GUIDE FOR RISK ASSESSMENT STUDIES REQUIRED FOR TRANSPORT INFRASTRUCTURES

Marie Thérèse LIZOT
ASN, France

Franck KALOUSTIAN
ASN, France

Gilles SERT
IRSN, France

Christophe GETREY
IRSN, France

ABSTRACT

IAEA safety requirements are implemented in France for the transport of radioactive material transport. For use and storage of radioactive material, the applicable rules depend on the installation category: basic nuclear installations (INB), classified installations for protection of environment (ICPE), hospitals, etc. Transport infrastructures like harbours, marshalling yards, and truck parking areas are submitted to IAEA requirements but had no specific regulation relative to accumulation of dangerous goods and all the more of radioactive material. Recently, the national regulatory infrastructure has been completed with a requirement to provide for each installation a risk assessment dealing with health impact on populations in case of accident (French law of 30 July 2003 completed by the decree of the 3 May 2007 concerning the transport infrastructures).

This law, relative to the prevention of technological and natural risks and also to damage reparation, requires that the transport infrastructure operator develops a risk assessment of accident scenarios with estimation of probabilities, seriousness, kinetics and health consequences. Accident severity may exceed the regulatory accident conditions of transport. “Domino” effects are to be considered. The result will be appreciated in terms of seriousness and probabilities using a criticality matrix with acceptance criteria that will be fixed by authorities. Means to reduce the risk in compliance with these criteria are operational measures or procedures able to reduce either probabilities or consequences.

Transport infrastructure operators have to perform their probabilistic risk assessments by May 2010. A guide makes easier and harmonized the expected studies. The Nuclear Safety Authority (ASN) and his technical support (IRSN) have been charged to produce the parts related to radioactive material.

First, it was decided to consider a consequence level above which risk should be characterized, valued at 50 mSv, considering the Q-system reference individual effective dose, the limit for observed stochastic effects and the intervention level recommended for public evacuation in the French national transport emergency plans.

ASN and IRSN are considering 10 groups of packages; for each of them, severe but realistic scenarios are provided with values of consequential doses.

INTRODUCTION

The IAEA safety requirements are implemented in France for the transport of radioactive material transport. For use and storage of radioactive material, the applicable rules depend on the installation category: basic nuclear installations (INB), classified installations for protection of environment (ICPE), hospitals, etc. Transport infrastructures like harbours, marshalling yards, and main truck parking areas on motorways are submitted to IAEA requirements but had no specific regulation relative to accumulation of dangerous goods and all the more of radioactive material. Recently, further to AZF explosion, the national regulatory infrastructure has been completed with a requirement to provide for each installation a probabilistic risk assessment dealing with health impact on populations in case of accident (French law of 30 July 2003 completed by the decree of the 3 May 2007 concerning the transport infrastructures).

This law, relative to the prevention of technological and natural risks and also to damage reparation, requires that the transport infrastructure operator develops a risk assessment of accident scenarios with estimation of probabilities, seriousness, kinetics and health consequences. Accident severity may exceed the regulatory accident conditions of transport. “Domino” effects are to be considered. The result will be appreciated in terms of seriousness and probabilities using a criticality matrix with acceptance criteria that will be fixed by authorities. Means to reduce the risk in compliance with these criteria are operational measures or procedures able to reduce either probabilities or consequences.

PART I: CONTENTS EXPECTED FOR THE IMPACT ASSESSMENT

The 2003 “AZF-law” requires that the operator of the facilities where dangerous goods in large quantities are handled or processed, including the most important transport infrastructures, provides to public authorities an Impact Assessment which must be updated every five years.
A particular feature of the transport infrastructure lies in the permanent variability of present dangerous goods, considering their nature, packaging, quantity, transit time in infrastructure and proximity of dangerous goods of different classes.
This assessment gives rise to a risk analysis that takes into account the probabilities of occurrence, the kinetics, and the seriousness of consequences of potential accidents. It defines and supports measures proposed to reduce the probabilities and the effects of such accidents. Its objectives are to characterize, analyze, evaluate, prevent and reduce probabilities and consequences of potential accidents in the transport infrastructure, taking into account human and industrial environment. Proposed measures should be technologically and economically feasible.
The assessment must consider all classes of dangerous goods. Even though class 7 hazards have specificities, the same general methodology applies. The assessment is performed in several steps as shown in figure 1.

