The "Q System" and the Radiotoxicity of the Radionuclides

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INTRODUCTION

The first edition of the International Atomic Energy Agency (IAEA) "Regulations for the safe transport of radioactive materials" was issued in 1962 (IAEA Vienna 1962). The transported radionuclides were distributed into three groups according to their radiotoxicity. The radiotoxicity was evaluated by means of an "injury index" taking into account the dose equivalent received following a "mean accident" by incorporation, by inhalation, by ingestion or by wound. The 1962 regulations introduced the terminology of type A and type B packages and the nature of "mean accident" during which a person can incorporate an activity equal to $1/10^6$ of the activity contained in the type A package. The reference dose equivalent was equal to 1/4 of the annual limit of equivalent dose for workers (in the following, we use "dose" in place of "equivalent dose").

Following these criteria the transported radionuclides were distributed into three groups of radiotoxicity :

Very high - High - Low or moderate.

The nature of "special form materials" and of "low specific activity materials (LSA)" was also introduced by reference to the incorporation of a mass superior to 1 mg.

These provisions are summarized in Table 1.

IAEA TRANSPORT REGULATIONS - 1962				
Table 1	Max. Activity/Package			
Type of package	Group of toxicity I	II	III	Special form
A	10μCi	10mCi	2Ci	20Ci
B	20Ci	20Ci	200Ci	2000Ci
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THE IAEA RADIOTOXICITY CLASSIFICATION (1963)

In 1963 the IAEA issued a "Basic toxicity classification of radionuclides" (IAEA Vienna 1963). In this document the radiotoxicity of a radionuclide is defined as "its capacity to produce a damage in an human being by means of the radiations it emits" when incorporated in the body.

This classification considers inhalation as the most significant route of incorporation. The radiotoxocity of a radionuclide is estimated as a function of the "maximum permissible annual intake by inhalation" equivalent to the present "annual limit of intake by inhalation (ALI)". The reference dose is the value of the annual limit of dose for workers (5 rem or 50 mSv).

Thus, the radionuclides are classified in four radiotoxicity groups according to their ALI by inhalation in the following manner :

1. Putting on a vertical axis the values of the A.L.I. of the radionuclides in μCi, a scale of values ranging from 10^{-3} μCi (37 Bq) to 10^{5} μCi ($3.7.10^{-3}$ TBq) i.e. extending on 8 orders of magnitude is obtained. Arbitrary limits of the A.L.I. have been choosen to define the groups :

- a horizontal line drawn at 1 μCi (37 KBq) delimits a class (interval 10^{-3}-10° μCi) gathering the most toxic radionuclides.

- taking a module of 10^{2} a line drawn at 10^{2} μCi (37.10^{2}KBq) delimits a class of "mean high toxicity".

- a third line drawn at 10^{4} μCi (37.10^{4} KBq) delimits a class of "mean low toxicity".

- lastly the radionuclides having an A.L.I. higher than 10^{4} μCi (37.10^{4} KBq) are gathered in the "low toxicity class".

2. The 1963 radiotoxicological classification takes also into account the mass of inhaled matter, and introduce definitively the consideration of the ALI in mass, calculated using the specific activity of the radionuclide. Putting the ALI in mass on a horizontal axis leads to a bidimensional classification organized in the plan.

The ALI in activity are associated with variable masses of material but these associated masses may reach values so high that it would be quite impossible for a man to incorporate at a time such a mass by inhalation. For example, the ALI in mass calculated for uranium 238 is about 4 grams. More generally, it was considered very improbable that one person could incorporate at a time by inhalation during an accident a mass of material exceeding 10 mg. Thus a vertical line drawn at 10 mg (10^{4} μg) delimits a number of radionuclides which although theorically of "high toxicity" could not be inhaled in sufficient quantity to reach the annual dose limits. By definition they are the nuclides of low specific activity (LSA) downgraded in the group IV of the classification (low toxicity). A similar reasoning considers that the radionuclides with an associated mass between 100 μg and 10 mg can not be considered as of high toxicity and downgrades them into group II (medium high toxicity).

