Transport of radioactive materials

Radioactive materials transports present particular hazards as they concern public highway.
INES scale

Effect on the environment and people

- 7: Major accident
- 6: Serious accident
- 5: Accident
- 4: Accident
- 3: Serious incident

Degradation of the defence in depth

- 2: Incident
- 1: Anomaly
- 0: Deviations
- Event below scale
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Why are radioactive materials transported?

- In France, approximately 900,000 packages are shipped every year

Since the beginning of the 19th century, uranium has been transported to help with the manufacturing of enamels and porcelains.

With the development of artificial radioactivity and fission energy applications in the 1960s, the volume of radioactive materials transported rose significantly.

The number of packages of radioactive materials transported each year worldwide for the requirements of nuclear or non-

- The nuclear fuel cycle

Every stage of the nuclear fuel cycle requires radioactive materials to be transported from one facility to another.

Extracted from the mine, uranium ore is transformed into nuclear fuel after refining and enrichment. The new fuel is then "burned" in nuclear power plants. The irradiated fuel is then reprocessed to produce a new fuel, MOX, or is stored.

A type B "package" for the transport of irradiated fuels.

Nuclear fuel cycle. Each arrow corresponds to the transport of radioactive materials.
Other radioactive products

A number of radioactive products are used for industrial (level gauges, density meters, humidity meters, sterilisation, gamma radiography, etc.), and medical (radiology, radiotherapy, sterilisation, etc.) requirements or in scientific research laboratories (dating, marking-out, non-destructive analyses, etc.).

Sealed radioactive sources, used for non-destructive testing, may be transported from one site to another.

Flows

The weight of the packages varies, all categories included, from a few grams (vials) to one hundred tones ("casks").

- 56% of the packages are transported to carry out technical inspections whereas 28% are for medical use.
- 15% concern the nuclear fuel cycle. The bulkiest and most radioactive transports include 200 annual loads for new fuels, 200 for irradiated fuels, around fifty for plutonium oxide powder and around twenty for new MOX fuels.
Hazards

☐ Irradiation

Workers and population may be exposed to the radiation emitted.
To prevent excessive exposure, the packaging must offer radiation protection with a thickness suited to the nature and intensity of the radiation. The ALARA principle must also be implemented.

☐ Contamination

The transfer of radioactive particles may produce the irradiation of people either internally, in the event of ingestion or inhalation, or externally, in the event of deposit on the skin or on the ground. It may be caused by either an insufficient decontamination of the surface of the package or leakage of the radioactive products.

☐ Criticality

Some specific geometrical and weight conditions of fissile materials may start a chain reaction. The resulting intense emission of gamma radiation and neutrons possibly combined with a sudden release of energy may cause the irradiation of people and the release of radioelements into the environment.

☐ Theft or misappropriation

Some sensitive materials, such as plutonium or enriched uranium, may be misappropriated for malicious intentions against which protection is required. For example, some vehicles are specifically equipped and monitored in real time using global satellite positioning systems (GPS) and escorted by the national police.

☐ Chemical pollution

Some packages may constitute chemical pollution hazards which must also be taken into account in safety assessments.
For example, uranium hexafluoride (UF₆), used to manufacture nuclear fuel, is highly reactive with the humidity in the air and in the event of an accident may form a hydrofluoric acid (HF) and uranium oxyfluoride (UO₂F₂) cloud.
Transport safety

The defence in depth concept

The “defence in depth” concept is applied to deal with the hazards related to the transport of radioactive materials. This concept comprises three components.

☐ The robustness of the packaging

The packaging is designed to take predetermined accident conditions into account. It must be as robust as the radioactivity contained is high. Tests are performed on representative samples to test their resistance to accidents. For example, for the transport of irradiated fuels or plutonium oxide in type B packages, the following is checked:

- resistance to impacts (48 km/h);
- resistance to perforation (drop onto a steel bar);
- resistance to fire (800°C fire for 30 minutes);
- resistance to immersion (under 200 m of water).

