# Assessment of Safety Distances to Be Implemented in Case of Accident In Radioactive Material Transportation

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## 1. INTRODUCTION

Transport accidents sufficiently severe to involve release or suspected release, or a fault in radiological safety, may occur. Populations and emergency response teams need to be protected to limit the associated dose intake. Thus safety distances need be fixed for a certain number of scenarios representative of possible accidents for the radioactive material transports which are current in France.

In order to improve the emergency response organization relative to radioactive material transportation, France has reviewed the guide for drafting the transport emergency response plans of local authorities (PSS-TMR : Dedicated Response Plan - Radioactive Material Transportation). This guide includes instructions to the first teams acting on the site of an accident to set up a safety perimeter matching the hazards. The shape and amplitude of this perimeter depends upon :

- the applicable dose criteria, in accordance with the existing regulations, so that the doses delivered to members of the public and response teams do not exceed the authorized thresholds,
- the severity of the accident scenarios selected to represent most typical or possible accidents.

## 2. INDIVIDUAL EXPOSURE REFERENCE LEVELS

**Individual radioactivity-exposure reference levels for emergency personnel**
The levels selected are those of the French regulations, which distinguish between two groups of emergency personnel :

a) The first group (Group 1) comprises personnel making up special technical and medical-attendance teams called out to radiological emergency situations (see photo 1). These personnel are covered by radiation monitoring and medical-ability examinations. Personnel in this group have undergone training aimed in particular at the risks associated with exposure to ionising radiation, and have special equipment for the particular type of radiological risks when engaged in operations.

b) The second group (Group 2) comprises personnel not belonging to special teams but participating under their normal mission assignments. They have training suited to the risks associated with exposure to ionising radiation.

The individual exposure reference levels for these two groups of emergency personnel are as follows:

- for Group 1 personnel :
  - effective dose of 100 mSv when performing assignments associated with their speciality,
  - effective dose of 300 mSv for personal protection.
- for Group 2 personnel :
  - effective dose of 10 mSv

Exceeding the reference levels may be admitted in exceptional cases in order to save human lives, for volunteer participants informed of the risks involved in their actions. In any event, the total effective dose over the entire life of the emergency personnel shall not exceed 1 Sv.

**Intervention levels associated with an individual exposure of populations to radioactivity**
The Ministry in charge of Health in France has fixed intervention levels for the public associated with an expected dose rate calculated by taking account of all the attack routes (external irradiation and internal contamination). The intervention levels are as follows [1] :

- an effective expected dose rate which exceeds the 10 mSv shall result in sheltering,
- an effective expected dose rate which exceeds the 50 mSv shall result in evacuation,
- an expected thyroid dose rate which risks exceeding 100 mSv shall result in intake by ingestion of stable iodine.

In normal operations, the statutory maximum annual exposure level for the public is 1 mSv.

**Dose and dose rate thresholds for use in drawing up safety distances**
A single individual dose criterion of 10 mSv was adopted to define the extent of the perimeter for protecting the population from radiological risks arising from a transport accident. This criterion applies to sheltering and evacuation as well.
This criterion is in line with the accident dose constraint of 50 mSv considered as the basis of the IAEA transport regulation and considers some safety margin.

It has to be applied whatever is the exposure pathway : external irradiation or internal contamination

To apply this dose criterion, an exposure period of 5 hours has been adopted. This time corresponds to the time needed to fully carry out an evacuation. At first the decision for evacuation was estimated to require one hour maximum to allow for the arrival of emergency response teams and for the first investigations needed to determine the extent of protection to be applied. Secondly the evacuation of the population requires some time. A 4-hour deadline has been adopted which is considered as the upper limit, bearing in mind that this depends very much on how built-up the affected area is.

The exposure period of 5 hours covers most of the transport accident scenarios for dose intake due to internal contamination. Radioactive material release and subsequent atmospheric dispersion in a plume will most often occur within a few hours even in case of fire. The 10 mSv dose criterion therefore corresponds to the total individual intake dose derived from the evaluation of each accident scenario.

Certain situations involving packages that have lost their protection shields with yet no release of material, lead to direct radiation at a uniform rate. Using the 10 mSv criterion and the 5 hours reference time leads to a reference dose rate of 2 mSv/hour. The way to use this value is described in part 5.

