SAFETY OF THE TRANSPORT OF RADIOACTIVE MATERIALS FOR CIVILIAN USE IN FRANCE

LESSONS LEARNED BY IRSN FROM ANALYSIS OF SIGNIFICANT EVENTS REPORTED IN 2012 AND 2013
Enhancing nuclear safety in France and abroad
IRSN, the Institute for Radiation Protection and Nuclear Safety, is the French national public expert on research and assessment of nuclear and radiological risks. IRSN was set up by Article 5 of Law 2001-398 of 9 May 2001 and its operation defined by Decree 2002-254 of 22 February 2002, modified on 7 April 2007 to take into account Law 2006-686 of 13 June 2006 on nuclear security and transparency. It is an independent industrial and commercial public establishment under the joint supervision of the ministers of defence, environment, industry, research and health.

It contributes to the implementation of public policies concerning nuclear safety and security, health and environmental protection against ionising radiation. As a research and expert appraisal organisation, it works together with all parties concerned by these policies while preserving its independence of judgement.

Operators are responsible for safety of their facilities. They must demonstrate relevance of technical and organisational solutions applied for this purpose (safety files and release impact studies).


IRSN assesses the files submitted by operators to the different competent authorities. It permanently analyzes plant operating experience feedback. It assesses exposure of man and the environment to radiation and proposes measures to protect the population in the event of an accident. Nuclear safety being largely science based, IRSN’s expertise capability is permanently enhanced through its research activities, usually developed in an international framework.

Local Information Committees (CLI) and the High Committee for Nuclear Transparency (HCTISN) gather the stakeholders concerned by nuclear facilities, and constitute leading bodies for access to information and monitoring of safety and security, health and environmental protection issues.
IRSN's Key Fields of Competence: R&D and Operational Assessment

- Nuclear safety and security, Reactors, Fuel cycle, Waste management, Transport, Radioactive sources
- Radiological protection of people (including patients)
- Environmental protection and monitoring
- Nuclear & radiological emergency management and operational intervention capability
- Training and education
- Information management and interaction with stakeholders and the public

In 2013, 1,790 staff members at 11 sites and a budget of €307 million

To find out more: www.irsn.fr
Every two years since 2008, IRSN has published the lessons learned from its analysis of significant events involving the transport of radioactive materials for civilian purposes in France. This report covers events reported during 2012 and 2013. Its aim is to present the main changes from previous analyses in order to highlight improvements and any advances that can be used to improve safety.

This report does not address protecting shipments from malicious intent, which is the purpose of specific regulation and efforts by IRSN in support of the relevant authority. The report format has been revised to facilitate reading and understanding by stakeholders and the public of the concrete safety and radiation protection issues associated with these shipments.

Each year in France, some 980,000 packages of radioactive materials for civilian use are part of some 770,000 shipments by road, railway, inland waterway, sea and air. IRSN dedicates significant resources to a continuous technical watch on the state of the safety of these shipments. For 2012 and 2013, this monitoring did not find evidence of degradation compared with previous years, particularly for industrial activities in the nuclear power industry, which raise the most significant safety issues. IRSN notes that none of the events that occurred over the two years had an impact on public health or environmental protection.

The analysis performed shows that events involving a defect in the closure of spent fuel shipping packages and deviations concerning the content of the packages, which had increased in 2010 and 2011, are now down, which would seem to confirm that the organisational measures implemented by those sending the packages have had a positive impact. Nevertheless, some trends observed during IRSN’s previous examination, which brought to light failures in the preparation of packages and their handling likely to result in more serious situations in the event of aggravating circumstances, have been confirmed. Even if most of the packages concerned contain low levels of radioactivity, recurrence of these events confirms the value of implementing appropriate preventive actions on the part of the companies involved.

Lastly, descriptions of several typical events that occurred in 2012 and 2013 provide illustrations of the analyses that were performed on actual cases.

I trust that you will find this report interesting reading and hope it meets your expectations.
KEY EVENTS
Approximately fifteen million hazardous material packages are transported every year in France, by road, rail, inland waterway, sea or air, of which around 980,000 are radioactive material packages for civilian use, representing approximately 770,000 shipments.

Some general information concerning the transport of radioactive materials in France

All radioactive material transport operations are covered by international regulations that are implemented in the form of regulatory mechanisms specific to each mode of transport. These regulations mainly stipulate that the consignor is responsible for package safety throughout the transport and the carrier is responsible for ensuring the proper delivery of the package.

The transport of radioactive materials involves a wide variety of substances, physical and chemical forms, radioactivity quantities and types of packaging (a package can range from 10 centimetres to 8 metres in length and its weight can vary between a few kilogrammes and more than 100 tonnes — see Figures 1 to 3). It is likely to cause risks to the health of people (workers and the population) or the environment; these risks mainly concern either exposure to the ionising radiation emitted by these materials, or contamination following the release of these materials outside the package, particularly in the event of an accident.

In France, the transport of radioactive materials* for civil uses concerns several main sectors of activities:

- The non-nuclear industry and industrial technical inspections sector represents approximately 55% of the packages** transported. This mainly consists of the sealed radioactive sources contained in the measuring devices used to detect lead in paint and in the gamma radiography projectors used in industrial radiography.
- The medical sector concerns nearly 30% of the packages transported. This consists of the radioactive tracers or sources destined for brachytherapeutic units in hospitals, cancer centres or clinical centres that have a nuclear medicine department.
- The industrial sector linked with nuclear power production (also called the fuel cycle sector) represents approximately 12% of the packages transported. This mainly consists of the radioactive substances used in nuclear fuel production and those produced through their irradiation in reactors. It should be noted that slightly more than half of the packages are transported to or from other countries.
- The research domain represents around 2% of the packages transported. The substances transported are, for example, radioactive sources, activated substances or spent fuel elements shipped to research centres.

Taking all sectors as a whole, approximately 95% of the packages are transported solely by road and the remaining 5% consists of multimodal transport, particularly by road and air (around 4% of the packages, which mainly consist of radiopharmaceutical packages being transported to other countries).

(*) The radioactive materials are ranked in Class 7 of the dangerous goods scale defined in the regulations governing the carriage of dangerous goods.

(**) The term “package” means the complete assembly consisting of the radioactive materials being transported and the packaging containing them.
For example, when spent fuel is transported between a nuclear power plant (NPP) operated by Électricité de France (EDF) and the AREVA plant in La Hague for processing, the transport operations covered by the regulations include all those that, in the event of non-compliance, may cause a risk during transport. The regulations concern (see Figures 4 to 6) cask loading in the NPP, the fuels in their transport cask and cask unloading in the La Hague plant, package transportation (irradiated fuels + cask) on public routes (road and rail) and possible storage in transit, and transport cask, design, production and maintenance.
In response to the risks associated with radioactive material transport operations, the same “defence-in-depth” safety approach is applied as that adopted for the nuclear facilities. This approach comprises three elements:

- the robustness of transport casks;
- the compliance and reliability of the transport activities;
- the emergency response in the event of an incident or accident.

In addition, safety must be addressed through constant vigilance and a continuous improvement approach that, among other things, takes into account the feedback available as well as the new technical knowledge gained.

The casks must be as robust as the radioactivity contained is high.

To ensure the protection of people and the environment, the radioactive material containment and ionising radiation protection of the casks used to contain large quantities of radioactivity (spent fuels, plutonium oxide, vitrified radioactive waste, or gamma radiography projectors for inspecting welds) must therefore be guaranteed to perform to defined levels under specified testing conditions for simulating serious transport accidents.

The robustness of the casks is tested in this context, generally on prototypes or designs, in standard tests simulating serious accident situations likely to be encountered during transport (impacts, dropping, fire or immersion in water).

In October 2013, 42.9% of the French people felt that there are considerable risks involved in the transport of hazardous materials.

**SOME CONTEXTUAL INFORMATION RELATING TO THE IRSN ANALYSIS OF TRANSPORT-RELATED EVENTS IN 2012 AND 2013**

The French regulations require that every significant event — that is to say, of a specified importance relative to criteria defined by ASN, the French Nuclear Safety Authority — that occurs in a radioactive substance transport operation must be reported to ASN within two working days of being detected, regardless of whether it had radiological consequences or not. The declarant must then send a detailed report of the event to ASN, including the corrective actions taken to avoid the event occurring again.

As part of its activities relating to radioactive material transport safety, the French Institute for Radiation Protection and Nuclear Safety (IRSN) analyses the events that occurred during transport and which were reported to ASN (referred to as transport-related events). The lessons learned provide IRSN with additional feedback that increases transport safety by improving the casks, operating practices or regulations.

As part of this analysis, IRSN also examines all of the transport-related events to learn more wide-ranging lessons concerning safety in the transport of radioactive materials for civilian uses in France. These lessons are stated in the reports that IRSN has published on the subject every two years since 2008; the first three reports published by IRSN** on this subject cover the period from 1999 to 2011. These reports are mainly intended to help to inform the public on the transport of radioactive substances, since the transport of hazardous materials is a matter of considerable concern to the French, as the IRSN barometers on how the French public perceives the risks and safety*** produced for approximately fifteen years show.

IRSN makes use of the feedback on the transport-related events in its activities conducting technical assessments of the package safety documentation on behalf of ASN (it has issued approximately 70–80 technical notices a year over the course of the last ten years).


(***) [http://www.irsn.fr/FR/IRSN/Publications/barometre/Pages/default.aspx](http://www.irsn.fr/FR/IRSN/Publications/barometre/Pages/default.aspx)
MAIN LESSONS LEARNED FROM THE IRSN ANALYSIS OF TRANSPORT-RELATED EVENTS IN 2012 AND 2013

The lessons learned by IRSN from its analysis of the transport-related events reported to ASN in 2012 and 2013 are stated in the fourth public report by IRSN; the main conclusions are given below.

General overview

Since 1999, approximately a hundred events are reported each year, which, compared with the annual transport flows of radioactive materials in France, represents, on average, one event per 10,000 packages transported. In 2012 as in 2013, the number of events has not changed significantly compared with previous years. Furthermore, the number of events that have had radiological consequences or which have resulted in a considerable degradation of the packaging components important to safety has reduced since the beginning of the ’00s.

The distribution of events by mode of transport, sector of activity, package type or reason for being reported to ASN is generally similar to that of previous years. The fuel cycle sector represents most of the declared events, with an average of around sixty events per year. This is followed by the medical sector with approximately thirty events per year, the majority of which correspond to package damage caused during handling operations in airport areas and to mostly temporary package losses during transit in these areas, then by the non-nuclear industry and industrial technical inspections sector, with less than ten events declared each year, and lastly the research sector with an average of around four events per year; for the last two sectors, most of the events are linked with documentation deviations such as incorrectly labelled packages, for example.

In 2012 and 2013, approximately thirty events in which the regulatory requirements relating to radiation level at the surface and around the package and contamination on the surface of the package and the vehicle were exceeded to a limited extent were reported. None of these events had significant radiological consequences for the workers, population or environment.

As a result, the overall analysis of the transport-related events declared in 2012 and 2013 does not reveal any reduction in safety during the transport of radioactive materials in France for this period, and notably the transports for fuel cycle activities, which involve the greatest safety issues.

Improvements seen and points requiring attention

Concerning the robustness of transport casks, and notably their ability to contain radioactive materials:

› On 18 April 2012, two fresh fuel transport casks fell 1–2 metres during handling in the freight area of Roissy-Charles de Gaulle Airport, Paris. Although the damage observed by IRSN after the two TN-BGC 1 packages fell (see Figure 7) did not have any direct consequence on safety when the event occurred, it showed that there are some doubts regarding the behaviour of this type of package in the event of an accident.

In order to improve the safety of this type of package, its designer has proposed certain structural modifications that have been authorised by ASN following a technical assessment by IRSN.

› Two new events involving anomalies in which the impact limiter screws on spent fuel transport casks were tightened incorrectly occurred at the end of 2013 and the beginning of 2014, although the number of events of this type was significantly down on 2011 following the introduction of organisational corrective actions. The designer of the casks concerned is studying whether the impact limiter closure parameters must be modified in this respect.

Each end of the casks used to transport spent fuel assemblies from the EDF reactors to the AREVA La Hague plant is fitted with a cap filled with wooden blocks, the role of which is to absorb mechanical shocks in the event of an accidental impact (dropping of a cask, or road crash) and to protect the gaskets used to provide the leaktightness of the containment system protecting the radioactive material in the event of a fire.
In addition, the results of an IRSN study conducted using numerical simulations have shown that the robustness of the spent fuel transport casks enabled them to resist a realistic fire whose characteristics exceeded the regulatory requirements relating to fire resistance (fire test simulated by 800°C flames completely enveloping the cask for 30 minutes).

Concerning the reliability of transport operations:

- The reduction in the number of events associated with a cask closure system defect and deviations regarding the content loaded in the spent fuel casks, in 2012 and 2013, appears to confirm that the organisational corrective measures taken by the cask consignors (such as, for example, performing more checks on all casks to be shipped and providing the operators responsible with additional training) are relevant.

- The events concerning package tie-down defects on or in the vehicle carrying them, require particular attention, as such tie-down defects can result in packages falling, notably on the road.

This study notably refers to the only transport accident in the world that exposed a type B package to a serious fire, which occurred on the RN4 main road in Fère-Champenoise in northern France on 5 April 2007. The fire was reported to have lasted an estimated 15–50 minutes in this accident.

(*) Consisting of a cask containing a sealed radioactive source

For example, a package containing a radioactive tracer cell was dropped onto the road during transport, when it was delivered to the Nîmes university hospital on 19 November 2012. Analysis of the event notably revealed that the vehicle used to transport the package was not fitted with tie-down straps. The director of the transport company had not checked the vehicle to ensure that the tie-down equipment and wedges required by the regulations were provided to the driver. In addition, the driver did not have any tie-down instructions.

This subject is studied by national and international working groups, which include IRSN, in order to set criteria for sizing the tie-down systems according to the mode of transport used (road, rail, air and sea) and to state, in the form of guides for the consignors and carriers, the best practices to be implemented in order to ensure the reliability of the cask tie-down systems.