The French competent authority for the transport of radioactive materials for civil use is the French Nuclear Safety Authority (ASN). It certifies the compliance of the design of the most radioactive packages or of the packages containing fissile materials, after technical assessment by IRSN.

A type A package for radiopharmaceutical sources.
Transport reliability

This reliability requires operations to be carried out in accordance with the rules stipulated in the regulations for the transport of dangerous goods, specific to each mode of transport.

The marking and labelling of packages and the placarding of vehicles provides information on the hazards caused by the transport. Documentation is available for the vehicle’s crew who are provided with suitable training. A radiation protection programme and a set of technical rules are applied, such as for example, package grouping limits. Compliance with these rules is checked during inspections organised by ASN and its regional divisions.

Intervention in the event of an incident or accident

An emergency management system is planned if an incident or accident were to occur. It aims to limit the consequences of incidents or accidents and in particular to implement possible measures required for protecting the public. This involves the availability of emergency plans and the periodic practice of emergency exercises.

The implementation of these plans is coordinated by the Prefect and involves both the public authorities and packages consigners or carriers:

- specialized brigades (Departmental mobile radiological intervention units or CMIR);
- radiation protection experts (IRSN, French Atomic Energy Commission);
- IRSN and other package experts; IRSN has a Technical Crisis Centre (CTC) for advising the authorities on the actions to take;
- local medical experts (hospital centres, etc.);
- engineers from ASN and its regional divisions, who may participate in the local emergency units set up by the Prefect.
Transport modes

International regulations
Two principles serve as the basis for the international regulations on the transport of radioactive materials:

- the consignor (and not carrier) is the first responsible for safety during transport;
- safety is based on the defence in depth concept, the first component of which is the robustness of the packaging. This must be adapted to the material transported and to predetermined transport accident conditions.

Transport mode
This is chosen according to the existing infrastructure, the economic considerations, the availability of a carrier, the weight of the package, the activity and half-life of the radioactive material, the distance to be travelled, the number of handling operations required and the risks of theft or misappropriation.

- Railway

Rail transport is a very safe mode of transport for bulky convoys and is in principle chosen for heavy or bulky packages, so long as a railway link is available. For example, almost all irradiated fuel designated for reprocessing is transported by rail to Valognes, then by road to the La Hague plant.

- Road

However, specific local and general traffic or parking rules applicable to the transport of radioactive materials prevent such transport to be blocked in congested traffic, particularly
during peak traffic times and in residential areas. Most packages containing pharmaceutical products and medical sources are delivered to hospitals by road.

**Sea**

Maritime transport represents 4% of all transport of radioactive materials. For example, the ships used to transport MOX fuel to Japan are designed according to the requirements of the International Maritime Organisation: they must be equipped with special and redundant devices such as double hulls, fire extinguishing and detection systems and anti-collision radars. They are approved by the authorities.

**Air**

Aircraft are often used to transport small, urgent packages on long distances, for example short lived radiopharmaceutical products.

**A SPECIAL CASE**

**Sending by post**

Only packages of very low-level material can be sent by national or international postal services.
Incidents and accidents

To date in France, one to two transport accidents on average occurred per year resulting in a release of radioactivity into the environment. These accidents have had limited consequences on human health and on the environment. In the most serious cases occurring in France, low levels of contamination were detected and it was possible to treat them via isolated decontamination operations.

List of significant accidents and incidents that occurred in France or that incurred the responsibility of French consignors.

**September 1983 ■ Montpellier**
A collision occurred in the railway station between a train and a baggage truck loaded with type A packages for medical use. The ballast was contaminated and cleaned rapidly. No one was contaminated.

**August 1984 ■ North Sea**
The Mont-Louis freighter transporting cylinders of UF$_6$ sank just off the Belgium coast. All of the containers were recovered. Sealing defects were detected resulting in a few kilograms of uranium hexafluoride being diluted in the sea without any notable consequences for the public or for the environment.