The effect thresholds adopted for chemically related risks to health, are for irreversible health effects the IDLH quantities (Immediately Dangerous to Life and Health) for hydrofluoric acid and the "renal lesion" effect threshold for uranium [2]. For uranium hexafluoride and uranyl nitrate, the irreversible-effects threshold is that equating to renal damage, that is, an inhalation of 15 mg. For hydrofluoric acid, the irreversible-effects threshold corresponds to the IDLH, that is, an inhalation of 15 mg.

## 3. RETAINED ACCIDENT SCENARIOS AND SAFETY-DISTANCE CALCULATION ASSUMPTIONS

A literature survey was conducted and about nine scenarios were selected for calculating the safety distances. These scenarios cover the following situations :
. atmospheric release of radionuclides, either involving fire or not,
. increased radiation level following a damage to radiation protection.

For scenarios including atmospheric releases, the following conditions were selected :
- a release at ground level, even in the event of fire, which allows concentrations to be revised upwards;
- two meteorological conditions: a low dispersion condition, with a light wind of 2 m/s (DF2) and a normal dispersion condition with a stronger wind of 5 m/s (DN5), which covers for the most probable meteorological situations.

The atmospheric dispersion models used are those of IRSN, namely, the SIGMA-ICARE code [3] for evaluating the impact in relation to the chemical toxicity of UF6, and the SIROCCO-CD code [4] for evaluating the radiological impact of radioisotope release.
The package damage assumptions selected for evaluating the source term are as follows: industrial packages and type ‘A’ packages not designed to withstand the transport-accident conditions defined by the IAEA [5] shall be assumed to have been destroyed in the retained accident scenarios. On the other hand, type ‘B’ or ‘C’ packages and packages containing fissile materials are designed to withstand tests simulating severe accidents such as defined by the IAEA [5]. For these packages, we retain accident scenarios whose severity exceeds the accidents defined by the IAEA, but which do not go as far as completely destroying the packaging containment.

- **A transport accident involving natural uranium concentrate**

The uranium concentrates are packed in drums - type-IP1 industrial packages - and shipped in ISO 20' containers. One container can contain 36 drums (i.e. approx. 14 tonnes of concentrate). We have assumed that 30% of the drums in one ISO container would lose their entire contents. Thus 4 tonnes of uranium concentrate would be spilled on the ground and some quantities are dispersed by wind [6] and fire [7].

- **A transport accident involving natural $UF_6$ in 48 Y packages**

The maximising case retained would be a release of $UF_6$ following a fire of sufficient severity to cause bursting of the package ; for a package without thermal protection, bursting would occur after about 30 minutes for a fire fully engulfing the package ; if the package is equipped with fire protection, bursting may still occur for longer fires with or without damage to this protection caused by a possible collision. Bursting would result in a potential release, initially, of approximately 75% of the contents of the initial 12.5 tonnes. This initial release would occur rapidly - within 30 seconds approximately. The 25% remaining in the packaging might vaporise fully, in a second phase, within 1 hour and 50 minutes if the fire continued [8]. The whole of the release evaporating into the atmosphere in the chemical form $UF_6$ would be transformed fully into HF and $UO_2F_2$, which is possible if the humidity of the air attains 70%. The chemical toxicities of the HF and $UO_2F_2$ are estimated separately.

- **A transport accident involving enriched $UO_2$ powder in BU-J packages**

The uranium oxide, in powder form, is packed in plastic bags, themselves placed in buckets. Each container contains three buckets. A cargo of uranium oxide can contain a maximum of 3560 kg of oxide (or 40 drums). Given the strength characteristics of ISO containers and the drums (AF type), it is assumed that four drums are burst open and that a third of their contents (1 bucketful) is spilled outside the package and container. 120 kg of oxide would be released into the environment, assuming a suspended quantity of 0.3 kg of $UO_2$ without fire [6] and 1.2 kg of $UO_2$ with fire [7]. The composition of the $UO_2$ retained is a natural source enriched to 3.25% in $^{235}U$.

- **A transport accident involving $PuO_2$ powder in FS 47 packaging**

The plutonium oxide powder is conditioned in metal boxes inside vinyl wrappers; the boxes are then placed inside a first then a second metal case, the consignment then being placed inside the packaging. This type-B package can contain a maximum of 19 kg of oxide. It is assumed that following a collision, a series of faults occurs in the package internal containment barriers. At least one box containing the plutonium oxide would leak in the packaging, and every empty gap in the packaging would be partly filled with powder aerosol on the basis of 9 g/m$^3$ of $PuO_2$ [9]. It is then assumed that the package is exposed to a fire sufficiently long to cause the failure of the seal of the external containment barrier of the packaging and that the whole of the thus-contaminated air, that is 7.4 litres, would escape into the environment. According to the above assumptions, 0.07 g of $PuO_2$ could be released.