These dispositions are summarized in Table 2 and Figure 1 :

TABLE 2			
IAEA's 1963 RADIOTOXIC. CLASSIFICATION			
DELIMITATION OF THE RADIOTOXICITY GROUPS			
Group of radiotoxity	A.L.I. in μCi	in Bq	A.L.I. in mass
High	< 1	37.10^3	<100 μg
Mean high	$1-10^2$	37.10^5	100μg<10mg
Mean low	10^2-10^4	37.10^7	<10mg
Low	> 10^4	>37.10^7	>10mg

This 1963 classification is not well known today. Nevertheless it is a basic element of radiation protection. It has inspired the 1967 IAEA's transport regulations (IAEA-Vienna 1967) and given birth to the present radiotoxicological classifications (EURATOM and FRANCE).

THE 1967 IAEA TRANSPORT REGULATIONS

A first revision of the transport regulations was made in 1964 but was not published. Thus we will consider the 1967 issue applied until 1973 as a reference text.

The 1967 issue adopts as a basic concept the notion of "mean accident" releasing 10^{-3} of the content of an A package and resulting in the incorporation by inhalation of 10^{-6} of the content by a person involved in this accident.

The reference dose is the quarterly limit of dose for workers i.e. 1/4 of the reference dose considered in the 1963 radiotoxicological classification, which results in a difference in the group delimitation.

Just as the radiotoxicological classification, the 1967 transport regulations takes in consideration the mass associated to the hypothetic incorporation (10^{-6}A2) and considers as very improbable the incorporation by a person of more than 10 mg of material.

DELIMITATION OF THE GROUPS AND COMPARISON WITH THE 1963 RADIOTOXICOLOGICAL CLASSIFICATION

The delimitation of the groups in the 1987 transport regulations was realized in a somewhat arbitrary basis. The limit for a group is the lowest value of the ALIs for the most toxic radionuclide of the group (ALI : 10^{-6} A2 content). By consideration of external irradiation, the maximum value of the activity intake for group 3 is limited to 20 μCi in the transport regulations whereas it is 100 μCi in the radiotoxicological classification. This results in a very different group distribution of the radionuclides between both classification (Table 3).

The distribution of the radionuclides is more regular in the radiotoxicological classification. In the transport regulations a majority of radionuclides is found in group IV.

TABLE 3		CLASSES OF RADIOTOXICITY			
		I	II	III	IV
Radiotoxic. classif. 1963	Activity limits μCi	10^{-4}-1	1-10^2	10^2-10^4	> 10^4
	Nb of radionucl.	40	43	145	19
Transport Regulations 1967	Activity limits μCi	10^{-3} 5.10^{-2}	$5\ 10^{-2}$ 3	3 20	>20
	Nb of radionucl.	22	13	74	150

THE 1973 IAEA'S TRANSPORT REGULATIONS

The fact that the activity limits for each group in the 1967 regulations was taken as the lowest ALI values of the radionuclides of the group was very limitative. The big innovation in the 1973 IAEA's transport regulations was the suppressions of the groups and the introduction of individual limits A1 and A2 for each radionuclide, instead of a single limit for the whole group.

The limit A1 accounts for the external irradiation dose emitted by the radionuclides and limit A2 for the committed dose equivalent resulting from the incorporation of 10^{-6} A2 by a worker or by a person of the public present on the site of the accident. The most significant pathway of internal contamination is the incorporation by inhalation (and incorporation by wound in some rare cases).

THE 1985 REVISION OF THE IAEA'S REGULATIONS : INTRODUCTION OF THE Q SYSTEM

The "Q system" proposed in 1982 by H.F. MAC DONALD and E.P. GOLDFINCH distinguishes the exposure pathways to man retaining two principal routes of exposure by a dispersable radionuclide besides external exposure to noble gases :

- incorporation by inhalation
- contamination of the skin and subsidiary incorporation by ingestion

The computed A2 values vary according to the importance of the dose received when the radionuclide is incorporated or enters in contact with the skin. Although these values have not been calculated by the authors to that purpose, they are by itself an expression of the radiotoxicity of the radionuclides taking into account not only one but various (3) exposure pathways of the human body including external irradiation.

By consideration of the masses of the radionuclides associated to the values of A2, one can obtain a bidimensional classification very similar to the 1963 classification, and which it is interesting to compare with the radiotoxicological classification included in the EURATOM directives (CCE EURATOM-BRUXELLES 1984). This comparison is made easier by the fact that in both cases the reference dose is the annual limit of the effective dose equivalent (50 mSv).

The EURATOM classification distributes the radionuclides into four groups defined by the following limits of activity (or mass) (Table 4).

