

REVIEW OF THE A_1 AND A_2 VALUES: FINAL CURTAIN?

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THE Q SYSTEM

IRSN

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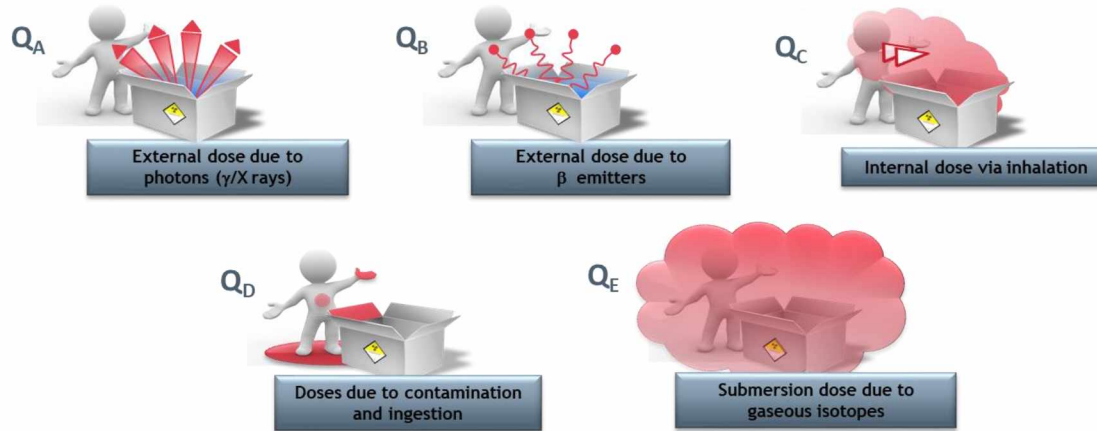
IRSN/IRSN-258 (ref. 06)

MEMBRE DE
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The Q system

[PRINCIPLES

The Q System was developed as a tool to perform a quick evaluation of **radiological consequences** in case of **accidents** involving a transport of radioactive materials, and to **classify radionuclides** according to their dangerousness in order to determine the **type of package** to be used.



General exposure model

- Loss of all safety functions
- 30 min
- 1 m of the package
- 300 m³ warehouse

Accident dose limits

- effective dose of 50 mSv,
- skin equivalent dose of 500 mSv,
- lens equivalent dose of 150 mSv

5 pathways

- external irradiation (effective, equivalent)
- inhalation, ingestion, contamination

Two activities are derived $\left\{ \begin{array}{l} A_1 = \min(Q_A, Q_B): \text{undispersible source, external exposure only; to be used for special form RM} \\ A_2 = \min(A_1, Q_C, Q_D, Q_E): \text{all other cases, internal/external exposure} \end{array} \right.$

The Q system

[HISTORY OF THE CLASSIFICATION SYSTEM

Q system first described during PATRAM 1980

- “Q₀ System” by Goldfinch & McDonald.
- Used since the 1985 edition

Legacy

- Radiotoxicity classification (1961 to 1967)
- A₁/A₂ System (1973)

Current A₁ and A₂ determined in 1995

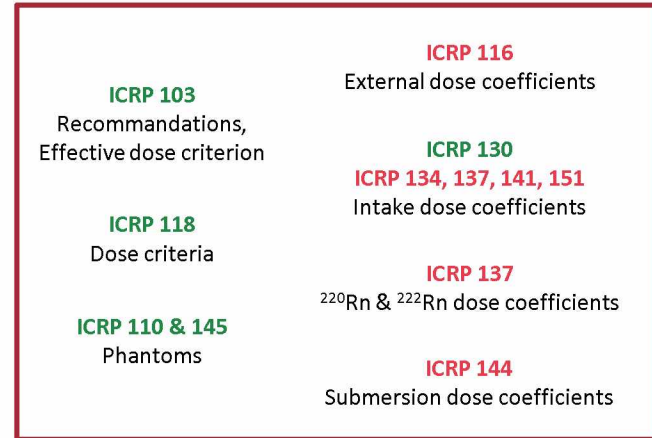
- ICRP 60 recommendations
- ICRP 38 spectra and ICRP 51 dose coeff. (Q_A)
- ICRP 68 intake dose coeff. (Q_C, Q_D)
- ICRP 32 Rn dose coefficients (Q_C)
- Cross et al. data (Q_B, Q_D)
- US Federal Guidance 12 (Q_E)
- Mostly deterministic methods

