IAEA TRANSSC Technical Expert Group on Radiation Protection

Working group on A_1/A_2

UPDATE OF THE Q SYSTEM TO DERIVE THE A_1/A_2 BASIC VALUES OF THE IAEA TRANSPORT REGULATIONS NO. SSR-6

Interim report of the WG A_1/A_2 for the 2021-2022 SSR-6 review cycle

Version 1.0

TABLE OF CONTENT

FIGURES AND TABLES

Figures

Tables

1. INTRODUCTION

The A_1 and A_2 values tabulated in the IAEA transport regulations SSR-6 have been determined to limit the contents of packages so that "*the radiological consequences […] are deemed to be acceptable, within the principles of radiological protection, following failure of the package after an accident*" (para. 402.1 in SSG-26) where the package has lost its safety and radiation protection functions. These values were derived from the "Q system" (where "Q" stands for "Quantity") radiological model, based on 5 different exposure scenarios and described in the advisory material SSG-26, using reference doses of 50 mSv (effective dose), 500 mSv (equivalent dose to the skin) and 150 mSv (equivalent dose to the lens of the eye). It is considered that exposures below these limits would not lead to significant health detriment, either deterministic or stochastic in the event of an accident.

A_1 and A_2 values are also often used to express the package standard performances required in the different transport conditions defined in SSR-6, as they represent equivalent radiological consequences for whatever radionuclide is involved.

The current Q system is the heir of, successively, the radiotoxicity classification system used in the 1961, 1964 and 1967 editions of the Regulations, and the "A_1/A_2 system" derived in the 1973 edition. The Q system was first introduced in the 1985 edition No. SS6, using a similar method to the "A_1/A_2 system", taking into account the latest changes in ICRP recommendations (ICRP 26) at that time. The A_1 and A_2 values were then updated with the 1996 edition of the Regulations No. ST-1 to use the then new ICRP 60 recommendations and the latest data from ICRP at that time. Since then, they have remained unchanged in subsequent editions.

However, ICRP has published updated and more complete data that supersede the previous data sets. New means of calculation are also available. Furthermore, there was a need in some countries to have A_1/A_2 values for additional radionuclides. Unfortunately, simple calculations of additional A_1/A_2 values or recalculation of existing values only using Appendix I of SSG-26 led to inconsistencies, and the unavailability of required information to do this task or to interpret the basic radionuclide values provided in the transport regulations were identified by several organizations. Some of the determined problems in the current Q system are listed below:

- Q and A values are calculated using outdated input data,
- inhalation dose coefficients are partly not consistent with the dose coefficients of ICRP 68,
- some of the dose coefficients listed in SSG-26, seem to be "calculated backwards" from Q values listed in SSG-26, therefore some values (especially for small coefficients) cannot be reproduced,
- Q values are limited to 1 000 TBq without justification or documentation,
- determination of "unlimited" values for LSA material is not thoroughly documented,
- treatment of progenies is not always consistent and differs between the Q value pathways,
- some assertion (low ingestion dose, low impact of multiple pathway principle, arbitrary derivation of $Q_A = Q_F = 10^4\ Q_C$ for alpha emitters etc.) are not properly justified,
- approximations done in the physics for energy deposition.

In response to these problems, members of TRANSSC asked for an international meeting since several institutions were discussing the Q system. The first meeting held in September 2013 gathered participants from the following institutions: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Japan Nuclear Energy Safety Organisation (JNES, now Nuclear Regulation Authority, NRA), Public Health England (PHE, now UK Health Security Agency, UKHSA) and World Nuclear Transport Institute (WNTI). However, as no complete proposal was available, the TRANSSC committee concluded at its November 2013 meeting (TRANSSC 27) that no change to SSR-6 Safety Standard could be provided. It was, however, identified that further meetings were needed to exchange views and conclusions about possible improved

methods and associated results. 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 (WG A_1/A_2) for the IAEA Transport Regulations was founded. The Japanese National Maritime Transport Institute (NMRI) and Mitsubish Heavy Industries - Nuclear Systems and Solution Engineering Co., Ltd (MHI NS ENG) joined the group in 2016. The European Organization for Nuclear Research (CERN) joined in 2018. WG A_1/A_2 is now associated to the TRANSSC Technical Expert Group on Radiation Protection (TTEG-RP).

The scope of the WG was then defined as follows:

- reviewing the method and data used to determine the Q values,
- discussing impact of changes in A values on a scientific basis,
- discussing further improvements of the current Q system,
- providing and recording details on the new methods and results.

2. REVIEW OF THE Q SYSTEM

Previous recommendations and available data (ICRP 38, ICRP 51, ICRP 60, and ICRP 68) have been updated (ICRP 103, ICRP 107, ICRP 116 and ICRP 130) and now include new kinds of data such as extended nuclear data (spectra for beta and neutron emitters, delayed beta / prompt and delayed gammas / neutrons, etc.), new or updated fluence-to-dose coefficients (skin dose coefficients in the event of contamination for all the radiation available in ICRP 107, effective dose coefficients for beta and for neutrons, etc.), updated and new intake coefficients. Most coefficients are based on an updated computational phantom (ICRP 110) and are tabulated for different radiation fields. The higher incidence of eye cataracts than previously expected was also considered (ICRP 118).

The updated ICRP data can be used within the current Q system with similar analytical calculation methods. However, the current dose calculation model is not adapted to process these new data in entirety. Some of the new data correspond to radiations, the dose contributions of which were previously not explicitly considered in the Q system, and for which new calculation methods are necessary. For that purpose, the WG agreed to use a new calculation approach based on Monte Carlo (MC) methods (probabilistic approach to describe as precisely as possible the transport of radiation) considering all particles (photons, electrons, neutrons, alphas, protons) and their interactions with matter as well as secondary particles resulting from different interactions (e. g. Bremsstrahlung, (n,p) reactions, etc.). Different Monte-Carlo codes (MCNP, FLUKA, GEANT4, PHITS) and cross section databases (ENDF, JEFF, etc.) were used by the working group. The choice of this method and the different software used allow for reliable calculations for the proposed revision of the "Q system" and should make it stable for the future.

For this review, the general principle of the Q system is kept in its current form as much as possible, as the WG agreed that it represents a reasonable accident scenario in which a Type A package is damaged because of a severe transport accident and all of its contents is released leading to the exposure of a person standing for 30 min at a distance of 1 m from the package or in a confined area of 300 m^3 volume. In the current Q system, five different exposure pathways resulting in a dose to this person are considered; for each exposure pathway the activity limit in the package is calculated in such a way that, in case of such an accident, the dose taken by anyone in the vicinity of the damaged package would be limited by the worst of the following criteria:

- an effective dose of 50 mSv (the worker dose limit at the time the original Q system was devised), or
- an equivalent dose to the skin of 500 mSv, or
- an equivalent dose to the eye of 150 mSv, though this criterion was eventually not considered.

These activities are called the Q values. The 5 Q values are:

- Q_A the activity that would give rise to an effective dose of 50 mSv from external gamma radiation.
- Q_B the activity that would give rise to a skin dose of 500 mSv from external beta radiation.
- Q_C the activity that would give rise to an effective dose of 50 mSv from inhalation.

- Q_D the activity that would give rise to a skin dose of 500 mSv from skin contamination or an effective dose 50 mSv through subsequent ingestion.
- Q_E the activity of a noble gas that would give rise to an effective dose by submersion of 50 mSv, or an equivalent dose to the skin of 500 mSv, whichever is the more restrictive. Q_E is listed instead of Q_D for noble gases.

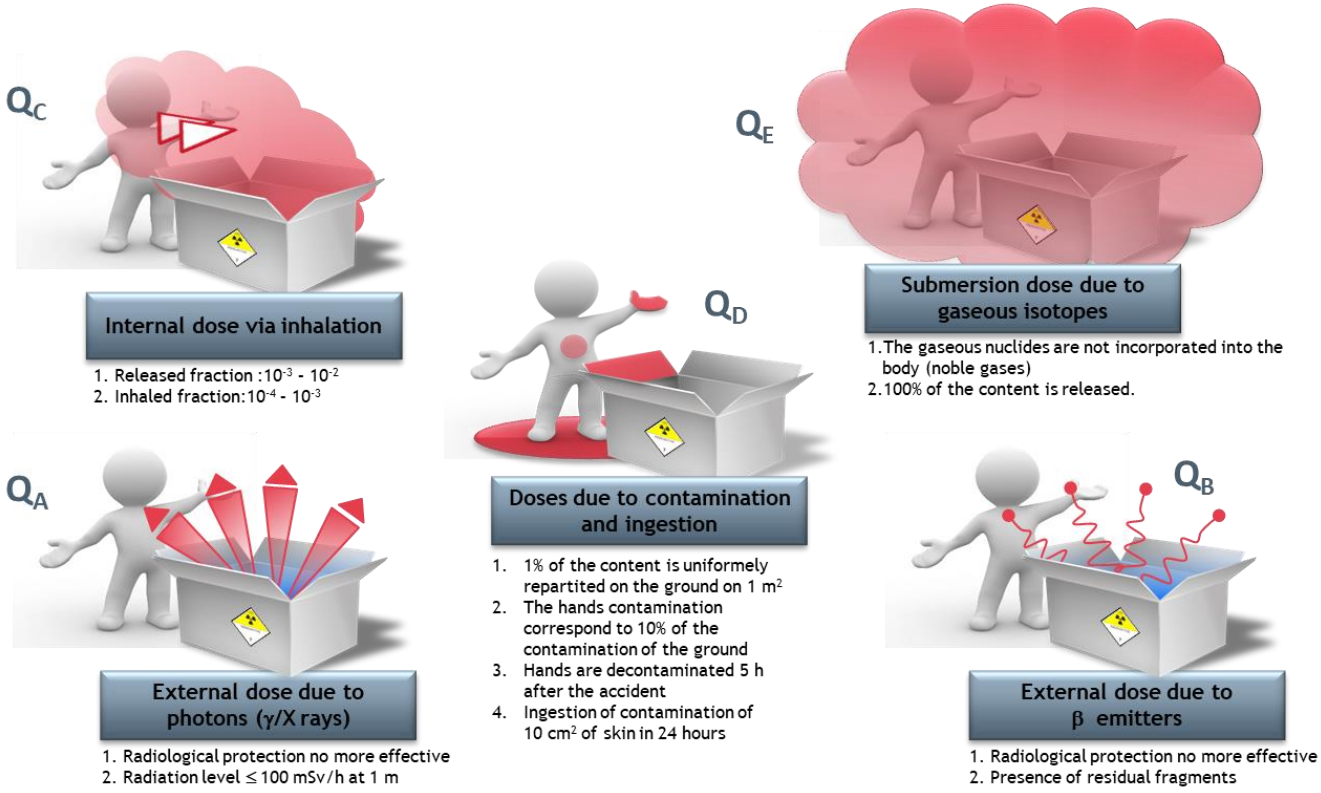

Figure 1. Exposure scenarios considered in the Q system

A_1 is the lowest of Q_A and Q_B and is thus used to characterize undispersible radioactive material such as "special form radioactive material" defined in the regulations, as only external radiations are considered. A_2 is the lowest of all the Q values. In the original A_1/A_2 System (IAEA, 1973), to protect against any possible effects of bremsstrahlung radiation, an upper cut-off limit of 1 000 Ci was applied to the A_1 and A_2 values. When the Q system was revised in the 1990s, this upper limit was retained at 40 TBq, although it was recognized that it was an arbitrary value. The Q values have an upper arbitrary limit of 1 000 TBq although no reference to this limit could be found in any documentation.

These cut-off limits are still under discussion within the WG.

3. EVALUATION OF Q_A AND Q_B

3.1. Derivation of the current Q system

The Q_A value is the activity of a given radionuclide in the material contained in a Type A package damaged in an accident that leads to an effective dose of 50 mSv from external exposure of the whole body to gamma and X-rays. The exposure scenario for Q_A considers that after the accident the damaged package no longer provides shielding and that the person is standing at 1 m from the source and is exposed for 30 minutes.

The Q_A value is obtained using the equation:

$$Q_A = \frac{DL_{eff}}{\dot{e}_{pt} \cdot t}$$

where DL_{eff} is the dose criterion for effective dose (50 mSv), $\dot{e}_{pt}$ is the effective dose rate from a point source from gamma or X-rays at 1 m (Sv Bq^{-1} h^{-1}) per unit activity and t is the exposure time (0.5 h). Current values of the effective dose rate $\dot{e}_{pt}$ at 1 m are calculated using the linear attenuation formula.

Alpha and neutron emitters are not considered in this evaluation and are treated in the current Q system through special considerations.