**June 1987 ■ Lailly-en-Val**
A semi-trailer transporting a package containing irradiated fuels had an accident. The trailer swerved into the ditch, and the package tipped over and got partially stuck in the loose soil of the verge. The package was recovered after approximately thirty hours. The crash did not affect the leak-tightness of the package and did not cause any damage other than superficial.
July 1990  ■  Saclay
A package containing a bottle of iodine 131 for medical uses, which broke during transport, was opened. The receptionist was contaminated. He received a dose to the thyroid estimated at 0.6 mSv.

November 1991  ■  Cherbourg
Hoisting equipment broke and a package containing irradiated fuel was dropped on a docked ship. Only superficial damage was observed with no radiological consequences.

March 1996  ■  Le Havre
A cylinder of uranium hexafluoride suspended from hoisting equipment became unhooked and the cylinder was dropped on another cylinder still chocked to the docked ship. The cylinders were slightly deformed with no consequences on the containment of the material. It was possible to continue their transportation following assessment by IRSN.

February 1997  ■  Apach
A convoy of three wagons, transporting irradiated fuel packages on its way to Germany, derailed in a marshalling yard. Only the track and the axles and buffers of one wagon were damaged.

November 1997  ■  The Azores
The ship MSC-Carla sank off the Azores Islands with three irradiators on board containing highly radioactive sources. These irradiators, manufactured in France, were on their way to a Boston hospital (USA). Assessments showed that due to deep immersion (approximately 3,000 m), the effect of dilution, following degradation of the radioactive sources by corrosion, would limit the risks of exposure of the populations consuming the fish products. The doses calculated were at most $5 \times 10^{-9}$ mSv/year.

January 1998  ■  Les Adrets
Packages containing iodine solution were crushed in the van transporting them during an accident on the A8 motorway. The contaminated asphalt was removed.
Spring 1998 ■ Valognes

A number of cases of contamination higher than the standards were highlighted for packages and wagons transporting irradiated fuel coming from nuclear power plants and going to La Hague reprocessing plant. The doses produced by the contamination for the workers and the population remained lower than 1 mSv, even for the worst case exposure scenarios. Nevertheless, stricter decontamination and inspection methods were implemented in the nuclear power plants to prevent contamination standards from being exceeded again in this way.

October 1999 ■ Langres

A truck transporting 900 smoke detectors containing americium sources was entirely destroyed by a fire on the A31 motorway. Contamination of the verge over a surface area of 1 m² was recorded and a soil sample collected showed an activity of 3,700 Bq/kg. The driver, the local gendarmes and fire fighters, i.e. a total of 40 people present at the scene of the fire underwent analyses to check that they had not been contaminated. The event was classified at level 1 on the “INES - Transport” severity scale.

December 2001 ■ Roissy

A radiation leak was detected in New Orleans by a driver driving a package coming from Sweden via transit to Roissy airport (Paris). The load consisted of 1,000 iridium 192 pellets with a total activity of 366 TBq distributed in three cases designated for industrial radiography uses. When the package was opened it revealed a packaging error: the lids of two out of three cases had become unscrewed, and a number of pellets had escaped from the cases in horizontal position during transport and spilled into the gap around the plug and the package. Blood samples taken on several Roissy operators made it possible to determine recent exposure and one or more older exposures for one of the operators. Additional examinations revealed that one of the employees received a dose possibly reaching 100 mSv. The Swedish authorities classified the event at level 3 on the INES scale.
August 2002 ■ Roissy

A type A package fell and was crushed on a section of internal road in a reserved area of the airport. The package, loaded with 5 GBq of iodine 131, in powder form in a capsule, fell from the truck transporting it to the aircraft. After falling, the package was most probably crushed by following vehicles, resulting in a loss of containment and dispersion of radioactive material on the road. Radiological measurements confirmed the presence of plumes of very localised contamination with a dose rate of 0.1 to 0.2 mGy/h on contact. A safety perimeter was set up around the contaminated area. The radioactive half-life of iodine 131 (8 days) and the initial measurement results indicated that the highest dose rates should revert to normal within eight to ten weeks maximum.