Chronology	ICRP Recom.	IAEA		Method
		Transport regulations	Method description	
1959	ICRP 1			-
1961		SS6	SS7	Radiotoxicity 3 groups
1962				SS9
1964	ICRP 6	SS6		Radiotoxicity 8 groups
1966	ICRP 9			
1967		SS6		SS9
1969	ICRP 15			Radiotoxicity 7 groups
1973		SS6	SS37	
1977	ICRP 26			A ₁ /A ₂ System
1982				SS9
1985		SS6		
1987			SS7	Q System
1991	ICRP 60			
1996		ST-1		SS115
2002			TS-G-1.1	
2007	ICRP 103			
2014				GSR Part 3
2018		SSR-6		
2022			SSG-26	

The Q system

[GENERAL ORGANIZATION

- WG A₁/A₂ created in September 2013 to review the Q System.
 - Difficulties to reproduce the method → Which confidence to define values for new RN?
 - New ICRP **recommendations**
 - New ICRP **data**
 - New calculation methods and approaches
- Calculation process agreed in 2016
 - Databases** are evaluated using ICRP philosophy & data
 - All particles** are considered (n, e⁺, e⁻, γ/X and α)
 - Use of **Monte-Carlo** calculation methods
 - Validation process**: 4 MC codes, 3 database-processing tools
- The fundamental approach of the Q system is not changed
 - The current scenarios represent a reasonable approach for the sake of safety

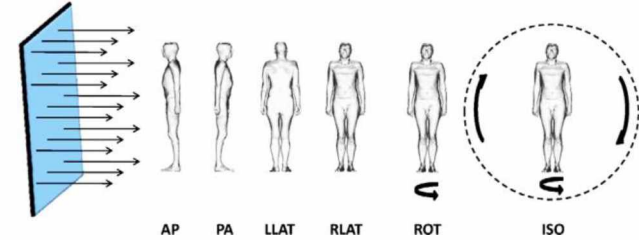
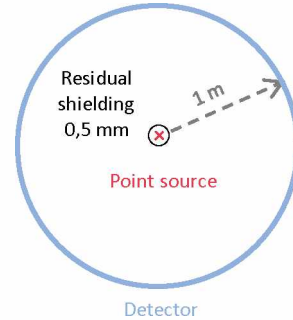


OVERVIEW OF THE UPDATE

Overview of the update

[EXTERNAL DOSE: Q_A AND Q_B

- Source as a point, detector as a sphere of radius 1 m (centered on the source)
- Residual shielding of 0.5 mm (stainless steel)



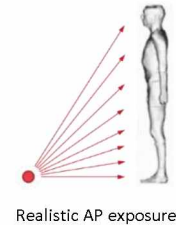
ICRP 116 exposure geometries

[Fluence calculations per unit energy emitted

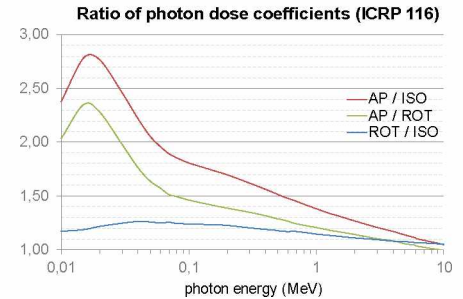
- Dose evaluated with any set of dose coefficients, any irradiation geometry and any spectrum

[Which irradiation geometry?

- Unlikely that an exposed person will remain static
- Parallel beam not realistic 1 m away from a small source
- No dose coefficients for all particles for LLAT, RLAT and ROT
- Differences between ROT and ISO are small



Realistic AP exposure



The WG decided to keep the ISO geometry dose coefficients

Overview of the update

[Q_A AND Q_B : DOSE DUE TO ($\alpha, n\gamma$) REACTIONS

- When α interacts with matter, neutrons can be emitted: e. g. $\alpha + {}^7\text{Li} \rightarrow {}^{10}\text{Be} + n$
 - This reaction is sought for certain sources such as Cm-Be
 - γ are also emitted in the process
- (α, n) reactions were not taken into account in the Q system
 - External dose due to α emissions were considered through an arbitrary $Q_F = 10^4 Q_C$ value
 - Except for ${}^{248}\text{Cm}$, ${}^{252}\text{Cf}$ and ${}^{254}\text{Cf}$, **neutrons were not considered**
 - ↗ *Now evaluated using ICRP 107 neutron spectra from SF, the WG transfer functions, and ICRP 116 dose coefficients*
 - ↗ *But ICRP 107 does not provide any spectrum for ($\alpha, n\gamma$) reactions*
- No « fast » way to evaluate the n/ γ dose for all alpha emitters
 - More than 130 radionuclides
 - Many targets (O, F, Be, Li, etc.)