- **A transport accident involving irradiated fuels in TN12, TN13, TN17 or LK100 packages**

The packages used for transporting irradiated fuel are type-B packages. They may contain up to 12 irradiated fuel assemblies of the PWR type, or 32 irradiated fuel assemblies of the BWR type. A package might be subjected to fire of sufficient duration for the package sealing to incur damage (i.e. around two hours). Assuming that 5% of the fuel rods are broken following mechanical impact prior to the fire, the source term escaping from the packaging via the seals would comprise the entire gaseous fission products released by the 5% of broken fuel rods. For a specific burnup of 55,000 MWj/tU and a cooling time of 180 days, the quantity of radioactive fission gas available at release for 160 broken fuel rods corresponding to 12 assemblies of 264 fuel rods, would be as follows [10]:

Krypton 85 activity = $3.85.10^{16}$ Bq
Iodine 129 activity = $1.43.10^{11}$ Bq
Tritium activity = $2.43.10^{15}$ Bq

It is assumed that solid fission products would not escape from the packaging and that the gaseous release would last 15 minutes.

- **A transport accident involving uranyl nitrate in LR 65 tanks**

Uranyl nitrate is shipped as an aqueous solution in liquid form. LR 65 tanks are industrial type packages containing 16,000 litres of solution in a single compartment. The retained accident scenario, involving a severe fire, results in bursting of the tank due to the pressure of the saturating vapour after opening of the decompression systems, assuming that the latter are insufficient to contain the pressure. Assessment of this scenario requires prior thermal analysis, which is in progress. In the interim, we have taken a release assumption of 10% of the contents being vaporised into the atmosphere.

- **A transport accident involving radioisotopes for medical use**

In most cases, radiopharmaceutical products are packaged in a cube-shaped carton around twenty centimetres per side. Certain are packaged in metal cylinders. A carrier van can contain a large number of these small type-A or excepted packages. The scenario considered is a fire affecting a van loaded with ten technetium generators, type-A packages, each containing 1 A2, that is, 0.6 TBq. It will therefore be assumed that 6 TBq of Mo 99 would be volatilised in the fire.

- **A transport accident involving a gamma radiography device**

We have considered a gamma radiography device loaded with a sealed source of 20 TBq of iridium 192, corresponding to a maximum load. It is assumed that the integrity of the sealed source is not compromised, but that the source is ejected out of its transport package.

- **A transport accident involving large industrial sources**

The largest sources currently transported in France are 7400 TBq sources of Co 60 in F168 packages, type B(U). The accident scenario assumes that the source would be totally uncovered.

## 4. SUMMARY OF CALCULATED SAFETY DISTANCES

The safety distances calculated for this study are shown in **Table 1**. These distances vary from a few metres to a few kilometres. For most of the retained scenarios, the safety distance to set up is not greater than 500 metres, except where UF6 and uranyl nitrate are involved.

**Table 1 : Summary of calculated safety distances**

| Accident scenario | With fire | Quantity released into the atmosphere | Safety distances DF2[(1)] | DN5[(1)] | Number of A2[(2)] released or involved |
|---|---|---|---|---|---|
| **$U_3O_8$ nat** in ISO 20' container | no<br>yes | 13 kg<br>50 kg | < 100 m<br>< 100 m | | < A2<br>< A2<br>(A2eq.=485 kg) |
| **$UF_6$** in 48Y cylinder | yes | 12.5 tonnes of UF6 | 1800 m | 1100 m | 1.7 A2<br>(A2eq.=7.28 t for UF6 nat) |
| **$UO_2$ enr** in BU-J package in ISO 20' container | no<br>yes | 0.3 kg<br>1.2 kg | < 100 m<br>< 100 m | | < A2<br>< A2<br>(A2eq.=97 kg) |
| **$PuO_2$** in FS 47 package | no | 0.07 g $PuO_2$ | 200 m | 150 m | 1.46 A2<br>(A2=48 mg for $PuO_2$) |
| **Irradiated fuel** in TN 12 package | yes | gaseous fission products | 450 m | 300 m | 3900 A2 |
| **Uranyl nitrate** in LR 65 mobile tank | yes | 1,700 litres | 1200 m | 700 m | 65 A2 |
| **Radioisotope** for medical use in type A package | yes | 6 TBq of Mo 99 | < 100 m | | 10 A2<br>(A2=0.6 TBq) |
| **Gamma radiography device** 20 TBq of Ir 192 | no | N/A | < 100 m | | 40 A2 |
| **Industrial sources** 7400 TBq of Co60 in type B(U) package | no | N/A | 500 m | | 18500 A2 |