Step 1: Collecting data
Description of infrastructure and its environment: the site activities, working methods and organization are described as well as the additional hazards inferred by external environment. Sensitive targets are indicated (urban areas, density of population…).
The transport fluxes, times of presence of dangerous goods and applied security measures are described including available emergency response means.

Step 2: Identification of hazard sources

Hazard sources are equipments the failure of which is liable to cause sanitary consequences due to the dangerous properties of the materials contained. Identification of hazard sources must be as exhaustive as possible; it must include a characterization of the hazards associated with products (flammability, toxicity, sensitivity to the explosion...) and the analysis of all possible hazardous situations. The experience feedback from the past recorded accidents should be used.

Step 3: Risk analysis

The first action is to identify characterize and classify the risks in terms of intensity of the consequences as a function of distance to the infrastructure.
Then the identified dangerous phenomena have to be quantified, in terms of intensity and kinetics of effects and probabilities and seriousness of consequences.

Sanitary threshold for intensities of radiological phenomena

For a given toxic material (other than radioactive), three thresholds are considered for the level of exposure:

- the threshold of the irreversible effects (SEI) beyond which irreversible effects for the health of the exposed persons may be observed,
- the threshold of the first lethal effects (SEL CL 1) beyond which a 1 % mortality can be observed in the exposed population,
- the threshold of the significant lethal effects (SEL CL 5), beyond which a 5 % mortality can be observed in the exposed population.

The determination of these thresholds requires the precise knowledge of the nature and the seriousness, in particular in terms of mortality, sanitary effects that were associated to the incorporation by man of a given quantity of the considered substance.
To determine similar thresholds for the radioactive materials, the first difficulty is that sanitary effects vary according to the nature of radiation and the body organ affected. Accordingly, the available data do not allow establishing curves of exposure leading respectively 1 % and 5 % of deaths. The second difficulty stands on the consideration of only deterministic effects in these thresholds, while radiation protection always consider both deterministic effects arising in the short term (erythema, necrosis or fibrosis for a local irradiation, modifications of the blood formula, ..) and stochastic effects arising in the long term (cancers or leukaemia...). It is at present retained by the international authorities in radiation protection that, while there is no precise threshold for the stochastic effects, these effects are minor for doses below 50 mSv which is the lower limit of actually observed stochastic effects.
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Besides, the international regulations for the safe transport of radioactive substances have been established to limit to approximately 50 mSv the maximum effective dose that a person from the public or the emergency response team may absorb in the event of an accident.
In addition, the levels of intervention to limit public exposures in radiological emergencies are fixed in France to 10 and 50 mSv, respectively for the sheltering and the evacuation of the populations. As a whole it is considered that single exposures below 50 mSv have minor health impacts.
Then, noting that it is not possible to establish thresholds of seriousness associated to the determinist and stochastic effects for radioactive substances which are "equivalent" to thresholds given for the toxic materials, it was decided to use in France the only value of effective dose of 50 mSv for the evaluation of the levels of risk in the risk assessment for the transport infrastructures.
Additionally, as regards the chemical toxicity associated with certain radioactive substances, it has been considered that the available thresholds relative to their chemical properties must be held.

Kinetics
For the safe operation of infrastructure safety and emergency measures should be efficient in regard with the development time of the dangerous events.