Necessity to develop a method to address this kind of reaction

Overview of the update

[Q_A AND Q_B : DOSE DUE TO ($\alpha, n\gamma$) REACTIONS

Use of SOURCES4C software and TALYS code

O and Be targets are studied

- Oxides are common chemical forms
- Beryllium has a high multiplication factor

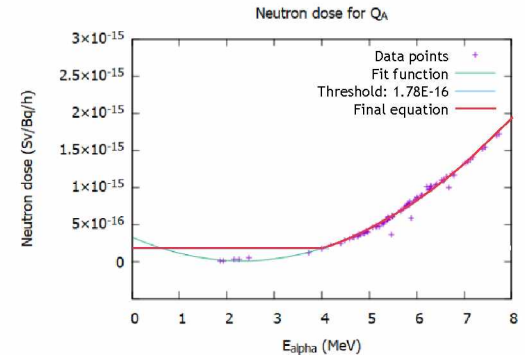
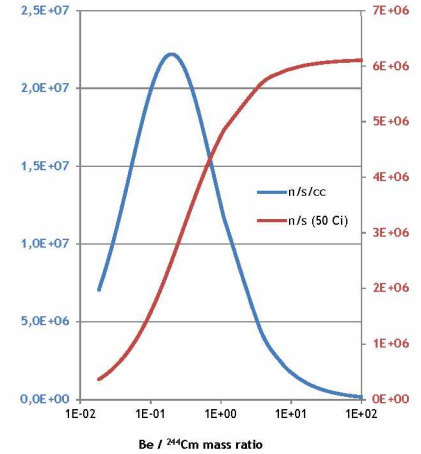
Ratio between the RN and the target to cover most current uses:

- Mass ratio of 5 for Be
- Atomic ratio of 5 for O

Development of energy-to-dose equations by the WG

Eventually, the former Q_F can be discarded

- It was conservative for most RN, e.g. ^{241}Am , ^{244}Cm
- Not conservative for e.g. ^{212}Bi

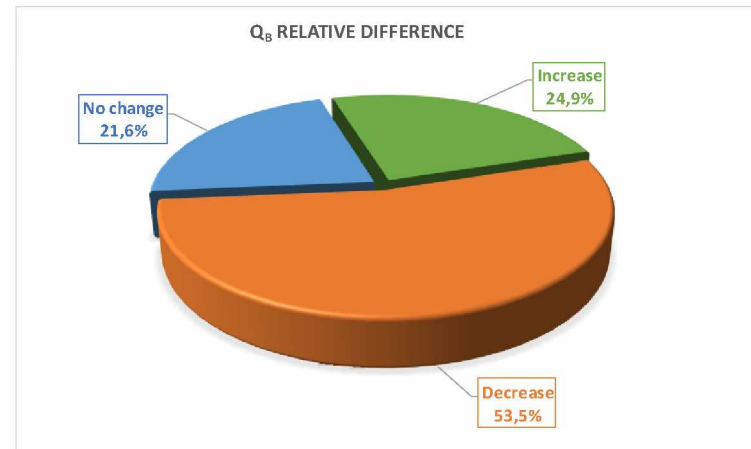
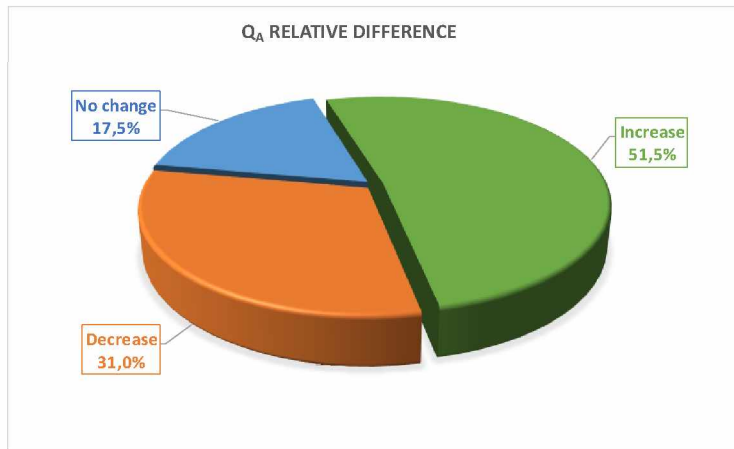