For alpha emitters it is not in general appropriate to calculate Q_A and Q_B values for special form material, because of their relatively weak gamma and beta emissions. The former A_1/A_2 System introduced an arbitrary A_1 value of 10^3 A_3 (ancestor of Q_C) for alpha emitters. In recognition of the good record in the transport of special form radioactive material and the reduction in many Q_C values for alpha emitters by a factor of up to 10 after the update of the A_1/A_2 System to the Q system in 1985, a tenfold increase in the arbitrary factor of 10^3 above was used: the Q system now specifies an additional value for alpha emitters, called Q_F, which was then arbitrarily set at 10^4 Q_C and is listed instead of Q_A. It is unclear whether this figure was also destined to account for (α, nγ) reactions.

In the few cases of spontaneous fission neutron emitting radionuclides (^{252}Cf, ^{254}Cf and ^{248}Cm) the Q_A value takes account of the contribution of neutron irradiation to the dose. The Q_A value for ^{252}Cf was evaluated using the dose rate per unit activity taken from ICRP Publication 74, and the values for the other two radionuclides were based on the ^{252}Cf dose rate per unit activity allowing for their respective neutron emission rates relative to ^{252}Cf. With these special cases, it is unclear whether neutrons from spontaneous fissions and (α,n) reactions were considered.

The Q_B value is the activity of a given radionuclide in a source contained in a Type A package damaged in an accident that leads to an equivalent dose to the skin of 500 mSv or to the eye of 150 mSv, from external exposure to beta particles. The exposure scenario for Q_B considers that after the accident the source provides some residual shielding and that the person exposed is standing at 1 m from the source and is exposed for 30 minutes.

The Q_B value is obtained using the equation:

$$Q_B = \frac{DL_{skin}}{\dot{e}_{\beta} \cdot t}$$

where DL_{skin} is the dose criterion for dose to the skin (500 mSv), $\dot{e}_{\beta}$ is the equivalent dose rate to the skin from a point source from beta particles at 1 m (Sv Bq^{-1} h^{-1}) per unit activity and t is the exposure time (0.5 h). Current values of the effective dose rate $\dot{e}_{\beta}$ is calculated using a complex deterministic formula based on a shielding factor for the maximum energy of the beta spectrum assuming a thickness of the residual shielding and the dose rate in water evaluated by Cross et al considering the Continuous Slowing Down Approximation (CSDA).

The consideration for a residual shielding comes from the 150 mg·cm^{-2} absorber introduced in the calculations of the current Q_B values. It is stated as an arbitrary figure originally chosen to simulate either residual shielding between the radioactive source and the bystander (due to package debris or because of the capsule containing the source), or auto-shielding of the source itself. This value is not properly documented in SSG-26 and was mentioned as a simple derivation of an assumption made in the 1973 edition of the IAEA Regulations. Indeed, a thickness of 0.2 mm of steel was considered as a reasonable assumption for ^{90}Sr, then was used to derive the Q_B values of all other radionuclides. This 0.2 mm of steel later became this “shielding factor” of 150 mg·cm^{-2}.

For both Q_A and Q_B, the radioactive material is treated as a point source, values of photon energies and yields were provided by ICRP publication 38, and the dose conversion factors from exposure free-in-air to effective dose were obtained from data tabulated in ICRP publication 51 for an isotropic radiation geometry. No single

method for the interpolation of the data is provided in relevant documents and this operation may differ and lead to different results in when calculating Q_A and Q_B values.

3.2. Update proposed by the WG

At the beginning of the revision work, it was decided to directly calculate the Q_A and Q_B values using MC-simulation tools, with a focus on a short list of about 20 radionuclides of importance, taking into account the main types of radiation emitted; the dose coefficients were directly encoded in the input files. However, because of the issue related to the choice of the field geometry at that time and the desire to compare different calculation tools, it was decided to evaluate surface fluence through a detector located at 1 m from the point source, then to process the results using the fluence-to-dose coefficients agreed upon (anteroposterior AP, rotational ROT or fully isotropic ISO field). The fluence at the detector depends on the physical processes and interaction cross-sections of the particles on their way to the detector used in the corresponding code. Therefore the code output was well-suited for validation procedures. For photons, electrons and positrons, fluences were calculated for energies from 1 keV to 10 MeV with a bin width at least equivalent to what is used in [1]ICRP 116. for neutrons, the bins were derived from the spectra used in ICRP publication 107. Besides, this new method makes it possible on the one hand evaluation of any radionuclide as long as their spectra is known, on the other hand to manage with less effort the evolution of the values when new standards on spectra will be published, instead of recalculating the values for each radionuclide.

The WG also decided that the principle of using only one type of radiation to determine either the effective dose or an equivalent dose, and not allowing for all kinds of particles, should be revised since ICRP recommendations now provide coefficients for most of the incident radiations of interest, and new calculation techniques (large scale MC methods) are now available that allow precise evaluation of the associated total exposure of persons. For example, effective dose coefficients now exist for beta, neutron and gamma emissions meaning that the Q_A value for ^{137}Cs can now take into account effective dose due to both its gamma and beta emissions.

The geometric model is as follows: a sphere of 1 m radius with a point source at the centre of the sphere, surrounded by a residual shielding made of 0.5 mm of stainless steel with a density of 7.8; the inner part of the 1-m radius sphere is made of air. The fluence is recorded at the surface of the 1-m sphere. Considering that backscattering was taken into account when deriving the ICRP 116 dose coefficients, it was decided that the 1-m-radius sphere would be the boundaries of the calculation universe.

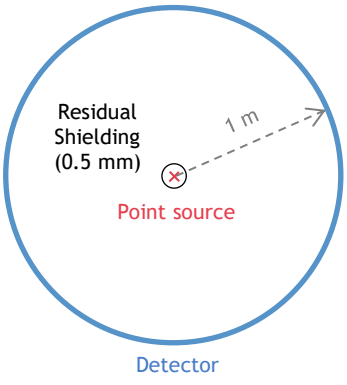

Figure 2. MC model considered to derive Q_A and Q_B.

With regards to the residual shielding of 0.2 mm of steel originally considered in deriving the Q_B values, after further investigations on actual sources, it was found that, except for ^{90}Sr, no other special form radioactive source would be protected by such a thin layer of stainless steel, the minimum being between 0.4 and 0.6 mm for sources such as ^{192}Ir where the minimum thickness is sought to reach maximum efficiency for gammagraphy.

[1] For example, a bin width of 1 keV could be used, resulting in 10 000 calculations for each kind of particle in that case, between 1 keV and 10 MeV.

Besides, the 0.2 mm thickness is only used for the beta window protector, which represents only one face of the encapsulated source, the rest of the capsule being more than 1 mm in thickness. In the end, a reasonable thickness of 0.5 mm was retained for both Q_A and Q_B.

The WG agreed that the irradiation field should average the exposure from a severe transport accident (where a type A package would lose its contents) and that ICRP 116 defined dose coefficients for a parallel beam of ionising radiation, which is unrealistic for a point source only 1 m away from a person. It was decided to keep the ISO field of irradiation (though ROT would also be a reasonable candidate for which the dose rates would increase by less than 30% compared to the ISO field). Besides it was considered unlikely that someone will remain static for more than 30 minutes (except if he lays unconscious next to the source).

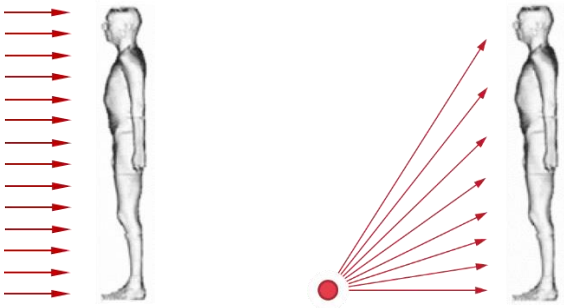

Figure 3. ICRP 116 AP exposure geometry vs. realistic AP exposure geometry

Now Q_A and Q_B respectively represent the total effective dose and total equivalent dose to the skin (or the lens of the eye) for all kinds of primary and secondary particles (photons, electrons, positrons, neutrons) that can contribute to the dose; they are no longer limited to the effects of photons or electrons.

An important question was raised during the review of Q_B: using ICRP 116 coefficients means that all $Q_{B,skin}$ values mix mean skin dose coefficients for photons and neutrons and local skin-equivalent dose coefficients for electrons, which are not derived from the same calculation method. The WG then decided to homogenize the calculation method by deriving local skin-equivalent dose coefficients for photons and neutrons; it meant creating new dose coefficient databases using the same method presented in the ICRP publication 116. The issue is important as it also concerns the Q_D calculations. For the special case of positrons, the WG used the coefficients derived by Bourgois et al. since the same method was applied. The dose for local skin dose is evaluated at a local position through the skin in the body, and not averaged over the full skin. Local skin dose coefficients are slightly more conservative compared to skin dose coefficients.

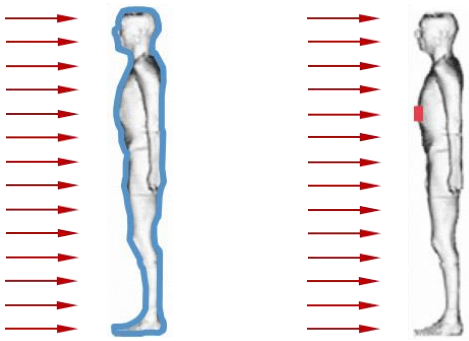

Figure 4. Mean skin dose vs. local skin dose geometries

The method to derive Q_A and Q_B can then be summarized as follows:

- MC calculations, for each individual energy bin, of fluences using a point source with residual shielding and a 1-m-radius sphere detector;

- evaluation of $\dot{e}_{eff}$ and $\dot{e}_{eq}$ (replacing $\dot{e}_{pt}$ and $\dot{e}_{\beta}$) for each radionuclide using the fluences previously calculated weighted by their energy spectra, and the dose conversion factors as follows:
  - values of photon, neutron, electron and positron energies and their respective yields are provided by ICRP publication 107; other sources may be used when ICRP 107 spectra were considered incomplete (e. g. treatment of dual β+/β- emitters for which the JEFF3.3[2] database was used to differentiate the spectra, or treatment of (α, nγ) reactions for which the TENDL database was used);
  - fluence-to-dose conversion factors were obtained from data tabulated in ICRP publication 116 for an isotropic radiation geometry; when data were not available, the WG evaluated and published their own dose conversion factors using the same method as ICRP to derive those quantities (e. g. conversion factors for the equivalent dose to the most exposed surface of the skin[3]).
- evaluation of Q_A and Q_B using the current Q system formula described above; in this framework, following information and recommendations stated ICRP publications 103[4] and 118, it was decided to keep the dose criteria of 50 mSv (effective) and 500 mSv (equivalent, skin) as being reasonable. For the lens of the eye, it was suggested to use a criterion of 250 mSv corresponding to half of the one-shot dose for which ICRP 118 indicate that a deterministic risk of cataract exists. A $Q_{B,eye}$ value was then derived.

As for neutrons, spontaneous fission spectra are derived from the ICRP 107 while (α,nγ) spectra are treated through the SOURCES4C and TALYS codes. For that case, the WG performed systematic studies including all possible alpha emitters. Based on SOURCES4C, the neutron dose as a function of the alpha mean energies has been determined, while the photon contribution has been calculated with the TALYS code as a function of monoenergetic alpha energies. From these calculations, a database was derived allowing for the calculations of neutron and gamma emission rate and dose contributions for all alpha emitters. Two mixture targets were considered in the systematic study: Be (mass ratio of 5) because this is the most penalizing, and O (molar ratio of 5) because this is the most common (oxide forms). In the end, the arbitrary Q_F value is discarded.

4. EVALUATION OF Q_C

4.1. Derivation of the current Q system

The Q_C value for a radionuclide transported in a non-special form is determined by consideration of the inhalation dose to a person exposed to the radioactive material released from a damaged Type A package following an indoor or outdoor accident; indoor scenarios consider a storeroom or a cargo handling bay with a volume of 300 m^3 and four room air changes per hour; outdoor scenarios consider the effect of the wind 10 to 100 m away from the package. It is considered that a fraction of 10^{-2} to 10^{-3} of the activity will be instantly resuspended in the air and that, considering a time exposure of 30 min, a person in the vicinity of the package would inhale of 10^{-3} to 10^{-4} of the resuspended fraction. Therefore, a total fraction of 10^{-6} of the activity released by the package contributes to an internal effective dose due to inhalation.

