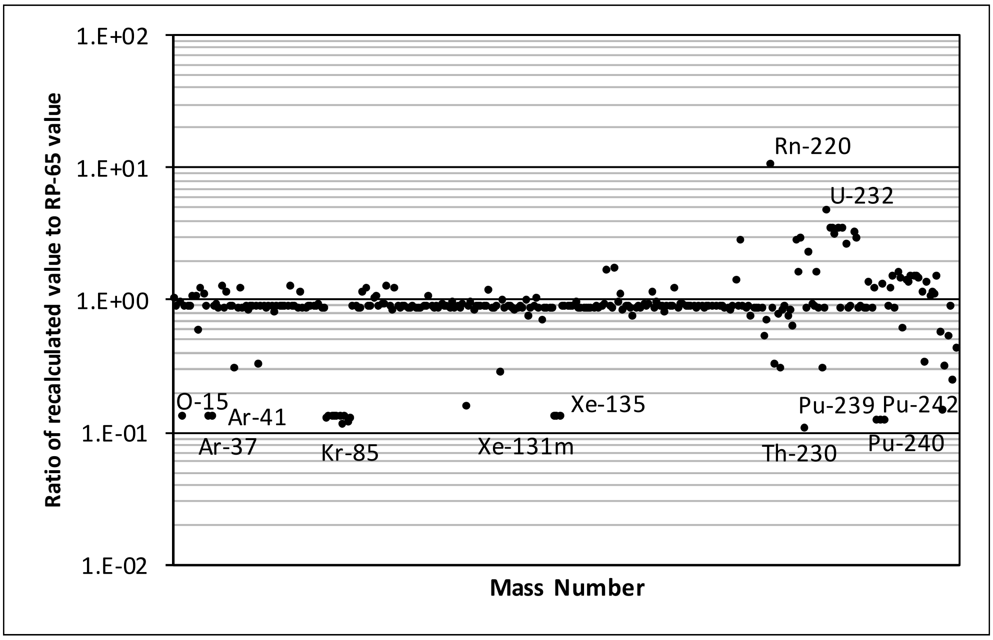

Figure 1. BRACCS exemption concentrations

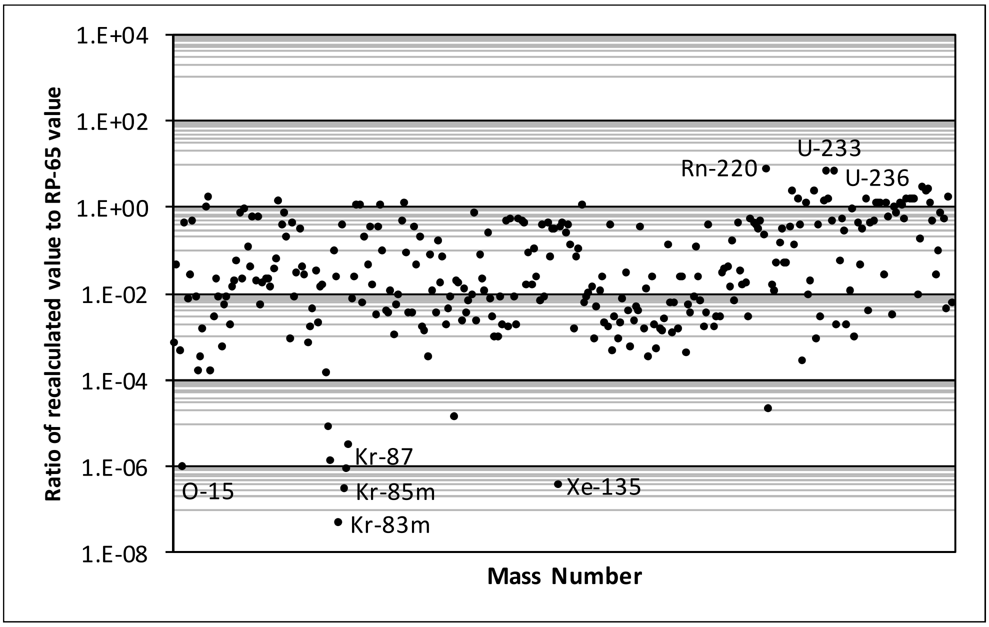

Figure 2. BRACCS exemption values

The recalculated exemption concentrations (Figure 1) can be summarized as follows.

