TRANSSC 39 - WASSC 48
Review of the $A_1$ and $A_2$ values
The Q System
The Q System

Reminder

Scope
- The Q System has been developed as a tool to perform a quick evaluation of radiological consequences in case of accidents involving a transport of radioactive materials.
- Described in Appendix I of IAEA SSG-26.

Model
- During a transport accident, the dose to a person exposed in the vicinity of a damaged package (1 m, 30 min, warehouse of 300 m$^3$) should not exceed:
  - effective dose of 50 mSv,
  - skin equivalent dose of 500 mSv,
  - lens equivalent dose of 150 mSv.

The Q System allows calculation, for each nuclide, of the activities “$A_1$” and “$A_2$” needed to exceed one of the reference doses:
- $A_1$: undispersible source, external exposure only; to be used for SFRM
- $A_2$: all other cases, internal/external exposure and contamination
The Q System

★ The 5-pathway exposure scenarios

**Q_C**
Internal dose via inhalation
1. Released fraction: $10^{-3} - 10^{-2}$
2. Inhaled fraction: $10^{-4} - 10^{-3}$

**Q_A**
External dose due to photons ($\gamma$/X rays)
1. Radiological protection no more effective
2. Radiation level ≤ 100 mSv/h at 1 m

**Q_B**
External dose due to $\beta$ emitters
1. Radiological protection no more effective
2. Presence of residual fragments

**Q_D**
Doses due to contamination and ingestion
1. 1% of the content is uniformly repartited on the ground on 1 m$^2$
2. The hands contamination correspond to 10% of the contamination of the ground
3. Hands are decontaminated 5 h after the accident
4. Ingestion of contamination of 10 cm$^2$ of skin in 24 hours

**Q_E**
Submersion dose due to gaseous isotopes
1. The gaseous nuclides are not incorporated into the body (noble gases)
2. 100% of the content is released.
The Q System

Issues

- Difficulties to reproduce the method
  - Different publications
  - Methods sometimes unclear or inconsistent
  - Lack of traceability of what was actually done
  - Justification of different choices and parameters

- Accuracy and adequacy of the method for new radionuclides?

- Many changes since 1996:
  - ICRP 103 recommendations
  - ICRP 107 spectra and ICRP 116 dose coefficients
  - ICRP 130 introduced new intake dose coefficients
  - More publications, databases and tools dedicated to dose evaluations
  - Improved calculation tools: possibility to use (quick) probabilistic methods (Monte-Carlo)

- An international WG was created in 2014 to review the Q System
  - Now part of the IAEA TTEG for Radiation Protection
## Q System

Main differences between the current Q-System and the expected update

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<th>Deterministic &amp; Probabilistic</th>
<th>Probabilistic (Monte-Carlo)</th>
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<tr>
<td>1 radionuclide -&gt; 1 value : necessity to perform lengthy calculations in case of updates of the spectra and dose coeff.</td>
<td>1 energy -&gt; 1 fluence per energy bin -&gt; 1 value : any radionuclide can be considered ; updates of spectra and dose coeff. quickly taken into account</td>
<td>1 unified method + detailed report</td>
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<td>Several sources</td>
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# Q System

Main differences between the current Q-System and the expected update

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<th>Update of the Q-System</th>
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<td>$Q_a$</td>
<td>Effective dose (photons)</td>
<td>Effective dose (all radiations)</td>
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<td>$Q_b$</td>
<td>Equivalent dose (beta radiations)</td>
<td>Equivalent dose to the skin (all radiations)</td>
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<td>Effective dose due to inhalation (all radiations)</td>
<td>Effective dose due to inhalation (all radiations)</td>
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<td>Equivalent dose to the skin due to contamination</td>
<td>Equivalent dose to the skin due to contamination (all radiations)</td>
</tr>
<tr>
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<td>(beta radiations)</td>
<td></td>
</tr>
<tr>
<td>$Q_e$</td>
<td>Effective dose due to inhalation of noble gases (all</td>
<td>Effective dose due to inhalation of and external exposure to noble gases (all</td>
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<tr>
<td></td>
<td>radiations)</td>
<td>radiations)</td>
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<tr>
<td></td>
<td>Equivalent dose to the skin due to external</td>
<td>Equivalent dose to the skin due to external exposure to noble gases (all</td>
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<td>exposure to noble gases (beta radiations)</td>
<td>radiations)</td>
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<td></td>
<td>Equivalent dose to the skin due to external exposure</td>
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<tr>
<td></td>
<td>to noble gases (beta radiations)</td>
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<tr>
<td>$Q_f$</td>
<td>External effective dose due to neutrons ($= 10^4 Q_c$)</td>
<td>Now included in $Q_a$ and $Q_b$ (effective and skin equivalent doses)</td>
</tr>
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The Q System

Scope of the WG

- **Reviewing the method and data used to determine the Q values**
  - $Q_A$ and $Q_B$ as a first step (ICRP 107, ICRP 116) $\rightarrow$ $A_1$
  - $Q_C$, $Q_D$, and $Q_E$ once new ICRP recommendations will be published $\rightarrow$ $A_2$

- **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.