The Q_C value is then obtained using the equation:

$$Q_C = \frac{DL_{inh}}{10^{-6} \cdot e_{inh}}$$

[2] The use of the ENDF/B-VIII.0 database, more up-to-date, is envisaged for the next update. No significant modification is expected.

[3] Average over any 1 cm^2 area of exposed skin, regardless of the area exposed, at a nominal depth of 70 µm

[4] Table 5 and Table 8 of ICRP 103 states that a reference level of 100 mSv, set for the highest planned residual dose from a radiological emergency, may be used, especially for "other rescue operations" (different from the saving ones). Para. 241 explains that a reference "one-off" exposure of 50 mSv could be used, and that dose rising towards 100 mSv would always require protective actions. Para 278 explicitly addresses emergency situations with mentioning the planned residual doses in the range of 20 to 100 mSv. Therefore, the 50 mSv criterion was kept by the WG. The 100 mSv reference level was also introduced in the 2013-59/EURATOM directive in Europe.

where DL_{inh} is the dose criterion for the internal effective dose due to inhalation (50 mSv) and e_{inh} is the inhalation dose coefficient in Sv/Bq. Current values of the dose coefficients are documented to be from ICRP publication 68 for a particle size (Activity Median Aerodynamic Diameter, AMAD) of 1 µm and the most restrictive chemical form (generally type S – slow rate absorption), though investigations made by the WG showed that some dose coefficients could be different.

4.2. Update proposed by the WG

The WG A_1/A_2 did not question the scenario of exposure. e_{inh} were updated according to ICRP publications 130, 134, 137, 141 and 151. ICRP 130 states the current AMAD of 1 µm should correspond to the exposure of the public, while current values were derived for workers – in fact, the "workers" dose coefficient is similar to the "adult" dose coefficients; ICRP 130 also states that, for occupational exposure, the default value generally recommended for the AMAD is 5 µm and that, when the size distribution of the radioactive aerosol is not known, the default AMAD value of 5 µm should also be used. Consequently, the proposed revised Q system uses the highest inhalation dose coefficient for the AMAD values of 1 µm and 5 µm.

The adult coefficients were taken into account. The WG considered that it would be overly conservative to consider age-dependent dose coefficients such as those currently derived in the ICRP publication 72 (also included in ICRP publication 119)[5].

5. EVALUATION OF Q_D

5.1. Derivation of the current Q system

The Q_D value is determined from the dose to the skin of a person contaminated with non-special form radioactive material as a consequence of handling a damaged Type A package. The contamination can then be ingested, resulting in an internal contamination. In this scenario, it is considered that 1% of the package contents are spread uniformly over an area of 1 m^2 and that handling of the debris could result in contamination of the hands to 10% of this level; the exposed person does not wear gloves but washes their hands within a period of 5 h. Therefore, it is considered that a fraction of 10^{-3} of the total package activity is spread on the hands when estimating the dose to the skin.

The $Q_{D,skin}$ value is then obtained using the equation:

$$Q_{D,skin} = \frac{DL_{skin}}{10^{-3} \cdot \dot{h}_{skin} \cdot t}$$

where DL_{skin} is the dose criterion for equivalent skin dose (500 mSv), $\dot{h}_{skin}$ is the equivalent skin dose rate per unit activity and per unit area from a surface source spread on the skin ($Sv.Bq^{-1}.m^{-2}.s^{-1}$) and t is the exposure time (5 h or 1.8×10^4 s).

There are no ICRP publications related to dose coefficients due to contamination $\dot{h}_{skin}$ (only ICRP 59 served as a basis to determine equivalent dose limitation to the skin; ICRP 118 completed that work for the eye lens). The current Q system evaluates the skin contamination Q_D values with the dose coefficients taken from Cross et al. which uses Monte Carlo calculations for an air/water interface, for a source of 100 cm^2 (or 1 cm^2), the dose being calculated by integration at depths in water between 60 and 80 µm through a surface of 1 cm^2.

The possible uptake of radioactive material via ingestion was considered, assuming that a person may ingest all the contamination from 10^{-3} m^2 (10 cm^2) of skin over a period of 24 h, resulting in an intake fraction of the total radioactive content of 10^{-6}.

[5] As a matter of fact, the age-dependent intake coefficients from ICRP 72 have not yet been updated.

The $Q_{D,ing}$ value is then obtained using the equation:

$$Q_{D,ing} = \frac{DL_{ing}}{10^{-6} \cdot e_{ing}}$$

where DL_{ing} is the dose criterion for the internal effective dose due to ingestion (50 mSv) and e_{ing} is the ingestion dose coefficient in Sv/Bq. Current values of the dose coefficients can be found in the ICRP publication 68. However, the current Q system considers that the inhalation dose, using the same 10^{-6} fraction, will always be more restrictive than the ingestion dose according to data found in ICRP publication 68. Therefore $Q_{D,ing}$ is not evaluated.

5.2. Update proposed by the WG

While the Cross et al. method, based on MC calculations, is close to the one used for the current review of the Q system, the WG agreed to consider an air/skin cube model detailed in ICRP Publication 116 for more accuracy and standardization with the other Q values (which is also consistent with the way Q_B coefficients were evaluated). The models include a surface source (instead of the ICRP 116 parallel beam) of 38.5 cm^2 representing a hand palm. The dose is then integrated at depths between 50 and 100 µm on the most exposed 1 cm^2 surface.

Contrary to the fluence method used to derive Q_A and Q_B the MC models simulate energy dependent dose coefficients in case of O_D for all types of primary particles, for each energy bin of 1 keV. Those coefficients are then convolved with the decay emission spectra database (ICRP 107) to produce the dose coefficients for each radionuclide in Sv/Bq.

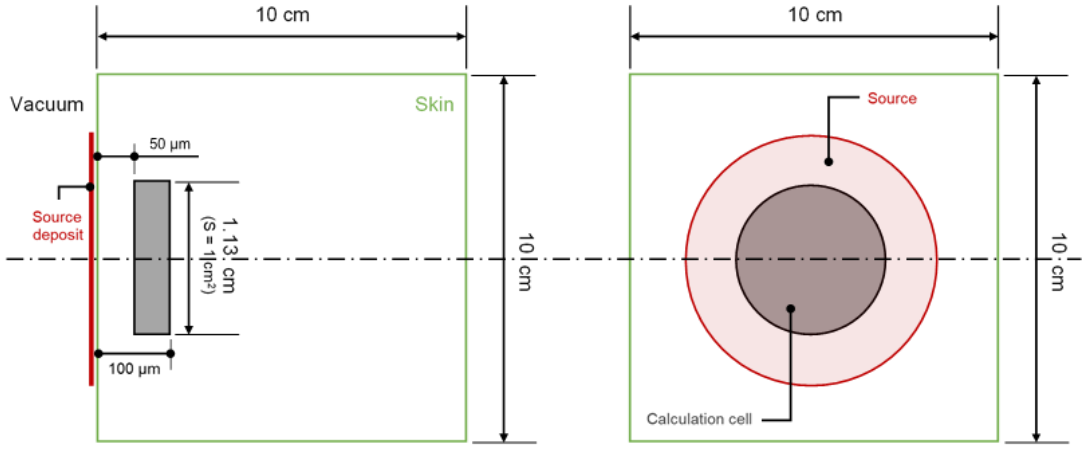

Figure 5. MC model considered to derive $Q_{D,skin}$

The WG also evaluated the skin dose due to contamination by alpha emitters. New local skin dose coefficients for all particles were evaluated and published by the WG. Regarding the special case of alpha particles, when the incident energy emitted is in the [5-7] MeV range, considerable discrepancies in dose between the different particle transport codes used were found. The WG noticed that, at those energies, when alpha particles begin to reach the scoring volume, only secondaries are responsible for the dose. Those discrepancies were explained by the corrections implemented in the Bethe theory for low energy alpha that differ in the simulation tools. The WG then agreed to consider the maximal dose coefficients among the three different evaluations (using an average would, at most, divide the dose coefficients by a factor of 3 for an energy of 5 MeV and would not significantly change anything above 7 MeV). Also, due to the deeper penetration into the skin of secondary protons, the calculated doses are higher than expected.

Eventually, since ingestion dose coefficients were updated in ICRP publications 130, 134, 137, 141, 151 and that the assumption made by the Q system, that ingestion dose is always insignificant, is not always correct (e.g. for iodine isotopes), the WG also decided to evaluate $Q_{D,ing}$.

6. EVALUATION OF Q_E

6.1. Derivation of the current Q system

The Q_E value for gaseous isotopes which do not become incorporated into the body (i.e noble gases) is determined by consideration of the submersion dose following their release in an accident when transported as non-special form radioactive material in either a compressed or an uncompressed state. The scenario and assumptions are identical as those used to derive Q_C, except that, in the case of Q_E a release fraction of 1 is assumed. Both effective dose and equivalent skin dose are calculated.

The Q_E value is then obtained using the equation:

$$Q_E = \frac{DL_{sub} \cdot V_{eq}}{10^{-3} \cdot \dot{h}_{sub} \cdot t}$$

where DL_{sub} is the dose criterion for either external effective dose due to inhalation (50 mSv) or equivalent skin dose (500 mSv), $\dot{h}_{sub}$ is the effective or skin dose coefficient in $Sv.s^{-1}.Bq^{-1}.m^3$, V_{eq} is the average equivalent volume in which the gas is released considering a ventilation of 4 h^{-1} (i.e. 694 m^3) over the time of exposure t (0.5 h). Current values of the dose coefficients $\dot{h}_{sub}$ are found in the U.S. Federal Guidance Report No. 12.

Special consideration is given to ^{222}Rn as its decay products are solid radioisotopes that can be deposited in the lung, thus delivering an inhalation dose. ICRP publication 32 was used to address the ^{222}Rn case. ^{220}Rn, which faces the same issue, is not considered in the current Q system. The dose coefficient being given in Sv/Bq, the Q_C formula was used, considering a 100% release fraction.

^{85}Kr is treated differently. Originally, a Q_E value of 14 TBq was derived, leading to a A_2 value of 10 TBq. SSR-6 introduced a 10x factor to be used when addressing the consequences of normal and accident conditions of transport on the release of radioactive material, i. e. a practical A_2 value of 100 TBq is allowed to be used. This special provision was introduced in the 1973 Edition of the regulations and was retained ever since. It was derived on the basis of a comparison of the potential radiation dose to the whole body, or to any critical organ, of persons exposed within 20 m of a source of Kr-85. In 2009 the validity of this factor was discussed. It was found that, in normal conditions of transport, using a A_2 value of 100 TBq and the scenario described for Q_E with a duration of exposure of 200 h, the equivalent skin dose limit of 50 mSv for the public would be respected with a safety factor of 63. In accident conditions, the calculations were made at 100 m and 15 m from the package: in the most conservative case, there is a safety factor of 3 compared to the 500 mSv criterion.

6.2. Update proposed by the WG

In the proposed revised Q system, the parameters for calculating Q_E remain unchanged. Only the dose coefficients are updated by using new publications: ICRP publication 144 (reproduced in publication 151) for effective and skin equivalent dose coefficients and ICRP 137 publication for ^{220}Rn and ^{222}Rn. Though the U.S. Federal Guidance Report No. 12 was updated in Report No. 15, the ICRP publications were retained for standardization. However, for consistency purposes, the semi-infinite cloud model used in the Guidance was also considered to choose the dose coefficients from ICRP publication 144.

ICRP 144 dose coefficients are calculated with voxel based adult male and female phantoms from ICRP 110. To calculate the dose to the skin, polygon mesh skin models of the adult phantoms were constructed, and the equivalent skin dose was estimated between 50 µm and 100 µm depths.

Regarding the special provision for ^{85}Kr, the WG did not have time to properly address the calculations and hypotheses made in 2009 – this could be addressed later, for example during the possible revision cycle. However, rather than using a multiplication factor, the WG advises that para. 659 of SSR-6, where this factor is used, should directly mention the A_2 value of ^{85}Kr to be considered in the safety demonstrations related to the release of radioactive material. This would avoid any discrepancy between what was considered in para. I.73 of SSG-26 and the value that could be considered in para. 659 of SSR-6.

7. TREATMENT OF PROGENIES

7.1. Basis of the current Q system

The Q system introduced a "10-day rule" to account for the progenies in the evaluation of the A_1 and A_2 values. This rule states that:

- if the half-life of daughter radionuclides is less than 10 days and lower than that of the parent radionuclide, then the mixture is considered in equilibrium,
- in all other cases, the radionuclides should be considered in a mixture law by the consignor / designer.