> Almost all the nuclides, aside from the noble gases, were underestimated by about 10%.

> Nuclides with mass numbers above 200 were overestimated by factors of 1.1–10.
> Noble gas nuclides, especially Rn-220, show larger variations.

The recalculated exemption concentrations (Figure 2) can be summarized as follows.
> Almost all the nuclides were underestimated.
> Nuclides U-233, U-236, and Rn-220 were overestimated.
> Noble gas nuclides, especially Rn-220, show larger variations.

Discussion

After examining the potential causes of the differences between the RP-65 values and recalculated values, we considered the following possibilities:
> The calculations involved different scenarios, such as different exposure pathways (e.g., inhalation, ingestion);
> Different numerical values were used, such as different dose coefficients for inhalation and ingestion; and
> Other factors.

Below, to evaluate the accuracy of BRACSS calculation, a criterion was set as an acceptable range within twice and half in the ratio of deviation from the SSR-6 value.

Exemption concentrations

Since these values were underestimated by about 10% for nuclides other than noble gases, we considered the scenarios used in the recalculations. Specifically, we reexamined the idea of external exposure. For example, in the case of solid radiation sources, we had only considered external exposure from dispersible solid radiation sources, not from gaseous radiation sources. Meanwhile, for gaseous sources, we had only considered exposure from gaseous sources, not from dispersible solid sources. We therefore identified which scenarios should be considered and amend scenarios. Table 2 compares the scenarios used before and after making these amendment.

Amending the scenarios in this way corrected the 10% underestimation for non-noble-gas nuclides (Figure 3). This suggests that the previous discrepancies were mainly caused by considering wrong scenarios of RP-65. This change meant that the values for both the noble gases and many other nuclides that were previously underestimated (specifically, H-3, O-15, Ar-37, Ar-41, Kr-74, Kr-76, Kr-77, Kr- 79, Kr-81, Kr-83 m, Kr-85, Kr-85 m Kr-87, Kr-88, Xe-131 m, Xe-133, and Xe-135) were now almost the same as the RP-65 values. However, the value for Rn-222 was still overestimated by a factor of 6.64.

Table 2. Changes in the evaluation of gaseous nuclides for exemption concentration scenarios (Workplace, Normal use)

Scenario	Scenario			
	Previous		Modified	
	Gaseous	Other Material*	Gaseous	Other Material*
A1.1 External exposure from handling a dispersal solid source	X	X	—	X
A1.1 External exposure from handling a gaseous source	X	X	X	—
A1.2 External exposure from a 1 m^3 source	X	X	—	X
A1.3 External exposure from a gas bottle source	X	X	X	—
A1.4 Inhalation of dusts	X	X	—	X
A1.5 Ingestion from contaminated hands	X	X	—	X

*Here, the RP-65 [3] scenarios are used for spilled solids, non-spilled solids, liquids, capsules, and foils.

