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Review of current Q system and the A_1/A_2 values of the IAEA Transport Regulations

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Abstract

The current Q system of the Transport Regulations published by the International Atomic Energy Agency (IAEA) was developed in the 1980s for calculation of A_1/A_2 values, i.e. the activity limits for type A packages. Over the years, the need came up for some additional A_1/A_2 values for nuclides not listed in the IAEA Transport Regulations SSR-6. Therefore, the German Federal Office for Radiation Protection (BfS) and the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) granted a research project with the objective to analyse the methods used in the current Q system and to establish a program for the calculation of Q and A_1/A_2 values.

The calculation tool Ber*QA*Trans enables not only to recalculate already known A values for nuclides listed in the IAEA Transport Regulations SSR-6, but also to determine the Q and A values for new radionuclides. The recalculation results of Ber*QA*Trans are in good agreement with the Transport Regulations SSR-6 for most of the A values. Furthermore, it is possible to recalculate Q and A values not even on the up to now used older data basis of ICRP publication 38 but also by using recent nuclide data presented in ICRP publication 107. Also newer dose rate coefficients published by International Commission on Radiological Protection (ICRP) can be used.

During the development of the calculation program Ber*QA*Trans many lacks and inconsistencies in the documentation and problematic issues of the current Q system were identified and are briefly discussed in this paper.

Other institutions made similar approaches to analyse and/or revise the Q system. In 2013, the work of these groups was also recognized by TRANSSC (Transport Safety Standards Committee) members. To gather their work an international working group was founded in Cologne. This Working Group on review of A_1 and A_2 Values for the IAEA Transport Regulations had several meetings with the aim of a comprehensive review and revision of the current Q system. First results and proposals were presented to TRANSSC in June and September 2015.

Introduction

The current Q system of the IAEA Transport Regulations was developed in the 1980s for calculation of A_1/A_2 values, i.e. the activity limits for type A packages [1]. The system was integrated into the IAEA Transport Regulations in 1985, superseding the previous A_1/A_2 system of 1973, with a comprehensive revision in the 1990s.

The Q system is based amongst others upon following dose criteria: the effective dose to a person should not exceed 50 mSv and the equivalent dose to the skin should not exceed 500 mSv [2]. In the current Q system described in Appendix I in the Advisory Material SSG-26 [2] five (main) exposure pathways are taken into account (see Figure 1). For these pathways nuclide specific activity limits (so called Q values) are calculated:

- external photon dose (Q_A),
- external beta dose (Q_B),
- inhalation dose (Q_C),
- skin dose and ingestion dose due to contamination transfer (Q_D), and
- submersion dose (Q_E).

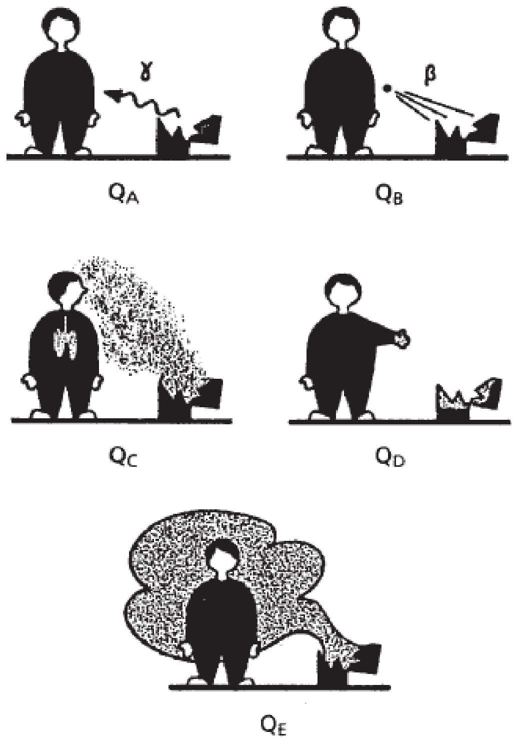

Figure 1 Exposure pathways in the Q system (picture taken from: [3])

In addition, there is a sixth pathway for alpha emitters; this dose value is named Q_F. All of these Q values are considered separately, i.e. it is possible to reach the maximum dose (50 mSv or 500 mSv, respectively) in each of these pathways. As this is only true for a relatively small number of nuclides, this method is retained [2].