- The number of reported events concerning the industrial and technical inspections sector may seem low compared with the number of casks transported (only one event for more than 70,000 casks transported). Analysis of the reasons for reporting these events (documentation and labelling errors — see Figure 8, tie-down defects or cask damage caused during handling) lead us to believe that the event identification and reporting methods of the consignors and carriers concerned are not as efficient as those of the nuclear fuel cycle sector stakeholders. This suggests that these operators either have an insufficient knowledge of the regulatory requirements or are less sensitive to the risks associated with ionising radiation. This feedback confirms the usefulness and importance of setting up actions to increase the awareness of and regularly train the small-scale nuclear sector.

Figure 8 / Mandatory posting of signs indicating that a package containing highly radioactive materials is being carried.
Par exemple, le 19 novembre 2012, lors d’une livraison au Centre hospitalier universitaire de Nîmes, un colis contenant une fiole de traceur radioactif est tombé sur la route en cours de transport. L’analyse de l’événement a notamment révélé que le véhicule utilisé pour le transport n’était pas pourvu des sangles devant permettre d’effectuer l’arrimage du colis. A ce sujet, le gérant de la société de transport n’avait pas effectué de contrôle du véhicule utilisé afin de vérifier que les moyens d’arrimage et de calage requis par la réglementation étaient mis à disposition du conducteur. En outre, le conducteur ne disposait pas de consignes d’arrimage.
OVERVIEW OF THE TRANSPORT OF RADIOACTIVE MATERIALS
OF THE TRANSPORT OF RADIOACTIVE MATERIALS

Of the approximately fifteen million hazardous material packages transported every year in France, by road, rail, inland waterway, sea or air, around 980,000 consist of radioactive materials packages for civilian use, representing approximately 770,000 shipments. These shipments are subject to stringent rules, notably relating to the classification of materials and packages and to the provisions for controlling safety both under normal transport conditions and under accidental transport conditions.

REGULATORY FRAMEWORK RELATING TO THE CARRIAGE OF DANGEROUS GOODS

In order to avoid the nuisances associated with the hazards of the transported materials whenever possible, the transport of hazardous materials is subject to special safety regulations. The main principles of these regulations have been defined by the Economic and Social Committee (ECOSOC) of the United Nations (UN), in the form of recommendations presented in a “Recommendations on the Carriage of Dangerous Goods” (also called the “Orange Book” — see Figure 1.1). These recommendations form the common core of all regulations relating to the carriage of hazardous materials applicable worldwide. The UN “Orange Book” defines a classification of these materials that notably takes into account the different properties of the hazardous materials transported (explosive, inflammable, toxic, radioactive, etc.) and the different types of associated risks (explosion, fire, exposure to ionising radiation, etc.).

What are the different classes of dangerous goods defined in the “Orange Book”? There are nine main classes that group the goods by type of danger (see Figure 1.2):

- **Class 1**: Explosive substances and objects
- **Class 2**: Flammable gases (compressed, liquefied or dissolved), non-flammable/non-toxic gases and toxic gases
- **Class 3**: Flammable liquids
- **Class 4**: Flammable solids
- **Class 5**: Oxidising substances and organic peroxides
- **Class 6**: Toxic materials and infectious substances
- **Class 7**: Radioactive materials
- **Class 8**: Corrosive substances
- **Class 9**: Miscellaneous dangerous goods

Figure 1.1 / UN Recommendations on the Transport of Dangerous Goods.

Figure 1.2 / Logos representing the different classes of dangerous goods.
There are specific regulations relating to each mode of transport used to carry packages containing radioactive materials.

The technical and organisational rules applicable to the transport of radioactive materials (Class 7) are drawn up at the international level under the coordination of the International Atomic Energy Agency (IAEA). When the nature and the quantity of the materials justify, IAEA recommends that they should be conditioned in packages whose performance is suited to the risks caused by the materials transported, to ensure protection against ionising radiation, avoid the dispersion of the materials, provide protection against the effects of the heat they release and prevent the conditions required for a fission chain reaction. These IAEA recommendations (see Figure 1.3), which are included in the UN Orange Book, are transposed into “modal” regulations, meaning that they are specific to each mode of transport.

Figure 1.3 / IAEA regulations on the transport of radioactive material.


In France, ASN, the Nuclear Safety Authority, is responsible for producing the safety regulations relating to the transport of radioactive materials for civilian use and checking that they are applied.

Which regulations relate to which mode of transport?

The “modal” regulations relating to the national and international inland transport of dangerous materials inside Europe are drawn up by the United Nations Economic Commission for Europe (UNECE):

› Transport by road  ➔ European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) — see Figure 1.4.
› Transport by rail  ➔ Regulations concerning the International Carriage of Dangerous Goods by Rail (RID) — see Figure 1.4.
› Transport by inland waterways  ➔ European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) — see Figure 1.4.

The “modal” regulations relating to the transport of dangerous materials by air (Technical Instructions for the Safe Transport of Dangerous Goods, by the International Civil Aviation Organisation — see Figure 1.4) and by sea (International Maritime Dangerous Goods Code (IMDG Code), by the International Maritime Organisation — see Figure 1.4) are drawn up at the international level.

Figure 1.4 / Documents regulating the transport of dangerous goods by land, air or sea.
MAJOR ASPECTS CONCERNING THE SAFE TRANSPORT OF RADIOACTIVE MATERIALS

The requirements relating to the transport of radioactive materials concern all operations and conditions associated with the movement of these materials on public roads. As well as the transport of radioactive materials between the consignor site and the consignee, these requirements therefore concern all steps required in its implementation, such as the loading and unloading of the packages used, any storage in transit, and the design, fabrication, maintenance and repairing of packages.

The requirements relating to the transport of radioactive materials concern all operations and conditions associated with their movements.

The transport of radioactive materials concerns a wide variety of materials, physical and chemical forms, quantities of radioactivity and conditionings; it can generate risks of different types, such as the risks of dissemination (contaminating people or the environment), the risks of exposure to ionizing radiation (human exposure to radiation) or the risks of heat generation (heat is produced through radioactive decay), chemical risks (for example, toxicity if natural uranium is ingested, toxicity and corrosion if uranium hexafluoride is released, etc.), the risks of explosion (flammable gases are produced through radiolysis or thermolysis) or else the risks of criticality (a fission chain reaction can cause serious human exposure to radiation as well as the dispersion of radioactivity into the environment).

What is radiolysis?
Radiolysis is the decomposition of chemical substances under the effect of ionizing radiation. For example, when water decomposes (H₂O molecule), a flammable gas, hydrogen (H₂), is formed. The radiolysis of organic matter also results in the production of methane (CH₄), another flammable gas.

What is thermolysis?
Thermolysis is the decomposition of chemical substances under the effect of heat. As with radiolysis, water thermolysis releases hydrogen and the thermolysis of organic matter also releases methane.

The safe transport of radioactive materials is ensured by applying the “defence-in-depth” concept in three main areas:

› The robustness of transport packages, which must be designed to control the risks associated with the radioactive materials transported under all transport conditions, including accidents; in this respect, the different transport conditions are simulated by means of tests of varying severity.

› The compliance and reliability of transport operations are based on meeting the regulatory and design requirements, providing the personnel involved in the transport operations with suitable training and taking into account operational feedback.

› The response to any incidents or accidents, via a dedicated emergency management system designed to limit the consequences of the incidents or accidents and set up the necessary measures to protect people and the environment.
The requirements stated by the international regulations relating to the robustness of the packages for use in transporting the radioactive materials depend on the type and quantity of materials being transported.

In this respect, the regulations distinguish between six types of conditioning, in bulk or in packages (the term “package” means the contents (the radioactive materials) as well as the container (the packaging)):

› **Transport in bulk** is only authorised for very slightly radioactive or very slightly contaminated materials.

› **Excepted packages** (see Figure 1.5) are designed to contain low quantities of radioactivity. They hold their radioactive content only under “routine” transport conditions (the demands are representative of those found during transport and when the packages are handled). They are notably used to transport certain radiopharmaceutical products and inspection devices using low-activity radioactive sources.

› **Industrial packages** (IP — see Figure 1.6) are designed to contain low specific activity materials (their activity per unit of mass is expressed in becquerel per gramme, or Bq/g) or surface-contaminated objects. They hold their radioactive content and limit the radiation leaks during moderately serious transport incidents (notably, being dropped from a limited height, and a metal bar being dropped on the package). They are mainly used to transport uranium ore, concentrate or compounds, slightly contaminated equipment or waste (gloves, cloths, syringes, tools, etc.) sent to a surface disposal centre for this type of waste, or fresh nuclear fuels intended for NPPs.

› **Type A packages** (see Figure 1.7) are designed to contain radioactive materials in quantities that do not exceed the statutory activity threshold set for each radionuclide to ensure that the dose received in the event of an accidental package breach does not prevent a safety intervention in response to the accident. 70% of these packages concern therapeutic radioactive sources used in hospitals.

› **Type B packages** (see Figure 1.8) are designed to contain large quantities of radioactivity. Their containment, ionising radiation protection and, when applicable, criticality risk prevention performance must be guaranteed under test conditions defined to simulate serious transport accidents (dropping from a height of 9 metres onto an unyielding target, dropping from a height of 1 metre onto a punch bar, resisting a 800°C fire for 30 minutes, and being immersed under 15 metres or 200 metres of water). These transport shipments particularly concern spent fuels, highly radioactive sources, plutonium and long-lived highly active radioactive waste (vitrified waste, for example).

› **Type C packages** are designed to contain large quantities of radioactive materials for air transport. Their containment, ionising radiation protection and criticality risk prevention performances must be guaranteed under test conditions that are more stringent than for type B (hitting a target at a velocity of 90 metres per second, dropping from a height of 3 metres onto a punch bar, and resisting a 800°C fire for 60 minutes). In France, no type C packages are used to transport radioactive materials for civilian use.
In France, shipments of radioactive materials represent approximately 6% of all dangerous material transports — in other words, around 980,000 packages a year. These shipments concern the nuclear fuel cycle but mainly also the medical domain as well as the “conventional” (non-nuclear) industrial and research sector.

The distribution of radioactive materials by package type, by sector of activity and by mode of transport has not revealed any notable changes in the last ten years.

The radioactive material packages are mainly transported by road.

More than three-quarters of the excepted packages, which constitute most of the transport flows, are used in the sector of conventional industry and technical inspection, whereas two-thirds of the type A packages are sent by the medical sector.

More than 90% of industrial package shipments are intended for the nuclear fuel cycle, whereas more than 90% of the type B package shipments involve gamma radiography projectors used in industry.

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**OVERVIEW OF THE TRANSPORT OF RADIOACTIVE MATERIALS BY SECTOR OF ACTIVITY**

**Fuel cycle in France**

The fuel cycle (see Figure 1.11) concerns all operations relating to fuel fabrication, its irradiation in reactors, and the management of the spent fuel. Traditionally, the cycle begins with the extraction of the uranium ore and ends with the disposal of the spent fuels or of the radioactive waste produced when they are processed, and also includes the recycling of the recoverable materials resulting from their processing.

The fuel cycle represents approximately 12% of the number of packages transported (in other words, around 19,000 shipments, representing a total of 114,000 packages a year). Slightly more than half of these packages (58,000 a year) are transported to or from other countries.

**Fabrication and supply of nuclear fuel:**

Uranium ore is shipped from mines operated by AREVA in other countries (Niger, Canada, Kazakhstan, Australia and South Africa) in industrial packages (IP-type) and transported in 20’ ISO containers to the COMURHEX-Malvési plant at Narbonne in southern France. In this plant, it is transformed into uranium hexafluoride (UF₄) and then transported in IP-type packages to the Tricastin COMURHEX plant at Pierrelatte in south-eastern France, for conversion into uranium hexafluoride (UF₆).

The UF₆ is then transported in Model 48Y “cylinders” — containers with a diameter of 48” (1.22 metres) — to the Georges Besse II plant at Pierrelatte, for enrichment (that is to say, to increase the proportion of $^{235}$U.

**Figure 1.11 / The nuclear fuel cycle and the different associated forms of radioactive materials transported.**

Approximately 12% of the radioactive material packages transported each year in France comes from the industrial sector linked with nuclear power production.
atoms in the uranium from 0.7% to around 5%) by means of a centrifugation process. It should be noted that some of the enriched UF₆ is also imported directly from the United States or Russia.

The enriched UF₆ is shipped to the FBFC (Franco-Belge de Fabrication de Combustible) plant in Romans-sur-Isère in south-eastern France in Model 30B “cylinders” — containers with a diameter of 30” (0.76 meter) — loaded into a UX-30 or COG-OP-30B protective overpack, to be transformed into uranium oxide powder (UO₂) for compression into pellets. These pellets are then inserted into zirconium alloy cladding to make fuel rods that, when assembled, form fuel assemblies (see Figure 1.12).

**Figure 1.12 / Diagram of a fuel rod and assembly.**

The fresh UO₂ fuel assemblies produced in the FBFC plant in Romans-sur-Isère are transported to the EDF NPPs in FCC packages (industrial packages for fissile materials). In addition, the assemblies containing a uranium and plutonium dioxide mixture (MOX assemblies) produced at the MELOX plant in Marcoule from plutonium oxide (PuO₂) recovered from irradiated fuel, are transported to the EDF NPPs in MX 8 or FS 65 packages (type B packages for fissile materials).

**Removal of the irradiated fuel:**

After they have been used in the core of the nuclear reactors in France and other countries (the Netherlands and Italy), the UO₂ or MOX irradiated fuel assemblies are shipped in TN 12/2, TN 13/2 or TN 17/2 (type B) packages to the AREVA plant in La Hague in northern France for processing.

**Recoverable materials produced by processing the irradiated fuel:**

The PuO₂ produced by processing irradiated fuels at the AREVA plant in La Hague is shipped to the MELOX plant in FS 47 (type B) packages for the fabrication of MOX fuel assemblies. The uranyl nitrate produced is transported in LR 65 portable tanks (industrial packages) from the La Hague plant to the AREVA plant in Pierrelatte for conversion into uranium sesquioxide (U₃O₈) for later reuse in fabricating fuel assemblies.

