STUDY OF SEVERAL POTENTIAL EXPOSURE PATHS FOR ON-SITE TRANSPORT ACCIDENT SCENARIOS TO DEFINE A FRENCH ON-SITE Q-SYSTEM

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ABSTRACT

Following a request of the French Defence Transport Safety Committee, consideration has been given to the activity content limits corresponding to exemption of package design approval by the competent authority for on-site handling and transport of radioactive materials. We have built a system that is both consistent with the Q-system and specific to on-site transports of radioactive materials. It leads to activity content limits different from those authorised on a public road along with requirements, such as instructions to be applied by the drivers in case of on-site incidents or accidents, transmission of alert, means of radiation detection or radiation protection equipment available to the drivers and the emergency staff.

INTRODUCTION

Following a request of the French Defence Transport Safety Committee, consideration has been given to the activity content limits corresponding to exemption of package design approval by the competent authority for on-site handling and transport of radioactive materials.

The study methodology is the same as the one used for the Q-system developed in the IAEA Advisory Material for Transport Regulations under which various exposure pathways are considered, each of which might lead to radiation exposure, external or internal, to individuals in the vicinity of a Type A package involved in a transport accident. In the Q-system, specific assumptions concerning the exposure pathways are used along with radiological criteria which allow to determine, for individual radionuclides, the activity content limits for special form (non-dispersible) and non-special form (dispersible) authorised to be transported in Type A packages on a public road.

After a review of the scenarios described in the Q-system, we have checked if the values of the parameters used in these scenarios (exposure times, distances, release fractions, etc.) should be kept or modified to account for the actual conditions of the transport performed within nuclear sites. When it is justified to modify some of the parameter values, the activity content limits need to be recalculated.

REMINDER OF THE Q-SYSTEM

The Q-system is the calculation system used to determine the maximum activity of radioactive materials that can be transported in a Type A package, for each radionuclide. The basic principle is that the activities should be tolerable if a package is involved in an accident and if it loses its confinement and shielding functions.

The Q-system is based on five scenarios (A, B, C, D, E), involving external or internal exposure of individuals close to the package on which the accident occurred. Each scenario corresponds to a particular exposure pathway, and the activity content limit Q for each radionuclide is calculated,

assuming that an individual will stay one meter from the damaged package during less than 30 minutes with respect of the following dosimetric criteria:
- the effective dose, or the committed effective dose received by an individual close to a damaged package, shall not exceed the dose limit of 50 mSv,
- the equivalent dose, or the committed equivalent dose to organs including the skin, received by an individual involved in an accident, shall not exceed the dose limit of 500 mSv, or 150 mSv in the case of the lens of the eye.

Thus, five activity content limits were determined for each radionuclide, denoted Q_A, Q_B, Q_C, Q_D and Q_E respectively. The value A1 for materials in special form (i.e. in solid non-dispersible form or in the form of a strong sealed capsule) is equal to the minimum value of Q_A and Q_B (external exposure scenarios). The value A2 for materials in non-special form is equal to the minimum value of Q_A, Q_B, Q_C, Q_D and Q_E.

The five following scenarios are considered:

- Scenario Q_A : External dose due to photons

Q_A is calculated assuming that an individual 1 m from the damaged package that has lost all protections during the accident, is exposed to the maximum external dose rate (assumption of a point source without shield) over the entire body, due to γ or X rays, equal to 50 mSv for 30 minutes.

- Scenario Q_B : External dose due to β emitters.

Q_B is calculated assuming that an individual 1 m from the damaged package that is no longer protected at all following the accident, is exposed to the maximum external dose rate to the skin, due to β radiation, equal to 500 mSv for 30 minutes.

- Scenario Q_C : Internal dose via inhalation

Q_C is calculated assuming that an individual close to the damaged package will inhale a fraction of the package content put in suspension at the time of the accident, thus committing a maximum internal dose equal to 50 mSv. Three scenarios involving workers and members of the public located inside a room, in a vehicle and outdoors are considered.

- Scenario Q_D : Dose to the skin by contamination

Q_D is calculated assuming that an individual using his bare hands to manipulate a damaged package containing material in non-special form is exposed to the maximum external dose rate to the skin, by direct contact to β emitters, equal to 500 mSv for 5 hours.

- Scenario Q_E : Submersion dose due to gaseous isotopes

Q_E is calculated assuming that an individual located in a closed room where 100% of the activity content or the package has been released in gaseous form is exposed to the maximum external dose rate equal to 50 mSv for 30 minutes.

The parameters used in the scenarios are summarized in Table 1.