The resulting A values for the IAEA Transport Regulations [4] are calculated as follows: The A_1 value (for special form material) is defined as the minimum value of Q_A and Q_B, and (if applicable) Q_F. The A_2 value (for non-special form material) is defined as the minimum value of A_1, and Q_D or

Q_E, respectively. There are additional assumptions and calculation rules for deriving *Q* and *A* values according to the Q system, which are not mentioned here in this brief description of the system. Even in the Advisory Material [2] not all necessary assumptions are documented [5], [6].

Calculation tool Ber*QA*Trans

Over the years, in Germany as well as in other countries the need came up for some additional *A* values for nuclides not listed in the IAEA Transport Regulations. Therefore, the German Federal Office for Radiation Protection (BfS) and the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) granted a research project with the objective to analyse the methods used in the current Q system, and to establish a PC program for the calculation of *Q* and *A* values.

Therefore, as a first step GRS had to analyse the whole Q system in detail. Amongst many other publications (often from the 1970s and 1980s) that form the basis for the current *Q* and *A* values two publications are important: First, the report of the National Agency for Environmental Protection (ANPA) written in 1994 [7], in which new calculation methods for Q_A and Q_B values were laid down; for these newly calculated *Q* and *A* values were afterwards introduced into the Transport Regulations in the 1990s. And secondly, the report by Health Protection Agency (HPA) of 2011 [6], which is also a review of the Q system and its calculation methodologies in order to create the calculation tool SEAL [8] for calculating *Q* and *A* values, and exemption values according to the current Q system.

The GRS calculation tool Ber*QA*Trans was designed not only to (re-)calculate existing *Q* and *A* values, but also to calculate new values for nuclides not listed in [4] or [2], and to enable to introduce new nuclide data [5]. The current Q system is based upon rather old data, e.g. ICRP 38 [9], ICRP 51 [10] or ICRP 68 [11]. Meanwhile, newer data is available, that is partly integrated in Ber*QA*Trans.

Ber*QA*Trans is a Microsoft Excel program written in VBA code. It provides many calculation options, e.g. to use newer nuclide data, or to variate dose conversion factors. Values for 373 nuclides are listed in [4], with Ber*QA*Trans it is possible to calculate *Q* and *A* values for 768 nuclides, using current calculation methods of the Q system. As an additional benefit of Ber*QA*Trans and in contrary to [2], the result tables Q_A and Q_F are shown in separate columns, so that for every alpha emitter the *Q* values for photon dose and for alpha dose can be checked simultaneously. A more detailed description of Ber*QA*Trans and the development of its calculation methods can be found in [5].[1]

Findings and Results

Recalculation of *Q* and *A* values with Ber*QA*Trans

Ber*QA*Trans was used to recalculate the whole set of *Q* and *A* values as well as the dose rate coefficients $\dot{e}_{\mathrm{pt}}$, $\dot{e}_{\beta}$, and $\dot{h}_{\mathrm{skin}}$ for Q_A, Q_B, and Q_D listed in [3] using the calculation methods and data of the current Q system. Comprehensive tables with results and comparison with [3] can be

[1] Report GRS-343: in German, available at http://www.grs.de/publikation/grs-343

found in the Annex of the GRS report GRS-343 [5]. These Q and A values calculated with Ber*QA*Trans are in good agreement with the values tabulated in [3]. However, resulting A values for eight nuclides (^{26}Al, ^{47}Ca, ^{166}Dy, ^{202}Pb, ^{225}Ra, ^{92}Sr, ^{96m}Tc, and ^{231}Th; see Table 1) showed a higher deviation from values of the current Q system by a factor of more than two [5]. Deviations of A values, e.g. for ^{26}Al, ^{47}Ca, ^{166}Dy, ^{225}Ra, ^{92}Sr, and ^{231}Th are documented in [6] as well. Reasons for discrepancies are for example different Q values restricting the corresponding A value due to the calculation methods used, or different treatment of progeny.

