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Review of Current Q System and the A_1/A_2 Values of the IAEA Transport Regulation

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Historical overview - development of the Q system

- MacDonald, Goldfinch: Radioactive Material Transport Package Activity Release Limits. IAEA-TECDOC-375 (1986)
- **Development of the Q system** as basis of an **improved** A_1/A_2 system considering (at this time) up-to-date recommendations of ICRP

- Today, basis for calculation of *A* values are different exposure pathways of *Q* values ($Q_A,\ldots,Q_E$)
- Both, *A* values and *Q* values are activities given in unit TBq

Current Q system (1)

- Q system shall provide inherent safety
- Developed in 1985 with a revision of the Transport Regulations of the IAEA
- Provides calculation methods of allowed activity quantities in Typ A packages
- A values are calculated for radioactive material
  - in special form (A1 value) and
  - in non-special form (A2 value)

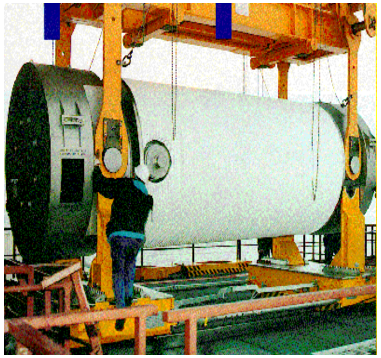
Current Q system (2)

- The Q system was aligned in 1996 to (at this time) new recommendations of ICRP publication 60 of 1990
  - new definition of quantity effective dose
  - Reviewed dose coefficients for inhalation and ingestion
  - New dose coefficients for external exposure (US EPA FGR-12)
  - Reviewed dose calculation of gamma radiation and beta radiation
  - Reviewed assessment of neutron radiation

Current Q system (3)

- The current Q system
  - Provides nuclide dependent A_1/A_2 values
  - Allows to transport radioactive material independently of shape or quantity (as long as rules of the Q system and Transport regulations are satisfied)

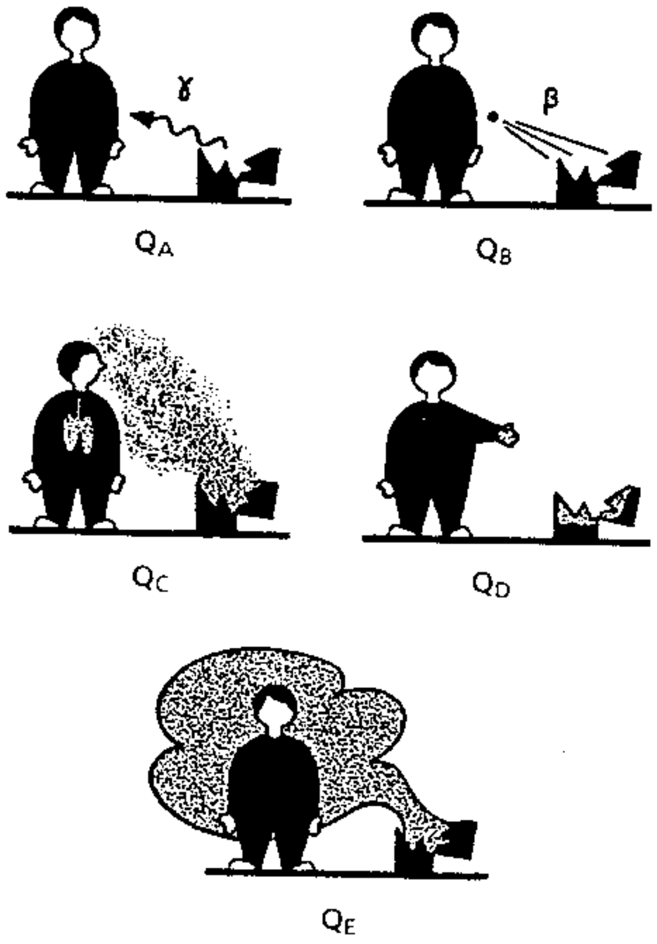
- Additional regulations are given for
  - Fissile material
  - Uranium hexafluoride (UF_6)