Table 1 - Exposure pathways, scenarios and parameters of the Q-system

Exposure pathways	Parameters
External irradiation by photons	• Effective dose limit : 50 mSv • Distance to package : 1 m

	• Exposure time : 30 minutes
External irradiation by ß emitters	• Equivalent dose limit to the skin : 500 mSv • Distance to package: 1 m • Exposure time : 30 minutes
Internal contamination by inhalation inside a room	• Effective dose limit : 50 mSv • Fraction put into suspension : 10^{-3}-10^{-2} • Room volume : 300 m^3 • Air change rates in the room : 4 h^{-1} • Inhalable fraction : 10^{-4}-10^{-3} • Breathing rate : 1.2 $m^3.h^{-1}$
Internal contamination by inhalation in a vehicle	• Effective dose limit : 50 mSv • Fraction put into suspension : 10^{-3}-10^{-2} • Vehicle volume : 50 m^3 • Air change rates in the vehicle : 10 h^{-1} • Inhalable fraction : 10^{-3} • Breathing rate : 1.2 $m^3.h^{-1}$
Internal contamination by inhalation outdoors	• Effective dose limit : 50 mSv • Distance to package : 100 m downwind • Fraction put into suspension : 10^{-3}-10^{-2} • Inhalable fraction : 3.3 $x10^{-7}$ • Breathing rate : 1.2 $m^3.h^{-1}$
Skin contamination	• Equivalent dose limit to the skin : 500 mSv • Distance to package : on contact • Exposure time : 5 hours • Spilled fraction : 1% of the package over 1 m^2 • Contaminating fraction : 10% of the spilled fraction
External irradiation by gaseous isotopes	• Equivalent dose limit to the skin : 500 mSv • Room volume : 300 m^3 • Air change rates in the room : 4 h^{-1} • Exposure time : 30 minutes

MODIFICATIONS MADE TO Q-SYSTEM PARAMETERS

Accident conditions

Speed before collision is less than 40 km/h (speed limit on most sites). It is assumed that the driver does not remain trapped in the vehicle at this speed, and is therefore able to perform the actions recommended for the situation.

Exposed individuals

- Driver
- Intervention personnel
- Witness on the place and at the time of the accident
- Witness in a building close to the place of the accident

Scenarios

- Driver scenario

It is assumed that the driver has an operational electronic dosimeter with an alarm set to 50 µSv. Two situations can arise:

1. The dosimeter alarm is triggered at the time of the accident, meaning a dose due to γ radiation exceeding 50 µSv : the driver leaves the place of the accident and informs the intervention personnel. It is estimated that the driver spent 15 seconds at a distance of 1 m from the package before the alarm was triggered.
2. The dosimeter alarm is not triggered at the time of the accident, meaning that the dose due to γ radiation is less than 50 µSv. The driver then performs the following operations:
   - Examines the package inside the vehicle: 5 minutes at 1 m from the package, wearing a mask
   - Informs the intervention personnel : no exposure
   - Marks the site : 2 minutes beyond 5 m
   - Waits for intervention personnel : 3 minutes beyond 5 m
   - Leaves the place of the accident after the arrival of the intervention personnel (this procedure should be specified)
   - No contamination to the hands since elastomer protection gloves are worn
   - If the dosimeter alarm trips while the driver is performing these operations, meaning that the dose due to γ radiation is greater than 50 µSv, the driver leaves the place of the accident and the situation is the same as situation 1.

Since an operational electronic dosimeter is worn with an alarm set to 50 µSv, this scenario is not critical for external irradiation due to γ radiation, but it is important for internal contamination.

- Intervention agent scenario

Intervention personnel wearing a mask and elastomer protection gloves arrive on the site of the accident 5 minutes after being called by the driver, or 10 minutes after the accident.

It is assumed that the intervention agent is equipped with an operational electronic dosimeter with an alarm set to 50 µSv. Two situations can arise:

1. The dosimeter alarm is not triggered at the time of the accident, meaning that the dose due to γ radiation is less than 50 µSv. The intervention agent then performs the following operations:
   a) Measurement of the dose rate at 1 m from the package and of surface contact smears : 2 minutes
   b) Site mapping at 10 m from the package, either to verify the marking put in place by the driver, to confirm it or move it, or to put marking into place : 15 minutes
   c) If the package is damaged and if an immediate action is taken to repair the package, 1 minute at 1 m
   d) The case in which a longer action is necessary is not considered, since it would then require concerted action
   e) Fire: intervention agent wearing appropriate clothing and individual breathing apparatus, fire hose at 3 m for 5 minutes
   f) Rain: placement of sand bags to block the drains, 15 minutes at 10 m.

2. The dosimeter alarm trips, meaning that the dose due to γ radiation is greater than 50 μSv, the intervention agent does not approach the package closer than the trigger point. He performs operations c) to f) directly.