April 2007 ■ Route Nationale 4

A van transporting a type B package loaded with a high-level source of caesium had a serious collision followed by a high-intensity fire. A team from IRSN was rushed to the scene to check the condition of the package and to place it in a safe location. All of the package’s nuts and bolts had loosened due to the heat but the radiation protection was not damaged. The radioactive material remained entirely contained in the package.

THE INES SEVERITY SCALE ADAPTED TO THE TRANSPORT OF RADIOACTIVE MATERIALS

A severity scale was developed by the French Nuclear Safety Authority and the IRSN to facilitate the understanding of transport accidents and incidents. It was inspired by the “INES” (international nuclear event scale) scale adopted by the IAEA. Following agreement by the Conseil supérieur de la sûreté et de l’information nucléaires (French Higher Council for nuclear information and safety), it came into force on 1st October 1999.

The IAEA then specified the INES scale application modalities for transport events.
Packages adapted to the hazards

Packages are designed so that the radiological hazards relating to the materials transported are controlled in normal conditions and in accident conditions of transport as defined in the regulations.

Where applicable, specimens of packagings are subjected to tests to demonstrate their resistance. These tests are as severe as the hazards are significant. The packages* are classified into four main categories. Additional rules apply when the packages are loaded with fissile materials, with regard to the criticality risk.

**Excepted packages**

- very low radioactivity;
- radiopharmaceutical products and small sources for industry, radiology, research and lead analyzers;
- no special resistance conditions;
- 400,000 packages per year.

**Industrial packages**

- low concentration of radioactivity;
- ore, concentrated or composed of uranium, low level waste sent to a surface disposal facility (gloves, cloths, syringes, etc.);
- resistance to a drop from a maximum height of 1.2 m, which varies according to the weight of the package;
- stacking test (stacking of packages);
- for industrial packages containing fissile materials: resistance to same mechanical and thermal tests as Type B packages and to immersion at 15 m and submitted for ASN approval after technical assessment by IRSN;
- 100,000 packages per year.
- **Type A packages**
  - medium radioactivity;
  - new nuclear fuels, sources with therapeutic use, soil humidity and density testing equipment;
  - water spray test simulating heavy rain;
  - resistance to a drop from a maximum height of 1.2 m for packages designed for solid materials, and from a height of 9 m for packages designed for liquids or gases;
  - penetration test with a 6 kg rod released from a height of 1 m for packages designed for solid materials and from a height of 1.7 m for packages designed for solids and gases;
  - for type A packages containing fissile materials: resistance to same mechanical and thermal tests as Type B packages and to immersion at 15 m and submitted for ASN approval after technical assessment by IRSN;
  - 300,000 packages per year.

- **Type B packages**
  - high radioactivity;
  - irradiated fuels, highly radioactive sources, plutonium, vitrified radioactive waste, gamma radiography weld testing equipment;
  - resistance to impacts at 48 km/h (drop from 9 m) on an undeformable target**, or resistance to the drop of a 500 kg plate from a height of 9 m for packages weighing less than 500 kg;
  - resistance to a drop on a punch from a height of 1 m;
  - resistance to 800°C fire for 30 minutes;
  - resistance to immersion up to 200 m for the most radioactive packages;

* A package consists of the contents (radioactive materials) and the container (more or less complex packaging).

** In the event of impact during transport, the structures hitting the packages are generally deformable, which makes most accidents less severe than the resistance test with an impact at 48 km/h on an undeformable target.
Regulations: drafting and application

IAEA technical guidelines

Most of the countries using radioactive materials are members of the International Atomic Energy Agency (IAEA). This agency drafts the guidelines for protecting people and the environment from the effects of radiation during transport. The IAEA recommends the minimum performances for packages, depending on their type, that aim to guarantee protection against radiation and the containment of materials and prevent the conditions needed for a chain reaction from being fulfilled.

IAEA’s guidelines are then transposed into national regulations. For example, IAEA’s guidelines are at the origin of the criteria adopted by the French regulations in terms of transport system contamination. Therefore, the following contamination levels must not be exceeded on the accessible surface areas of the package and the means of transport:

- 4 Bq/cm² for low toxicity alpha, beta and gamma emitters,
- 0.4 Bq/cm² for other alpha emitters.
In France

- **Regulation of the safety of transport for civil use by the French Nuclear Safety Authority (ASN)**

ASN is responsible for regulating the safe transport of radioactive materials for civil use. It checks that the regulations are respected and must approve new type B packages or packages loaded with fissile materials, before they can be used on public highways.