Current Q system (4)

The current Q system knows 5 (or 6) exposure pathways

- Q_A: external photon dose
- Q_B: external beta dose
- Q_C: inhalation dose
- Q_D: skin dose and ingestion dose due to contamination transfer
- Q_E: submersion dose



- Q_F: alpha emitter ("special case" of Q_C)

Current Q system (5)

- Distance: 1 m
- Exposure time: 30 minutes
- Applied dose limits:
  - 50 mSv effective dose
  - 500 mSv equivalent dose (incl. skin dose)
  - 150 mSv dose for the lens of the eye

- $A_1 = \min \{Q_A, Q_B, (Q_F)\}$
- $A_2 = \min \{Q_A, Q_B, Q_C, Q_D, Q_E, (Q_F)\}$

Work of GRS regarding the Q system

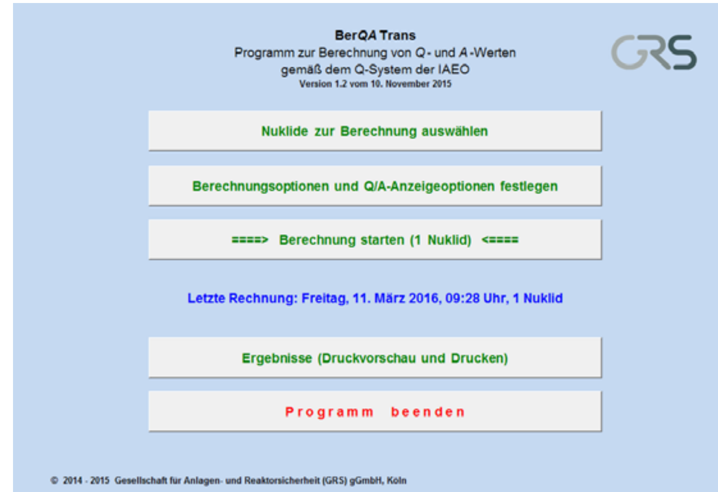
- Federal Office for Radiation Protection (BfS) and Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) granted GRS research projects
- Aims of this research projects (amongst others):
  - Analysis of the current Q system
  - Development of a calculation tool for calculation of *Q* and *A* values for new nuclides
- Some issues of the current Q system were detected
- Calculation tool BerQATrans developed for recalculation of current and of new *Q* and *A* values according the current Q system
- Publication in GRS report No. GRS-343

Some issues in the current Q system

- *Q* and *A* values are partly based on outdated input data
- Dose coefficients listed in TS-G-1.1/SSG-26 for Q_C values are partly not consistent with dose coefficients of ICRP 68
  - No reference is given for dose coefficients in TS-G-1.1/SSG-26
- Dose rate coefficients in TS-G-1.1/SSG-26 seem to be calculated backwards from listed *Q* values
  - Main impact for for small coefficients
- *Q* values are limited to 1000 TBq without justification
- Determination of “unlimited” values for LSA material is not documented in detail
- Treatment of progeny differs between the *Q* value exposure pathways

Calculation tool Ber*QA*Trans

- Written in MS Excel VBA
- Designed to
  - Recalculate existing *Q* and *A* values listed in SSG-26,
  - Calculate new values for nuclides not listed in SSG-26.
- With Ber*QA*Trans it is possible to use up-to-date nuclide data from ICRP publications 107, 116, or 119
- Calculation of *Q* and *A* values for 768 nuclides (373 nuclides are listed in SSR-6) using calculation methods of the current Q system



Ber*QA* Trans
Programm zur Berechnung von *Q*- und *A*-Werten gemäß dem Q-System der IAEO