This concept was introduced in the 1973 regulations as follows: if the daughter radionuclide is assumed to come into equilibrium with the parent during a transport of 50 days maximum, A_1 is calculated for both the parent and the daughter, and the most limiting of the two values is assigned to the parent nuclide. The same rule applied for parent radionuclides having short-lived daughter of a half-life not greater than 10 days. In the current Q system, a mixture rule is applied considering the activity of the parent only.

7.2. Issues and update proposed by the WG

While the principles seem simple, the WG noted that, for many radionuclides considered in "transient" equilibrium, nothing is clearly explained in SSG-26 and hypotheses had to be considered by members of the WG to derive the current values. For example, with the ^{47}Ca / ^{47}Sc couple, it appears that the current value was calculated after 10 days of in-growth, instead of assuming equilibrium. This hypothesis does not apply to other radionuclides in equilibrium.

Another issue was raised by ^{47}Ca / ^{47}Sc decay chain: the 10-day rule should allow for the consideration of the activity of the parent radionuclide only, meaning that this "super parent" (for example referred to as "$^{47}Ca+$") will virtually contain the radiation emissions of all its daughter radionuclides (i.e. $^{47}Ca+$ emits radiations from both ^{47}Ca and ^{47}Sc). Therefore, the A value of a mixture should always be lower than that of the parent alone, i.e. more restrictive (using the same activity of the parent). This was not the case for the ^{47}Ca / ^{47}Sc decay chain in the current Q system because the A values of the mixture was higher than that of ^{47}Ca alone.

A simple example to explain this issue is ^{137}Cs / ^{137m}Ba decay chain; let's consider a mixture consisting of 1 TBq of ^{137}Cs and 0.944 TBq of ^{137m}Ba. Since, the 10-day rule allows the consignor to consider only the activity of the parent radionuclide, only 1 TBq of ^{137}Cs is taken into account: in that case, ^{137}Cs inherently contains the energy emissions of ^{137m}Ba (i.e. the famous 662 keV gamma emission), therefore the Q_A value of ^{137}Cs in equilibrium with ^{137m}Ba is 1.9 TBq. Using the mixture rule on those two pure radionuclides with Q_A of 1 620 TBq and 1.8 TBq respectively, with a total activity of 1,944 TBq, will give the same "quantity of Q_A" (i.e. hazard level) as 1 TBq of ^{137}Cs (noted "^{137}Cs +") with a Q_A value of 1.9 TBq.

Q-values can be affected by the transport duration, consequently dose calculations need to be consistent with the exposure scenario. Participants of the WG noted the example of irradiated targets for medical isotopes extraction that may be transported only hours after their irradiation (mainly due to the limited half-life of the radionuclides). Besides, mixtures may not be in equilibrium when loaded in a package. However, mixtures can be transported a significant time after their creation, meaning they will reach an equilibrium even before they

are transported. For some cases, the activity transported could therefore become higher than the A value during the transportation.

Another question was raised: how to deal with complex chains with several branches, some of them having half-live higher than that of parent? The simple and practical answer is to consider the full chain in equilibrium (though this could be conservative in many cases). The issue was especially clear for ^{230}Pa where only a part of the decay chain was considered. Overall, in practice, for such cases, the WG recognized that a risk of error appears in the calculation of the quantity of A_1 or A_2 to be put in a package when dealing with radionuclides that can belong to two or more different decay chains with different parents.

The WG then suggested that the Q and A values could be given without progeny and that the consignor should work out the value for mixture transported. The current updated table 2 still uses the 10-day rule but the WG can easily provide individual values without such rule, for single radionuclides (e. g. values for ^{137}Cs and values for ^{137m}Ba).

In the end, for all radionuclides in which the 10-day rule applies, the WG evaluated the Q and A values at equilibrium, whether “transient” or “secular”. While the distinction seems meaningless since both equilibria are calculated at an infinite time by definition, the WG had to define a time at which a transient equilibrium occurs to facilitate the calculation process: 1,000 times the half-life of the mother radionuclide was chosen.

8. UNLIMITED VALUES

8.1. Basis of the current Q system

The current Q system considers an upper cut-off of the mass of radionuclides that can be absorbed (inhalation or ingestion). This corresponds to a physical limitation of the human body. The mass limit for inhalation corresponds to 10 mg and is used to define the “unlimited value” in both deriving the Q_C and A values. Therefore, considering that, by definition, inhaling 10^{-6} Q_C leads to an effective dose of 50 mSv, an activity is considered unlimited if its corresponding mass is lower than 10^{-4} Q_C/g.

As for skin contamination, it was considered that typically 1–10 mg/cm^2 of dirt present on the hands would be readily discernible and would be removed promptly by wiping or washing, irrespective of the possible activity. Considering that, by definition, being contaminated by 10^{-3} Q_D/m^2 lead to an equivalent skin dose of 500 mSv, an activity is considered unlimited if its corresponding mass is lower than 10^{-5} Q_D/g.

8.2. Update proposed by the WG

The WG decided to continue following the same rules.

Currently there is no mass limit defined for A_1 values though “unlimited” values are defined in the current SSG-26 and SSR-6. The WG then decided to use a mass criterion of 1 ton. While this value sounds arbitrary, it corresponds to the mass limit used to define “bulk quantities” of radioactive material when dealing with exemption values (cf. IAEA GSR Part 3). The objective is that the point source assumption can no longer be used because such mass would strongly decrease the exposure, so that it is never possible to reach an effective dose of 50 mSv or an equivalent skin dose of 500 mSv in 30 minutes at 1 m, whatever the mass of material involved.

8.3. Special case of enriched uranium

The WG faced a difficulty to evaluate the Q values of enriched unirradiated uranium (the irradiated case being not considered), especially Q_C. Currently, it is considered that unirradiated U enriched to less than 20% has unlimited Q values. SSG-26 explains that the definition of ASTM C996-90 was used to evaluate the Q values. This standard defined “commercial” unirradiated uranium as natural uranium can be contaminated with ^{232}U, ^{236}U and fission products (^{99}Tc) to certain limits depending on the enrichment level of ^{235}U. ^{234}U present in natural uranium (because it belongs to the ^{238}U chain) also increases through the enrichment process. It is also

underlined that the SSR-6 definition of "unirradiated uranium" does not completely match the C996-90 definition as it includes traces of plutonium and does not consider the presence of ^{232}U.

Considering all those isotopes, including plutonium, in a mixture ended in significantly lowering the enrichment limit, down to 11%, for which the Q_C of the enriched uranium can be considered "unlimited". This issue is still under discussion within the WG.

9. MULTI-PATH CUMULATIVE DOSE

With the new method presented above, Q_A and Q_B are now described as total effective dose and total skin equivalent dose, respectively, due to all radiations. As such, they inherently cumulate the effects of all radiations; A_1 can then be clearly considered as the most restrictive value of Q_A and Q_B since they are different kind of doses that cannot add up.

As for A_2 values, considering the release of a certain quantity of radioactive material, it seems reasonable to assume that, if a fraction of the package activity contributes to the dose of a scenario, another fraction may contribute to the dose of another scenario. Theoretically, during an accident, an individual may be exposed to more than one exposure pathway. Thus, to evaluate the total dose received by such an individual, it may be possible to cumulate the effects of different scenarios considering either the effective dose or the skin equivalent dose, as follows:

- effective dose:
  - an average respirable release fraction of 0,1 % of the contents is involved in the evaluation of Q_C, while a dispersion of a 1 % fraction of the contents is assumed when evaluating Q_D,ing; then the rest (98,9 % which is close to 100 %) remains available to contribute to external irradiation dose leading to Q_A. Thus $A_{2,eff}$ can be calculated with these three contributions considering the effective dose with the aforementioned fractions; or
  - the total radioactive content released (fraction of 100 %) will contribute to calculate the submersion effective dose leading to Q_E, which does not change the current method;
- skin equivalent dose:
  - a release fraction of 1 % is at the origin of the contamination taken into account in the evaluation of $Q_{D,skin}$, the rest (99 %) remains available to contribute to the skin equivalent dose taken into account when evaluating Q_B. Thus $A_{2,skin}$ can be calculated with these two contributions considering the skin equivalent dose with the aforementioned fractions.
  - the total radioactive content released (fraction of 100 %) will contribute to calculate the submersion equivalent dose to the skin to Q_E, which does not change the current method.

The $A_{2,cumul}$ value would then be the minimum of ($A_{2,eff}$; $A_{2,skin}$; Q_E).

Current SSG-26 explains in para. I.79 that multiple exposure pathways were not retained because the "*examination of table I.2 shows that this consideration applies only to a relatively small number of radionuclides*". No further element was presented to support this assertion. Besides, in this justification, a comparison between Q_A and Q_B was mentioned though they do not represent the same kind of dose. The influence of those considerations was evaluated by the WG. Contrary to what was stated in SSG-26, the consequences on the A_2 values are significant. The current updated table 2 does not consider the multiple pathway hypothesis.

10. VALIDATION PROCESS

The new calculation method developed from 2016 is only based on the use of several databases either produced from the WG or from other sources, such as ICRP publications:

- decay emission spectra (all Q values),
- source-energy-to-fluence coefficients, for each energy bin and each particle (Q_A, Q_B),
- energy-dependent fluence-to-dose conversion coefficients for each particle and each kind of dose of interest (Q_A, Q_B),
- mean-energy-to-dose coefficients for alpha emitters (Q_A),
- energy-dependent dose coefficient coefficients ($Q_{D,skin}$),
- intake dose coefficient for each radionuclide (Q_C, $Q_{D,ing}$), with special considerations for ^{220}Rn and ^{222}Rn,
- external dose coefficient for noble gases (Q_E).

Compared to the previous method, it is no longer necessary to evaluate the Q values with direct calculations (from the spectrum to the Q value). In this regard, it is possible to develop tools dealing with those databases. As such, they can easily be updated with future databases.

CERN, GRS, IRSN and MHI NS ENG developed such interfaces; these tools mainly served the purpose of comparing the results derived from different sets of code/library. The WG then developed a single reference tool called CORAL, that aim at gathering and comparing the different databases created by the WG, and evaluating the Q and A values using any kind of hypothesis and database. The previous early interfaces developed by the members of the WG were eventually used to validate the processing method of the databases by CORAL. The WG proposed TRANSSC Member States and the IAEA to release a custom version of CORAL to facilitate the evaluation of any Q and A_1/A_2 values among transport stakeholders.

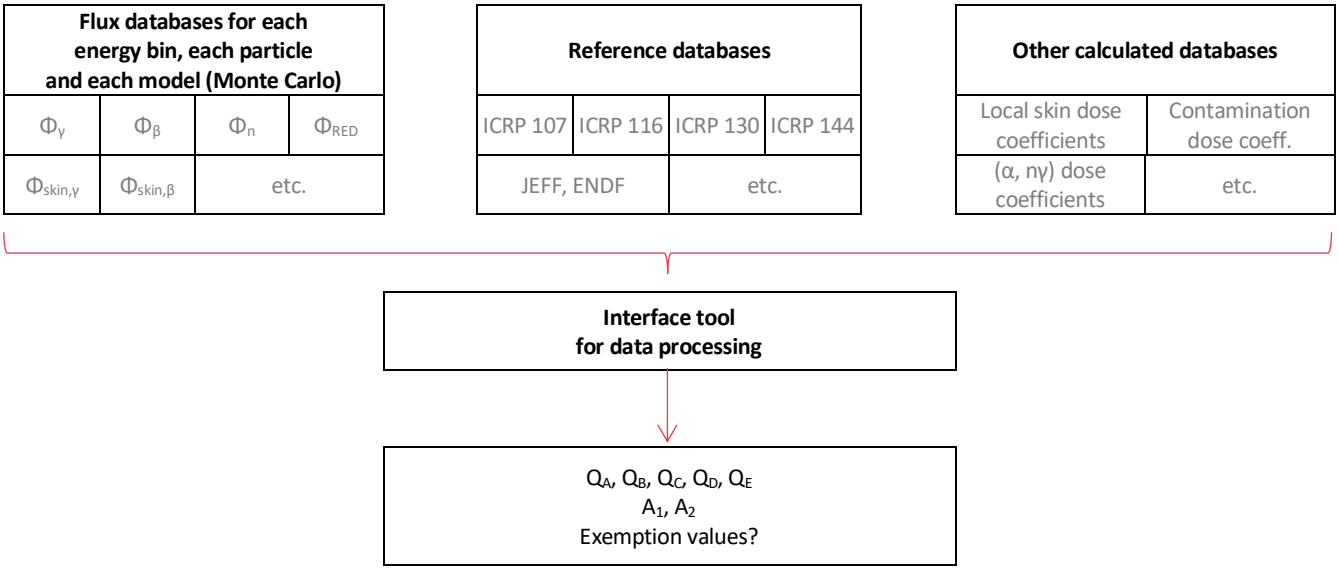

Figure 6. Overview of the tool principles to evaluate the radionuclide basic values.