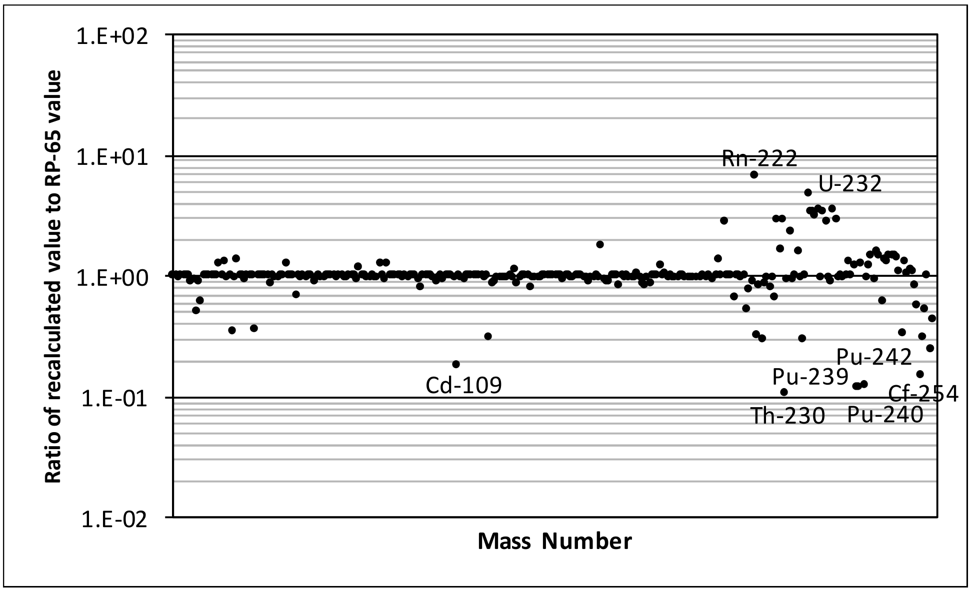

Figure 3. BRACSS exemption concentrations after scenario adjustment

<u>Rn-222</u>

Since the above results indicate that the Rn-222 value may have been different for reasons other than the scenario used, we also considered the following changes.

> Re-examining the Rn-220 dose conversion coefficient for inhalation.

> Changing the B2.8 scenario parameter c (rate of burning source to ash) and the reference dose.

Figure 4 shows the results of implementing these changes. Here the exemption concentrations are generally close to the RP-65 values, although the values for Tl-204 and Cf-254 fall outside the acceptable range (being more than double and less than half of the RP-65 values, respectively). We thus investigated these nuclides in more detail as follows.

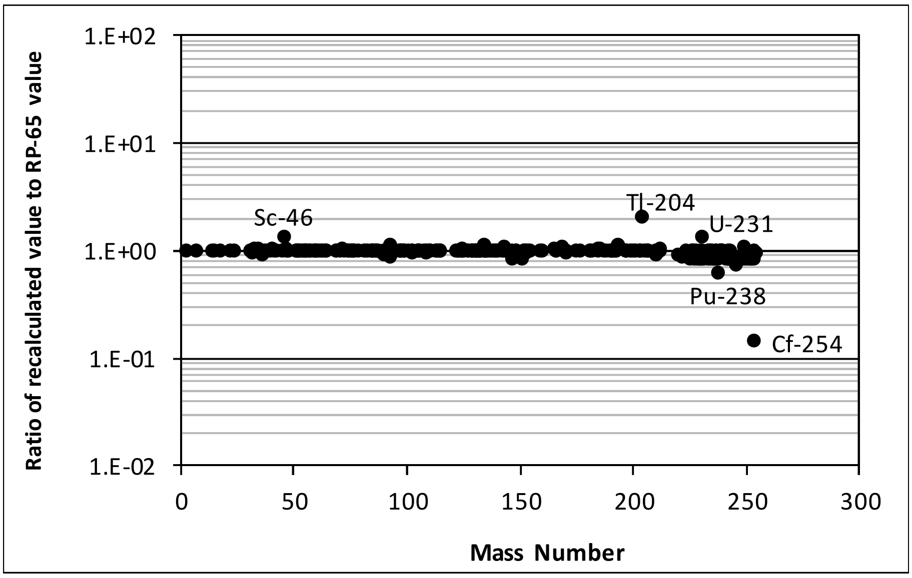

Figure 4. BRACSS exemption concentrations after changing the Rn-222 scenario

Tl-204

The only source of Tl-204 is as a foil, so scenario A1.1 (external exposure due to handling a dispersible solid radiation source) is not covered by the previous exemption concentration scenario. However, we investigated considering scenario A1.1 by back-calculating from RP-65 values.