GRS

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Ergebnisse *A*-Werte

Rechnung von Montag, 22. August 2016, 11:30 Uhr

Nuklid	chem. Form	Halbwertszeit	Q_A (TBq)	Q_B (TBq)	Q_C (TBq)	Q_D (TBq)	Q_E (TBq)	Q_F (TBq)	A_1 (TBq)	A_2 (TBq)
Ac-225	S	10 d	4,8E+00	7,7E-01	6,3E-03	2,9E-01	--	6,3E+01	**8E-01**	**6E-03**
Ac-227	F	21,773 a	1,0E+03	1,2E+02	9,3E-05	3,5E+01	--	9,3E-01	**9E-01**	**9E-05**
Ac-228	F	6,13 h	1,1E+00	5,3E-01	2,0E+00	4,9E-01	--	1,0E+03	**5E-01**	**5E-01**
Ag-105	S	41 d	2,0E+00	1,0E+03	6,4E+01	2,5E+01	--	--	**2E+00**	**2E+00**
Ag-108m	S	127 a	6,7E-01	5,6E+00	1,4E+00	5,6E+00	--	--	**7E-01**	**7E-01**
Ag-110m	S	249,9 d	4,0E-01	1,7E+01	4,2E+00	2,0E+00	--	--	**4E-01**	**4E-01**
Ag-111	S	7,45 d	4,2E+01	1,8E+00	2,9E+01	5,9E-01	--	--	**2E+00**	**6E-01**
Al-26	M	7,16E+05 a	4,2E-01	1,3E+00	2,8E+00	8,2E-01	--	--	**4E-01**	**4E-01**
Am-241	M	432,2 a	2,9E+01	1,0E+03	1,3E-03	3,3E+02	--	1,3E+01	**1E+01**	**1E-03**
Am-242m	M	152 a	4,0E+01	4,5E+01	1,4E-03	9,9E-01	--	1,4E+01	**1E+01**	**1E-03**
Am-243	M	7,38E+03 a	5,0E+00	2,1E+02	1,3E-03	4,0E-01	--	1,3E+01	**5E+00**	**1E-03**
Ar-37		35,02 d	1,0E+03	1,0E+03	--	1,0E+03	k. W.	--	**4E+01**	**4E+01**
Ar-39		269 a	k. W.	6,3E+01	--	--	1,8E+01	--	**4E+01**	**2E+01**
Ar-41		1,827 h	9,1E-01	2,9E-01	--	--	3,1E-01	--	**3E-01**	**3E-01**

Results of the research project of GRS (1)

- Recalculation of most nuclides of SSR-6 using Ber*QA*Trans
  - deviations from tabulated values are up to a factor of two
- 8 nuclides show larger deviations than a factor of two
  - ^{26}Al, ^{47}Ca, ^{166}Dy, ^{202}Pb, ^{225}Ra, ^{92}Sr, ^{96m}Tc, ^{231}Th (see next slide)
- **Good agreement of values calculated with Ber*QA*Trans**
- Identification of issues

Results of the research project of GRS (2)

Nuclide	Remarks to values calculated with Ber*QA*Trans
^{26}Al	Q_B value lesser than in SSG-26; therefore, Q_A value restricts A_1/A_2 values
^{47}Ca	Q_A and Q_B values lesser than in SSG-26; now Q_B values restricts A_1 value
^{166}Dy	Q_B value lesser than in SSG-26; therefore, A_1 value lesser too
^{202}Pb	Q_D value higher than in SSG-26 and “unlimited”; therefore A_1/A_2 values “unlimited” too
^{225}Ra	Q_B value and Q_C value higher than in SSG-26; therefore, A_1 value and A_2 value higher
^{92}Sr	Q_C value calculated with progeny in TS-G-1.1 (2008)
^{96m}Tc	Q_C and Q_D values calculated with progeny in TS-G-1.1 (2008)
^{231}Th	higher deviation of Q_C value, possibly calculated with progeny in TS-G-1.1 (2008)