**Waste from the fuel cycle:**

The very-low-level waste (VLLW) is transported to the very-low-level waste disposal facility (Cires) in Morvilliers in north-eastern France, and the low- and medium-level short-lived waste (LMLW-SL) are transported in type A or industrial packages to the CSA waste disposal facility in Soulaines-Dhuys in north-eastern France (see Figure 1.13).

**Figure 1.13 / Aerial view of the CSA disposal facility.**

The high-level and long-lived waste (HLW-LL) generated when fuel assemblies from foreign countries are processed at the AREVA plant in La Hague is returned to the country of origin of the assemblies concerned (Germany, Netherlands, Japan, Switzerland, Belgium, Australia, etc.) in type B packages.

**Transport of radioactive waste and spent fuels involving an EU Member State**

European Union Council Directive CE 2006/117/EURATOM, as transposed into French law by Decree 2008-1380 of 19 December 2008, sets out a system of control and authorisations required prior to the transport of any radioactive waste or spent fuel from, through or to an EU Member State. The Directive can be used to check that the different countries concerned have agreed to the transport beforehand.
The tools and equipment contaminated in nuclear power plants are serviced and maintained by the Tricastin operational hot unit (BCOT), the SOCODEI waste and industrial releases conditioning company and the SOMANU nuclear maintenance company. Most of them are transported in type A or industrial packages.

**Medical sector**

Approximately 260,000 packages containing radioactive sources for medical use (nuclear medicine) are transported every year in France. These sources are carried in excepted or type A packages, by road or air, to hospitals throughout France and in other countries.

The radioactive source packages intended for medical use represent approximately 30% of packages containing radioactive materials transported each year in France.

The main consignor is CIS Bio International (180,000 packages transported in 2013), which is the leading French producer of radiation therapy and medical imaging (scintigraphy) radioisotopes, such as molybdenum-99 ($^{99m}$Mo), whose radioactive decay produces metastable technetium-99 ($^{99m}$Tc) in technetium generators, thallium-201 ($^{201}$Tl), yttrium-90 ($^{90}$Y), different iodine isotopes — iodine-131 ($^{131}$I), for example, etc. The unsealed sources can be conditioned in different ways depending on use (solid sources for radiotherapy, liquid sources for scintigraphy, etc.).

In 2013, 64% of the packages sent by CIS Bio International were destined for other countries. As these sources are radioactive for a very short time, ranging from a few hours (6 hours, in the case of $^{99m}$Tc) to a few days (8 days, in the case of $^{131}$I), the shipments sent to countries outside Europe are transported by air. Roissy—Charles de Gaulle Airport is the main departure point of the medical radioisotope packages sent outside France by CIS Bio International (around 50,000 packages were sent in 2013).

In addition, the Mallinkrodt Company based in the Netherlands sends approximately 45,000 packages each year to French hospitals. Amersham, a GE Healthcare group member based in the UK, also supplies technetium generators.

**Industry and technical inspections**

More than half of packages containing radioactive material transported annually in France are destined for industrial sectors that are not part of the fuel cycle.

Around 55% of the packages containing radioactive materials transported concern “conventional” industry and industrial technical inspections (530,000 packages a year). These are primarily sealed radioactive sources (mainly cobalt-60) used in industrial irradiation equipment (for sterilisation use in sectors such as the pharmaceutical and agri-food industries), and measuring devices containing a sealed radioactive source such as the following:

- Gamma radiography devices (containing caesium-137 or iridium-192 sources — see Figure 1.14) used in industrial radiography in various sectors such as the aeronautical, automotive and metallurgical industries. These devices are transported in type B packages (see Figure 1.15);

![Figure 1.14 / GAM-80 gamma radiography unit.](image)

![Figure 1.15 / Transport package for a CEGEBOX gamma radiography unit.](image)
Research domain

The research domain represents around 2% of the packages transported (approximately 19,000 packages a year). The materials, which are mainly transported in excepted or type A packages, consists of radioactive sources (such as unsealed sources, as in Figure 1.18, for cellular biology research), activated materials or spent fuel elements (pieces of fuel rods, for example), sent to research centres (primarily those of CEA, the French Alternative Energies and Atomic Energy Commission), as well as contaminated objects or waste from these centres.

Gamma densimeters (containing cobalt-57, caesium-137 or americium-241 sources — see Figure 1.16) used in the building and public works sectors to measure the density and humidity of the ground and constructions. These devices are transported in type A packages;

Figure 1.16 / Gamma densimeter.

Lead analysers (containing cobalt-57 or cadmium-109 sources - see Figure 1.17) used in real-estate inspections (to check lead levels in paint and pipework). These devices are transported in excepted packages.

Figure 1.17 / Niton XLP 300 unit using x-ray fluorescence to analyse lead levels.

Figure 1.18 / Handling of radioactive sources under a fume hood in a nuclear medicine department.
OVERALL ANALYSIS OF SIGNIFICANT EVENTS
2 OVERALL ANALYSIS OF SIGNIFICANT EVENTS

Regulation requires that every event that occurs in connection with the transport of radioactive materials, whether it has radiological consequences or not, must be reported to the ASN. If it involves a significant event, the reporting party must submit a detailed report of the event to the ASN, specifically noting the corrective actions intended to prevent its recurrence.

This chapter describes the lessons learned by IRSN from its analysis of transport-related events for civilian use reported to the ASN in 2012 and 2013 and the main trends observed compared with previous years. This analysis seeks to identify changes since the previous public report, as well as issues that may require additional vigilance by those involved in transport (including operating conditions and safety management aspects).

This analysis does not address those aspects related to the protection of transport against malicious acts, which is covered by a specific regulation and IRSN actions in support of the relevant authorities.

Who is responsible for the safety of a transport of radioactive materials?

The consignor is responsible for the safety of the package transported and must thus guarantee its integrity throughout the transport. The consignor is liable as of the time it delivers the package and the shipping declaration to the carrier. This is intended to ensure compliance with regulatory requirements throughout the chain of transport.

The carrier is responsible for ensuring proper transport. Prior to transport, the carrier must obtain a certificate of approval stating that the loading meets the requirements of national and international regulation. He must check that the information provided by the consignor is complete and available. The carrier is subject to requirements regarding the tie-down of packaging, labelling and vehicle maintenance. The consignor may designate the carrier as its agent for the declaration of events that may occur during the shipment of the package.

Information about notifications of events that occurred during the transport of radioactive materials

In accordance with the “modal” regulations in force, consignors of packages containing radioactive materials must provide notification for every event affecting a transport, whether or not it has radiological consequences. This covers all events that occur during transport operations; that is, during the course of the transport itself or during the loading, unloading or inspections of packages before and after transport on public roads.

These notifications are prepared using the form in the ASN’s 2005 guide to the reporting of significant events, Guide de déclaration des événements significatifs de l’ASN*. They are then transmitted to ASN and IRSN, which provides technical support to ASN. The two agencies conduct regular analyses of the notifications.

The overall analysis of the events declared to ASN is highly dependent on the depth of analysis provided in these reports. Indeed, with the exception of a small number of events for which additional information is readily available, these event reports constitute IRSN’s main source of information. In the majority of cases, the consignors do not provide sufficient analysis in these documents. The reports on many events thus simply identify the “direct or observed” causes, often limited to failures of human origin (errors on the part of the individuals involved in the event). In this regard, failing to properly identify the basic, root causes of events prevents a full assessment and understanding of the different kinds of technical, organisational or human failures that caused them and, consequently, prevents identification of the related generic or recurrent aspects. This has a critical impact on the overall analysis performed and the lessons that can be learned.

In accordance with Article 7 of the order on the land transport of dangerous goods of 29 May 2009 as amended, all significant events that occur during operations associated with the transport of a package containing radioactive materials must be declared to ASN within two business days after the event is detected.

Except for recognised emergency situations, declarations of significant events must be made within two working days of detection. When the event concerned is significant, the declarant must then submit a detailed report of the event to ASN within two months of the declaration. This report is intended to provide information that may not have been known when the event was declared. Specifically, the report must present the sequence of the event, an analysis of its causes and consequences (for example, measurement results) and the measures taken, particularly technical and operational, to prevent its recurrence.

IRSN analyses the events reported to ASN to enhance safety in the transport of radioactive materials.
IRSN expects consignors and carriers to include an analysis of the fundamental or root causes of significant transport-related events in reports that they submit to ASN. This in-depth analysis is critical to identifying the possible recurring or generic causes of the events and to defining more relevant corrective actions that can improve safety in this area.

This observation, shared by ASN, recently led the agency to remind all consignors and carriers concerned about the expectations in terms of the analysis of causes of significant events and proposals for corrective action.

**Assessment of events and analysis of the main trends observed during 2012 and 2013 compared to previous years**

As in previous reports concerning the assessment of events that occurred between 1999 and 2011, events involving the onsite transport of packages and shipments sent from abroad (except those with consequences in France) are not included in this report. As a result, certain figures presented may differ slightly from those that ASN includes in its annual reports on the state of nuclear safety and radiation protection. In addition, this report does not address transport-related events involving national defence activities.

Number of events declared and their classification on the INES scale

Between 1999 and 2013, 1,525 transport events involving radioactive materials were declared to ASN, for an average of 102 events per year. In terms of the annual transport flows of these materials, the average event frequency is approximately one event per 10,000 packages shipped.

What are "onsite transport operations"?

Onsite transport operations are defined in article 1.3 of the order of 7 February 2012, which sets general rules for regulated nuclear facilities. These operations concern:
- the transport of dangerous goods inside the perimeter of a regulated nuclear facility outside the buildings and storage areas; that is, the transport of dangerous materials:
  - from a building of a regulated nuclear facility or a storage area to the exit of that facility’s perimeter;
  - from the boundary of the perimeter of a regulated nuclear facility to a building or storage area belonging to that facility;
  - between two buildings or two storage areas of the same regulated nuclear facility;
  - any other transport transiting the perimeter of a regulated nuclear facility;
- operations contributing to transport safety, including inside buildings and storage areas; that is, all operations necessary for transport, particularly on public roads, for example: conditioning, loading the packaging content, closing the packaging, loading on the transport vehicle, all pre-transport inspections, unloading and other operations necessary for transport and contributing to transport safety.

What is the INES scale?

The International Nuclear Event Scale (INES) has been applied to events involving the transport of radioactive materials that occur in France since 1999. This scale is intended to help the media and the general public understand the importance of safety for nuclear incidents and accidents. It defines seven levels of severity.

The classification of an event on the INES scale, proposed by the consignor in its event declaration, is assessed by ASN, based primarily on the potential or actual radiological consequences of the event and on the deterioration of safety-related packaging components (specifically, the containment of the radioactive material).
The number of events classified at level 1 or higher on the INES scale has declined since the early 2000s (Figure 2.1). Events that ASN considers to be “relevant for safety” are included in the “below scale” category.

After declining steadily between 2001 and 2008, the number of events classified as “below scale” returned to a level comparable to that of the 1999-2001 period. This could be explained in large part by a change in the interpretation of the classification criteria for certain kinds of events.

Only one event was classified as level 1 on the INES scale in 2013.

### Table 2.2 / Classification by level on the INES scale of events declared during the 2010-2013 period.

<table>
<thead>
<tr>
<th>INES classification</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not specified</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Below scale</td>
<td>43</td>
<td>54</td>
<td>69</td>
<td>52</td>
</tr>
<tr>
<td>Level 0</td>
<td>58</td>
<td>41</td>
<td>48</td>
<td>44</td>
</tr>
<tr>
<td>Level 1</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Level 2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>105</td>
<td>123</td>
<td>98</td>
</tr>
</tbody>
</table>

### Distribution of events by sector of activity

The number of events declared annually depends in large part on the efficiency of systems implemented by consignors and carriers to detect and declare these events. The analysis of the distribution of the annual number of events by sector of activity (Figure 2.2) shows significant disparities, particularly between the nuclear industry (fuel cycle and nuclear research) and consignors in the small-scale nuclear sector (non-nuclear power industry and technical inspections, as well as the medical sector).
Which regulatory documents must accompany the transport of packages containing radioactive materials?

The consignor must prepare a transport document to accompany the package. It must certify that the conditioning of the radioactive materials complies fully with the requirements and provide the primary information regarding the consignment (means of transport, contact information for the consignor and consignee) and the package(s) transported, such as the number of packages in the consignment, designation of the packaging, classification(s) of the dangerous materials involved, UN number and description of the radioactive materials transported (list of the main radionuclides, physical form and activity). In addition, other documents, such as the driver training certificate and the safety instructions, must be in the transport vehicle.

Packages are marked individually (identifying the consignor and recipient, weight of the package, package type and dimensions). A label identifying the radiation level (label 7A, 7B or 7C, also referred to, respectively, as I-white, II-yellow, and III-yellow - Figure 2.3) is affixed to each. This label must note the content or list of the main radionuclides, total activity, and transport index (TI), determined based on dose rates measured before shipping at a distance of one metre from the package. In the case of transport of fissile material, the package must also include a label (7E) indicating the criticality risk (Figure 2.3).

In addition, each vehicle transporting packages other than excepted packages shall display a 7D placard and an orange placard identifying the nature of the danger and the UN number (Figure 2.4).

Most events involving medical sector packages occur during transport operations at airports.

The number of events in 2012 and 2013 involving packages from the medical sector remained at a level comparable to that of the previous two years. Nearly two-thirds of these events concern medical packages.

In the industry and technical inspections sector, the number of events reported annually, which had declined in 2008 (c.f., the IRSN public report on transport-related events in France between 1999 and 2009*), remained below 10 (eight declarations in 2012 and seven in 2013). However, as this sector represents more than half of transport flows in France (Figure 1.9), this number appears to be significantly underestimated, as suggested by the frequency of transport events by sector of activity (number of events declared in relation to the number of packages transported - Table 2.3).