- The current scenarios represent a reasonable approach for the sake of safety
Methodology and parameters
Methodology and parameters

$Q_A$ and $Q_B$: calculation methodology

- Monte Carlo calculation codes
  - MCNP (IRSN, PHE)
  - PHITS (MHI NS ENG)
  - GEANT (GRS)
  - FLUKA (CERN)

- Source as a point, detector as a sphere of radius 1 m (centered on the source)

- Residual shielding of 0.5 mm (stainless steel)

- Energy flux calculation for each energy bin

- Fluxes can then be used with any set of dose coefficients, any geometry and any spectrum
  - ISO, ROT, AP, etc.
  - also convenient in case of updates of those data
Methodology and parameters

- Q_A and Q_B: model for beta radiation

SSG-26 mentions the use of a shielding factor with d = 150 mg/cm².

- Simulates remnant shielding (SSG-26) or auto shielding (PATRAM 80).
- Not documented (derivation from a 1973 SS6 consideration).

  - thickness of 0.2 mm ~ stainless steel capsule (beta window protector of some ⁹⁰Sr sources).

Consideration of remnant/auto shielding

- Alright for the purpose of determining A₁
- Issues in deriving A₂: any physical form (powder, gas, etc.) shall be considered

The WG considers a thickness of 0.5 mm of stainless steel

- In accordance with most special form sources capsules
- also accounts for the auto-shielding and matrices of RM
Methodology and parameters

Q_A and Q_B: mean vs. local skin dose

Issues in deriving skin doses using ICRP 116:
- **Mean skin dose coefficients** are used for gamma and neutrons
  - Skin is seen as a global organ
- **Local skin dose coefficients** are used for electrons
  - Most exposed skin surface

The methods to derive those coefficients are different!
- Inconsistencies in the calculations of the total dose

Homogenization of the method
- New databases were evaluated by the WG
- LSD for positrons, neutrons and photons
Methodology and parameters

Q_A and Q_B: interim results for A_1

Main hypotheses:
- 368 radionuclides from SSR-6
- Local skin dose coefficients (new)
- All radiations (new) except those from (α,γ) reactions
- Shielding for all radiations (new)
- ISO geometry as stated in SSG-26
- Progenies consideration from SSR-6

Unchanged A1 value
A1 decrease vs current A1 value
A1 increase vs current A1 value
Methodology and parameters

**Qc**: calculation methodology

- Intake current dose coefficients come from the ICRP 68
  - **AMAD 5 µm** was considered, type S when available
  - Only a few cases explicitly addressed the chemical form (H, C, S, Ni, I, Hg)

- Difficulty to deal with the updates from ICRP 130
  - Many new aerosol sizes (from 0.001 µm to 20 µm), new types, new forms
    - However, ICRP 130 states that **AMADs of 5 µm (workers) and 1 µm (public) should be used**
  - Chemical form seemingly addressed in more cases

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<th>Isotope</th>
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<th>Worst case form</th>
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<td>Form</td>
<td>Description</td>
</tr>
<tr>
<td>H-3</td>
<td>Organic</td>
<td>Carbon tritide</td>
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<tr>
<td>C-14</td>
<td>Vapour</td>
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<td>Ca-45</td>
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<td>Type S</td>
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<td>Co-60</td>
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<td>Type S, Cobalt oxide</td>
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<td>Type S, carbonate, oxide, tritide</td>
</tr>
<tr>
<td>Tc-99m</td>
<td>Type S, 5 µm</td>
<td>Type S</td>
</tr>
</tbody>
</table>
Methodology and parameters

**Q\textsubscript{D}: calculation methodology**

- **Q\textsubscript{D},ingestion** to be updated together with **Q\textsubscript{C}** using **ICRP 130** dose coefficients
- **Q\textsubscript{D},contamination** to be determined using Monte-Carlo methods.

Two models and sets of parameters (validation, comparison)

- Cross et al. model (current Q System)... with modification of the medium (skin)
- ICRP 116 model... with modification of the source (deposit)

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**Interim results for Q\textsubscript{D}**

- 34% Q\textsubscript{D} equivalent to current value
- 33% Q\textsubscript{D} increase >10% vs. current value
- 33% Q\textsubscript{D} decrease >10% vs. current value
Methodology and parameters

**QE**: under progress

- **Current dose coefficients come from:**
  - Federal Guidance 12: equivalent dose to the skin
  - ICRP 68: effective dose (based on FG 12 calculations)

- **Update of those publications: FG 15 and ICRP 130**

- **Current discussions on defining a method to evaluate QE**
  - FG 15 has to be reviewed: is it consistent with the general methodology of the WG?
    - Easy to use
    - Relies on Monte-Carlo method
    - Only a few radionuclides concerned
    - Infinite cloud is conservative vs. room of 300 m³
  - Use of Monte-Carlo calculations within the WG to test:
    - The effect of the ICRP 110 phantom vs. simple sphere
    - The effect of the size and orientation of the room