Q system from the point of view of other organizations

- **Review of the Q system by several other organizations**
  - (e.g. Health Protection Agency with report HPA-CRCE-027, September 2011)
    - Development of calculation program
    - Recalculation of *Q* and *A* values
    - Calculation of new nuclides
- Suggestion of TRANSSC (Transport Safety Standards Committee) members
  - **meeting of organizations from France, Japan, Germany, and United Kingdom was held in September 2013 at GRS in Cologne, Germany**

Q system from the point of view of other organizations

- Foundation of an international working group
  - **“Working group on review of A_1 and A_2 values for the IAEA Transport Regulations”**
  - Aim: review and update of calculation methods of the Q system according the actual state-of-the-art of science and technology

International Working Group

- Beginning in 2014 the working group met several times
- Request by TRANSSC in September 2015
  - Calculation of *Q* and *A* values for 5 new nuclides
  - Calculations were performed by HPE, NRA and GRS
    - Results of Ber*QA*Trans from GRS are shown below
    - Data used from ICRP 38, ^{193m}Ir with data from ICRP 107

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	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}

Review of *Q* and *A* values

- Use of Monte-Carlo methods
  - State-of-the-art method
  - Including all particles of interest
  - Taking all relevant particle interactions into account
  - Considering secondary particles
    - E.g. bremsstrahlung
  - Several issues of the current Q system can be solved
  - Disadvantage: Computing time
- International working group defines conditions for Monte-Carlo simulations

New Code Development: MCBAS

- Monte-Carlo Based A-value Simulator (MCBAS)
  - C++ based code
  - Currently under development by GRS
- Modular structure
  - Simple change or update of input files
    - Nuclear data
    - Dose coefficients
    - New nuclides
    - Neutron sources (AmBe, etc.)
- Decoupled from Monte-Carlo simulations

MCBAS – Decoupling from MC Simulations

- Time consuming MC simulations done in advance
  - MC simulations generate flux spectra
    - For all particles of interest (α, γ, β–, β+, n)
    - For certain energies
      - 5 keV steps up to 100 keV particle energy
      - 10 keV steps above 100 keV particle energy
      - Smaller steps for neutrons
    - For all relevant particles passing a surface at 1 m distance
  - All flux spectra form a database
  - Database serves as input for MCBAS

MCBAS – Advantages

- Independent of time consuming MC simulations
  - MCBAS is very fast
  - Installation on PCs without MC codes
- Modularity
  - Simple update of input files
- Fast calculation (without further MC simulations) of
  - New nuclides
  - Neutron sources
- Main Disadvantage: Energy uncertainty of real particle energy and next available simulated flux spectra
  - Max. 2.5 keV for energies below 100 keV
  - Max. 5 keV for energies above 100 keV

MCBAS – Status and First Results

- A_1 values can be calculated
- Procedure for A_2 values will be discussed within the WG
- Qualification process is ongoing
- Improvement of statistics and error analysis to be performed
- First results: Comparison of dose rate coefficients $\dot{e}_{\mathrm{pt}}$ for photons between MCBAS and Ber*QA*Trans

Nuclide	$\dot{e}_{\mathrm{pt}}$(MCBAS) [Sv/Bq/h]	$\dot{e}_{\mathrm{pt}}$(BER) [Sv/Bq/h]	Ratio	Nuclide	$\dot{e}_{\mathrm{pt}}$(MCBAS) [Sv/Bq/h]	$\dot{e}_{\mathrm{pt}}$(BER) [Sv/Bq/h]	Ratio
^{60}Co	2.18E-13	2.2E-13	1.01	^{18}F	8.23E-14	9.2E-14	1.12
^{134}Cs	1.43E-13	1.4E-13	0.98	^{192}Ir	6.83E-14	7.5E-14	1.10
^{137}Cs	5.33E-14	5.3E-14	1.00	^{85}Kr	2.31E-16	2.1E-16	0.91
^{154}Eu	1.08E-13	1.1E-13	1.02	^{106}Rh	1.86E-14	1.9E-14	1.02

Thank you for your attention!