	Recalculated value / RP-65 value
Without A1.1 scenario	2.02
With A1.1 scenario	0.996

This comparison shows the correcting the illegible value in printed in RP-65 also changed the RP-65 value from 6.06 E+03 to 8.06E+03.

The scenario with the highest dose contribution (decision scenario) in the scenario group that determines Tl-204's exemption concentration is A1.2 (external exposure from a 1 m^3 source), and this was still true after adding scenario A1.1: among scenarios A1.1–A1.5, scenario A1.2 made the highest contribution to the dose. From the above results, we thus decided to add foil as a target nuclide for scenario A1.1 (dispersible solids).

When we considered the impact of this change to scenario A1.1 on the other nuclides, we found that no other nuclide was affected by this parameter change. Therefore, after reviewing the effect of adjusting the scenario to include foils, we decided to set the target states for each nuclide as shown in Table 3 below.

Table 3. Target nuclide characteristics for each scenario

Scenario				Nuclide State
Exemption Conc.	Normal	A1.1	External exposure from handling a source	S, F, G
		A1.2	External exposure from a 1 m^3 source	L, S, SM, C, F
		A1.3	External exposure from a gas bottle	G
		A1.4	Inhalation of dusts	S, G
		A1.5	Ingestion from contaminated hands	S
Exemption Value	Normal	B1.1	External exposure from a point source	L, S, SM, C, F
		B1.2	External exposure from handling a source	L, S, C, F, G
	Accident	B2.1	Spillage: External exposure from hand contamination	L, S
		B2.2	Spillage: External exposure from facial contamination	L, S
		B2.3	Spillage: External exposure from a contaminated surface	L, S
		B2.4	Spillage: Ingestion from hands	L, S
		B2.5	Spillage: Inhalation of re-suspended activity	L, S
		B2.6	Spillage: External dose from aerosol or dust cloud	L, S
		B2.7	Fire: Contamination of skin	L, S, SM, C, F, G
		B2.8	Fire: Inhalation of dust or volatiles	L, S, SM, C, F, G
		B2.9	Fire: External exposure from combustion products	L, S, SM, C, F, G

L: liquid, S: dispersible solid, SM: solid material, C: capsule, F: foil, G: gas

Cf-254

The decision scenario for Cf-254 is A1.4 (dust inhalation). However, when we recalculated the values, we found that the deciding scenario was A1.2 (external exposure from a 1 m^3 source), with scenario A1.4 making only the second-largest contribution to the dose. This large contribution by scenario A1.2 meant that the ratio of the recalculated and RP-65 values was 0.14. In other words, as long as we include scenario A1.2, the resulting value will be ten times more severe than the RP-65 value. However, excluding scenario A1.2 changed the deciding scenario to A1.4, as described in RP-65 , and the ratio also improved to 0.85.

	Recalculated value / RP-65 value
Without A1.2 scenario	0.85
With A1.2 scenario	0.14

Given this, we convince it is highly probable that scenario A1.2 (external exposure from a 1 m^3 source) was not considered when calculating the RP-65 value for Cf-252.

<u>Other nuclides</u>
In addition to the improvements produced by re-examining Tl-204 and Cf-254, we were also able to improve the recalculated results by reviewing the following nuclides.

> Sc-46: Clarified the unclear printed description of the RP-65 value from 6.29 E+00 to 8.29E+00.
> U-231 : Clarified the unclear printed description of the average photon energy per modification from 6.20E-02 to 8.20E-02 MeV.
> Pu-238 : Clarified the unclear printed description of the effective committed dose per unit inhalation from 8.20E-05 to 6.20E-05 Sv/Bq.

	Recalculated value / RP-65 value	
	Before	After
Sc-46	1.32	1.0
U-231	1.32	0.998
Pu-238	0.63	0.83

Figure 5 shows the results of recalculating the exemption concentrations based on the above improvements. These results confirm that, after re-examining the items listed below, the recalculated and RP-65 values are now almost the same.

> Identify which scenarios should be considered and which should be ignored.
> Consider the nuclide’s characteristics (Liquid, Solid, Gas, etc.).
> Amend unclear printed values.