<table>
<thead>
<tr>
<th>Sector of activity</th>
<th>Frequency of events (2012-2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cycle</td>
<td>1/1,900 packages</td>
</tr>
<tr>
<td>Medical</td>
<td>1/9,600 packages</td>
</tr>
<tr>
<td>Industry and inspection</td>
<td>1/71,900 packages</td>
</tr>
<tr>
<td>Research</td>
<td>1/5,600 packages</td>
</tr>
</tbody>
</table>

Table 2.3 / Frequency of events declared by sector of activity during the 2012-2013 period.

At first glance, this could appear to be linked with the radioactive materials transported (primarily, sealed sources) which are, by their nature, less involved in the kinds of events typically encountered in the fuel cycle sector (for example, package contamination or leaks). However, the analysis of the reasons for declaring these events (such as documentation and labelling errors, tie-down defects, or damage to packages during handling), in principle independent of the type of radioactive material transported, suggests that the methods for identifying and declaring events used in industrial and technical inspections sector are not as robust as those used by the nuclear fuel cycle sector. For IRSN, this may be explained by insufficient knowledge of the regulatory requirements by the users or less awareness of the risks associated with ionising radiation. This operating experience confirms the importance of actions to inform and develop awareness in the small-scale nuclear sector.

ASN was recently assigned responsibility for performing inspections on those involved. The agency created a dedicated organization to carry out targeted inspections of companies with extensive radiation-related activities and whose operating experience (including events and assessments of doses received by operators) underscores the need for corrective and preventive actions. Some of these inspections identified deviations concerning transport documents specifying the characteristics of the radioactive materials shipped (documentation deviations), which were not immediately identified by the targeted

companies. Inadequacies were also noted in the area of radiological monitoring.

Last, the research sector experiences an average of four events per year. That number has been stable, overall, since 1999. The main reason for declaring an event in 2012 and 2013, as in previous years, involved documentation deviations.

Distribution of events by means of transport

Between 50-60% of events reported each year concern road transport (Figure 2.5). In 2012 and 2013, 80% of these events were attributable to fuel cycle activities, although this sector represents only slightly more than 10% of the packages transported by road. These events included two roadway collisions and run-off-road accidents reported in 2012 and four in 2013. None of these accidents had a direct consequence on the safety of the packages transported:

- 21 January 2013: during an operation at the Saint-Rambert-d’Albon rail yard, an axle of a wagon carrying depleted uranium from the AREVA plant at Pierrelatte to the Netherlands went off the rails;
- 16 September 2013: a train heading to Sellafield, Great Britain carrying empty TN28-VT packages intended for the transport of compacted or vitrified waste containers derailed;
- 23 December 2013: during rail yard operations in Drancy-Le Bourget, a wagon transporting a TN 13/2 package loaded with spent fuel from an NPP in Nogent-sur-Seine heading to the AREVA plant at La Hague, partially went off the rails at a switch. This event is addressed in detail in chapter 3 of this report.

Last, of the two events that occurred in 2012 and 2013 during sea transport (Figure 2.5), one was due to contamination of a drum containing natural uranium ore. The other was due to a closure defect on the protective package of a UF₆ cylinder (see “Closure defect of UF₆ cylinder transport overpacks,” addressed in the section, “Events related to package closure defects”, below).
With regard to the distribution of events by type of package until 2013 (Figure 2.6):

- As every year, the largest number of declared events continue to involve **type A packages** (on average, 35 events per year). Approximately half of these events concern package damage during airport handling;
- In 2012 and 2013, the number of events involving **type B packages**, which rose sharply in 2010 and 2011 as a result of a large number of tightening defects on packaging impact limiter bolts and the discovery of "foreign matter" in their cavity (objects or materials not included in the packaging loading plan), returned to a level comparable to that of preceding years (between 15 and 20 events per year);
- The number of events involving **industrial-type packages** has increased since 2012. Nearly all of these events concern the fuel cycle (transport of contaminated tools, low specific activity wastes and uranium in mineral or UF₆ form). The reasons for declaring most of these events involve documentation or labelling errors and the presence of contamination on the packaging surface;
- Last, the number of events involving **excepted packages** remains very low in relation to the number of this type of package transported every year (Table 2.4). Because the vast majority of excepted packages are shipped within the small-scale nuclear sector, this low number could be explained by a lack of awareness on the part of the consignors concerned regarding compliance with the criteria for declaring events.

**Table 2.4** / Frequency of events declared by type of package during the 2012-2013 period.

<table>
<thead>
<tr>
<th>Package type</th>
<th>Frequency of events (2012-2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type B</td>
<td>1/580 packages</td>
</tr>
<tr>
<td>Type A</td>
<td>1/8,500 packages</td>
</tr>
<tr>
<td>Industrial Package</td>
<td>1/4,000 packages</td>
</tr>
<tr>
<td>Excepted</td>
<td>1/54,100 packages</td>
</tr>
</tbody>
</table>

As in every year since 1999, the highest number of declared events involve type A packages.

**ANALYSIS OF THE MAIN TYPES OF EVENTS THAT OCCURRED IN 2012 AND 2013 COMPARED TO PREVIOUS YEARS**

To identify generic lessons in connection with its analysis of event experience feedback, IRSN classifies transport-related events declared to ASN into 10 standard categories. These ten categories address 85% of the events declared since 1999. The remaining 15% of events that are not categorized do not pose a significant safety issue for the transport of radioactive materials.

For comparison, the change in the average annual number of events associated with this event typology is presented (Figure 2.7) for 1999-2009, 2010-2011 and 2012-2013.
The types of events corresponding to the categories used by IRSN are:

- **documentation events** (documentation and labelling): deviations, oversights and errors concerning information required in transport documents or on package labels,
- **radiological events**: exceeding the limits set by regulation on the radiation level around the package and the contamination on the surface of the package or the transport vehicle,
- **damage to packages during handling**: damage resulting from impacts during handling operations,
- **package theft or loss**: loss of packages, whether permanent or temporary, following theft, delivery error or during airport handling,
- **tie-down defects**: deviations from the package tie-down plan,
- **package closure defects**: deviations concerning the closure of a waste drum (broken band), an ISO-type container (door locked incorrectly), or a UF6 cylinder transport overpack (pin improperly engaged) and the incorrect tightening of the bolts of the cavity lid or of the package’s impact limiter (poor tightening torque or bolts that can be loosened by hand),
- **non-conforming content**: the presence, in the packaging, of objects or materials not authorized for loading, such as “foreign matter” that may have fallen into the cavity of the packaging during loading, equipment such as straps and hoods, that was not removed or liquids (water or oil) present as a result of incomplete drying or the failure of a piece of equipment used above the packaging (lubricant leak),
- **collisions, run-off-road accidents and derailments**: incidents and accidents that occur on the roadway (collisions, fender-benders, run-off-road accidents) and during rail transport (derailments, crashes),
- **deviations from regulations**: deviations resulting from improper implementation of safety requirements on the choice of type of package (erroneous package classification, shipping of radioactive materials in conventional packages) or failure to comply with a regulatory requirement (overlooking a radiological measurement, lack of driver certification, no extinguisher on board the vehicle),
- **package non-conformities**: deviations in package design (including non-conforming bolts and component dimensions different than those specified in the safety analysis report) or use in conditions not provided for in the user’s manual (including lack of a gasket and error in the nature of the inerting gas).

The increase observed compared to 2010 and 2011 is attributable to the industrial inspections sector (Figure 2.8). Several of these declarations followed ASN observations during inspections conducted in connection with controls on small-scale nuclear activities. This confirms that those concerned must improve their identification and notification of these kinds of deviations.

The two main reasons for notification concerning the 148 events classified as level 1 or higher on the INES scale since 1999 are the theft or loss of packages and damage to packages during handling (Table 2.6).

<table>
<thead>
<tr>
<th>Category</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theft or loss of package</td>
<td>51</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Package damage during handling</td>
<td>20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Radiological event</td>
<td>10</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Package closure defect</td>
<td>11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Non-conforming content</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Documentation and labelling</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Package non-compliance</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2.6 / Number of events classified at level 1 or above on the INES scale since 1999.

The most frequently-used categories of events and those where the number of events has increased in recent years are analysed later in this document.

**Documentation-related events**

Missing transport documents and errors in those documents or package labelling (omission or error in transcribing data on the transport documents or affecting package labelling, specifically concerned the transport index) were the primary reasons for reporting an event in 2012 and 2013 (nearly one in five events).
Regarding the nuclear fuel cycle, documentation-related events declared in 2012 and 2013 concerned primarily packages that did not require certification (80% of cases) and, in particular, the transport of contaminated tools from EDF nuclear power plants. In most cases, the analysis presented in the event reports does not provide adequate detail, preventing identification of the root causes of these events. With regard to their nature (errors in transcribing values between measurement results and transport documents, between the documents and the package label, and errors in measurement unit), IRSN hypothesizes that this type of event may result from lack of vigilance on the part of employees responsible for preparing the packages and shipping them. This could result from the routine nature of these shipments.

IRSN emphasizes that although these events do not generally jeopardise transport safety, the mistakes that cause them could have consequences in the event of an incident or accident. Such consequences could make it difficult to identify the type of package and material transported, which would be detrimental to managing the accident situation. In that regard, IRSN notes that it is important for package consignors to strengthen the provisions intended to prevent failure to comply with documentation-related requirements, particularly by creating awareness among and providing regular training for operators in charge of the related actions (radiation protection technicians and persons responsible for checking shipping documents and labelling).

**Events of a radiological nature**

The number of package surface contamination events in 2012 and 2013 remained comparable to that of previous years (Figure 2.9). Between 1999 and 2002, this number was high because of inappropriate procedures regarding the immersion, in the spent fuel pools of EDF nuclear power plants, of packaging intended to transport irradiated fuel assemblies. That number fell sharply over the next 10 years. It was exceeded on limited occasions (the maximum level measured was 37 Bq/cm² in radioelements that emit beta rays for a regulatory limit of 4 Bq/cm²).

In addition, the number of times the radiation levels exceeded regulatory requirements in 2012 and 2013 remains comparable to that of prior years. The excesses noted were also limited (the largest concerned a transport of contaminated tools, where the radiation level on the surface of the package was measured at the destination site at 2.3 mSv/h compared to a regulatory limit of 2 mSv/h).

It should be noted that given contamination and radiation levels measured, none of these events had significant consequences for employees or the public.

![Figure 2.9 / Change in the number of radiological events reported from 2010 to 2013.](image)

**What radiological inspections are performed on packages after they are shipped?**

International regulation requires checking radiation level and non-fixed contamination on the surface of the package (contamination that can be removed from a surface under routine transport conditions, for example, vibrations or bad weather) before shipping any package containing radioactive materials. Thus, the radiation level must not exceed 5 µSv/h anywhere on the external surface of an excepted package. For other kinds of packages, the regulatory criteria are 2 mSv/h on the surface of the package and 0.1 mSv/h at two metres from the surface of the transport vehicle (the radiation level may, however, reach 10 mSv/h in contact with the package in the case of transport under "exclusive" use*). The maximum level of authorised contamination is 4 Bq/cm² for low toxicity beta, gamma and alpha emitters** and 0.4 Bq/cm² for the other alpha emitters. These limits are the average values applicable for a surface of 300 cm² of any part of the surface of the package.

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*Exclusive use shall mean the sole use, by a single consignor, of a conveyance or of a large freight container, in respect of which all initial, intermediate and final loading and unloading is carried out in accordance with the directions of the consignor or consignee.

**Low toxicity alpha emitters are: natural uranium, depleted uranium, natural thorium, uranium-235 or uranium-238, thorium-232, thorium-228 and thorium-230 when contained in ores or physical and chemical concentrates; or alpha emitters with a half-life of less than 10 days.
Events associated with impacts during handling

Package damage associated with impacts during handling in 2012 and 2013 was the second-leading reason for an event declaration (18% of the events reported, the majority of which were classified below the INES scale).

Only one of the 40 events of this type reported in 2012 and 2013 did not involve airport handling operations. As in previous years, damaged packages were associated primarily with medical sector consignors (35 of the 40 packages - Figure 2.10).

Given the limited activity and the nature of the radionuclides transported, they are shipped in excepted or type A packages (Figure 2.11). Regulations do not require that those packages be designed to resist severe impact, unlike type B packages or those containing fissile materials. Thus, because such packages are more sensitive to impact, they are subject to more frequent damage during airport handling, which is often fast-paced, given volumes shipped and time pressure.

None of the 40 events related to impacts during airport handling reported in 2012 and 2013 led to a loss of containment of the radioactive materials transported or to radiological exposure of employees or the public.

However, it should be noted that none of the 40 events declared led to a loss of containment of the radioactive materials transported or to radiological exposure of employees or the public.

In this context, CIS Bio International, the company that ships the packages most frequently involved in this type of event, organized meetings with the airlines in 2013, specifically including Air France, to alert them to the radiological risks associated with handling events. With the drop in the number of events in 2013, these actions appear to have borne fruit. Given high employee turnover in the businesses concerned, IRSN believes that it is important to continue such information actions directed to airlines and companies performing these handling operations.

Package theft and loss

With regard to the potential radiological consequences for the public, the theft or loss of packages or radioactive materials transported is the most common reason for declaring events classified at level 1 or above on the INES scale (35% of these events during the 1999-2013 period). If a package reported lost is found, ASN generally reclassifies the event at level 0 on the INES scale.

The 11 package losses reported in 2012 and 2013 (Figure 2.12) involved type A or excepted packages. Nine of these events concerned medical-use packages. The packages involved in six of these events were transported by air and lost temporarily at their arrival airport. Ultimately, ASN classified them as level 0 on the INES scale. For the three other events, the packages, transported by road, were
never found or their content was lost. These events were classified:

- level 1 on the INES scale: a type A package transporting an iridium-192 source from radiotherapy equipment was sent by the Gustave Roussy Institute in Villejuif, France and found to be empty when opened on 6 April 2012 by the receiving company (Mallinkrodt, Holland). The investigation conducted by ASN during an inspection at the Institute revealed that the procedures for unloading the source outside of the equipment in which it was used, and preparing the package had been followed. Furthermore, given the results of the radiological measurements performed before shipping, the investigation concluded that the source was likely lost during transport or after its arrival at the recipient company;

- level 2 on the INES scale: a type A package transporting a cell containing a fluorine-18 solution was lost during transport on the public road on 19 November 2012 in Nîmes and never found. This event, presented in chapter 3 of this report, was due to a tie-down defect of the package in the transport vehicle;

- level 1 on the INES scale: an excepted package transporting two unsealed iodine sources was lost during delivery to the Robert Debré hospital in Paris on 14 August 2013.