As a general rule, when discrepancies between results within the MC simulations could not be explained, the most penalizing values were retained. In most cases, the differences were less than 10%. The most dramatic case was the treatment of alpha contamination to evaluate $Q_{D,skin}$ for which high discrepancies were observed in the [5-7] MeV range due to the different physics used by the MC codes (cf. above). Finally, the databases produced by the WG as well as the CORAL code have been validated within the WG.

11. SUMMARY OF CHANGES

The following section summarizes the differences between the current Q system and the update proposed by the WG. The interim list of A_1 and A_2 values derived by the WG using the method described throughout this report is given in Table 4.

Table 1. History of the radionuclide classification methods used in the transport regulations

Chronology	ICRP Recom.	IAEA			Classification Method
		Transport	Method	BSS	
1959	ICRP 1				-
1961		SS6	SS7		Radiotoxicity 3 groups
1962				SS9	
1964	ICRP 6	SS6			Radiotoxicity 8 groups
1966	ICRP 9				
1967		SS6		SS9	Radiotoxicity 7 groups
1969	ICRP 15				
1973		SS6	SS37		A_1/A_2 System
1977	ICRP 26				
1982				SS9	
1985		SS6			Q System
1987			SS7		
1991	ICRP 60				
1996		ST-1		SS115	Q System (revised)
2002			TS-G-1.1		
2007	ICRP 103				
2012		SSR-6	SSG-26		
2014				GSR Part 3	
2018		SSR-6			
2022			SSG-26		

Table 2. Changes in the calculations method between the current Q system and the proposed update

	Current Q system	Update of the Q system
Recommendations	ICRP 60	ICRP 103
Spectra	ICRP 38	ICRP 107
	No data	SOURCES4C and TALYS for (α,nγ) spectra
		JEFF3.3 database for dual β^+/β^- emitters
External dose coefficients	ICRP 51 (Q_A)	ICRP 116 (Q_A, Q_B, $Q_{D,skin}$)
	Cross et al. (Q_B, $Q_{D,skin}$)	
	Federal Guidance Report 12 (Q_E) ICRP 32 (Q_E for Rn)	ICRP 144 (Q_E) ICRP 137 (Q_E for Rn)
Intake dose coefficients	ICRP 68 (Q_C, $Q_{D,ing}$)	ICRP 130, 134, 137, 141, 151 (Q_C, $Q_{D,ing}$)
Calculations	Deterministic & Probabilistic	Probabilistic (Monte-Carlo)
	1 radionuclide → 1 value: necessity to perform lengthy calculations in case of updates of the spectra and dose coefficients	1 energy → 1 fluence or dose per energy bin → 1 value: any radionuclide can be considered; updates of spectra and dose coefficients quickly taken into account
	Several sources, documentation missing	Unified method + detailed report

Table 3. Radiations considered in each Q value between the current Q system and the proposed update

	Current Q system	Update of the Q system
Q_A	Effective dose (photons)	Effective dose (all radiations)
Q_B	Equivalent dose to the skin (beta radiations) Equivalent dose to the eye mentioned but not evaluated	Equivalent dose to the skin (all radiations) Equivalent dose to the eye (all radiations)
Q_C	Effective dose due to inhalation (all radiations)	Effective dose due to inhalation (all radiations)
Q_D	Effective dose due to ingestion (all radiations), not evaluated.	Effective dose due to ingestion (all radiations)
	Equivalent dose to the skin due to contamination (beta radiations)	Equivalent dose to the skin due to contamination (all radiations)
Q_E	Effective dose due to external exposure via submersion in noble gases (photons)	Effective dose due to external exposure via submersion in noble gases (all radiations)
	Equivalent dose to the skin due to external exposure via submersion in noble gases (beta radiations)	Equivalent dose to the skin due to external exposure via submersion in noble gases (all radiations)
Q_F	External effective dose due to neutrons (= 10^4 Q_C)	Discarded: now included in Q_A and Q_B (effective and skin equivalent doses)

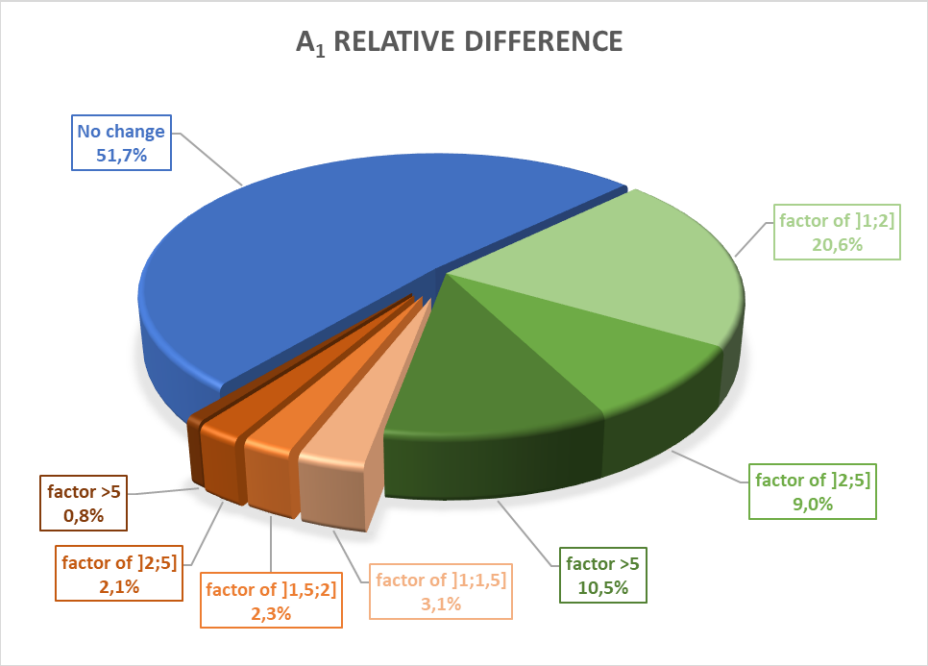

Figure 7. Changes in A_1 values between the current Q system and the proposed update

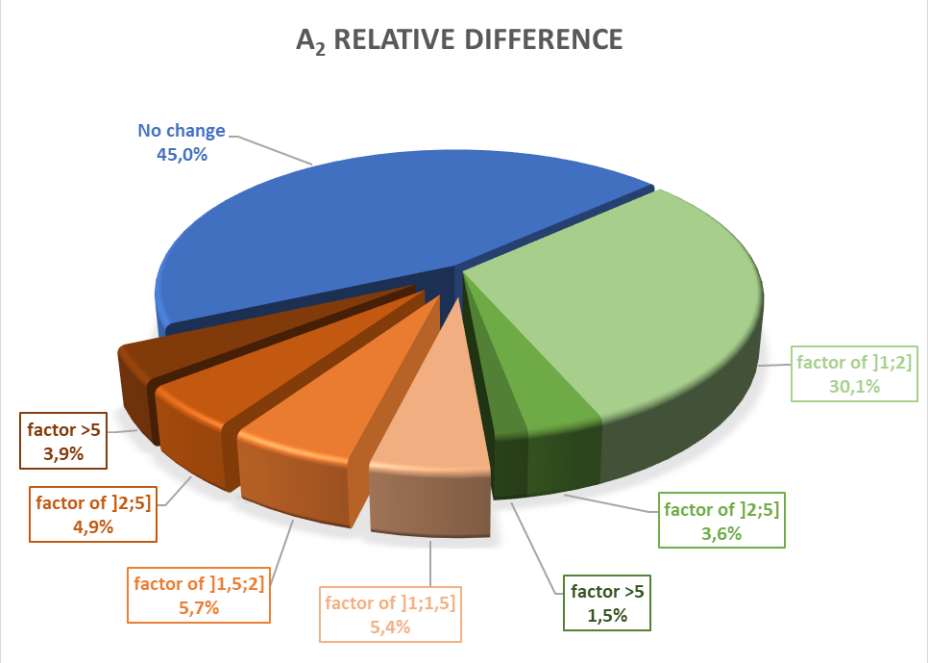

Figure 8. Changes in A_2 values between the current Q system and the proposed update

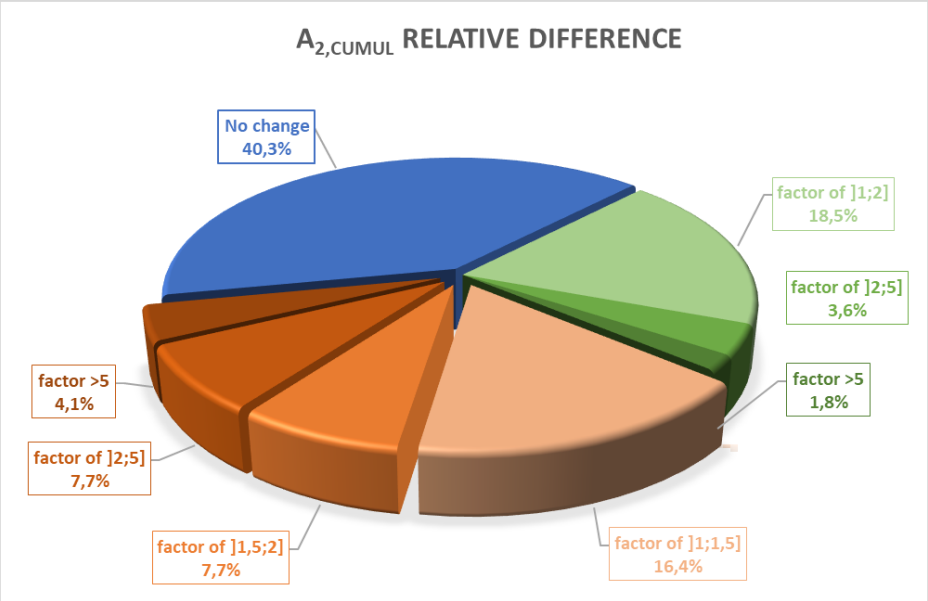

Figure 9. Changes in A_2 values between the current Q system and the proposed update if multiple pathway exposure is considered

REFERENCES

IAEA publications

[1] International Atomic Energy Agency: *Regulations for the Safe Transport of Radioactive Material – 2018 Edition*, IAEA Safety Standards, Specific Safety Requirements, No. SSR-6, Vienna, 2018.

[2] International Atomic Energy Agency, *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition)*, IAEA Safety Standards, Specific Safety Guide, No. SSG-26, Vienna, 2022.

[3] International Atomic Energy Agency: *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, Jointly sponsored by EC, FAO, IAEA, ILO, OECD/NEA, PAHO, UNEP, WHO, IAEA Safety Standards, General Safety Requirements Part 3, No. GSR Part 3, Vienna, 2014.

ICRP publications

[4] International Commission on Radiological Protection: *Radionuclide Transformations - Energy and Intensity of Emissions*, ICRP Publication 38, Annals of the ICRP, Vol. 11-13, 1983.

[5] International Commission on Radiological Protection: *Data for Use in Protection Against External Radiation*, ICRP Publication 51, Annals of the ICRP, Vol. 17, No. 2, 1987.

[6] International Commission on Radiological Protection: *The Biological Basis for Dose Limitation in the Skin*, ICRP Publication 59, Annals of the ICRP, Vol. 22, No. 2, 1992.

[7] International Commission on Radiological Protection: *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Annals of the ICRP, Vol. 21, No. 1, 1991.

[8] International Commission on Radiological Protection: *Dose Coefficients for Intakes of Radionuclides by Workers*, ICRP Publication 68, Annals of the ICRP, Vol. 24, No. 4, 1994.

[9] International Commission on Radiological Protection: *Conversion Coefficients for use in Radiological Protection against External Radiation*, ICRP Publication 74, Annals of the ICRP, Vol. 26, No. 3-4, 1996.

[10] International Commission on Radiological Protection: *The 2007 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 103, Annals of the ICRP, Vol. 37, No. 2-4, 2007.

[11] International Commission on Radiological Protection: *Nuclear Decay Data for Dosimetric Calculations*, ICRP Publication 107, Annals of the ICRP, Vol. 38, No. 3, 2008.

[12] International Commission on Radiological Protection: *Adult Reference Computational Phantoms*, ICRP Publication 110, Annals of the ICRP, Vol. 39, No. 2, 2009.