Use of FG 15 vs. FG 12 (current list)

- QE increase >30%
- QE decrease >30%
- QE variation <30%

Use of FG 15 vs. FG 12 (current list)

- QE increase >30%
- QE decrease >30%
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Methodology and parameters

A₂: multi-path cumulative dose principle

- Each scenario considers release fractions (participating to the dose):
  - Q_A, Q_B and Q_E: 100%
  - Q_C: 10⁻² - 10⁻³
  - Q_D: 10⁻²

- If a fraction of the activity contributes to the dose of a scenario, other fractions will contribute to the dose of other scenarios:
  - Total effective dose:
    - Q_A (~99%), Q_C (10⁻³), Q_{D,ingestion} (10⁻²); or Q_E (100 %)
  - Total skin equivalent dose:
    - Q_B (~99%), Q_{D,contamination} (10⁻²)

- This issue was addressed in §1.86 of SSG-26 but was not retained because it “applies only to a relative small number of radionuclides”

- Eventually, this statement will be checked.
Methodology and parameters

Neutron emitters

- In the current Q System, neutrons are considered negligible
  - No clear justification
  - Not even mentioned for $Q_D$ and $Q_E$
  - An arbitrary $Q_F = 10^4 Q_C$ was introduced to account for alpha and neutrons in $Q_A$
    - For radionuclides the $Q_A$ of which is too high
    - i.e. ~30 alpha emitters

- In fact, deterministic calculations were difficult to compute
  - The new method now permits to determine $Q_A$, $Q_B$, $Q_D$ and $Q_E$ values for neutrons

Preliminary results

- The current $Q_F$ covers $Q_A$ for 90% of spontaneous fission neutron emitters
- Updated $Q_A$, $Q_B$, $Q_D$ and $Q_E$ now account for the effects of spontaneous fission neutrons
Methodology and parameters

Neutron emitters

- \((\alpha,n)\) reactions are not yet considered
  - SF spectra exist in the ICRP 107
  - Watt-Cranberg spectra are well known

- \((\alpha,n)\) reactions depend mostly
  - on the target element
  - on the target/radionuclide mass ratio

- O and Be targets will be chosen
  - Oxydes are common material
  - Berylium has a high multiplication factor

- Mass ratio still under discussion
  - \(~0.1 \text{ to } 2\) for identified real sources
  - \(10\) covers \(~95\%\) of the maximal fluence

- \(\gamma\) emissions will also have to be considered
Parents and progenies
Parents and progenies

Current state

**Values for all radionuclides (parents or progenies) will be calculated**
- This is due to the new method for deriving A values (fluxes & doses coeff. databases)
- SSR-6 may then present $A_1$ and $A_2$ values for ~1 200 radionuclides, not only ~400
- Need to consider the same radionuclides as GSR Part 3 (consistency)?

**Should the consignor use the mixture law for all parents + progenies?**
- Common practice in safety reports
- Some transports are done **within hours** after the production of radionuclides
  - *The Q System currently applies the unclear and unjustified “10-day rule”*
- Footnotes are **sources of confusion** (many proposals to the TRANSSC to clarify them)
- But sometimes **difficult** to do that in practice
  - *All consignors may not have the necessary knowledge ➔ risk of error*
  - *Introducing values for all progenies would overcomplicate Table 2*

**An internationally validated tool might be needed**
Evaluating Q and A values

Tools developed by the WG for processing databases and comparing results
- Could be easily modified to automatically process the $A_1/A_2$ values and quantities
- Validation process and testing
- IAEA release

| Flux databases for each energy bin, each particle and each model (Monte Carlo) |
|-----------------|-----------------|-----------------|-----------------|
| $\Phi_Y$        | $\Phi_B$        | $\Phi_n$        | $\Phi_{RED}$    |
| $\Phi_{conta}$  | $\Phi_{sub}$    | etc.            |

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<td>Local skin dose coeff. for $n$</td>
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<td>Local skin dose coeff. for $e^+$</td>
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Interface tool for data processing

Q_A, Q_B, Q_C, Q_D, Q_E
A_1, A_2
Exemption values?
Further steps
Further steps

➡️ Global schedule

- Two meetings per year (TTEG before TRANSSC)
  - You are welcome to join!

- Main work to be finished
  - $(\alpha,n\gamma)$ reactions (no identified difficulty but many calculations)
  - Parents & progenies (quick once a decision is made)
  - $Q_C$ and $Q_{D,ingestion}$ (depends on ICRP schedule)
  - $Q_E$ (no identified difficulty but possibly many calculations)

➡️ Dedicated IAEA meeting

- Final decision about method of calculating $A_1$ and $A_2$ values cannot only be based on radiation protection considerations:
  - impact on transport economy and feasibility also need consideration

- Dedicated IAEA meeting to discuss the remaining issues in order to facilitate the final decision
Discussions