Table 1 Calculated nuclides with higher deviation from values of the current Q system

Nuclide	Remarks to values calculated with Ber*QA*Trans
^{26}Al	Q_B value lesser than in [2]; therefore, Q_A value restricts A_1/A_2 values
^{47}Ca	Q_A and Q_B values lesser than in [2]; now Q_B values restricts A_1 value
^{166}Dy	Q_B value lesser than in [2]; therefore, A_1 value lesser too
^{202}Pb	Q_D value higher than in [2] and “unlimited”; therefore A_1/A_2 values “unlimited” too
^{225}Ra	Q_B value and Q_C value higher than in [2]; therefore, A_1 value and A_2 value higher
^{92}Sr	Q_C value calculated with progeny in [3]
^{96m}Tc	Q_C and Q_D values calculated with progeny in [3]
^{231}Th	higher deviation of Q_C value, possibly calculated with progeny in [3]

Also, dose rate coefficients for pathways Q_A, Q_B, and Q_D were recalculated. For many nuclides significant differences between calculated coefficients [5] and listed coefficients [3] were found. All these recalculated dose rate coefficients were used as input parameter for calculating Q and A values with Ber*QA*Trans giving the very good results discussed above. It seems that dose rate coefficients listed in [3] were “calculated backwards” from the Q values given in the same document. As there is an undocumented limit of 1000 TBq for each pathway, these limits were probably taken into account resulting in to high dose rate coefficients for nuclides with limited Q values. For nuclides ^{252}Cf, ^{254}Cf, and ^{248}Cm the tabulated Q_A values are superseded by special Q values representing doses from neutron emissions. Even in these cases, it seems that the (neutron dose) Q values accidentally were taken to calculate dose rate coefficients for external photon dose. Comparative tables of dose rate coefficients are given in GRS report GRS-343 [5].

Current Q system

The description of the Q system and its calculation methods is laid down in [4] and [2]. With only these two publications proper (re-)calculation of Q and A values is not possible. Even by means of some additional reports, e.g. [7], a recalculation of listed values is difficult. It was necessary to partly rely on auxiliary literature from the 1970s and 1980s. Also the HPA report [6] as well as private communication with colleagues from HPA (now Public Health England, HPE) had a significant impact in investigating the whole Q system.

The calculation methods in the current Q system are not documented sufficiently in order to reproduce all required details. Hence, misinterpretations can occur. The current *Q* and *A* values are based upon calculations with rather old data, even if there is newer data available. However, it is not possible to reproduce all current *Q* and *A* values exactly.

Some of the occurred problems in the current Q system are listed below:

- *Q* and *A* values are partly calculated using outdated input data,
- dose coefficients listed in [2] for Q_C values are partly not in coincidence with the dose coefficients of ICRP 68 [11]; however, no reference is given for the dose coefficients in [2],
- dose rate coefficients listed in [2], seems to be “calculated backwards” from *Q* values listed in [2], therefore some values (especially for small coefficients) show high differences compared to new calculated ones,
- Q values are limited to 1000 TBq without justification or documentation,
- determination of “unlimited” values for LSA material is not thoroughly documented,
- treatment of progeny differs between the *Q* value pathways.

More findings as well as detailed explanations of these issues are described for example in [6] and [5].