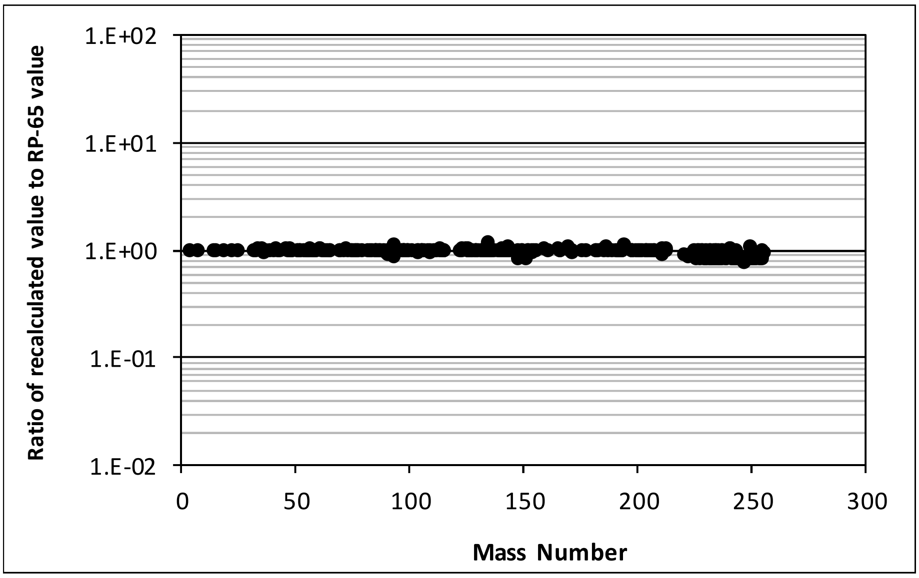

Figure 5. BRACSS exemption concentrations after all adjustments

Exemption values

For most of the nuclides where the exemption values were underestimated, at first, the smaller of the effective dose and skin equivalent dose was used for the calculation. But using values of closer to the current equivalent dose for each nuclide by back calculating, it close to RP-65 exemption value (Figure 6). That is, we believe that RP-65 [3] was also calculated after selecting a scenario for either the effective or skin equivalent dose for each nuclide.

After selecting appropriate scenarios, we only found differences between the recalculated and RP-65 values for the gaseous nuclides Ar-41, Kr-74, Kr-83 m, Kr-76, Kr-88, O-15, Rn-220, Rn-222, Xe-131m, and Xe-133.