TABLE 4

EURATOM RADIOTOXICITY CLASSIFICATION

	ALIS OF THE RADIONUCLIDES		
GROUP	ACTIVITY		MASS
	μCi	Bq	mg
I	10^{-3} - 1	2.10^{1}-4.10^{4}	< 0,1 mg
2	1 - 10^{2}	5.10^{4}-5.10^{6}	< 0,1 mg
3	10^{2} - 10^{4}	5.10^{6}-5.10^{8}	
4	> 10^{4}	> 5.10^{8}	> 10 mg

It may be interesting to class the nuclides listed in the Table 1 of the 1985 transport regulations according to their increasing values of A2 and ALI=10^{-6}A2 in activity, the nuclides having the same value of A2 being secondly classified according to their increasing value of A2 in mass.

The classification obtained may then be compared with the EURATOM classification taking note of the group to which they belong. Normally, the nuclides having the lowest values of A2 must fall in group I, then in group 2, etc. This comparison shows that there is a good agreement between both classifications. Almost all the radionuclides with the lowest values of A2 and ALI happen to be in group I of the EURATOM classification. The exceptions concern nuclides with ALI in mass above 0.1 mg.

The problem becomes then a little more complex because A2, for a given number of radionuclides is limitated by the dose received by external irradiation (A2 < A1). But this discrepancy disappears when considering the A2 values calculated on the basis of the incorporation by inhalation (Qc).

There rises a second difficulty due to taking into account the dose received by skin contamination (using Qd instead of Qc for the calculation of A2) which results in downgrading a certain number (90) of radionuclides. In this particular case, one can calculate a "fictive ALI" by dividing the A2 value by 10^{6} and continue to compare their ranking with the EURATOM classification.

Among the 90 radionuclides concerned :

- 15 fall in the same radiotoxicity group
- 55 fall from group 3 to group 2
- 20 fall from group 4 to group 2.

Taking into account contamination of the skin by consideration of the Qd value increases the apparent toxicity of the radionuclides radionuclides concerned. This may be due to the calculation hypothesis, which assumes a time of contact of 5 hours with the skin, although the exposure time commonly used in the case of accidental exposures ranges generally from 1/2 hour to 1 hour.

To summarize, although it was not developped to this purpose, the "Q system" by use of some arrangements, may provide a good basis for establishing a classification of the radionuclides according to their radiotoxicity. This classification would account not only for the incorporation risk but also for the external irradiation risk. Finally, although the IAEA has been the promoter of the first radiotoxical classification in date (1963) it has not carried out its work. Presently, there is no radiotoxicological classification in the IAEA basic safety standards (AIEA safety series N° 9).

Thus, some expressions such as "radionuclides emitters of high or low toxicity" refer to no existing classification criteria. This gap could be easily filled by adoption of a classification which could be inspired as we have just exposed it, from the calculations made for transportation purposes.

Insofar as it accounts for both irradiation and incorporation risk, the availability of such a radiotoxicological classification could for example help to solve the problem of calculation of limits for surface contamination of the packages. In the same concern, it could perhaps help to define some secondary limits relative to exemption or disposal of some low level contaminated materials.

CONCLUSION

This work constitues an effort of reflexion about some aspects of the transport regulations and their incorporation into the general IAEA radiation protection regulations. Its aim is not to give rise to the nth revision of the transport regulations which have already been deeply modified during the last decade. But the practice of the transport of radioactive materials raises always new practical problems and calls for the definition of new secondary limits. These adaptations must be carried out in continuity with the main concepts of the transport regulations and in accordance with the general IAEA radiation protection standards.

REFERENCES

A basic toxicity classification of radionuclides, IAEA Vienna (1963)

Basic safety standards, IAEA Vienna, Safety Series N°9, (1984)

Journal officiel des Communautés Européennes, CCE L 265 (1984)

MAC DONALD H.F., GOLDFINCH E.P., *The "Q system" for the calculation of A1 and A2 values within the AIEA's regulations for the safet transport of radioactive materials*, CEGB, TPRD, R-83-(1983)

Regulations for the safe transport of radioactive materials, Safety Series N°6, IAEA Vienna (1962), Safety Series N°6, IAEA Vienna (1967), Safety Series N°6, IAEA Vienna (1973), Safety Series N°6, IAEA Vienna (1985).

FIG 1 - TABLE FOR A BASIC TOXICITY CLASSIFICATION OF RADIONUCLIDES