In answer to these problems, members of TRANSSC asked for an international meeting since other institutions than HPA/PHE and GRS were discussing the Q system, too. The first meeting held at the GRS premises in Cologne in September 2013 was joined by participants from the following institutions: Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Japan Nuclear Energy Safety Organisation (JNES; now Nuclear Regulation Authority, NRA), PHE, World Nuclear Transport Institute (WNTI) and GRS. Afterwards, the participants agreed that the current Q system should be reviewed, and the International Working Group on Review of A_1 and A_2 Values for the IAEA Transport Regulations was founded.

Summary

GRS has analysed the current Q system of the IAEA Transport Regulations [4] and established the calculation tool Ber*QA*Trans for calculating *Q* and *A* values. Ber*QA*Trans enables not only to recalculate already known *Q* and *A* values listed in [4] and [2], but also to determine *Q* and *A* values for new nuclides or to use more up-to-date data published by ICRP. *A* values recalculated with Ber*QA*Trans according to the current Q system are in very good agreement with the tabulated values, e.g. given in [3] and [2], except for eight nuclides. Problems with these nuclides are widely discussed in [5] and [6], a brief explanation is given in this paper.

While GRS investigated the Q system many lacks and inconsistencies in the documentation of the Q system were identified. These and similar findings were also made by other organisations. Some of these issues are briefly discussed in this paper. More explanations and extended discussions of this topic can be found in [5] and [6].

Outlook

Beginning in 2014 the International Working Group on Review of A_1 and A_2 Values for the IAEA Transport Regulations met several times. Also, new participants from other institutions and countries took part in this group, e.g. U.S. Department of Transportation (DOT), National Maritime Research Institute (NMRI), or MHI Nuclear Systems and Solutions Engineering Co. The working group results are reported to TRANSSC regularly. The actual work of the working group is covered by a separate paper at PATRAM 2016 [12].

Calculations using Ber*QA*Trans were performed as part of the work within the International Working Group on Review of A_1 and A_2 Values for the IAEA Transport Regulations. While the working group decided to introduce Monte Carlo methods for deriving new Q and A values, it was necessary to use also deterministic methods by SEAL and Ber*QA*Trans. These calculations for all nuclides of [4] allow analysing the influence of using new data, e.g. ICRP 107 [13], without changing the calculation method itself. As a second example, Q and A values for five new nuclides (^{135m}Ba, ^{69}Ge, ^{193m}Ir, ^{57}Ni, and ^{83}Sr) shall be included in the next revision of the IAEA Transport Regulations SSR-6 and SSG-26. Calculations were performed by GRS (see Table 2, with data from ICRP 38 [9], ICRP 51 [10] and ICRP 68 [11]), HPE, and NRA, using Ber*QA*Trans, SEAL, or BRACSS (calculation tool of NRA [14]), respectively. Results were presented to TRANSSC in February 2016. The new values selected from the results of these organisations shall be added in the new draft revision of the IAEA Transport Regulations.

Table 2 *Q* and *A* values for new nuclides calculated with Ber*QA*Trans

Nuclide	Q_A (TBq)	Q_B (TBq)	Q_C (TBq)	Q_D (TBq)	A_1 (TBq)	A_2 (TBq)
^{135m}Ba	1.6×10^{1}	1.0×10^{3}	3.3×10^{2}	5.9×10^{-1}	2×10^{1}	6×10^{-1}
^{69}Ge	1.3×10^{0}	7.1×10^{0}	1.7×10^{2}	4.5×10^{0}	1×10^{0}	1×10^{0}
^{193m}Ir a)	8.3×10^{2}	1.0×10^{3}	4.2×10^{1}	4.2×10^{0}	4×10^{1}	4×10^{0}
^{57}Ni	5.9×10^{-1}	2.0×10^{1}	8.9×10^{1}	3.3×10^{0}	6×10^{-1}	6×10^{-1}
^{83}Sr	1.4×10^{0}	1.4×10^{1}	1.5×10^{2}	8.7×10^{0}	1×10^{0}	1×10^{0}

a) no nuclide data available in ICRP 38 [9], therefore calculated with data from ICRP 107 [13]

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