Given the small number of this type of event, IRSN has not drawn any generic lessons concerning them. IRSN notes that just one of the 11 lost packages reported in 2012 and 2013 was due to a tie-down defect of a package on its transport vehicle. The work and analysis underway at the national and international levels on the problem of package tie-down are described in chapter 3 of this report.

Events related to package closure defects

Tightening defects on impact limiter bolts

The packaging used to transport irradiated fuel assemblies from EDF reactors (Figure 2.13) to the AREVA plant at La Hague includes an impact limiter at each of the two ends, constituted of wooden blocks. The impact limiters’ role is to absorb mechanical impacts and protect the gaskets maintaining the leaktightness of the radiological material containment system in case of fire.

The impact limiter fastening bolts - eight per limiter - are greased and tightened using a torque wrench (Figure 2.14) to hold the impact limiter in place in the event of accidental impact (e.g., package that falls or roadway collision).

In 2011, eight events (Figure 2.15) were declared after the observation, during unloading operations of this type of package at the AREVA plant at La Hague, that one or two screws could have been loosened by hand. Before 2011, only three comparable events had been declared.

Because of this increased number of events and the potentially serious consequence of a loss of impact
limiter fastening bolts during accidental impact, particularly in the case of fire after an accident, in early 2012, ASN asked EDF to implement an action plan to correct the anomalies noted. A working group composed of EDF, AREVA and TN International (as the designer of the packaging involved) analysed the possible root causes of these events.

The analysis revealed that poor lubrication of the impact limiter bolts on the packaging could have allowed vibration during transport to loosen the screws.

This analysis showed that because of a lack of precision in the operating instructions for the packaging provided to EDF, EDF’s own operating documents were imprecise. As a result, the bolts may not have been lubricated completely, resulting in incomplete tightening. This, in turn, could cause the bolts to loosen from vibration during transport. In addition, two failures to comply with requirements were identified. They involve the order in which the impact limiter bolts must be tightened and the 30-minute waiting period recommended by TN International between placing the bolts and tightening them. This period is necessary to ensure that the temperature of the impact limiter and the rest of the packaging is uniform before closure (thus preventing the risk that the bolts will loosen from differential thermal expansion during transport). The analysis concluded that the non-compliances were related to the fact that the operators responsible for preparing the packages were unfamiliar with these requirements.

Based on that analysis, TN International placed a mark on the impact limiters to prevent deviations in the order in which the bolts are tightened. The operating documents were updated to include the 30-minute waiting period between the time the bolts are placed and tightened. In addition, a dual inspection of the bolt tightening, using two different torque wrenches and performed by two different operators, was implemented. These actions are traced in a checklist to be validated by the operators during package preparation.

The number of such events has declined over the last two years, which should be analysed in light of the gradual implementation of these provisions in 2012. They were extended to all EDF nuclear power plants (NPPs) starting in October 2013. However, two new events, which occurred on 12 December 2013 (involving a package sent by the Cattenom NPP) and on 13 February 2014 (involving a package sent by the Belleville-sur-Loire NPP), show that the provisions have not yet entirely eliminated them. Given the situation, the EDF/AREVA/TN International working group was reconvened to determine whether additional operational or design measures are necessary. Increased tightening torque of the impact limiter fastening bolts is one of the solutions under investigation.

In addition, as an ASN inspection conducted in February 2014 at an EDF NPP revealed, the instruction regarding the waiting period between setting the bolts and tightening them is not always followed, although it now appears in the operating documents and the checklist of actions to perform during package preparation. This observation illustrates the need for EDF to develop its efforts to raise awareness and train the operators concerned at all NPPs on the revised instructions and operating practices.

Closure defects on the UF₆ cylinder transport overpacks

In 2010 and 2011, the discovery of three different shipments with poorly engaged ball-lock pins (which hold the parts of the protective packages in place, see Figure 2.19) affecting several of this model’s packages led AREVA, as consignor, to analyse the causes of poor engagement or disengagement of the ball-lock pins during transport. These events were presented in the previous public report*.

Figure 2.15 / Change in the number of events related to tightening defects on packaging impact limiters reported to ASN.

Figure 2.19 / Disengagement of a ball-lock pin.

This analysis was based on inspections of several shipments of UF₆ cylinders, one of which led to the declaration of an event on 8 February 2012. This enabled AREVA to identify the human and organisational causes (ball-lock pin locking defect), as well as a non-conformity in some of the packages due to the use of ball-lock pin models that differed from those specified in the safety analysis report of the protective package. This non-conformity appeared to result from the designer’s failure to properly inform users in both France and abroad about restrictions imposed on the model of pin to be used after similar events occurred in the United States in the past.

In addition to replacing all the ball-lock pins in its packaging stocks, AREVA trained the operators in charge of pre-shipping inspections and set up additional controls involving visual inspections, tensile tests and a photograph of each pin to confirm that it is properly engaged.

IRSN noted that since implementation of these actions, no new event related to a locking defect has been reported to ASN. This suggests that the appropriate measures were taken.

In addition, when the uranium is enriched in uranium 235, packages must prove resistant under a series of impact and fire tests, without loss of leaktightness, which would compromise the prevention of criticality risks. In this case, to ensure that they are protected against impact and fire, containers containing UF₆ are transported on the public road in protective packages. In France, one of the package models used is of U.S. design (UX-30 type), composed of two half-packages maintained in the closed position by 10 ball-lock pins and saddle webbing (Figure 2.18).

Events related to non-conforming content

Events in this category involving the presence of “foreign matter” in packages of irradiated fuel should be highlighted.

What does “foreign matter” refer to?
The term “foreign matter” refers to objects or matter found in the packaging cavity that are not included in the loading plan.

This specifically involves packaging closure bolts or organic matter (gaskets, bits of fabric or adhesive tape) that probably fell into the packaging cavity accidentally during loading, unloading or packaging maintenance.
Until 2008, such material was discovered only rarely in the cavity of packaging loaded with irradiated fuel assemblies and was thus not a common reason for declaring an event to ASN (one event reported in 2000 and one in 2003).

With the implementation of systematic inspections of packaging cavities to detect the possible presence of foreign matter, the number of events reported since 2009 has increased.

In 2008, large quantities of organic material in a packaging cavity were discovered by chance during analysis of the gaseous composition of the cavity to quantify the production of flammable gas by radiolysis of aqueous residues. Following that discovery, systematic inspections of the presence of foreign matter in packaging cavities were implemented at the AREVA plant at La Hague during the unloading of irradiated fuel assemblies and during periodic packaging maintenance.

This heightened vigilance led to an increase in the number of events declared since 2009.

In addition, the analysis of the events declared since 2009 revealed a design defect in the orifice plugs providing access to the packaging cavity, after loading, to dry and depressurize the cavity. The geometry of the gasket groove ensuring plug leaktightness did not properly maintain the gasket, which on several occasions was drawn into the cavity by the difference in pressure between the packaging cavity and plug handling tool. Following implementation of operating precautions, the subsequent modification of the geometry of the groove of this gasket in 2011, and the gradual replacement of the orifice plugs of the packaging concerned during scheduled maintenance, no events related to the presence of gaskets in the packaging cavity were reported in 2012 and 2013.

Figure 2.20 / Change in the number of events reported related to the discovery of foreign matter during the 2009-2013 period.

In response to the risks of damage to the materials transported, the coating of the packaging cavity with metallic components and the production of flammable gas through radiolysis or thermolysis, EDF and AREVA implemented an action plan to ensure the cleanliness of the cavity of the irradiated fuel assembly packaging at ASN’s request. This plan specifically provides for EDF to conduct a systematic inspection to confirm that no foreign matter is present in the cavity when the packaging is loaded. The decline in the number of events declared in 2012 and, in particular, in 2013 compared to previous years (Figure 2.20) seems to confirm that appropriate operational measures were taken.
3
REMARKABLE EVENTS
3 REMARKABLE EVENTS

This chapter presents four of the most remarkable transport-related events occurring during the 2012–2013 period, which illustrate certain types of events covered in the chapter presenting the global analysis of events.

EVENT OF 18 APRIL 2012 IN WHICH TWO PACKAGES WERE DAMAGED AFTER BEING DROPPED DURING HANDLING

This event illustrates the issue of handling packages containing radioactive materials in airport areas, which, during the 2012–2013 period was the second most frequent cause of events related to the transport of radioactive materials reported to ASN.

Background

On 17 April 2012, from its factory in Romans-sur-Isère, CERCA, a subsidiary of AREVA group specialising in the fabrication of fuel elements for research reactors, sent nine TN-BGC 1-type packages to McMaster University in Hamilton, Canada. Each package was loaded with a new uranium silicide-based (U$_3$Si$_2$) fuel element, of which the uranium enrichment in isotope 235 was 19.95%.

The first phase of transport was carried out via road between the CERCA plant in Romans-sur-Isère and the Paris Charles de Gaulle Airport. The packages transported were arranged either alone or in pairs in a wooden structure, this assembly making up one pallet (Figure 3.2). The packages arranged in pairs were secured by straps, and all pallet assemblies were tied down to the lorry in the horizontal position with another type of strap.

TN-BGC 1 package design

Approved as a type B package, in accordance with regulations, the TN-BGC 1 package design comprises a cylindrical body, with a diameter of approximately 30 cm and a length of 1.80 m. The package is protected against impact by a 60-cm parallelepiped-shaped aluminium cage (Figure 3.1) along with a cylindrical protective impact limiter made of balsa wood, located on the upper part of the transport cask.

Figure 3.1 / The TN-BGC 1 package.

Figure 3.2 / Package conditioning.
Brief event description

On 18 April 2012, the lorry was unloaded in the cargo area of Roissy Charles de Gaulle Airport, by a forklift from a subcontractor of Air Canada Cargo. The pallets were handled one after the other and transferred to a transit hangar.

At around 6:40 AM, during the unloading operation, the forks of the lift were positioned too deeply under one of the pallets to be unloaded, which, when the forks were lifted, caused the pallet located behind the pallet being unloaded to lose equilibrium and subsequently drop to the ground, from a height of between 1 and 2 meters.

This event had no impact on workers, the public or the environment. Radiation measurements taken at around 6:50 AM by a specialist on the site revealed no contamination on package surfaces or the ground, nor an abnormal radiation level.

The IRSN package examination team came to the cargo area of the Paris Charles de Gaulle Airport to perform a technical assessment of the event.

Within the IRSN, the "package examination" team, alerted by the IRSN Transport Operations division (EOT), was sent to the site to perform a visual inspection of the condition of the packages (Figure 3.3) and propose to ASN actions to be implemented to ensure their recovery then evacuation under the safety conditions required for this type of operation.

Analysis of the event’s causes and corrective actions

The event analysis, presented by AREVA in its event report, identified various causes attributable jointly to human and organisational factors as well as technical factors related to the tie-down configuration and handling equipment.

As concerns human and organisational factors, the analysis revealed a lack of knowledge on the part of the forklift driver, of the plan for tying down the packages on the vehicle, and in particular the fact that since the pallets were tied down two-by-two on the vehicle, the pallet located behind the one being handled was no longer tied down to the vehicle. In this light, the analysis showed that the driver had not inspected the tie-down of the pallets before handling them. According to AREVA, the drop of the packages could have been a result of rapid movements on the part of the
driver, who did not, it seems, take any special precautions when using the forklift.

Concerning corrective actions, AREVA informed the company that performed the aforementioned unloading operations of the identified failures, qualified as “safety culture failures”, and proposed to it actions to increase awareness among staff. Although the lack of control and inquisitiveness on the part of the operator in charge of handling the packages played a certain role, the analysis presented by AREVA also identified technical factors favouring the occurrence of the incident. The fact that the pallets were tied down in pairs meant that the one located behind the first pallet to be handled had to be untied. For this reason it could not be maintained on the lorry when it was destabilised by the forks of the lift. In this regard, it appears that the lift used, equipped with forks that were too long, was not appropriate for the handling operation it was to perform.

Corrective actions proposed by AREVA included the provision of a piece of wood between the pallets to prevent the forks from going too far during unloading and individual tie-down of each of the pallets transported to prevent them from falling in a sort of domino effect in the event of an impact during unloading.

Lessons learned

The damage identified by IRSN after the drop of the two TN-BGC 1 packages confirmed the existence of uncertainty concerning the behaviour of packages of this type in the event of an accident.

Background

Between October 2008 and March 2012, several MOX fuel rod transport campaigns were led between the MELOX plant in Marcoule and the FBFC plant in Dessel, Belgium, for the manufacturing of MOX fuel assemblies. These transport operations were carried via road in FS 65-1300 packages (Figure 3.4), classified as type B packages loaded with fissile materials.

During their storage prior to transport, the fuel rods are packaged in batches of approximately 200 to 300 rods, in a parallelepiped-shaped box, in which they are kept in the form of sticks secured in place by straps made of synthetic fibres. During their loading in the cask and transport, the rods remain in this box.

The package consignor, MELOX, a subsidiary of the AREVA group in charge of MOX fuel manufacturing,
had commissioned TN International, a subsidiary of the AREVA group in charge of the design, manufacture and management of the group’s transport casks, to carry out its transport operations. To this end, the safety analysis performed for the FS 65-1300 package design loaded with MOX fuel rods was carried out by TN International, which also applied to ASN to obtain the certificate of approval for these transport operations.

What is a package design certificate of approval?