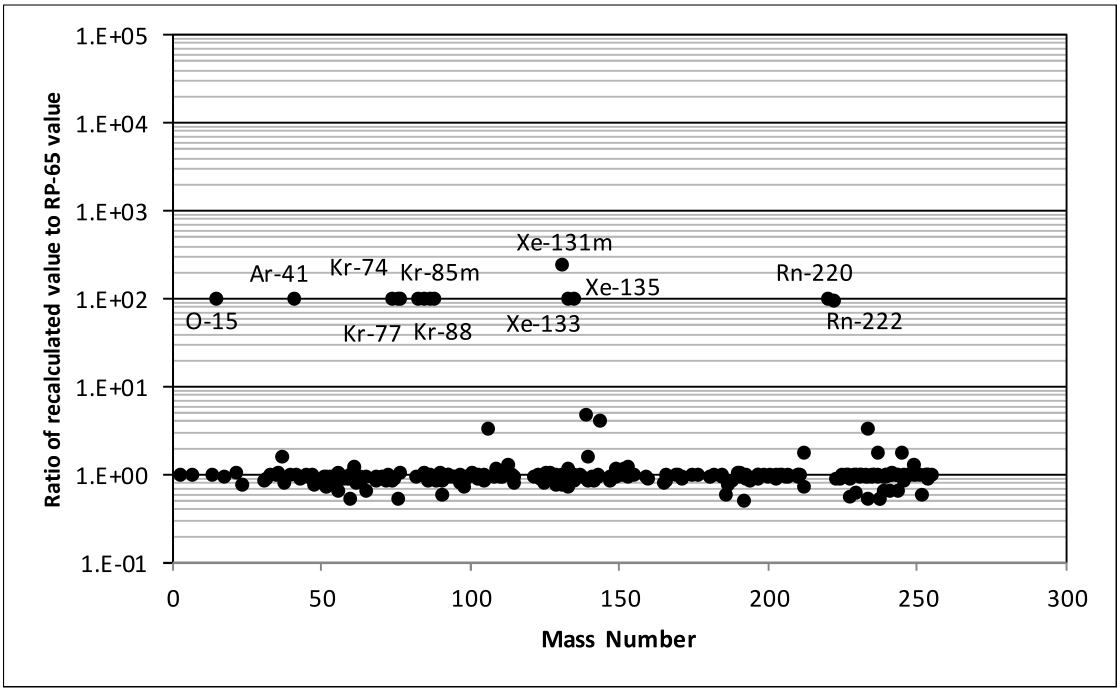

Figure 6. BRACSS exemption values after selecting appropriate scenarios

In RP-65, the calculation formulas for scenarios B2.7–B2.9 give the proportions of the radiation source that are converted into ash, droplets, water vapor, and volatile substances by fire. In the explanation accompanying scenario B2.8, liquid and gaseous sources are described as being 100% converted, compared with only 1% for other sources. However, in the calculation formula for scenario B2.8, only liquid sources were treated with a conversion rate of 100%, which we believe is a description error.

Similarly as the explanations accompanying scenarios B2.7 and B2.9 are believed to be inadequate, We recalculated the results for the accident (fire) scenario with 100% of gaseous nuclides being converted; the results are shown in Figure 7. Here, the values for all gaseous nuclides except Xe-131 m and Xe-133 agree with the RP-65 values. These results suggest it is highly probable that RP-65 should read “the transfer ratio of gaseous nuclides in the accident (fire) scenario is 100%.”

Progeny nuclides

RP-65 [3] takes progeny nuclides into consideration for three nuclides (Ru-106, Ce-144, and Th-234), meaning that the original values should have been calculated by including progeny nuclides contribution. For these nuclides, using the β-ray end point energy including progeny nuclides enabled us to improve their calculated exemption values.