[13] International Commission on Radiological Protection: *Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures*, ICRP Publication 116, Annals of the ICRP, Vol. 40, No. 2-5, 2010.

[14] International Commission on Radiological Protection: *ICRP Statement on Tissue Reactions and Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context*, ICRP Publication 118, Annals of the ICRP, Vol. 41, No. 1-2, 2012.

[15] International Commission on Radiological Protection: *Compendium of Dose Coefficients based on ICRP Publication 60*, ICRP Publication 119, Annals of the ICRP, Vol. 41, Supplement 1, 2012.

[16] International Commission on Radiological Protection: *Occupational Intakes of Radionuclides Part 1*. ICRP Publication 130, Annals of the ICRP, Vol. 44, No. 2, 2015.

[17] International Commission on Radiological Protection: *Occupational Intakes of Radionuclides Part 2*. ICRP Publication 134, Annals of the ICRP, Vol. 45, No. 3, 2016.

[18] International Commission on Radiological Protection: *Occupational Intakes of Radionuclides Part 3*. ICRP Publication 137, Annals of the ICRP, Vol. 46, No. 3, 2017.

[19] International Commission on Radiological Protection: *Occupational Intakes of Radionuclides Part 4*. ICRP Publication 141, Annals of the ICRP, Vol. 48, No. 2, 2019.

[20] International Commission on Radiological Protection: *Occupational Intakes of Radionuclides Part 5*. ICRP Publication 151, Annals of the ICRP, Vol. 51, No. 1-2, 2022.

[21] International Commission on Radiological Protection: *Dose coefficients for external exposures to environmental sources*. ICRP Publication 144, Annals of the ICRP, Vol. 49, No. 2, 2020.

Publications of the WG

[22] Jones, K. A.; Cabianca, T.; Harvey, M. P.; Hughes, J. S.; Brown, I. K.; Anderson, T.: *Review of Methodologies to Calculate A_1 and A_2 Values, and Exemption Values*, Health Protection Agency (HPA), HPA-CRCE-027, Chilton, Didcot, Oxfordshire, October 2011

[23] B. Louis, G. Sert, S. Vecchiola, A. Konnai, U. Büttner, T. Cabianca, T. Anderson, I. Brown, *Findings and future work of the International Working Group on review of A_1 and A_2 values*, Paper No. 4028, Packaging and Transportation of Radioactive Materials, Proceedings of the PATRAM 2016 symposium, Kobe, Japan, 2016.

[24] U. Büttner, F.-N. Sentuc, J. Endres: *Review of current Q system and the A_1/A_2 values of the IAEA Transport Regulations*, Paper No. 4005, Packaging and Transportation of Radioactive Materials, Proceedings of the PATRAM 2016 symposium, Kobe, Japan, 2016.

[25] N. Hayakawa, Y. Hirao, *Development of BRACSS code for recalculating Q values by Monte Carlo method*, Paper No. 4031, Packaging and Transportation of Radioactive Materials, Proceedings of the PATRAM 2016 symposium, Kobe, Japan, 2016.

[26] J. Endres, F.-N. Sentuc, U. Büttner: *Review of Current Q System and the A_1/A_2 Values of the IAEA Transport Regulation*, Proceedings of the EUROSAFE Forum 2016, pp. 283-289, Munich, Germany, 2017.

[27] B. Louis, S. Thomas, J. Bez, M. Moutarde, F. Gauthier, T. Cabianca, I. Brown, M. Foster, J. Endres, H. Eberhardt, M; Hishida, N. Hayakawa, T. Frosio, P. Bertreix, *Review of the A_1 and A_2 values: progress, development and outcomes*, Paper No. 1368, Packaging and Transportation of Radioactive Materials, Proceedings of the PATRAM 2019 symposium, New Orleans, LA, USA, 2019.

[28] S. Thomas, J. Bez, B. Louis, *Review of the A_1 and A_2 values: impact of all radiations on Q_A and Q_B*, Paper No. 1402, Packaging and Transportation of Radioactive Materials, Proceedings of the PATRAM 2019 symposium, New Orleans, LA, USA, 2019.

[29] J. Bez, S. Thomas, B. Louis: *Review of the A_1 and A_2 values: an overview of the new calculation method*, Paper No. 1403, Packaging and Transportation of Radioactive Materials Proceedings of the PATRAM 2019 symposium, New Orleans, LA, USA, 2019.

[30] T. Cabianca: *The Work of The IAEA TRANSSC Special Working Group On A_1 and A_2 Values*, Paper No. 1367, Packaging and Transportation of Radioactive Materials, Proceedings of the PATRAM 2019 symposium, New Orleans, LA, USA, 2019.

[31] I. Brown, T. Cabianca: *The Effect of Shielding on A_1 and A_2 values*, Paper No. 1409, Packaging and Transportation of Radioactive Materials, Proceedings of the PATRAM 2019 symposium, New Orleans, LA, USA, 2019.

[32] T. Frosio, P. Bertreix, C. Theis, Y. Donjoux, T. Cabianca, I. Brown, M. Foster, J. Endres, H. Eberhardt, N. Hayakawa, B. Louis, S. Thomas, J. Bez, *Computation of Radioactive Material Transport Limits Within A_1/A_2 Working Group at IAEA TRANSSC*, IEEE Access, vol. 8, pp. 29040-29054, February 2020.

[33] T. Frosio, P. Bertreix, N. Menaa, S. Thomas: *Calculation and benchmark of fluence-to-local skin equivalent dose coefficients for neutrons with FLUKA, MCNP, and GEANT4 Monte-Carlo codes*, Journal of radiological protection, Volume. 41, No. 3, August 2021.

[34] T. Frosio, P. Bertreix, N. Menaa, S. Thomas, H. Eberhardt, J. Endres: *Photons fluence to local skin Dose coefficients and benchmark with three Monte-Carlo codes. Application to the computation of radioactive material transport limits*, Applied Radiation and Isotopes, Volume 176, S. 109892, October 2021.

[35] T. Frosio, P. Bertreix, N. Menaa, S. Thomas: *Skin dose contamination conversion coefficients. Benchmark with three simulation codes*, Journal of radiological protection, Volume. 42, No. 1, November 2021.

Other publications of interest

[36] H. F. Macdonald, E. P. Goldfinch: Dosimetric Aspects of Type A Package Contents Limits under the IAEA Regulations for the Safe Transport of Radioactive Materials, Radiation Protection Dosimetry Vol. 1 No.1, pp. 29-42, 1981.

[37] L. Bourgois, R. Antoni: *Fluence to local skin absorbed dose and dose coefficients for monoenergetic positrons using Monte-Carlo code MCNP6, Applied Radiation and Isotopes*, vol. 107, pp. 372-376, 2016.

[38] W. G. Cross, N. O. Freedman, P. Y. Wong: *Beta ray dose distributions from skin contamination*, Radiation Protection Dosimetry, Vol. 40, No. 3, pp149-168, 1992.

[39] E. F. Shores: *SOURCES-4C: Code System for Calculating (α, n), Spontaneous Fission, and Delayed Neutron Sources and Spectra*, LA-UR-02-1839, Los Alamos National Laboratory, 2002.

[40] A. J. Koning, S. Hilaire, M. C. Duijvestijn: *TALYS-1.0*, Proceedings of the International Conference on Nuclear Data for Science and Technology, 2007, Nice, France, 2007, pp. 211-214, EDP Sciences, 2008.

[41] M. B. Chadwick et al. : *ENDF/B-VII.0: Next generation evaluated nuclear data library for nuclear science and technology*, Nuclear Data Sheets, Volume 107, Issue 12, pp. 2931-3060, December 2006.

APPENDICES

Appendix 1. List of current and new A_1/A_2 values

Table 4. Changes in A_1 and A_2 values between the current Q system and the proposed update

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Ac-225	8E-01	4E+00	6E-03	7E-04	5,00	0,12
Ac-227	9E-01	4E+01	9E-05	5E-04	44,44	5,56
Ac-228	6E-01	1E+00	5E-01	6E-01	1,67	1,20
Ag-105	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Ag-108m	7E-01	7E-01	7E-01	3E-01	1,00	0,43
Ag-110m	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Ag-111	2E+00	4E+01	6E-01	7E-01	20,00	1,17
Al-26	1E-01	4E-01	1E-01	1E-01	4,00	1,00
Am-241	1E+01	4E+01	1E-03	2E-03	4,00	2,00
Am-242m	1E+01	4E+01	1E-03	2E-03	4,00	2,00
Am-243	5E+00	5E+00	1E-03	2E-03	1,00	2,00
Ar-37	4E+01	Unlimited	4E+01	Unlimited	-	-
Ar-39	4E+01	4E+01	2E+01	2E+01	1,00	1,00
Ar-41	3E-01	9E-01	3E-01	3E-01	3,00	1,00
As-72	3E-01	2E-01	3E-01	2E-01	0,67	0,67
As-73	4E+01	4E+01	4E+01	3E+01	1,00	0,75
As-74	1E+00	1E+00	9E-01	1E+00	1,00	1,11
As-76	3E-01	2E-01	3E-01	2E-01	0,67	0,67
As-77	2E+01	4E+01	7E-01	7E-01	2,00	1,00
At-211	2E+01	2E+01	5E-01	4E-03	1,00	0,01
Au-193	7E+00	8E+00	2E+00	3E+00	1,14	1,50
Au-194	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Au-195	1E+01	2E+01	6E+00	6E+00	2,00	1,00
Au-198	1E+00	3E+00	6E-01	7E-01	3,00	1,17
Au-199	1E+01	1E+01	6E-01	7E-01	1,00	1,17
Ba-131	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Ba-133	3E+00	3E+00	3E+00	2E+00	1,00	0,67
Ba-133m	2E+01	2E+01	6E-01	7E-01	1,00	1,17
Ba-135m	2E+01	3E+01	6E-01	7E-01	1,50	1,17
Ba-140	5E-01	4E-01	3E-01	3E-01	0,80	1,00
Be-7	2E+01	2E+01	2E+01	2E+01	1,00	1,00
Be-10	4E+01	Unlimited	6E-01	6E-01	-	1,00

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Bi-205	7E-01	7E-01	7E-01	7E-01	1,00	1,00
Bi-206	3E-01	3E-01	3E-01	3E-01	1,00	1,00
Bi-207	7E-01	7E-01	7E-01	4E-01	1,00	0,57
Bi-210	1E+00	4E+01	6E-01	6E-01	40,00	1,00
Bi-210m	6E-01	2E+00	2E-02	2E-03	3,33	0,10
Bi-212	7E-01	5E-01	6E-01	1E-03	0,71	0,00
Bk-247	8E+00	8E+00	8E-04	2E-03	1,00	2,50
Bk-249	4E+01	4E+01	3E-01	7E-01	1,00	2,33
Br-76	4E-01	3E-01	4E-01	3E-01	0,75	0,75
Br-77	3E+00	4E+00	3E+00	4E+00	1,33	1,33
Br-82	4E-01	4E-01	4E-01	4E-01	1,00	1,00
C-11	1E+00	1E+00	6E-01	6E-01	1,00	1,00
C-14	4E+01	4E+01	3E+00	4E+00	1,00	1,33
Ca-41	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Ca-45	4E+01	4E+01	1E+00	1E+00	1,00	1,00
Ca-47	3E+00	8E-01	3E-01	2E-01	0,27	0,67
Cd-109	3E+01	4E+01	2E+00	3E+00	1,33	1,50
Cd-113m	4E+01	4E+01	5E-01	8E-01	1,00	1,60
Cd-115	3E+00	3E+00	4E-01	4E-01	1,00	1,00
Cd-115m	5E-01	1E+00	5E-01	6E-01	2,00	1,20
Ce-139	7E+00	9E+00	2E+00	3E+00	1,29	1,50
Ce-141	2E+01	2E+01	6E-01	7E-01	1,00	1,17
Ce-143	9E-01	4E+00	6E-01	6E-01	4,44	1,00
Ce-144	2E-01	2E-01	2E-01	2E-01	1,00	1,00
Cf-248	4E+01	4E+01	6E-03	8E-03	1,00	1,33
Cf-249	3E+00	3E+00	8E-04	2E-03	1,00	2,50
Cf-250	2E+01	6E+00	2E-03	3E-03	0,30	1,50
Cf-251	7E+00	1E+01	7E-04	2E-03	1,43	2,86
Cf-252	1E-01	1E-01	3E-03	4E-03	1,00	1,33
Cf-253	4E+01	4E+01	4E-02	1E-01	1,00	2,50
Cf-254	1E-03	4E-03	1E-03	2E-03	4,00	2,00
Cl-36	1E+01	4E+01	6E-01	5E-01	4,00	0,83
Cl-38	2E-01	2E-01	2E-01	2E-01	1,00	1,00
Cm-240	4E+01	4E+01	2E-02	3E-02	1,00	1,50
Cm-241	2E+00	2E+00	1E+00	2E+00	1,00	2,00
Cm-242	4E+01	4E+01	1E-02	1E-02	1,00	1,00