Probabilities
To determine the probability of aggression to the packages of radioactive materials, operators must determine package presence rates in infrastructure, and then combine them with probabilities of initiating event (explosion, fire...). Operators must know types of packages for radioactive materials flowing in their infrastructure as well as average times of presence and numbers of these packages.
When the operator has no statistical and analytical elements significant to warrant initiating event probabilities, it can use standard probabilities made available by the competent authority. Special attention is required to characterize the “domino” internal and external effects.
Probabilities may be grouped according to the following table:

Table 1: Probability scale proposed for transport infrastructures

Category of probability		**E**	**D**	**C**	**B**	**A**
Nature of estimation and order of magnitude	Qualitative	Extremely unlikely	Very unlikely	Unlikely	Probable	Ordinary
	Quantitative	Below 10^{-5}	Between 10^{-5} and 10^{-4}	Between 10^{-4} and 10^{-3}	Between 10^{-2} and 10^{-3}	Above 10^{-2}

Seriousness
It translates potential impairment of persons by the effects of a dangerous phenomenon. It combines the intensity of the phenomenon with the vulnerability of the area exposed to these effects. Seriousness is expressed as the number of exposed persons. Estimated potential doses take into account the protection measures planned including sheltering and evacuation when the event and effects kinetics do not impair their efficiency.

Table 2: Consequence scale

Consequences seriousness level	**Number of persons present in the zone where the threshold of 50 mSv is exceeded**
Disastrous	> 1 000
Catastrophic	between 100 and 1 000
Important	between 10 and 100
Severe	< 10
Moderate	<1

Step 4: Characterization and control of accident consequences
For each hazardous phenomenon a cartographic representation of distribution of the effects out of the transport infrastructure should be provided.
Then each hazardous phenomenon should be positioned in a matrix of criticality expressed with coordinates of probability and seriousness. This matrix allows qualifying the risk as controlled or not and make the necessaries iterations if the risk is deemed unacceptable.

Indeed, three acceptability domains are defined:

- a red area: probability and number of exposed persons corresponding to accidents in these areas have to be reduced out of the red zone,
- an orange area: where accidents have a probability and a number of exposed persons that correspond to these areas, an intermediate priority applies to risk reduction measures ; these measures should however be proposed in the impact assessment,
- a green area: it corresponds to accidents with lower priority risk characteristics.

For dangerous goods classes other than class 7, it has been decided in France to adopt an exclusion limit (red area) bounding the present impact (seriousness x probability) for SEL CL1 or SEL CL5 consequence levels of general road traffic accidents considering that this impact is accepted by the general public.
For class 7 materials, the SEL CL1 and SEL CL5 thresholds cannot be determined. But, noting that public perception of class 7 hazards is more acute than for other dangerous goods, it is envisaged to use the same impact exclusion limit SEL CL1 for the selected threshold of 50 mSv. The case study presented in part III give a first idea to appreciate the feasibility of this option. Then the criticality matrix for class 7 could look like:

Gravity : People exposed above 50 mSv	**Probability (per year and per infrastructure)**				
	E	D	C	B	A
Above 100 000					
10 000 – 100 000					
1 000 – 10 000					
100 – 1 000					
10 - 100					
1 - 10					
None					

For phenomena in the red and orange areas, measures to reduce the potentials of danger must be proposed taking into consideration operating constraints. For example the possibilities will be studied of modifying the localization of the potentials of danger, of reducing the traffic of certain substances, of limiting the stopping time in the infrastructure in function of the classes of danger and of modifying the emergency response actions. At this stage decision from local public authorities may be necessary for selection and confirmation of measures which could create traffic restrictions.

PART II: APPLICATION TO CLASS 7 PACKAGE-MODELS

The ASN and IRSN worked out a guide aiming at providing elements of methodology and data needed for characterizing the dangers related to the radioactive substances. Given the variety of packages of radioactive materials, it has been chosen to retain, by type of radioactive material (and therefore by risk type), only one package. This package is called "package-model". The same approach had been adopted for the working out of the technical elements of the French guides for preparing transport emergency plans to be used either by public authorities or by operators.

The package-model is selected among a family of packages to maximize the risks to be assessed while considering at the same time:

- contents in the largest quantities in terms of potential danger (radiological or toxic consequences),
- the highest transport frequencies,
- the lowest "robustness" for the packages.