Overview of the update

[Q_A AND Q_B : EVOLUTION OF VALUES

■ Main hypothesis

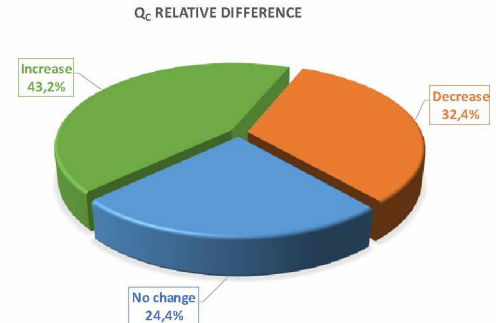
- 387 radionuclides from SSR-6
- Local skin dose coefficients (new)
- ICRP 107 spectra, ICRP 116 dose coefficients (new)
- All radiations, including ($\alpha, n\gamma$) reactions (new)
- Residual shielding for all radiations (new)
- ISO geometry
- Progenies consideration from SSR-6
- Unlimited Q_A and Q_B value ~ 1 tonne (new)



Overview of the update

[INTAKE DOSE: Q_C AND $Q_{D,ING}$

- All new intake data from ICRP are published (publications 130, 134, 137, 141 and 151)
- Scenarios kept as is
 - Q_C : resuspension factors and breathing rate for 30 minute → total factor of 10^{-6}
 - $Q_{D,ing}$: spreading on the ground, transfer to hands then mouth within 24h → total factor of 10^{-6}
- Method agreed by the WG
 - **Inhalation**: conservative values for particle sizes (AMAD) of 5 μm (workers) and 1 μm (public)
 - **Ingestion**: now fully considered
 - Worst chemical form is used, as in the current Q System
- Noteworthy outcomes
 - Except for iodine isotopes, ingestion is not the leading scenario
 - The ^{235}U enrichment, below which the A_2 value of U(enriched) is unlimited, is no longer 20 % (closer to 11%)



Overview of the update

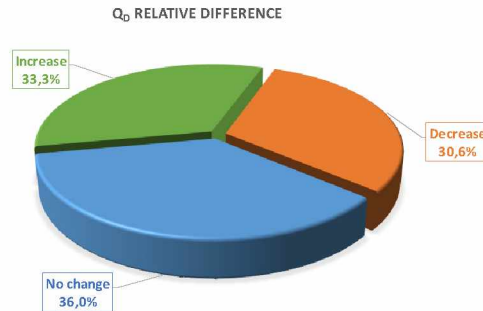
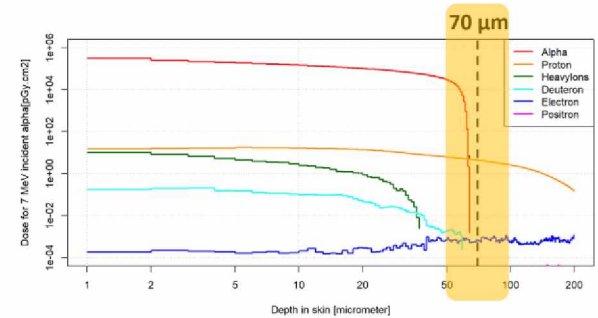
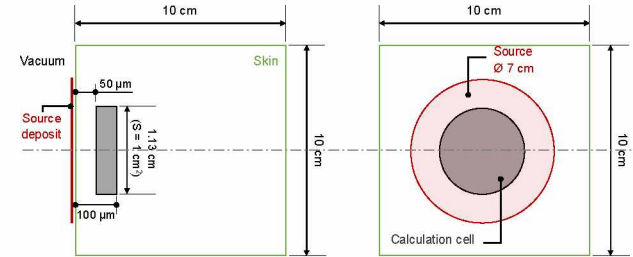
[CONTAMINATION DOSE: $Q_{D,SKIN}$

Dose due to contamination determined using MC method

- ICRP 116 model for local skin dose
- Surface source instead of parallel beam
- Evaluation of energy-dependent dose coefficients

Alpha contamination (+ secondary protons)

- Effect on the dose significant above 7 MeV
- Important decrease in $Q_{D,skin}$ values for high-energy α emitters
➤ ...and other RN with alpha-emitting daughters (10-day rule)