- **Regulation of the physical protection of sensitive transport**

Regulation against malicious actions is placed under the responsibility of the Senior Official for Defence and Safety for the Ministry of Energy.

*Homogeneous international regulations facilitate international transport.*
Role of IRSN

IRSN helps regulate the safe transport of radioactive materials, by carrying out technical assessments on package design Safety Reports (approximately 100 reports per year), and assisting with the issue of approvals by ASN. Furthermore, IRSN contributes to the management of risks relating to transport through its research work on physical protection and safety. The Institute participates with the development of international guidelines under the aegis of IAEA and organises training courses on the regulations. It also participates with the inspections carried out by ASN and with the emergency organisation implemented in the event of transport accidents. Finally, transport of the most sensitive materials is monitored in real time by IRSN.

The strength of the handling trunnions on the packages was assessed by IRSN.
The “TÉNÉRIFE” and “PEECHEUR” programmes can be cited among the research and studies conducted by IRSN in this field.

- **The TÉNÉRIFE programme**
  How do UF₆ packages behave under violent fire conditions? Are thermal protections necessary? These questions can be answered using the results of six fire resistance simulations from the TÉNÉRIFE programme.

- **The PEECHEUR programme**
  It helps us understand how overheated packages break under gaseous UF₆ pressure.
**ALARA principle**
The ALARA (As Low As Reasonably Achievable) principle is applied to transport: according to this principle, the exposure doses received by the workers or the public during transport must be maintained at the “as low as reasonably achievable” level.

**Becquerel per centimetre square (Bq/cm²):**
The becquerel is the unit of measurement for radioactivity. It corresponds to a disintegration per second, irrespective of the nature of radiation emitted (alpha, beta, gamma or neutron).

**INES scale**
The INES scale came into force worldwide in 1991. It covers the nuclear events occurring in all civil nuclear facilities and during the transport of radioactive materials coming from or on their way to these facilities. In France, this scale has been used for basic nuclear installations since 1994 and for transport since 1999.

**mGy**
Milligray - International system unit of absorbed radiation dose.

**MOX**
Uranium oxide and plutonium-based fuel.

**mSv**
Millisievert - International system unit of dose equivalent.

**Nuclear fuel**
Fissile material (capable of undergoing fission reactions) used in a reactor for developing a nuclear chain reaction. After being used in a nuclear reactor, the fuel is said to be “irradiated”.

**Radioactivity**
A property of some chemical elements where the nuclei disintegrate spontaneously to form other elements whilst emitting ionising radiation.
The Institut de radioprotection et de sûreté nucléaire (French Institute of Radiation Protection and Nuclear Safety) is in charge of the scientific assessment of nuclear and radiological risks. A public body of industrial and commercial nature, IRSN carries out research and assessment missions for the public authorities and general public. A reference organisation in France and worldwide, it brings together over 1,700 people covering various disciplines from life sciences to nuclear physics. It conducts research and assessments in the following fields of application:

- protection of the population and the environment against ionising radiation hazards;
- safety of facilities and the transport of nuclear materials and their protection against malicious acts;
- inspection of nuclear materials and products that may be used for the manufacturing of weapons;
- emergency management.

It also helps provide information to the public.

Transport of radioactive materials

Public authorities pay special attention to transport of radioactive materials, which is a sensitive phase of the fuel cycle.

This brochure shows the defence in depth approach which is promoted by IRSN in view of guaranteeing the safety of these transports.

Head office
31, avenue de la Division Leclerc
92260 Fontenay-aux-Roses
RCS Nanterre B 440 546 018

Telephone
+33 (0) 1 58 35 88 88

Postal address
B.P. 17
92262 Fontenay-aux-Roses Cedex
France

Website
www.irsn.fr