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Cm-243	9E+00	9E+00	1E-03	2E-03	1,00	2,00
Cm-244	2E+01	4E+01	2E-03	2E-03	2,00	1,00
Cm-245	9E+00	1E+01	9E-04	2E-03	1,11	2,22
Cm-246	9E+00	2E+01	9E-04	2E-03	2,22	2,22
Cm-247	3E+00	3E+00	1E-03	2E-03	1,00	2,00
Cm-248	2E-02	7E-02	3E-04	5E-04	3,50	1,67
Co-55	5E-01	5E-01	5E-01	5E-01	1,00	1,00
Co-56	3E-01	3E-01	3E-01	3E-01	1,00	1,00
Co-57	1E+01	1E+01	1E+01	1E+01	1,00	1,00
Co-58	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Co-58m	4E+01	4E+01	4E+01	4E+01	1,00	1,00
Co-60	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Cr-51	3E+01	4E+01	3E+01	4E+01	1,33	1,33
Cs-129	4E+00	4E+00	4E+00	4E+00	1,00	1,00
Cs-131	3E+01	4E+01	3E+01	4E+01	1,33	1,33
Cs-132	1E+00	2E+00	1E+00	2E+00	2,00	2,00
Cs-134	7E-01	7E-01	7E-01	7E-01	1,00	1,00
Cs-134m	4E+01	4E+01	6E-01	8E-01	1,00	1,33
Cs-135	4E+01	Unlimited	1E+00	1E+00	-	1,00
Cs-136	5E-01	5E-01	5E-01	5E-01	1,00	1,00
Cs-137	2E+00	2E+00	6E-01	5E-01	1,00	0,83
Cu-64	6E+00	6E+00	1E+00	1E+00	1,00	1,00
Cu-67	1E+01	1E+01	7E-01	8E-01	1,00	1,14
Dy-159	2E+01	4E+01	2E+01	4E+01	2,00	2,00
Dy-165	9E-01	1E+01	6E-01	7E-01	11,11	1,17
Dy-166	9E-01	4E-01	3E-01	3E-01	0,44	1,00
Er-169	4E+01	4E+01	1E+00	1E+00	1,00	1,00
Er-171	8E-01	3E+00	5E-01	6E-01	3,75	1,20
Eu-147	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Eu-148	5E-01	5E-01	5E-01	5E-01	1,00	1,00
Eu-149	2E+01	3E+01	2E+01	3E+01	1,50	1,50
Eu-150 (short lived)	2E+00	2E+01	7E-01	8E-01	10,00	1,14
Eu-150 (long lived)	7E-01	7E-01	7E-01	5E-01	1,00	0,71
Eu-152	1E+00	1E+00	1E+00	7E-01	1,00	0,70
Eu-152m	8E-01	8E-01	8E-01	8E-01	1,00	1,00
Eu-154	9E-01	9E-01	6E-01	6E-01	1,00	1,00

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Eu-155	2E+01	2E+01	3E+00	4E+00	1,00	1,33
Eu-156	7E-01	7E-01	7E-01	7E-01	1,00	1,00
F-18	1E+00	1E+00	6E-01	7E-01	1,00	1,17
Fe-52	3E-01	2E-01	3E-01	2E-01	0,67	0,67
Fe-55	4E+01	Unlimited	4E+01	4E+01	-	1,00
Fe-59	9E-01	9E-01	9E-01	9E-01	1,00	1,00
Fe-60	4E+01	Unlimited	2E-01	3E-01	-	1,50
Ga-67	7E+00	8E+00	3E+00	4E+00	1,14	1,33
Ga-68	5E-01	4E-01	5E-01	4E-01	0,80	0,80
Ga-72	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Gd-146	5E-01	4E-01	5E-01	4E-01	0,80	0,80
Gd-148	2E+01	4E+01	2E-03	4E-03	2,00	2,00
Gd-153	1E+01	2E+01	9E+00	1E+01	2,00	1,11
Gd-159	3E+00	2E+01	6E-01	7E-01	6,67	1,17
Ge-68	5E-01	4E-01	5E-01	4E-01	0,80	0,80
Ge-69	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Ge-71	4E+01	Unlimited	4E+01	4E+01	-	1,00
Ge-77	3E-01	6E-01	3E-01	6E-01	2,00	2,00
Hf-172	6E-01	5E-01	6E-01	5E-01	0,83	0,83
Hf-175	3E+00	3E+00	3E+00	3E+00	1,00	1,00
Hf-181	2E+00	2E+00	5E-01	6E-01	1,00	1,20
Hf-182	Unlimited	5E+00	Unlimited	2E-01	-	-
Hg-194	1E+00	1E+00	1E+00	5E-01	1,00	0,50
Hg-195m	3E+00	3E+00	7E-01	9E-01	1,00	1,29
Hg-197	2E+01	2E+01	1E+01	1E+01	1,00	1,00
Hg-197m	1E+01	1E+01	4E-01	4E-01	1,00	1,00
Hg-203	5E+00	5E+00	1E+00	1E+00	1,00	1,00
Ho-166	4E-01	6E-01	4E-01	6E-01	1,50	1,50
Ho-166m	6E-01	7E-01	5E-01	3E-01	1,17	0,60
I-123	6E+00	8E+00	3E+00	3E+00	1,33	1,00
I-124	1E+00	1E+00	1E+00	1E+00	1,00	1,00
I-125	2E+01	4E+01	3E+00	4E+00	2,00	1,33
I-126	2E+00	3E+00	1E+00	2E+00	1,50	2,00
I-129	Unlimited	Unlimited	Unlimited	5E-01	-	-
I-131	3E+00	3E+00	7E-01	8E-01	1,00	1,14
I-132	4E-01	5E-01	4E-01	5E-01	1,25	1,25

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
I-133	7E-01	2E+00	6E-01	7E-01	2,86	1,17
I-134	3E-01	4E-01	3E-01	4E-01	1,33	1,33
I-135	6E-01	7E-01	6E-01	7E-01	1,17	1,17
In-111	3E+00	3E+00	3E+00	3E+00	1,00	1,00
In-113m	4E+00	4E+00	2E+00	2E+00	1,00	1,00
In-114m	1E+01	5E-01	5E-01	3E-01	0,05	0,60
In-115m	7E+00	7E+00	1E+00	1E+00	1,00	1,00
Ir-189	1E+01	2E+01	1E+01	1E+01	2,00	1,00
Ir-190	7E-01	8E-01	7E-01	8E-01	1,14	1,14
Ir-192	1E+00	1E+00	6E-01	7E-01	1,00	1,17
Ir-193m	4E+01	4E+01	4E+00	5E+00	1,00	1,25
Ir-194	3E-01	4E-01	3E-01	4E-01	1,33	1,33
K-40	9E-01	Unlimited	9E-01	Unlimited	-	-
K-42	2E-01	2E-01	2E-01	2E-01	1,00	1,00
K-43	7E-01	1E+00	6E-01	7E-01	1,43	1,17
Kr-79	4E+00	4E+00	2E+00	2E+00	1,00	1,00
Kr-81	4E+01	Unlimited	4E+01	4E+01	-	1,00
Kr-85	1E+01	4E+01	1E+01	2E+01	4,00	2,00
Kr-85m	8E+00	8E+00	3E+00	3E+00	1,00	1,00
Kr-87	2E-01	2E-01	2E-01	2E-01	1,00	1,00
La-137	3E+01	4E+01	6E+00	6E+00	1,33	1,00
La-140	4E-01	5E-01	4E-01	5E-01	1,25	1,25
Lu-172	6E-01	6E-01	6E-01	6E-01	1,00	1,00
Lu-173	8E+00	8E+00	8E+00	8E+00	1,00	1,00
Lu-174	9E+00	1E+01	9E+00	9E+00	1,11	1,00
Lu-174m	2E+01	3E+01	1E+01	9E+00	1,50	0,90
Lu-177	3E+01	4E+01	7E-01	8E-01	1,33	1,14
Mg-28	3E-01	2E-01	3E-01	2E-01	0,67	0,67
Mn-52	3E-01	3E-01	3E-01	3E-01	1,00	1,00
Mn-53	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Mn-54	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Mn-56	3E-01	3E-01	3E-01	3E-01	1,00	1,00
Mo-93	4E+01	Unlimited	2E+01	6E+00	-	0,30
Mo-99	1E+00	4E+00	6E-01	6E-01	4,00	1,00
N-13	9E-01	1E+00	6E-01	6E-01	1,11	1,00
Na-22	5E-01	5E-01	5E-01	5E-01	1,00	1,00

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Na-24	2E-01	3E-01	2E-01	3E-01	1,50	1,50
Nb-93m	4E+01	Unlimited	3E+01	1E+01	-	0,33
Nb-94	7E-01	7E-01	7E-01	3E-01	1,00	0,43
Nb-95	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Nb-97	9E-01	2E+00	6E-01	6E-01	2,22	1,00
Nd-147	6E+00	9E+00	6E-01	7E-01	1,50	1,17
Nd-149	6E-01	3E+00	5E-01	5E-01	5,00	1,00
Ni-57	6E-01	6E-01	6E-01	6E-01	1,00	1,00
Ni-59	Unlimited	Unlimited	Unlimited	3E+01	-	-
Ni-63	4E+01	Unlimited	3E+01	2E+01	-	0,67
Ni-65	4E-01	5E-01	4E-01	5E-01	1,25	1,25
Np-235	4E+01	4E+01	4E+01	4E+01	1,00	1,00
Np-236 (short lived)	2E+01	3E+01	2E+00	2E+00	1,50	1,00
Np-236 (long lived)	9E+00	9E+00	2E-02	1E-02	1,00	0,50
Np-237	2E+01	Unlimited	2E-03	2E-03	-	1,00
Np-239	7E+00	7E+00	4E-01	5E-01	1,00	1,25
Os-185	1E+00	2E+00	1E+00	2E+00	2,00	2,00
Os-191	1E+01	2E+01	2E+00	2E+00	2,00	1,00
Os-191m	4E+01	4E+01	3E+01	1E+01	1,00	0,33
Os-193	2E+00	2E+01	6E-01	6E-01	10,00	1,00
Os-194	3E-01	4E-01	3E-01	4E-01	1,33	1,33
P-32	5E-01	7E-01	5E-01	6E-01	1,40	1,20
P-33	4E+01	4E+01	1E+00	1E+00	1,00	1,00
Pa-230	2E+00	2E+00	7E-02	2E-01	1,00	2,86
Pa-231	4E+00	3E+01	4E-04	5E-04	7,50	1,25
Pa-233	5E+00	5E+00	7E-01	7E-01	1,00	1,00
Pb-201	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Pb-202	4E+01	4E+01	2E+01	3E-01	1,00	0,02
Pb-203	4E+00	4E+00	3E+00	3E+00	1,00	1,00
Pb-205	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Pb-210	1E+00	4E+01	5E-02	3E-03	40,00	0,06
Pb-212	7E-01	4E-01	2E-01	1E-03	0,57	0,01
Pd-103	4E+01	4E+01	4E+01	4E+01	1,00	1,00
Pd-107	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Pd-109	2E+00	4E+01	5E-01	5E-01	20,00	1,00
Pm-143	3E+00	4E+00	3E+00	4E+00	1,33	1,33