- Scenario of a witness on the place and at the time of the accident
  - At the time of the accident : 1 minute at 5 m
  - After the accident : 4 minutes at 10 m, then 5 minutes minimum at the limit of the alarm of the driver's operational dosimeter, namely in an area in which the dose rate is less than 2.5 μSv/h.
- Scenario of a witness in a building on the accident place
  - 15 minutes at 5 m without protection, without being informed of the accident. Then evacuation if necessary.

Exposure pathways considered

- External irradiation by photons
- External irradiation by β radiation
- Internal contamination by inhalation of aerosols
- No skin contamination (intervention personnel wear elastomer protection gloves)
- No external irradiation due to gaseous isotopes alone (for example krypton or xenon), since in any case a release of such isotopes would result in doses lower than would be caused by other transported radionuclides
- No internal contamination by soluble gases that could be absorbed by the body after inhalation (for example I, C)
- No special scenario related to liquid contamination by a liquid radioactive material or a material that could be soluble or in suspension in the water, was considered. The only operations considered in evaluating the scenarios were operations performed by intervention personnel to block up drain openings.

Dose limits

- the effective dose or the committed effective dose to an individual close to a damaged package shall not exceed the dose limit of 50 mSv,
- the equivalent dose, or the committed equivalent dose affecting organs including the skin, received by an individual involved in an accident, shall not exceed the dose limit of 500 mSv, or 150 mSv in the case of the lens of the eye.

CALCULATION OF ACTIVITY QUANTITIES FOR ON-SITE TRANSPORT

Calculation of Q'_A for external irradiation by photons

It is assumed that the damaged package has lost all its protections. In the Q-system, Q_A is calculated assuming that an individual 1 m from the damaged package that has lost all protection during the accident is exposed for 30 minutes to the maximum external dose rate (assumption of a point source without shield) to the entire body of 50 mSv, or 0.1 $Sv.h^{-1}$, due to γ or X rays.

Since the dose due to external irradiation by photons is proportional to the time spent and is inversely proportional to the square of the distance from the source, Q'_A may be derived from Q_A for the exposed individuals.

Table 2 - Values of Q'_A

Exposed individuals	Scenario parameters	Q'_A
Driver	• 15 s at 1 m and dose less than 50 µSv	120 Q_A
Intervention agent	• 5 min at 3 m and dose less than 50 µSv	≅ 54 Q_A
Witness on the accident place	• 1 min at 5 m • 4 min at 10 m	≅ 375 Q_A
Witness in a building on the accident place	• 15 min at 5 m	≅ 50 Q_A

Calculation of Q'_B for external irradiation by beta radiation

It is assumed that the damaged package has lost all its protection. In the Q-system, Q_B is calculated assuming that an individual located 1 m from the damaged package that has lost all protection during the accident, is exposed to the maximum external dose rate (assumed point source without shield) to the skin of 500 mSv from β radiation, for 30 minutes.

The dose due to external irradiation by β radiation is proportional to the time spent, and may be supposed in a conservative approach as inversely proportional to the square of the distance from the source. Then Q'_B may be derived from Q_B for the exposed individuals.

Table 3 - Values of Q'_B

Exposed individuals	Scenario parameters	Q'_B
Driver	• 5 min at 1m • 5 min at 5 m	≅ 6 Q_B
Intervention agent	• 2 min at 1m • 15 min at 10 m • 3 min at 1 m or 5 min at 3 m or 15 min at 10m • or 5 min at 1m and 15 min at 10m	≅ 10 Q_B
Witness on the accident place	• 1 min at 5 m • 4 min at 10 m	≅ 375 Q_B
Witness in a building on the accident place	• 15 min at 5 m	≅ 50 Q_B

When individuals are at a distance exceeding 1 m from the package, attenuation of beta radiation due to air is underestimated in the calculation; so Q'_B is conservative. Anyway, Table 3 shows that the values of Q'_B for distances exceeding 1 m are not critical in determining the final value of Q'_B.

Calculation of Q'_C for internal contamination by inhalation

We consider only the two scenarios in the vehicle and outdoors. In the Q-system, Q_C is calculated assuming that the exposed individual commits a maximum internal dose of 50 mSv due to an activity equal to 10^{-6} x Q_C .

- Scenario inside the vehicle

- 5 m^3 vehicle volume, changed 10 times per hour

- the driver or the intervention agent inspects the package for 5 minutes
- he wears a mask with an efficiency of 100 (conventional dust + iodine cartridge)
- breathing rate 1.2 m^3/h
- resuspension factor: it can be assumed that the severity of the shock caused by a collision on-site is not as great as it could be on the public road, due to the speed limit. Furthermore, it has been assumed an enhanced performance of package containment at low energy impacts. Therefore, a severity attenuation factor 100 has been assumed for mechanical accidents, which means that the quantity of materials put into suspension will be 100 times less than in the Q-system.