The package design certificate of approval is a document issued by ASN, the French Nuclear Safety Authority that confirms the compliance of the package design with applicable regulatory requirements. It includes a definition of all radioactive materials that can be transported in the cask as well as the requirements for their conditioning and, where applicable, the transport conditions (meteorological conditions, maximum duration of transport, etc.). The certificate of approval is issued for a limited period, generally between 3 and 5 years, based on the analysis of the package design’s compliance with regulations, presented by the applicant. For packages containing fissile materials intended for transport across borders, the certificate of approval issued by ASN for the consignor must be validated by that of the recipient country.

Brief event description

On 8 October 2012, TN International notified ASN that it had detected a deviation involving the loading of FS 65-1300 transport casks used during previous transport campaigns. The deviation resulted from the presence of MOX fuel rod bundles still equipped with their securing straps in the casks, whereas these straps were not included in the description of authorised contents from the certificate of approval for the FS 65-1300 package, and the fact that their impact on transport safety was therefore not analysed in the package safety analysis report.

Analysis of event causes and corrective actions

The causes of this event were analysed together by TN International, as designer of the cask and drafter of the safety analysis report, and by the operator of the MELOX plant in charge of transport as consignor. This analysis revealed a lack of knowledge on the part of TN International concerning MELOX operating constraints, along with a lack of knowledge on the part of the consignor of the contents of TN International’s safety demonstration. The apparent problem was that the TN International department in charge of the safety analysis was not informed by the operator that straps would be used to package the MOX fuel rods. This arrangement, which was not included in the safety analysis specifications prepared by TN International and validated by MELOX, was therefore not taken into account in the analysis performed to support the approval request for the package design.

What influence does moderation have on the risk of an uncontrolled fission chain reaction?

During their movement in material, neutrons progressively transfer their energy during collisions with the nuclei of atoms with which they come into contact. This phenomenon, called “moderation” in nuclear physics, leads to an increase in the probability they will cause fission reactions when fissile material is present. The energy transferred is even greater with lighter nuclei, such as hydrogen. This explains why the presence of hydrogenated substances favours the risk of uncontrolled fission chain reaction.

After this deviation was discovered, transport of new MOX fuel rods between the MELOX plant and the FBFC plant in Dessel was interrupted.

After this deviation was discovered, transport between the MELOX plant and the FBFC plant in Dessel was interrupted by the consignor, and ASN asked TN International to provide an assessment of the impact the presence of the straps could have on package safety. TN International demonstrated that the presence of the straps did not affect the safety of the transport. The calculations indicated that the quantity of flammable gas liable to be produced by the radiolysis of the straps was small enough that it did not entail a risk of overpressure, or ignition, in the package cavity, for the period required for the transport operation, including the scenario in which transport contingencies extend this period. Furthermore, thermal tests performed on this type of strap indicated that it is not prone to the risk of thermolysis at the temperatures reached in normal transport conditions. The hydrogenated matter entering the composition of the materials in the straps is an element that favours the moderation of neutrons; however, TN International demonstrated that, considering the limited quantity of hydrogen present in the straps, there is no risk of uncontrolled fission chain reactions in the transport operations performed.

Following IRSN’s assessment of these elements, ASN and its Belgian counterpart AFCN issued, respectively, in October and November 2012, new certificates of approval authorising transport in a package in batches of strapped-down fuel rods; transport between the MELOX and FBFC plants could thus be resumed.

Considering the lack of compliance with transport authorisation conditions, this event was classified by the ASN as level 1 on the INES scale.

The department of the applicant in charge of the safety analysis was not informed by the operator that straps would be used to package the MOX fuel rods in bundles.
The operator had, for its part, not seen any particular problem with using straps during transport since it was not explicitly stated in the certificate of approval that any materials not described in the definition of contents were prohibited.

To correct this mutual misunderstanding of parameters included in the definition of transported contents, MELOX and TN International agreed to improve their document sharing for package design approval requests to keep each other up-to-date, through regularly organised meetings, of the validity of current transport cask approvals, making sure in particular to address changes in operations liable to impact the contents of safety analyses.

**Lessons learned**

For IRSN, this event illustrates the difficulties that package consignors can encounter in terms of understanding the definition of authorised contents in a certificate of approval, whether involving the characteristics of radioactive materials or components and related equipment (straps, covers, spacers, etc.).

For this reason, as part of its evaluation, IRSN gives special attention to the requirements established for descriptions of contents and readability of information included in certificates of approval, which are intended to simplify and limit the number of parameters to be checked to prevent risk of error during package loading operations. Compliance checks of contents records in shipment documents are also performed during inspections of consignors handling radioactive materials by ASN, with technical support from IRSN.

**EVENT OF 19 NOVEMBER 2012 CONCERNING LOSS OF A PACKAGE ON A PUBLIC ROAD**

This event illustrates the issue of lost packages of radioactive materials, which, considering the possible radiological consequences for the public, is the most frequent reason for reporting an event classified as level 1 or higher on the INES scale. In this case, this event was rated level 2 on the INES scale.

**Background**

Fluorine-18 is a fluorine isotope used as a radioactive tracer for cancer detection using medical imaging. It is produced using a cyclotron generally located near the location where it is to be used, due to its very short radioactive half-life, which means that it must be transported as quickly as possible.

One of the cyclotrons operated by CIS Bio International to produce fluorine-18-labelled molecules is located in Nimes. This site produces for the university hospitals of Nimes, Montpellier, Marseille and Avignon within periods compatible with the very short half-life of fluorine-18.

**Brief event description**

On 19 November 2012, during a delivery to the university hospital of Nimes, a type A package containing a flask of 18F-labelled fluodeoxyglucose (18F-FDG) fell onto a public road during its transport.

This package is in the shape of a metal case 20 cm long.

![Figure 3.5 / Cask similar to that involved in the event of 19 November 2012.](image)
and 28 cm in height (Figure 3.5). It encloses a lead containment reducing the amount of radiation emitted by the flask placed in its centre, of which the activity at the time it was sent was 20 gigabecquerels (GBq).

The driver of the delivery vehicle indicated that he had noticed on the way that the back door of the vehicle was slightly open and that a package had disappeared. The police were alerted by telephone by a witness who had seen the package on the side of the road. However, when the police arrived on the scene, the package was no longer there, and it was never found.

Considering the radiation risks involved on the day the package was lost, a radio alert was broadcast locally.

Analysis of event causes and corrective action

The day after the incident, ASN led a rapid-response inspection in the facilities of the company responsible for transport of the package on behalf of freight forwarder Isovital, which was hired by CIS Bio International for transport operations. This inspection focused particularly on the tying down and securing of the package in the transport vehicle as well as provisions for the training of staff in charge of these operations. This event was also covered in a detailed analysis performed by Isovital, the conclusions of which supported those of ASN.
In its analysis report, Isovital asked the transport company to implement an action plan to increase awareness and provide internal training for staff (drivers and managerial staff) regarding transport instructions, including tie-down, and controls to be performed prior to each shipment. Isovital also asked its sub-contractor to equip and inspect replacement vehicles to a level comparable to that of the vehicles normally used. The failure on the part of the transport company manager to comply with the order on the transport of dangerous materials, along with negligence on the part of the driver, were seen by ASN as signs of a failure in the safety culture of this company. Considering the non-compliance with basic transport rules and the potential radiological consequences of losing the package, ASN classified the event as level 2 on the INES scale.

Lessons learned

For IRSN, this event underlines the importance that carriers must place on tie-down requirements for packages of radioactive materials. For several years now, events caused by failures to comply with tie-down requirements have been reported to ASN on a regular basis.

This important subject is addressed by working groups at the national and international level, since events of this type also occur abroad. These working groups, in which IRSN participates, establish design criteria for tie-down according to the method of transport used (road, rail, air and sea) and prepare guides of best practices for the use of consignors and carriers to ensure reliable tie-down.

EVENT OF 23 DECEMBER 2013 INVOLVING DERAILED WAGON AT THE DRANCY-LE BOURGET MARSHALLING YARD

Three significant events occurring in 2012 and 2013 involved the derailment of a wagon containing radioactive materials. The event of 23 December 2013, although having no direct impact on transport safety, gained broad media coverage due to the type of radioactive materials transported (irradiated fuel assemblies) and the location of the incident (a train station in the Paris region, near residential areas).

Background

As part of transport of radioactive materials associated with fuel cycle activities, after being used in nuclear reactor cores, irradiated fuel assemblies are shipped in TN 12/2 or TN 13/2 type casks (type B packages) from EDF power plants to the AREVA plant in La Hague for reprocessing.

Brief event description

On 23 December 2013, around 4 PM, a railway convoy made up of a locomotive and one wagon carrying a TN 13/2 package loaded with irradiated fuel assemblies, shipped by EDF from Nogent-sur-Seine to the AREVA La Hague plant, partially left the tracks at a railway switch during an operating manoeuvre in the rail yard of Drancy-Le Bourget.

The Drancy-Le Bourget rail yard

The Drancy–Le Bourget rail yard has 48 railroad tracks extending over a length of 3 km. Situated across three towns in the department of Seine-Saint-Denis (Drancy, Le Blanc-Mesnil and Le Bourget), in the Île-de-France region, this cargo area receives nearly 250,000 freight wagons each year, of which 13,000 are loaded with hazardous materials (hydrocarbons, chlorine, ammonia and radioactive materials).
For transport operations, this type of package is placed inside a metal structure (presented in white in Figure 3.6), protecting it from any adverse weather conditions and preventing any contact with the package. The derailment, which occurred at a low speed (less than 20 km/h), did not destabilise the package.

Following SNCF’s activation of the alert provided for in the emergency plan implemented in each station liable to receive high-risk hazardous materials, the Paris fire brigade arrived just before 5 PM, to perform radiological controls around the package (dose rate and contamination of the external surface of the package). The controls results did not reveal any exceeded regulatory criteria.

The wagon was rerailed by SNCF the following morning, and the wagon was moved into “garage” position, pending ASN authorisation for it to continue on its way to the La Hague plant. After consultation with SNCF and TN International, the freight forwarder, ASN decided that the transport of the package involved in the derailment should be performed with another wagon.

Following ASN validation of the detailed action plan presented by TN International for completion of the transport operation, transshipment was completed on 27 December 2013. During the operation, dose rate checks were performed around the package, with results confirming those of the checks performed on the day of the event.

The new wagon was routed directly to the railway terminal of Valognes, where the package was then transferred by road to the La Hague plant, where it arrived on 30 December 2013. In compliance with regulations regarding the international transport of dangerous goods by rail (RID), radiological controls were then performed on the damaged wagon, revealing the existence of one point of contamination below a tie-down element. The wagon was decontaminated by TN International on 31 December 2013. According to the analysis performed by EDF, the contamination observed was due to radioactive particles made up of cobalt-60, from the water of the spent fuel pool in which the TN 13/2 cask was submerged for loading, and which detached from the package and fell inside the wagon either during package loading or during transport (http://www.asn.fr/Informer/Actualites/Incident-ferroviaire-de-Drancy-Le-Bourget-93). This non-compliance with regulatory criteria for contamination, which had no relation to the derailment of the wagon, was notified as an event by the package consignor.

Analysis of event causes and corrective actions

TN International’s examination of compliance of the documents associated with the wagon involved in the event did not reveal any non-compliance related to the design, manufacturing or maintenance of the wagon. Moreover, this same wagon had travelled this route several times—as it was the only one authorised for the transport of hazardous goods—without any problems since its last maintenance in 2012.

On the day of the event, a technical investigation was opened by the French Land Transport Accident Investigation Bureau (BEA-TT) to identify any technical failures that might have caused the wagon to derail. Legal experts were also designated to investigate responsibility in the event and identify any organisational causes or human errors that may have been made during switching operations.

What is the Land Transport Accident Investigation Bureau (BEA-TT)?

Created in 2004, under the auspices of the Ministry of Ecology, Sustainable Development and Energy (MEDDE), the BEA-TT has the mission of independently carrying out technical investigations of serious or potentially serious land transport accidents or incidents to establish the circumstances, identify the certain or possible causes and to issue safety recommendations to prevent similar accidents in the future.

Holding a key role in the prevention of land transport accidents, the BEA-TT has a purely technical mission. Its investigations are not intended to determine responsibility. Its scope includes railway and road transport, urban guided transport (metros and tramways), mechanical cable ways and inland navigation. It has a very broad investigation capacity, established by law, and has access to informational files and legal inquiries concerning the accidents it analyses. It is obligated to make the final reports of the investigations public.

The conclusions of the BEA-TT assessments are published on its website (http://www.bea-tt.developpement-durable.gouv.fr).
The conclusions of the different assessments, once known, should provide the reasons for the derailment. However, the assessment of the damaged wagon, carried out on 16 January 2014, revealed no non-compliance that could explain the derailment. Furthermore, no trace of seizure or damage was observed on the bogie that slipped out of the tracks (damage was observed on another bogie, appearing to be a consequence of the derailment). It also seems that the event was not a result of a wagon failure. As a result, this type of wagon is still used for the transport of radioactive materials.

Although this event did not call the safety of the irradiated fuel package into question, and had no impact on the safety of neighbouring populations and the environment, the fact that it occurred in a densely populated residential area, with 250,000 people living less than 2.5 km away from the station, led to broad media coverage of the event. It was an occasion for elected officials from neighbouring towns and residents’ associations to restate their opposition to the passage of trains loaded with hazardous materials, with many incidents having occurred over the past years, including the derailment of a wagon used to transport hydrochloric acid, which was empty at the time, just 12 days prior.

Lessons learned

During the event that took place on 23 December 2013, the train was rolling at a slow speed (less than 20 km/h), and the derailment did not result in destabilisation of the package, which could have caused it to drop. However, experience feedback concerning railway accidents in general remind us that such events can occur at much higher speeds.