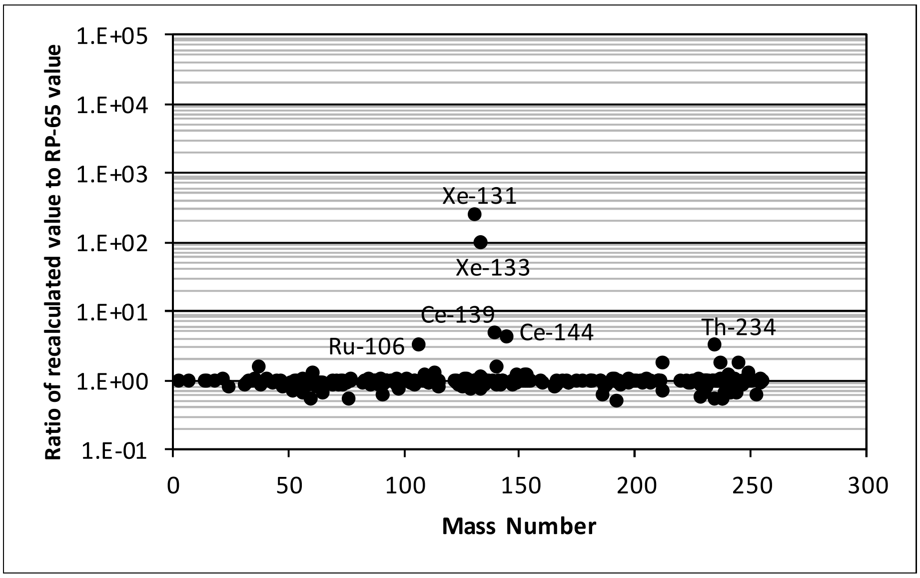

Figure 7. BRACSS exemption values after amending the accident (fire) scenario

<u>Ce-139</u>

In RP-65 , the value for scenario B1.2 (skin equivalent dose rate of [7 mg/cm^2 (Sv / h) / (Bq / cm^2)]), giving the effect of γ-ray irradiation on the basal layer of the epidermis, appears to be 1.9E-08. However, the printing is unclear and it could also be 1.9E-06. Assuming this latter value is correct, the ratio of Ce-139's recalculated exemption value to the previous one is 0.438, which is significantly better than the original value of 4.74. This change also improved the results for Ru-106, Ce-144, Th-234, and Ce-139; the recalculated results are shown in Figure 8.

After considering the nuclides whose recalculated exemption values differed from the RP-65 values, we focused on nuclides whose results were outside the optimum range (more than twice or less than half of the RP-65 values). Here, we found that all nuclides except Ce-139 fell within the target range.

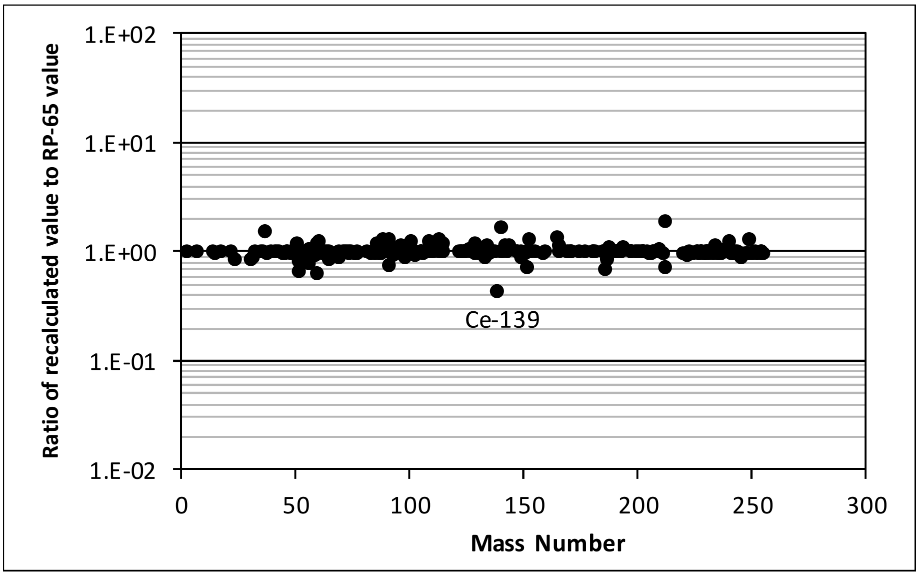

Figure 8. BRACSS exemption values after R7 value adjustment

As mentioned above, comparing the existing RP-65 exemption values with the recalculated ones led us to find that the differences between them were caused by several factors. However, by re-examining the scenarios and performing other optimizations, we have confirmed that BRACSS can produce values that good match the RP-65 values for most nuclides.

Conclusion

In this paper, we recalculated the exemption concentration and exemption values by the BRACSS code basically in accordance with the conditions indicated in RP-65.

As a result, there were many nuclides for which the results did not match the RP-65 values. Therefore, we re-examined the scenarios and modified the parameters within the reasonable range that could be estimated (for example, we modified the coefficients that depend on the nuclide properties), so that the BRACSS code could derive the values close to the RP-65 values for most nuclides.

However, there were some nuclides for which the results did not match the RP-65 values, even after re-examining the scenarios and other parameters. We think this mismatch is due to the fact that the initial circumstances, precise calculation conditions, and other related information have been lost or forgotten.

This also highlights the necessity of recording the calculation conditions in more detail when establishing regulatory values to be implemented to the Member States regulations. For example, in the IAEA expert meetings, we recommend it is essential to document the calculation scenario for each nuclide, as well as related technical background such as the scenario's appropriateness, to enable the basic figures to be reproduced.

References

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