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Pm-144	7E-01	7E-01	7E-01	7E-01	1,00	1,00
Pm-145	3E+01	4E+01	1E+01	9E+00	1,33	0,90
Pm-147	4E+01	4E+01	2E+00	2E+00	1,00	1,00
Pm-148m	8E-01	5E-01	7E-01	5E-01	0,63	0,71
Pm-149	2E+00	4E+01	6E-01	7E-01	20,00	1,17
Pm-151	2E+00	4E+00	6E-01	7E-01	2,00	1,17
Po-210	4E+01	4E+01	2E-02	2E-02	1,00	1,00
Pr-142	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Pr-143	3E+00	4E+01	6E-01	7E-01	13,33	1,17
Pt-188	1E+00	4E-01	8E-01	4E-01	0,40	0,50
Pt-191	4E+00	4E+00	3E+00	3E+00	1,00	1,00
Pt-193	4E+01	Unlimited	4E+01	3E+01	-	0,75
Pt-193m	4E+01	4E+01	5E-01	7E-01	1,00	1,40
Pt-195m	1E+01	2E+01	5E-01	6E-01	2,00	1,20
Pt-197	2E+01	4E+01	6E-01	7E-01	2,00	1,17
Pt-197m	1E+01	2E+01	6E-01	6E-01	2,00	1,00
Pu-236	3E+01	4E+01	3E-03	3E-03	1,33	1,00
Pu-237	2E+01	3E+01	2E+01	3E+01	1,50	1,50
Pu-238	1E+01	4E+01	1E-03	1E-03	4,00	1,00
Pu-239	1E+01	4E+01	1E-03	1E-03	4,00	1,00
Pu-240	1E+01	4E+01	1E-03	1E-03	4,00	1,00
Pu-241	4E+01	4E+01	6E-02	6E-02	1,00	1,00
Pu-242	1E+01	Unlimited	1E-03	1E-03	-	1,00
Pu-244	4E-01	6E-01	1E-03	1E-03	1,50	1,00
Ra-223	4E-01	2E+00	7E-03	2E-03	5,00	0,29
Ra-224	4E-01	4E-01	2E-02	8E-04	1,00	0,04
Ra-225	2E-01	1E+00	4E-03	2E-04	5,00	0,05
Ra-226	2E-01	6E-01	3E-03	2E-03	3,00	0,67
Ra-228	6E-01	1E+00	2E-02	1E-03	1,67	0,05
Rb-81	2E+00	2E+00	8E-01	2E+00	1,00	2,50
Rb-83	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Rb-84	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Rb-86	5E-01	6E-01	5E-01	6E-01	1,20	1,20
Rb-87	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Rb (natural)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Re-184	1E+00	1E+00	1E+00	1E+00	1,00	1,00

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Re-184m	3E+00	3E+00	1E+00	1E+00	1,00	1,00
Re-186	2E+00	4E+01	6E-01	7E-01	20,00	1,17
Re-187	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Re-188	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Re-189	3E+00	2E+01	6E-01	6E-01	6,67	1,00
Re (natural)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Rh-99	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Rh-101	4E+00	4E+00	3E+00	4E+00	1,00	1,33
Rh-102	5E-01	2E+00	5E-01	2E+00	4,00	4,00
Rh-102m	2E+00	5E-01	2E+00	5E-01	0,25	0,25
Rh-103m	4E+01	4E+01	4E+01	4E+01	1,00	1,00
Rh-105	1E+01	1E+01	8E-01	9E-01	1,00	1,13
Rn-222	3E-01	6E-01	4E-03	2E-03	2,00	0,50
Ru-97	5E+00	5E+00	5E+00	5E+00	1,00	1,00
Ru-103	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Ru-105	1E+00	1E+00	6E-01	5E-01	1,00	0,83
Ru-106	2E-01	2E-01	2E-01	2E-01	1,00	1,00
S-35	4E+01	4E+01	3E+00	4E+00	1,00	1,33
Sb-122	4E-01	1E+00	4E-01	7E-01	2,50	1,75
Sb-124	6E-01	6E-01	6E-01	6E-01	1,00	1,00
Sb-125	2E+00	3E+00	1E+00	2E+00	1,50	2,00
Sb-126	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Sc-44	5E-01	5E-01	5E-01	5E-01	1,00	1,00
Sc-46	5E-01	5E-01	5E-01	5E-01	1,00	1,00
Sc-47	1E+01	1E+01	7E-01	8E-01	1,00	1,14
Sc-48	3E-01	3E-01	3E-01	3E-01	1,00	1,00
Se-75	3E+00	3E+00	3E+00	3E+00	1,00	1,00
Se-79	4E+01	Unlimited	2E+00	3E+00	-	1,50
Si-31	6E-01	2E+00	6E-01	6E-01	3,33	1,00
Si-32	4E+01	4E+01	5E-01	2E-01	1,00	0,40
Sm-145	1E+01	4E+01	1E+01	3E+01	4,00	3,00
Sm-147	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Sm-151	4E+01	Unlimited	1E+01	1E+01	-	1,00
Sm-153	9E+00	3E+01	6E-01	7E-01	3,33	1,17
Sn-113	4E+00	4E+00	2E+00	2E+00	1,00	1,00
Sn-117m	7E+00	9E+00	4E-01	5E-01	1,29	1,25

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Sn-119m	4E+01	4E+01	3E+01	2E+01	1,00	0,67
Sn-121m	4E+01	4E+01	9E-01	1E+00	1,00	1,11
Sn-123	8E-01	2E+00	6E-01	7E-01	2,50	1,17
Sn-125	4E-01	3E-01	4E-01	3E-01	0,75	0,75
Sn-126	6E-01	5E-01	4E-01	9E-02	0,83	0,23
Sr-82	2E-01	2E-01	2E-01	2E-01	1,00	1,00
Sr-83	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Sr-85	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Sr-85m	5E+00	5E+00	5E+00	5E+00	1,00	1,00
Sr-87m	3E+00	3E+00	3E+00	3E+00	1,00	1,00
Sr-89	6E-01	1E+00	6E-01	6E-01	1,67	1,00
Sr-90	3E-01	3E-01	3E-01	1E-01	1,00	0,33
Sr-91	3E-01	6E-01	3E-01	6E-01	2,00	2,00
Sr-92	1E+00	8E-01	3E-01	8E-01	0,80	2,67
H-3	4E+01	Unlimited	4E+01	4E+01	-	1,00
Ta-178m	1E+00	1E+00	8E-01	9E-01	1,00	1,13
Ta-179	3E+01	4E+01	3E+01	4E+01	1,33	1,33
Ta-182	9E-01	9E-01	5E-01	6E-01	1,00	1,20
Tb-149	8E-01	8E-01	8E-01	8E-01	1,00	1,00
Tb-157	4E+01	4E+01	4E+01	3E+01	1,00	0,75
Tb-158	1E+00	1E+00	1E+00	5E-01	1,00	0,50
Tb-160	1E+00	1E+00	6E-01	6E-01	1,00	1,00
Tb-161	3E+01	4E+01	7E-01	8E-01	1,33	1,14
Tc-95m	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Tc-96	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Tc-96m	4E-01	3E+01	4E-01	3E+01	75,00	75,00
Tc-97	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Tc-97m	4E+01	4E+01	1E+00	2E+00	1,00	2,00
Tc-98	8E-01	8E-01	7E-01	3E-01	1,00	0,43
Tc-99	4E+01	Unlimited	9E-01	1E+00	-	1,11
Tc-99m	1E+01	1E+01	4E+00	5E+00	1,00	1,25
Te-121	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Te-121m	5E+00	6E+00	3E+00	3E+00	1,20	1,00
Te-123m	8E+00	9E+00	1E+00	1E+00	1,13	1,00
Te-125m	2E+01	4E+01	9E-01	1E+00	2,00	1,11
Te-127	2E+01	4E+01	7E-01	7E-01	2,00	1,00

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
Te-127m	2E+01	4E+01	5E-01	6E-01	2,00	1,20
Te-129	7E-01	2E+00	6E-01	6E-01	2,86	1,00
Te-129m	8E-01	2E+00	4E-01	5E-01	2,50	1,25
Te-131m	7E-01	7E-01	5E-01	6E-01	1,00	1,20
Te-132	5E-01	4E-01	4E-01	4E-01	0,80	1,00
Th-227	1E+01	9E+00	5E-03	2E-02	0,90	4,00
Th-228	5E-01	5E-01	1E-03	9E-04	1,00	0,90
Th-229	5E+00	1E+01	5E-04	3E-04	2,00	0,60
Th-230	1E+01	4E+01	1E-03	1E-03	4,00	1,00
Th-231	4E+01	4E+01	2E-02	1E+00	1,00	50,00
Th-232	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Th-234	3E-01	4E-01	3E-01	4E-01	1,33	1,33
Th (natural)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Ti-44	5E-01	5E-01	4E-01	1E-01	1,00	0,25
Tl-200	9E-01	9E-01	9E-01	9E-01	1,00	1,00
Tl-201	1E+01	2E+01	4E+00	5E+00	2,00	1,25
Tl-202	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Tl-204	1E+01	4E+01	7E-01	8E-01	4,00	1,14
Tm-167	7E+00	9E+00	8E-01	9E-01	1,29	1,13
Tm-170	3E+00	4E+01	6E-01	7E-01	13,33	1,17
Tm-171	4E+01	4E+01	4E+01	4E+01	1,00	1,00
U-230 (fast lung absorption)	4E+01	1E+01	1E-01	2E-03	0,25	0,02
U-230 (medium lung absorption)	4E+01	1E+01	4E-03	2E-03	0,25	0,50
U-230 (slow lung absorption)	3E+01	1E+01	3E-03	2E-03	0,33	0,67
U-232 (fast lung absorption)	4E+01	4E+01	1E-02	3E-02	1,00	3,00
U-232 (medium lung absorption)	4E+01	4E+01	7E-03	1E-03	1,00	0,14
U-232 (slow lung absorption)	1E+01	4E+01	1E-03	4E-04	4,00	0,40
U-233 (fast lung absorption)	4E+01	4E+01	9E-02	8E-02	1,00	0,89
U-233 (medium lung absorption)	4E+01	4E+01	2E-02	6E-03	1,00	0,30
U-233 (slow lung absorption)	4E+01	4E+01	6E-03	2E-03	1,00	0,33
U-234 (fast lung absorption)	4E+01	Unlimited	9E-02	8E-02	-	0,89
U-234 (medium lung absorption)	4E+01	Unlimited	2E-02	6E-03	-	0,30
U-234 (slow lung absorption)	4E+01	Unlimited	6E-03	2E-03	-	0,33
U-235 (all lung types absorption)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
U-236 (fast lung absorption)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
U-236 (medium lung absorption)	4E+01	Unlimited	2E-02	6E-03	-	0,30

Radionuclide	A_1		A_2		NEW / CURRENT	
	IAEA SSR-6	WG A_1/A_2	IAEA SSR-6	WG A_1/A_2		
	TBq	TBq	TBq	TBq	A_1	A_2
U-236 (slow lung absorption)	4E+01	Unlimited	6E-03	2E-03	-	0,33
U-238 (all lung types absorption)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
U (natural)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
U (depleted)	Unlimited	Unlimited	Unlimited	Unlimited	-	-
V-48	4E-01	4E-01	4E-01	4E-01	1,00	1,00
V-49	4E+01	Unlimited	4E+01	4E+01	-	1,00
W-178	9E+00	1E+01	5E+00	5E+00	1,11	1,00
W-181	3E+01	4E+01	3E+01	4E+01	1,33	1,33
W-185	4E+01	4E+01	8E-01	9E-01	1,00	1,13
W-187	2E+00	2E+00	6E-01	7E-01	1,00	1,17
W-188	4E-01	4E-01	3E-01	4E-01	1,00	1,33
Xe-122	4E-01	2E-01	4E-01	2E-01	0,50	0,50
Xe-123	2E+00	2E+00	7E-01	7E-01	1,00	1,00
Xe-127	4E+00	5E+00	2E+00	2E+00	1,25	1,00
Xe-131m	4E+01	4E+01	4E+01	4E+01	1,00	1,00
Xe-133	2E+01	4E+01	1E+01	2E+01	2,00	2,00
Xe-135	3E+00	5E+00	2E+00	2E+00	1,67	1,00
Y-87	1E+00	1E+00	1E+00	1E+00	1,00	1,00
Y-88	4E-01	4E-01	4E-01	4E-01	1,00	1,00
Y-90	3E-01	3E-01	3E-01	3E-01	1,00	1,00
Y-91	6E-01	1E+00	6E-01	6E-01	1,67	1,00
Y-91m	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Y-92	2E-01	2E-01	2E-01	2E-01	1,00	1,00
Y-93	3E-01	2E-01	3E-01	2E-01	0,67	0,67
Yb-169	4E+00	4E+00	1E+00	1E+00	1,00	1,00
Yb-175	3E+01	3E+01	9E-01	1E+00	1,00	1,11
Zn-65	2E+00	2E+00	2E+00	2E+00	1,00	1,00
Zn-69	3E+00	4E+01	6E-01	7E-01	13,33	1,17
Zn-69m	3E+00	3E+00	6E-01	6E-01	1,00	1,00
Zr-88	3E+00	3E+00	3E+00	3E+00	1,00	1,00
Zr-93	Unlimited	Unlimited	Unlimited	Unlimited	-	-
Zr-95	2E+00	1E+00	8E-01	1E+00	0,50	1,25
Zr-97	4E-01	4E-01	4E-01	3E-01	1,00	0,75