A package designed to transport radioactive material must provide the following safety functions: containment of radioactive material, radiation protection, maintenance of sub-criticality when transported material is fissile.

Regulations of transport of radioactive materials [TS-R-1, 2009 edition], which is international in scope, imposes a gradation for the requirements defined to prevent loss of the safety functions of package, based on the hazard inherent to the transported radioactive material.
Schematically, higher activities of transported materials imply more stringent requirements for performance of the package. Thus, packages containing low activities must only resist to routine conditions of transport, whereas those containing high activities or important masses of fissile material must ensure their safety functions in conditions of incidents, and even accidents.

Packages of type B and/or loaded with fissile materials are designed to withstand accident conditions of transport (drop from 9 metres of package specimen onto flat unyielding target or of a 500 kg plate onto the package specimen, drop from 1 metre of package specimen onto a vertical bar, 30-minute fire and immersion under water). In case of events of greater severity, package safety functions can be degraded, or even lost partially or totally. The industrial or type A packages are packages of which robustness can be compared to that of packagings used for the transport of chemical materials. The activity of the package contents is limited to ensure that health effects are limited to an effective dose less than 50 mSv for any person located in the vicinity of the package, even in case of total loss of the safety functions of the package. Industrial packages loaded with non-fissile uranium hexafluoride, are equipped with a fire protection but possibility of mechanical damage to this protection prior to fire has to be considered.

Excepted packages are characterized by the low activity of their contents; therefore, , health effects in case of accident should be limited even if they are transported in large numbers. Therefore, events involving these packages need not be evaluated in the impact assessment.

In light of the above, class 7 packages to consider in transport infrastructure impact assessments are: packages of type B and/or loaded with fissile material or uranium hexafluoride, industrial packages when loaded with liquid radioactive materials and type A packages when they are transported in large quantities. Situations with severity greater than applicable regulatory tests need be considered for these packages.

Nine package-models have been retained in the guide and are to be considered in the impact assessments, in particular:

- type B packages containing high activities:
    - a package of spent nuclear fuel,
    - a package of plutonium oxide,
    - a portable gamma gauge used for radiography,
- an industrial package containing fresh nuclear fuel,

- industrial packages containing uranium hexafluoride or uranyl nitride due to the chemical toxicity of these compounds and their products of reaction;
- a type A package, containing moderate activity, but carried in large number.

Selection of events to be retained is the responsibility of the infrastructure operator who has to determine their nature, maximum severity and likelihood. It seemed reasonable to retain five types of physical aggression scenarios on the basis, on the one hand of their probability of occurrence, on the other hand of the consequences they may cause. These scenarios are:

- the impact of a projectile resulting from a handling failure,
- the impact of a projectile resulting from an explosion in a vehicle or an equipment in the vicinity,
- the impact of a conveyance on the package,
- the impact of a package on an item of infrastructure, the impact velocity depending on speed of vehicles authorized on the infrastructure, as well as on handling heights when applicable,
- fire affecting a package with a variable severity (temperature and duration).

For each of these scenarios, the presence of water (strong rain or from fire-fighting operations) was chosen as aggravating factor.

Results from evaluations of radiological consequences provided in the guide concern event scenarios of severity higher than those required for package design: tests to simulate normal conditions or transport for type A and industrial packages and tests to simulate accident conditions or transport for type B packages and packages loaded with fissile material and uranium hexafluoride. So far, the scenarios considered in the guide are not necessarily the most severe that might occur in a given transport infrastructure.

Individual effective doses are evaluated considering following exposure pathways:

- internal exposure by inhalation within radioactive plume,
- external exposure to plume radiations,
- external exposure to radioactive deposits on the ground,
- external exposure to packages whose protection against radiation is deteriorated.

The radiological impact, expressed in individual effective dose, is evaluated by considering an attendance time from 3 to 5 hours at different distances. This time is regarded as representative of the time needed to complete the evacuation of persons threatened within a radius of 500 meters in urban area.