This confirms the importance that must be placed, as part of the defence-in-depth approach applied to radioactive materials transport safety, on the robust design of packagings used for these transport operations. In order to ensure the protection of the population and the environment, the higher the level of radioactivity contained in the cask, the more robust it must be. It is studied during the design of each type of packaging and tested, normally on a model, in representative tests of accident situations liable to be encountered during transport. As part of this, casks used for the transport of irradiated fuel assemblies (type B cask), such as that involved in the event, are subject to regulatory tests for impacts at 50 km/h (simulated by a drop from a height of 9 meters on an unyielding target) and to drop tests from a height of 1 meter onto a steel bar (Figure 3.7).
CROSS-DISCIPLINARY ISSUES
The ORSEC-TMR plan

To specifically address the interministerial directive of 7 April 2005 relating to action by public authorities in response to an event involving an emergency that may put the public at risk, each French department must have an emergency response plan ("ORSEC plan"). The specific provisions on the transport of radioactive materials (known as TMR in French) are included in the "ORSEC-TMR plan".

The ORSEC-TMR plan is activated in the event of an accident involving packaging containing radioactive materials, which may give rise to a radiological risk for the public or the environment, whether the packaging is transported by road, rail, inland waterway or air.

The ORSEC-TMR plan organises, mobilises, implements and coordinates all of the public and private facilities that can help to protect the general public, property and the environment. It is activated in the event of an accident involving packaging containing radioactive materials, which may give rise to a radiological risk for the public or the environment, whether the packaging is transported by road, rail, inland waterway or air.

The plan involves various parties, at both local and national level:

- at local level, the Prefect of the département where the accident occurred is responsible for activating the plan and mobilising the local emergency services. The consignor, or the carrier, of the package involved takes the necessary measures to alert the public.
What is the national plan for managing a major nuclear or radiological accident?

To enhance public safety in the event of a serious accident occurring in France or beyond French borders, taking into account the lessons learned from the Fukushima disaster in March 2011, and to deal with the possibility of accidents during the transportation of radioactive materials*, including at sea, the French government has produced the national emergency response plan for major nuclear or radiological accidents, which was published on 3 February 2014 (Figure 4.1).

As part of this plan, the Prime Minister, in conjunction with the President of the Republic, provides political and strategic leadership in an emergency and heads the interministerial emergency response group, which fulfils a key management role in this area at national level. Besides the ministries directly involved, this group brings together the ex officio competent safety authority (ASN or ASND), public bodies with the requisite expertise (IRSN) and representatives of the operator, where appropriate. This new plan divides the country into zones and départements and relies, in particular, on public safety and emergency response measures » http://www.sgdsn.gouv.fr/site_rubrique146.html.

Public authorities and the media, mitigate the consequences of the accident and implement the actions required to recover the package and any radioactive materials dispersed in the environment;

at national level, the French Nuclear Safety Authority (ASN) is responsible for advising the Prefect and accordingly relies on the technical expertise of IRSN. Depending on the consequences of the accident, the ministries of the Interior, Health, Industry and the Environment may become involved in emergency response measures and in supporting the Prefect’s actions. The package consignor and carrier, because of their specific knowledge of the characteristics of the transport operation and the radioactive materials, are also an integral part of the national emergency effort. For example, TN International, an AREVA Group subsidiary specialising in radioactive material transport, has an emergency centre that can communicate in real time with the competent authorities.

Once the material involved in the accident has been recovered and reshipped, the Prefect declares an end to the emergency. Post-accident management – including decontamination of the area affected, management of any contaminated land and crops, etc. – is not covered by the ORSEC-TMR plan.

What does the ORSEC-TMR plan include?

The ORSEC-TMR plan, formerly known as the specialised assistance plan for radioactive material transport, is specific to each département of France. It describes the composition and tasks of the various groups involved in the emergency response effort that are responsible for taking action, providing expertise or ensuring communications, the public authorities (the prefecture, the local fire and emergency services, the mobile radiological intervention unit, the police, etc.), the safety authority, IRSN, the consignor and the carrier, as well as any public or private organisations that may be called upon (Météo-France, the French National Railway Corporation SNCF, motorway operators, etc.)

The plan also defines the activation criteria (depending on the type of accident and package), the resources that can be mobilised at local and national levels and the emergency action to be taken in order to secure the accident site, and evacuate and protect members of the public. In this respect, it includes emergency instructions to enable first responders to quickly identify the types of packages and radioactive materials involved and their associated risks, choose the appropriate operational response and determine the exclusion zone around the package and the public protection zone to be set up. The “ORSEC-TMR” section concerns transportation by road, inland waterway, rail and air, and is applicable to both civil and military shipments. Transport by sea comes under the NUCMAR plan.

A sample ORSEC-TMR plan is available (in French) on » the government’s portal site and concerns the Bouches-du-Rhône département in the south of France*.

(*) http://www.bouches-du-rhone.gouv.fr/content/download/3731/21922/file/ORSEC%20transport%20de%20mat%C3%A9s%20radioactives.pdf
The role of IRSN in emergency response

IRSN participates in emergency management measures, particularly relating to transport accidents involving radioactive materials. It draws on its expertise to provide support for the safety authorities and government departments. In this context, it proposes technical, health or medical measures to ASN, designed to protect the general public and the environment.

To enable it to effectively provide technical support to the public authorities in the event of a transport accident involving radioactive materials, IRSN brings into operation its emergency response centre, which is based at its Fontenay-aux-Roses site near Paris.

To enable it to effectively perform its tasks, the Institute has an emergency response centre, based at its Fontenay-aux-Roses site near Paris, which can be activated 24/7 (Figure 4.2), and a team of responders (the “mobile unit”) that can be dispatched to the accident site with a view to organising the measures to be taken, liaising with the emergency response centre on essential technical matters and providing information and advice to the local authorities.

Videos of the general organisation of the emergency response centre and the technical assessment tools available in a nuclear emergency can be viewed on the IRSN website.

In the event of an emergency involving a shipment of radioactive materials, a “package evaluation” unit is responsible for analysing the consequences of the damage to the packages, particularly to the components ensuring their safety functions (radiological protection, containment, subcriticality), and evaluating the damaged package recovery plan proposed by the consignor or carrier.

IRSN’s “mobile unit” is an integral part of the civilian safeguards put in place at accident sites; it is under the command of the emergency operations commander, who coordinates operations on the ground, and mainly comprises:

- teams responsible for performing radiological controls on people and on samples taken in situ. For this purpose, IRSN’s laboratory mobile units (Figure 4.3) can be rapidly dispatched on site;
- in the event of a transport accident, a team responsible for gathering information on the condition of the packages involved in the accident (physical state, possible leaks of radiation or contamination, integrity of criticality risk prevention provisions, heat dissipation capacity of the packages, etc.) and passing it on to the emergency response centre.

Feedback from emergency exercises

At the time of writing this report, no transport accident involving radioactive materials had required activation of the ORSEC-TMR plan. However, certain events, such as the crash involving a Type B package on 5 April 2007 at Fère-Champenoise in north-eastern France and the handling incident that occurred at Paris Charles de Gaulle Airport on 18 April 2012 (described in Chapter 3 of this report), required the mobilisation of the local emergency services and some of the IRSN emergency teams, particularly the “mobile unit” teams responsible for conducting radiological measurements and collating information on the condition of the package.

At the time of writing this report, no transport accident involving radioactive materials had required activation of the ORSEC-TMR plan.

Emergency response exercises are organised at regular intervals to test the effectiveness of the full range of resources that would be deployed if the ORSEC-TMR plan were activated, and to ensure proper coordination between all parties involved, both locally and nationally. Furthermore, to take account of the fact that an accident occurring in France could have radiological consequences in neighbouring countries, an exercise simulating an accident involving a package of radioactive material at the French-Belgian border...
was recently organised to test coordination between the emergency response organisations (public authorities, safety authorities and their respective technical support agencies, etc.) of these two countries.

The purpose of these exercises is to enable the parties involved in emergency response to regularly practise their procedures in order to develop the skills of the first responders and acquire the reflexes necessary to be able to react rapidly and effectively in a real emergency. They also provide IRSN with an opportunity to test its operational capabilities on the ground (Figure 4.4). Each exercise provides feedback, which can be analysed to identify areas for improvement, ranging from the exchanges between the various parties involved and the expert assessment resources at their disposal to the actual response at the accident site.

Transport-related emergency exercises provide IRSN with an opportunity to test its operational capabilities on the ground.

IRSN’s actions in the wake of transport accidents involving radioactive materials, as well as its participation in the emergency response exercises conducted to date, have enabled the Institute to identify problems relating to the relay of information (number and condition of the packages involved, duration of any fire, layout of the accident site, etc.) from the site to the emergency response centre, particularly during the phase prior to the arrival of IRSN’s mobile unit at the accident site itself, i.e. when the only source of information is the local fire and emergency services or the mobile radiological intervention unit.

In this regard, the on-site team responsible for gathering information on the condition of the packages recently acquired an on-board camera system for transferring images in real time to the team member based outside the exclusion zone, who have the task of relaying observations to the emergency response centre; the team now also has ICT equipment that is more compact, making it easier to deploy.

**IRSN STUDY OF THE BEHAVIOUR OF PACKAGINGS DURING LONG-LASTING FIRES**

The regulations dictate that packages of radioactive materials must be designed to withstand an accident. To do this, the packages must retain their safety functions during tests intended to be representative of a major accident, including a 30-minute fire with a flame temperature of 800°C.

<table>
<thead>
<tr>
<th>1. Routine transport conditions: content not very dangerous*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to withstand the effects of acceleration and vibration</td>
</tr>
<tr>
<td>Ability to withstand a range of temperatures and pressures</td>
</tr>
</tbody>
</table>

Examples of packages:
* Instrument to test for the presence of lead in paint.
** Radiopharmaceutical product.
*** Irradiated fuel package being shipped from a nuclear power plant to the reprocessing plant.

<table>
<thead>
<tr>
<th>2. Normal transport conditions: content poses limited danger**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water spray exposure to rain at 5 cm/h for 1 hour</td>
</tr>
<tr>
<td>Stacking compression force equal to 5 times the weight of the package for 24 hours</td>
</tr>
<tr>
<td>Penetration 6 kg bar dropped from a height of 1 m</td>
</tr>
<tr>
<td>Free drop from max. 1.2 m depending on the mass of the package, onto an unyielding surface</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Accident transport conditions: dangerous content***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire test temperature of 800°C for 30 minutes</td>
</tr>
<tr>
<td>Immersion in 15 m of water for 8 hours</td>
</tr>
<tr>
<td>Free drop from 1 m onto a steel punch bar with a diameter of 130 mm</td>
</tr>
<tr>
<td>Free drop from 9 m onto an unyielding surface or crush test by dropping a 500 kg steel plate from a height of 9 m</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>4. Enhanced accident transport conditions: most dangerous content transported by air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire test temperature of 800°C for 60 minutes</td>
</tr>
<tr>
<td>Immersion in 200 m of water for 8 hours</td>
</tr>
<tr>
<td>High-speed impact: onto a rigid target at 90 m/s (324 km/h)</td>
</tr>
<tr>
<td>Burial: degraded heat exchange around the packaging</td>
</tr>
<tr>
<td>Free drop from 9 m onto an unyielding surface</td>
</tr>
<tr>
<td>Free drop from 3 m onto a cylindrical bar with a conical end (height 300 mm, diameter 25 mm at the tip)</td>
</tr>
<tr>
<td>Crushing: free drop of a 500 kg mass from a height of 9 m (steel plate measuring 1 x 1 m falling horizontally)</td>
</tr>
</tbody>
</table>

Figure 4.4 / Examination of damaged packages during a national emergency response exercise.

Figure 4.5 / Tests for each package type.
On 5 April 2007, at about 6.30 am, a van carrying a radioactive package was involved in an accident on the RN4 main road between Nancy and Paris, near Fère-Champenoise in north-eastern France.

The Russian-design type B package contained a sealed source of caesium-137 with an activity level of approximately 73 TBq, approved as a special form radioactive material. This package was being delivered to a French calibration laboratory.

The van collided with a heavy goods vehicle carrying dairy produce and burst into flames (the fire being primarily ignited by the fuel in the two vehicles).

It was officially estimated that the fire burned for between 15 and 50 minutes. This fire did not have any radiological consequences.

The diversity of the potential accident scenarios encountered may lead to the package being exposed to fire of varying intensity and duration, depending on the nature of the flammable products involved and the position of the package in the fire.

On this respect, at the time of the accident that occurred on 5 April 2007 at Fère-Champenoise in north-eastern France, which resulted in a Type B package being exposed to fire, it was officially estimated that the fire burned for between 15 and 50 minutes. This fire did not have any radiological consequences.

The diversity of the potential accident scenarios encountered may lead to the package being exposed to fire of varying intensity and duration, depending on the nature of the flammable products involved and the position of the package in the fire.

The results of IRSN research into the fire behaviour of different package designs intended for the transport of new or irradiated fuel assemblies and radioactive waste complement the tools used by the Institute’s experts in emergency situations to evaluate the integrity of the packages in the event of an accident.

In this context, using numerical simulations, IRSN has studied the fire behaviour of different package designs intended for the transport of new or irradiated fuel assemblies and radioactive waste.

The purpose of this research is to determine the duration of a fire characterised by a flame temperature of between 400°C and 1000°C that could lead to containment failure and the release of radioactive materials from the package. The results complement the tools used by IRSN’s emergency response centre experts to evaluate the integrity of packages in the event of an accident.

Worldwide, the only known transport accident involving a Type B package subjected to an intense fire occurred at Fère-Champenoise in 2007.

In this respect, at the time of the accident that occurred on 5 April 2007 at Fère-Champenoise in north-eastern France, which resulted in a Type B package being exposed to fire, it was officially estimated that the fire burned for between 15 and 50 minutes. This fire did not have any radiological consequences.

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Cross-disciplinary Issues

The packages studied (Figure 4.9 - for reasons of symmetry, only one-eighth of the package has been modelled) are assumed to have been damaged beforehand during regulatory drop tests. For each package type studied, the characteristics of the contents (thermal power, burn-up, etc.) were defined so as to maximise the temperature reached in the safety-related components (Figure 4.10).