Overview of the update

[SUBMERSION DOSE: Q_E

■ Q_E values currently determined with the U.S. Federal Guidance Report No. 12

- Except for ^{222}Rn (and ^{220}Rn) for which Q_E was determined using ICRP 32

■ All databases updated since then

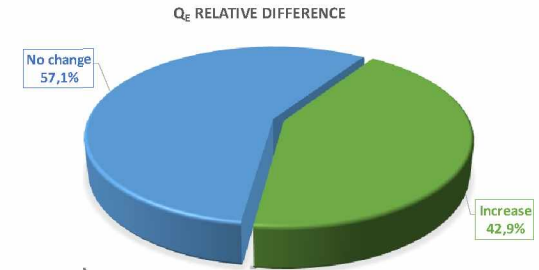
- FGR 12 was superseded by FGR 15
- ICRP 32 was superseded by ICRP 137

■ ICRP publications also include submersion dose coefficients

- **ICRP 144**: effective & skin equivalent dose coefficients (ICRP 145 phantom)
- **ICRP 151**: effective dose coefficients for different volumes (ICRP 110 phantom)
↗ *But no “volume” effect evaluated for the skin equivalent dose coefficients*

■ For consistency purposes, the WG decided to use **ICRP 144** and **ICRP 137** dose coefficients.

- No new Q_E value decreases



Overview of the update

[THE 10-DAY RULE: EQUILIBRIUM WITH PROGENIES

Q System definition of the « 10-day rule »

- if $T_{1/2}$ of daughter RN < 10 days and < $T_{1/2}$ of parent RN, then all RNs are in equilibrium
- In all other cases, they should be considered in a mixture law

Consequence: the parent RN bears the energy emissions of all RNs.

- Q (Parent RN+) is always lower than Q (daughters RN)

This rule allows the consignor to consider only the activity of parent RNs

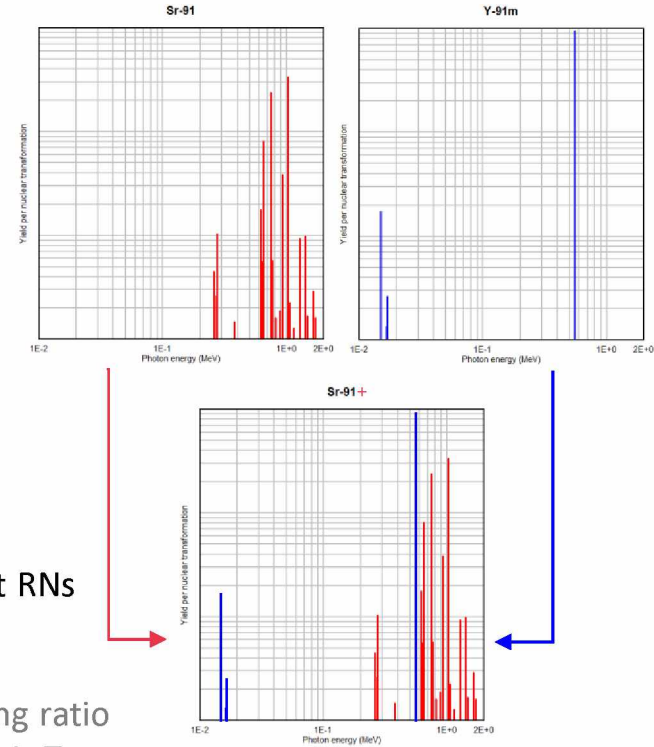
Two kinds of equilibria

- **Secular:** activity of daughter RNs = activity of parent RN x branching ratio
- **Transient:** the activity ratio daughter/parent highly depend on their $T_{1/2}$

↗ Many values for RNs in table 2 were not consistent with the rule. Use of another criterion?

The WG then considered the theoretical equilibria for each RN_i:

$$\frac{A_i(\infty)}{A_1(\infty)} = \left(\prod_{i=2}^i f_{i-1,i} \right) \frac{T_1^{i-1}}{\prod_{i=2}^i T_1 - T_i}$$

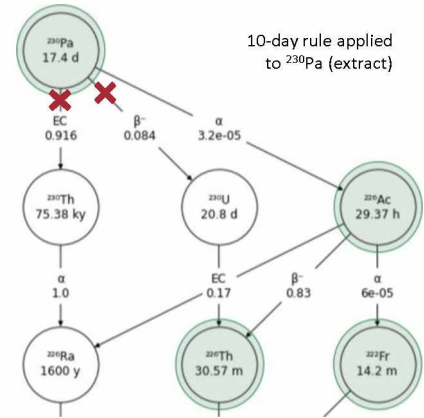


Overview of the update

[THE 10-DAY RULE: PROPOSALS OF THE WG

Also, practical issues with the 10-day rule:

- Transport can be done within hours
- Mixtures may not be in equilibrium when loaded in a package
- Branches of decay chains may be broken
- RNs may be forgotten if they were considered included in other decay chains



A solution to deal with all those issues, would be to let the consignor/designer perform the calculation using the mixture rule:

- ✓ More accurate: no penalizing/underestimating situation
- ✓ No footnote (a)
- ✓ Lesser risk of error of interpretation in the current method (“where does my ^{90}Y come from?”)
- ✗ Larger Table 2
- ✗ Stakeholders to quickly adapt to the new method
- ✗ Time of transport to be considered



Should SSR-6 allow the possibility to use both methods? Distribution of a validated tool?

OVERVIEW OF THE RESULTS

Overview of the results

[SUMMARY OF THE UPDATE

What was kept

- Exposure scenarios
- Effective and skin equivalent dose criteria
- Treatment of progenies through the 10-day rule
- Basis for the “unlimited values”

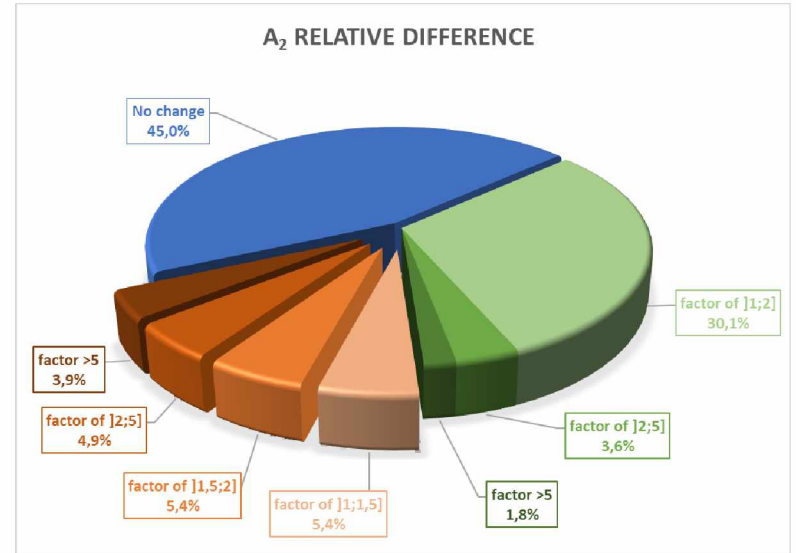
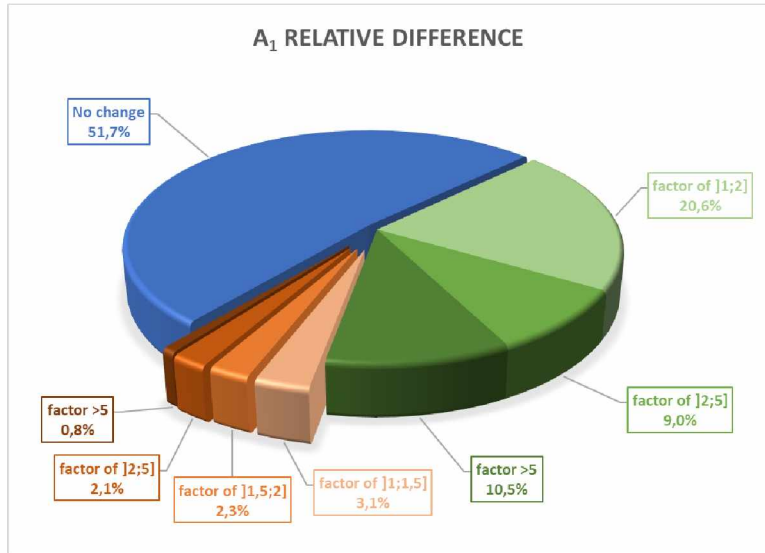
What was updated

- ICRP recommendations, data and calculation methods
- Effects from all radiations for all scenarios
- Eye lens accident dose criterion
- Simplification of the process for future updates
- Harmonization of the way doses are calculated (local and mean doses)
- Q_A and Q_B : harmonization of the model with a shielding factor, $(\alpha, n\gamma)$ taken into account
- Q_C : workers and public dose coefficients
- Q_D : ingestion dose calculated, α contamination considered
- Q_E : ICRP model considered
- Q_F : discarded



Overview of the results

[EVOLUTION OF A₁ AND A₂ VALUES



Discussions

[THANK YOU FOR YOUR ATTENTION !



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