The following conservative assumptions were chosen for the evaluation of the impact of releases:

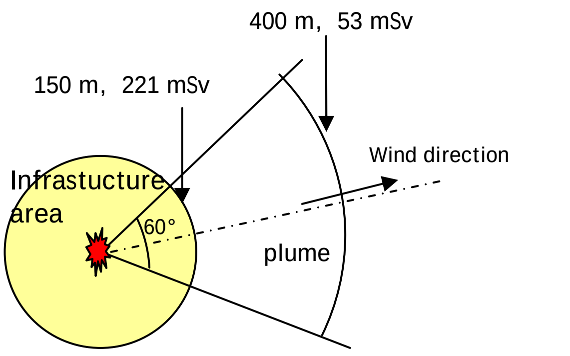
- rejection occurs at ground level,
- it is considered a dry weather and low diffusion conditions with a 2 m/s wind
- six age groups were considered (from infant to adult); doses presented in the guide are maximum doses received by the most sensitive age groups.

In the absence of validation of atmospheric dispersion calculation models for short distances, dose results reported in the guide are given for distances of at least 150 metres, assuming an unobstructed environment.

Individual effective dose results presented in the guide are related to unit quantity of released material when the dispersed mass is a function of the severity of the scenario which will be determined by the operator. Otherwise, envelope quantities are used, which results in conservative doses. An example of result is given in part III.

PART III: EXAMPLE OF APPLICATION (for illustration only)

A tally relative to the fluxes through a motorway parking area showed that type B packages carrying plutonium oxide are the only kind of package for radioactive material encountered. This area can also receive packages, tanks or containers of all other dangerous goods and has not implemented any specific prevention and mitigation measure. Loss of containment of a tank for flammable liquid is the retained reference accident. The known frequency for this accident is 1.48 $x10^{-6}$ per tank stop. This road parking area is experiencing an annual traffic of 100 tank stops. Loss of containment does not always lead to the occurrence of a danger for a neighbouring package. The annual frequency of loss of containment should be tempered by the number of events where the loss resulted in an explosion. Nevertheless, by conservatism, the fraction of explosions among containment losses is taken 1. The rate of presence on the parking area of packages carrying plutonium oxide is assumed 1%. In addition, it is conservatively assumed that for any tank explosion close to the type B package, the package is submitted to a severe impact by a projectile produced by the tank explosion resulting in a breach in its containment vessel and primary containments, with release of 1 g of aerosols of plutonium oxide powder. Finally, the probability of occurrence of the hazardous phenomenon is 1.48 $x10^{-6}$ (100 x 1.48 $x10^{-6}$ x 0.01 x 1).
The effective dose according to distance to the type B package is estimated between 221 mSv at 150 metres and 53 mSv at 400 metres. The parking area extends until 150 metres from the accident scene. It is supposed that the infrastructure area had been evacuated at time of explosion.



Gravity : People exposed above 50 mSv	Probability (per year and infrastructure)				
	E	D	C	B	A
Above 100 000					
10 000 – 100 000					
1 000 – 10 000	x				
100 – 1 000	x				
10 - 100	x				
1 - 10	x				
None	x				

For residential areas located close to the transport infrastructure, the diagram above shows that measures restricting the parking of vehicles containing class 7 packages in the vicinity of vehicles containing flammable liquids would have to be envisaged only in case this area of 0.072 km² has more than 100 000 residents, which does not seem realistic even for urban areas. However all hazardous phenomena raised for all classes of dangerous goods must be considered in such studies.

CONCLUSION

The described methodology applies to all hazardous materials. The ASN/IRSN guide should be published in October 2010 on the ASN Internet site. It should enable infrastructure managers to determine the specific impact of potential accidents involving radioactive materials in the transport infrastructures. When the first impact assessments dealing with radioactive hazards are received, an experience feedback will be drawn from the first results, which will be used to refine the approach and in particular the acceptability criterion.