(1) DF2 = low diffusion atmospheric conditions with a wind speed of 2 m/s, DN5 = normal diffusion atmospheric conditions with a wind speed of 5 m/s.
(2) A2eq. is the activity corresponding to an absorbed dose of 50 mSv for the different exposure scenarios assessed in the model (Q-system) used to derive radiation protection limits for transport.

## 5. SAFETY DISTANCES RETAINED FOR TRANSPORT ACCIDENTS INVOLVING RADIOACTIVE MATERIALS

If, at the beginning of an operation, little information is available as to the severity (or the absence of severity) of an accident, and until the results of the initial radioactivity measurements in the environment are known, it is recommended to apply the values for the so-called "reflex" safety distances.
These values are then replaced by so-called "deduced" values, obtained from the dose-rate and contamination measurements performed in the accident environment.
Finally, after analysis of the situation and estimating of the actual and potential risks and the probable duration of the operation, so-called “planned” values are applied.
The safety perimeter must be set up in priority downwind of the accident site.

- "Reflex" safety distances:
The safety distances recommended for a reflex set-up are associated with those in **Table 1**. Since this table offers quite a wide range of distances, it was thought appropriate in the reflex phase to reduce the number. The distance of 100 metres covers the majority of the selected accident scenarios, and should therefore be used in each severe case except for three special cases.

To recap, two values are selected for most cases, with another three for special cases:

- 100 metres for limited risk situations, which will represent the general case for all accidents involving transport of radioactive materials. This covers :
  - either packages of the excepted, industrial, or 'A' type ; in these cases, the type and quantity transported will generally limit the risk ;
  - or packages of other types, when it is judged that they have undergone only superficial damage, or no damage at all ;
- 500 metres for higher-risk situations, for packages containing materials representing a higher risk and when it is assumed that greater severity has occurred than that for which the packages were designed ; in this case (see figure 1), it may be decided to initiate a PSS-TMR (Emergency Response Plan Dedicated to Radioactive Material Transportation) ;
- 1000 m a special distance is also provided (see figure 2), for which it may also be decided to initiate a PSS-TMR :
  - for a tank of uranyl nitrate in a fire,
  - for a cylinder of UF6 in a fire.

Two main criteria - specified in **Table 2 -** can be used to select the correct reflex distance to be established, depending on the type of package. These criteria correspond to a heavily damaged package or a package directly affected by a severe fire. In the event of difficulty deciding, it is recommended to retain a prudent value, but one avoiding excess caution.

**Table 2 : scenario groupings for three safety distances**

| **Package type** | **Safety distances as per initial assessments of the packages** | | |
|---|---|---|---|
| | **Seriously damaged** | **Directly affected by a serious fire** | **Dose rate greater than 1 mSv/hr, beyond 100 metre from the package** |
| • Excepted<br>• Industrial (excluding UF6 and UNH)<br>• Type-A | 100 m | 100 m | improbable |
| • Type-B<br>• "Notified" packages (packages requiring prior notification to the authorities) | 100 m | 500 m | 500 m |
| • Tanks of uranyl nitrate (UNH)<br>• Industrial package of UF6 | 100 m | 1000 m | improbable |

- <u>"Deduced" safety distances</u>:

a) A third criterion – specified in Table 2 – is used to extend the safety distance if needed as deduced from measurements of dose rates performed all around the accident area. These measurements performed by specialized response teams of the Fire Brigade are likely to take place upon their arrival which may occur 1 or 2 hours after the accident ; the delay in obtaining the actual dose rate values should not delay the first measures taken to protect the population. The criterion of abnormally high dose rate of 1mSv/hour at 100 m corresponds to more than 1000 times the maximum value permitted in normal operation for packages shipped in non-exclusive use. The extension of the safety distance to 500 m should be sufficient to guarantee less than 1mSv/hour for the most unfavourable analysed scenario of the industrial source without protection.

b) Depending on the contamination measurements, it is recommended to place the safety perimeter beyond any area where contamination is detected on the ground to prevent the spreading of contamination.