Containment of radioactive materials

The components that ensure that radioactive materials are contained within a packaging (forming the "containment system") depend on the quantity of radioactivity and the package type. For a type B package, containment is usually provided by a steel shell between 2 and 30 cm thick, depending on the design, designed to withstand the extreme temperature conditions imposed by the regulations (accidental impacts at -40°C, 800°C fire), and by the gaskets ensuring leak tightness of the lid(s) and the packaging orifice plugs. These gaskets, which are generally in elastomer but can also be made of metal, are designed to limit the loss of radioactive contents at the temperature to which they are exposed under regulatory fire conditions. Their leak tightness is checked by measuring the leak rate before each shipment. In the case of fuel assemblies, the fuel rod cladding and end plugs constitute the first containment barrier to radioactivity release (Figure 4.8). The integrity of this barrier is not guaranteed in the event of a severe accident, however.

Figure 4.8 / Schematic diagram of a fuel rod

Figure 4.8 / Schematic diagram of a fuel rod

Description of the numerical simulations carried out, main results and lessons learned

The numerical calculations performed by IRSN are based on the use of a code developed by the Institute for 3D modelling of transport packaging and its contents. Modelling takes into account (1) the expansion of the materials and the real-time alteration of the spacing between the package components and (2) all modes of heat transfer between the package and the external environment and between the different package components (conduction, radiation, convection).

Figure 4.9 / Example of a package design studied.

Figure 4.9 / Example of a package design studied.

Figure 4.10 / Temperatures (in °C) reached in the package before (upper image) and after (lower image) the fire.
Based on the calculations performed for the different flame temperatures considered, i.e. between 400°C and 1000°C, it was possible to determine the fire durations leading to a potential release of radioactive materials from a package because of a loss of gasket integrity and, where applicable, failure of the fuel rod cladding (cf. Figure 4.11).

Thus, for the example corresponding to Figure 4.11 concerning a Type B package containing irradiated fuel assemblies, these results show that, during a hydrocarbon fire that "engulfs" the package in the open air, where the flame temperature is below 1000°C, there should be no release of radioactive materials from the package within a period of 4 hours in the absence of any impact that may compromise the integrity of the fuel rod cladding, or within an hour and a half if this cladding have already failed.

Furthermore, simple correlations have been derived from applying the results of these numerical calculations, enabling IRSN’s emergency response centre to rapidly assess the integrity of safety-related components of packages if the characteristics of the fire can be estimated, in particular its duration and intensity (flame temperature), depending on the nature of the flammable liquids present and the position of the package in the fire.

Figure 4.11 / - Examples of maximum permissible durations and temperatures of various fire scenarios.
IRSN's viewpoint on safety and radiation protection issues relative to French nuclear power plants in 2013
ABBREVIATIONS
ABBREVIATIONS

A

ADN
European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways

ADR
European Agreement concerning the International Carriage of Dangerous Goods by Road. The ADR contains several directives concerning the packaging, stowage, and identification of dangerous goods and their transport by road

ASN
Autorité de Sûreté Nucléaire, nuclear safety authority for civilian activities in France

ASND
Autorité de Sûreté Nucléaire pour les activités de Défense, nuclear safety authority for defence-related activities in France

B

BCOT
Base Chaude Opérationnelle du Tricastin, Tricastin Operational Hot Unit, a nuclear maintenance facility operated by EDF

Bq
Becquerel, unit of radioactivity (see glossary)

C

CEA
Commissariat à l’Énergie Atomique et aux Énergies Alternatives, French Alternative Energies and Atomic Energy Commission

CENTRACO
Centre Nucléaire de Traitement et de Conditionnement des Déchets Faiblement Radioactifs, low-level waste processing and packaging centre operated by SOCODEI

CERCA
Compagnie pour l’Etude et la Réalisation de Combustibles Atomiques. AREVA subsidiary specialising in the fabrication of fuel elements for research reactors

Cires
Centre Industriel de Regroupement, d’Entreposage et de Stockage, Cires waste collection, storage and disposal facility

CMIR
Cellule Mobile d’Intervention Radiologique, mobile radiological emergency response unit
CSA Waste Disposal Facility
Centre de Stockage de l’Aube, a disposal facility for low- and intermediate-level short-lived waste located in Soulaines-Dhuys in northeastern France

CTC
IRSN emergency technical response centre

E
ECOSOC
United Nations Economic and Social Council

EDF
Electricité de France

FBFC
Société Franco-Belge de Fabrication de Combustibles, fuel manufacturing subsidiary of AREVA

H
HCTISN
Haut Comité pour la Transparence et l’Information sur la Sécurité Nucléaire. The French High Committee for Transparency and Information on Nuclear Safety is responsible for providing information, consultation and debate on risks related to nuclear activities and the impact of these activities on the health of people, the environment and nuclear safety.

HLW-LL
High-level and long-lived waste

INES
International Nuclear Event Scale (see glossary)

IRSN
Institut de Radioprotection et de Sûreté Nucléaire, French Institute for Radiation Protection and Nuclear Safety

L
LILW-SL
Low- and intermediate-level short-lived waste

MOX
Mixture of uranium and plutonium oxides used in fabricating some types of nuclear fuel

N
NPP
Nuclear power plant, which may include several nuclear reactors at one site

NUCMAR
NUcléaire MARitime (emergency response)

ORSEC
Organisation de la Réponse de la SEcurité Civile, French emergency response plan

PWR
Pressurized Water Reactor

RID
Regulation concerning the International Carriage of Dangerous Goods by Rail

IAEA
International Atomic Energy Agency
### S

**SOCODEI**
SOciété pour le COnditionnement des Déchets et des Effluents Industriels, subsidiary of EDF that packages industrial waste and effluent

**SOMANU**
SOciété de MAintenance NUcléaire, company that performs nuclear maintenance

**Sv**
Sievert, unit used to measure exposure to radiation (see glossary)

### T

**TI**
Transport Index (see glossary)

### U

**UF6**
Uranium hexafluoride (see glossary)

### UN
United Nations

### V

**VLLW**
Very Low-Level Waste
IRSN's viewpoint on safety and radiation protection issues relative to French nuclear power plants in 2013
EVOLUTIONS SIGNIFICATIVES

GLOSSARY
Glossary

A

Accident or incident
Any unforeseen event occurring during normal operation that may have consequences for security, safety, public health, nature and the environment; the potential or real consequences of an accident are greater than those of an incident.

Activity
Number of spontaneous disintegrations – or decays - occurring in atomic nuclei per unit of time. The unit of activity is the becquerel (Bq).

Applicant
Entity requesting approval of a design for a package from the ASN.

AREVA
Industrial group specialising in energy.

B

Becquerel (Bq)
Unit of radioactivity, 1 Bq = 1 disintegration per second. The unit is very small and measurements often use a multiple of the Bq such as the megabecquerel (MBq) = 10^6 Bq = 1 million Bq. The Bq replaced the curie (Ci) which is the activity of 1 gramme of radium, 1 Ci = 3.7×10^10 disintegrations per second, or 37 billion Bq.

C

CIS Bio International
Subsidiary of the Belgian group Ion Beam Applications S.A. (IBA) which produces radioactive tracers and sources for brachytherapy in hospitals, cancer treatment centres and clinics with nuclear medical departments.

Containment
Keeping radioactive materials inside a defined space using a set of measures to prevent them from spreading in unacceptable quantities beyond this space; by extension, the set of measures taken to maintain this state.

Containment system
System designed to prevent or limit the spread of radioactive material outside the packaging.

Contamination
Presence of radioactive substances on the surface or inside any environment. For humans, contamination may be external (on the skin) or internal (by inhalation or ingestion).

Criticality
State of an environment in which a nuclear chain reaction is kept at a constant level.

Criticality accident
Uncontrolled nuclear chain reaction in an initially sub-critical environment.
**Dangerous good**
Substance that may present a serious danger for humans, property or the environment due to its physical or chemical properties, or by the nature of the reactions that it is likely to cause. It may be flammable, toxic, explosive, corrosive or radioactive. Dangerous goods figure in the list of dangerous goods in transport regulations or, if they do not appear on this list, are classified in compliance with international regulations.

**Defence-in-depth**
Safety principle which consists of implementing several successive and sufficiently independent levels of defence to effectively prevent degradation of safety functions of facilities, or packages, and equipment, to limit any consequences.

**Dose rate**
Radiation intensity (energy absorbed by matter per unit of mass and time) It is measured in grays per second (Gy/s).

**Euratom**
European public organisation responsible for coordinating research programmes on nuclear energy.

**Event relevant to safety**
Deviation reported by a licensee (or consignor) that does not fall under the criteria specified by the ASN.

**Exposure**
Absorption of ionising radiation (external exposure if the source is located outside the organism, internal exposure if the source is located within the organism).

**Fissile material**
Substance composed of radionuclides capable of fission.

**Fission**
The splitting of an atom’s nucleus as a result of bombardment by neutrons. During this reaction, neutrons and ionizing radiation are emitted and a great amount of heat is released.

**Fuel assembly**
Bundle of fuel rods, connected by a metal structure, used in nuclear reactors.

**Fuel cycle**
Set of industrial operations to which nuclear fuel is subject.

**Internal transport operation**
Transport of dangerous goods within the perimeter of a regulated nuclear facility outside the buildings and storage areas or any operation that contributes to its safety including those inside buildings and storage areas.

**International Nuclear Event Scale (INES)**
This scale, intended to facilitate understanding of the seriousness, in terms of safety, of nuclear incidents and accidents by the media and general public, defines seven levels of severity (from 1 to 7) depending on the consequences of the events.

**Ionising radiation**
Electromagnetic waves (gamma) or particles (alpha, beta, neutrons) emitted during the disintegration of radionuclides, which produce ions as they traverse matter.

**Irradiation**
Exposure, intentional or accidental, of an organism, substance or body to ionising radiation.
Isotopes
Elements whose atoms have the same number of electrons and protons, but a different number of neutrons. They have the same name and chemical properties but the nuclear properties (including likelihood of fission or radioactivity) may be different.

Maintenance
Maintenance constitutes the set of actions taken to maintain or restore equipment to a specified state or capable of providing a specified service.

MELOX
AREVA’s nuclear facility in which MOX fuel is produced for nuclear reactors in France and abroad.

Moderator
Material likely to slow down neutrons produced by nuclear fission.

Nuclear fuel
Fissile material (capable of undergoing a fission reaction) used in a reactor for initiating a nuclear chain reaction. After use in a nuclear reactor, it is referred to as irradiated fuel or spent fuel.

Nuclear safety
All technical and organisational measures relating to the design, construction, operation, permanent closure and dismantling of nuclear facilities and the transport of radioactive materials taken to prevent accidents and limit their effects.

Orange Book
Document containing UN recommendations for the transport of dangerous goods which constitute the basic requirements for safe shipment of dangerous goods by road, railway, inland waterway, sea or air, and serve as a basis for legal instruments that regulate the shipment of these goods by the various modes of transport.

Order on the transport of dangerous goods
Law specifying requirements applicable for national and international shipment of dangerous goods by road, railway and inland waterway within France; these rules may supplement those decreed in the ADR, RID and ADN and specify conditions for application.

Organizational and human factors
Factors affecting human performance, such as the skills, work environment, nature of tasks and organisation.

Package
The packaging with its radioactive contents as presented for transport.

Packaging
Assembly of components necessary to safely contain radioactive materials during transport. The packaging may include various specific materials intended to absorb radiation and ensure thermal insulation, service equipment, shock resistant structures, and systems for handling and stowage.

Plant operator
Physical or moral person operating a regulated nuclear facility.

Plutonium
Transuranian chemical element with atomic number 94 and symbol Pu; isotope Pu-239 has a radioactive half-life of 24,110 years.

Radioactive decay
Natural decrease in the nuclear activity of a
radioactive substance through spontaneous disintegration

**Radioactive half-life**
Time required for the quantity of atoms of a radioactive element to decrease by half

**Radioactive source**
Substance containing one or more radionuclides whose activity or concentration cannot be overlooked from the standpoint of radiation protection

**Radioactive substance**
Substance containing naturally-occurring or man-made radionuclides whose activity or concentration justifies radiological monitoring

**Radioactive waste**
Radioactive waste are radioactive substances for which no further use is planned or considered

**Radioactivity**
Property of certain chemical elements whose nuclei disintegrate spontaneously to form other elements while emitting ionising radiation

**Radioelement**
A natural or artificial radioactive element

**Radionuclide**
Radioactive isotope of an element

**Reprocessing**
Processing of used fuel to extract fissile and fertile materials (uranium and plutonium) for reuse and conditioning of various waste in a form fit for disposal

**Sievert (Sv)**
Unit used to measure biological effects produced by radiation on an exposed organism (a function of its nature and exposed organs). Since this unit is very large, a submultiple of the Sv, the millisievert (mSv), which equals $10^{-3}$ Sv or one thousandth of a sievert, is often used.

**Significant event**
Deviation having special importance according to the criteria of the ASN

**Specific activity**
Radioactivity per unit of mass of a radioactive substance (expressed in becquerels per gramme – Bq/g)

**Spent fuel**
Nuclear fuel that has been irradiated in the core of a reactor from which it is permanently removed

**TN International**
Logistics subsidiary of AREVA specialising in package design and transport of radioactive materials

**Transport Index (TI)**
Number designating highest radiation intensity (dose rate), in mSv per hour (mSv/h), that can be measured at a distance of 1 metre from the outside surfaces of the package. The value obtained is rounded up to the first decimal place (for example, if the dose rate at 1 meter is 0.0113 mSv/h, TI = 1.2). The number appears on package labels

**Transuranic elements**
Family of chemical elements that are heavier than uranium (atomic number 92); the main transuranic elements are: neptunium (93), plutonium (94), americium (95), and curium (96)

**Safety analysis**
Set of technical examinations for evaluating measures for ensuring nuclear safety based on the risk assessment
U

Uranium
Chemical element with atomic number 92 and symbol U and three natural isotopes: uranium-234, uranium-235 and uranium-238. Uranium-235 is the only naturally occurring fissile nuclide, a characteristic which explains its use as a source of energy.

Uranium hexafluoride (UF6)
Chemical compound of uranium used in the uranium isotope enrichment step during fabrication of nuclear fuel.