If Q'_C is the activity of the package, considering the scenario and the efficiency of the mask, the exposed individual can inhale 4.2×10^{-9} x Q'_C. The value of Q'_C must be less than 238 Q_C in order to reach the committed effective dose limit of 50 mSv.

- <u>Scenario outdoors</u>

1. <u>*Intervention agent*</u>

- wearing a mask with an efficiency of 100 (conventional dust+iodine cartridge)
- breathing rate 1.2 m^3/h
- resuspension factor : as above, it has been assumed that the quantity of materials put into suspension will be 100 times less than in the Q-system.
- atmospheric transfer coefficient: between 7 $\times 10^{-4}$ and 1.7×10^{-2} $s.m^{-3}$ at 100 m downwind, 30 times greater at 10 m, and 30 times greater more at a distance of a few meters.

If Q'_C is the quantity of activity in the package, the quantity inhaled at a distance of a few meters downwind, allowing for the amount put into suspension and assuming that a mask is worn, is equal to 3×10^{-10} Q'_C .The value of Q'_C must be less than 3330 Q_C in order to reach the committed effective dose limit of 50 mSv.

2. <u>*Intervention agent - Liquid fire scenario*</u>

The intervention agent who extinguishes the fire wears a self-contained breathing apparatus and therefore receives no dose by inhalation.

The presence of an intervention agent for radiation protection purpose may be envisaged at a distance of 10 m downwind under the following conditions:

- wearing a mask with an efficiency of 100 (conventional dust + iodine cartridge)
- breathing rate 1.2 m^3/h
- resuspension factor : the severity attenuation factor for mechanical accidents is not used in the case of a fire, so that the amount of materials put into suspension is equal to the amount in the Q-system
- atmospheric transfer coefficient: same as in the previous scenario of the intervention agent.

If Q'_C is the quantity of activity in the package, the quantity inhaled at a distance of a few meters downwind is of the order of 10^{-9} Q'_C, considering the amount put into suspension and assuming that a mask is worn.The value of Q'_C to achieve the committed effective dose limit of 50 mSv must be less than 1000 Q_C.

3. <u>*Witness in a building on the accident place*</u>

- breathing rate 1.2 m^3/h
- resuspension factor: as in previous scenarios, it has been assumed that the quantity of materials put into suspension will be 100 times less than in the Q-system
- atmospheric transfer coefficient: same as in the scenario of the intervention agent.

If Q'_C is the quantity of activity in the package, the quantity inhaled at a distance of a few meters downwind, allowing for the amount put into suspension, is equal to $3x10^{-9}$ Q'_C .
Therefore, 300 Q_C can be authorized without exceeding 50 mSv..

4. *Witness on the accident place*

Idem to the previous case of a witness in a building on the accident place.

Table 4 summarizes the values of Q'_C for the various exposed individuals.

Table 4 - Values of Q'_C

Exposed individual	Scenario	Q'_C
Driver or intervention agent	• inside the vehicle	≅ 238 Q_C
Intervention agent	• outside • liquid fire	≅ 3330 Q_C ≅ 1000 Q_C
Witness on the accident place	• outside	≅ 300 Q_C
Witness in a building on the accident place		≅ 300 Q_C

Determination of the activity content limit

Tables 2 to 4 show that, for each exposure pathway, the activity quantities associated to the limiting scenarios are equal respectively to 50 Q_A, 6 Q_B, 238 Q_c. Quantity authorized for transport in the Q-system is A2 = minimum (Q_A, Q_B, Q_c, Q_D, Q_E). By analogy, for on-site transport, the limiting activity quantity is 6 A2, A2 being the authorized activity on the public road.

CONCLUSION

The most restrictive scenario concerns external exposure by pure beta emitters. If only external exposure by photons and internal contamination by inhalation are considered, the activity content limits are between 50 and 238 A2.
As a compromise, it was concluded by the French Defence Transport Safety Committee and then decided by the Safety Authority :

- to fix the activity content limits corresponding to exemption of package design approval by the competent authority for on-site transport to 100 A2, A2 being the authorized activity on the public road, except for transport of materials and gaseous isotopes that are pure beta emitters radioactive;
- the approval being based on operational arrangements, the operators have to implement on-site instructions approved by the competent authority and to be applied by the drivers in case of on-site incidents or accidents. These instructions concern in particular alert transmission, appropriate radiation detection devices, radiation protection equipments available to the drivers and the emergency staff and the immediate wearing of protection equipments;
- approval by the competent authority for on-site transport of gaseous isotopes and pure beta emitter radioactive materials will be given on a case by case basis.

For other specific issues concerning fissile materials or uranium hexafluoride on-site transports which have not been addressed, it was concluded not to extend the thresholds applicable to the transport on public roads.