- "Planned" safety distances:
When after planned analysis the total duration and procedures of the operations, including a return to the normal situation are known, the safety distances may be adjusted to the planned values, which take account of the estimated dose rates and exposure durations to guarantee observance of the recommended yearly dose limits for the public and Group 2 personnel.
Note : even if the packages are completely intact, the presence of members of the public and participants in proximity to the packages must also be as restricted as possible and at least a few meters. At a distance of one metre from the package, the yearly dose limit of 1 mSv recommended for the public could be attained in approximately 10 hours.

**COMMENTS**
It is noticeable that, though containing much less quantities of radioactivity, severe fire accidents involving type IP-2 packages where the contents become highly pressurized when subject to fire, warrants more stringent protection measures : after some time accumulating energy inside a package of radioactive solution (as uranyl nitrate solution) or fusible solid (as uranium hexafluoride), until rupture, this energy is discharged, which causes a large mass of radioactive material to be released from the package.

**Photo 1 : Emergency response personnel during an exercise.** They are informed of radioactivity hazards and trained to wear appropriate protections.

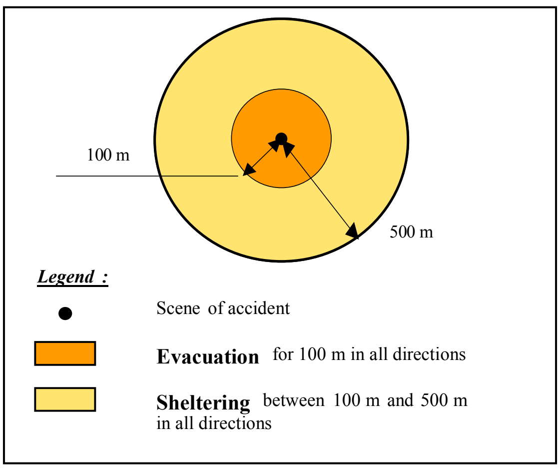
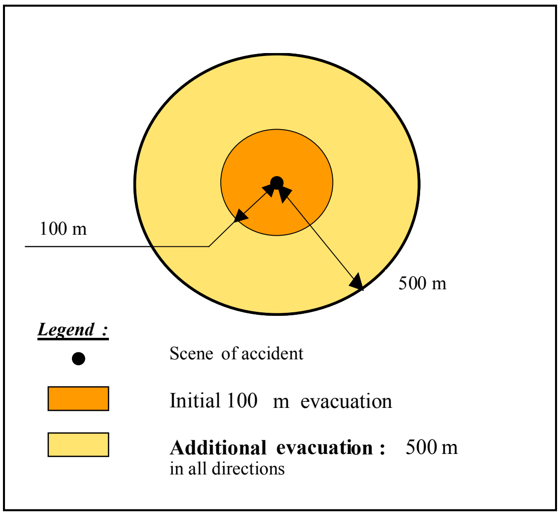



**Figure 1** : **Zones and protection measures corresponding to a safety distance of 500 m**

**Figure 2** : **Zones and protection measures corresponding to a safety distance of 1000 m**



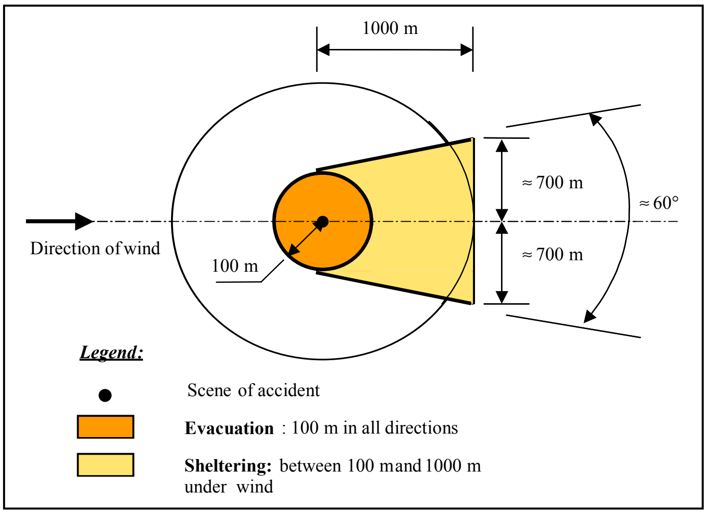




**Figure 3 : Supplementary zone and protection measure in case of radiation level greater than 1 mSv/h at 100 m**

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