Analysis of events occurring during transport of radioactive material in Spain from 2000 to 2020

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Eneko Zugazagoitia Hernando, María del Sol Ramírez Rayo and Fernando Zamora Martín

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Summary

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The transport of radioactive material, which falls under the transport of dangerous goods, plays an essential role in many sectors of activity that are fundamental to today's society, such as medicine, industry, research and the nuclear fuel cycle.

During the phases that make up a transport operation, various types of incidents or events may occur which are reported to the Nuclear Safety Council (CSN) and then recorded in its database *Transport management.*

This document, having characterised the transport of radioactive material in Spain and identified the legal framework to which it is subject, offers a detailed analysis of the 100 events that occurred in this area in the period between 2000 and 2020.

The analysis, which is approached taking into account the most relevant characteristics of the transport operations, identifies the most significant typical events and considers the severity of the events according to the INES Scale of the International Atomic Energy Agency (IAEA), as well as their consequences.

The analysis also reports on lessons learned and actions derived for a number of remarkable events in the period, and lastly assesses trends in events and compares the conclusions reached in the Spanish national framework with the international context.

I. Introduction

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Despite thorough application of safety requirements, undesirable events can occur in any activity involving risks, with a potential negative impact on people and the environment. The transport of radioactive material is no exception to the rest of the risky activities that are accepted by our society and, therefore, incidents may occur in its development. However, effective implementation of the requirements defined by the regulations will minimise the likelihood of occurrence of events and their radiological impact.

Historically, there have been no internationally reported events during transport of radioactive material with very serious radiological consequences [1], which supports the requirements developed over more than 50 years within the IAEA, which are transposed into international and Spanish regulations regarding the transport of dangerous goods. These good results also indicate that the implementation of the requirements and their monitoring by the regulatory authorities has been highly effective.

The analysis of events occurring during the development of a risky activity is one of the most important mechanisms to try to reduce risk, as this analysis can provide very important information (commonly referred to as "lessons learned"), which can be used to modify the operating procedures of the entities involved, to refocus the control processes of the competent authorities and even to define new regulatory requirements. The aim is to reduce the likelihood of similar events occurring.

In addition to the analysis of lessons learned from individual events, it can be useful to carry out a global analysis of events over a given period of time. These global studies make it possible to determine questions such as which events occur more frequently and why, whether there is repetitiveness in their causes, how they evolve over time according to changes in the practice during which they occur, or whether there are factors in the scenarios of the events that have a greater impact on their occurrence.

The conclusions of these overall analyses make it possible to obtain a picture of the level of risk of a given activity, such as transport of radioactive material, to specify the sectors in which the activity is carried out where this risk is most significant and, from the perspective of a regulatory body such as the CSN, to assist the planning of regulatory actions as important as the issuing of standards and the performance of its supervision and monitoring activities.

II. Objective

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The aim of this publication is to report on the events that have occurred during transport of radioactive material in Spain between 2000 and 2020 and to carry out a detailed analysis of these events. This will consider parameters associated with the events, such as the type of radioactive material and packaging involved, the mode and phase of transport in which they occurred or the sectors of activity affected within the different applications of the radioactive material.

The analysis shall include a study of the main causes of the events and their consequences and significance for radiation safety, their scenarios and the main trends observed in these events over the period of analysis.

Finally, a comparison will be made between the case study of events in Spain and that analysed in other similar international studies.

This analysis will make it possible to identify the lessons learned from the events and the regulatory actions developed by the CSN in response to them, analysing their suitability and impact on the reduction of the trends of the most significant events.

III. Scope

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The analysis will affect events occurring during transport of radioactive material that have been reported to the CSN between the years 2000 and 2020, both included, in compliance with the established regulatory requirements. This period essentially coincides with the period during which the events have been recorded in the events database included in the CSN's corporate computer application referred to as *Transport Management.*

The events under analysis include those that fall within the definition of an *event during transport of radioactive material,* included in CSN Instruction IS-42 [2], which is also included in the definitions section of this publication.

The analysis will also include some types of *non-compliances* regulated by article 5 of CSN Instruction IS-34 [3], which have occurred since the date of its publication (4 February 2012) and which are of greater safety significance. In particular, the following:

- Where a breach has been detected of any of the limits established by the Dangerous Goods Transportation Regulations in terms of dose rate or contamination.
- When any significant incident or damage affecting the packages has been observed that could compromise their safety.
- When the type of packaging used was not suitable for the contents transported.

Non-compliances detected during the inspection processes performed by the CSN –such as those relating to the labelling and marking of packages, vehicle placarding, transport documentation or vehicle stowage– are outside the scope of this analysis and are therefore not considered 'events' for its purposes. These non-compliances are the subject of specific analyses, such as the reports on the results of the annual programmes of inspections concerning transport of radioactive material, which are periodically published on the CSN website.

IV. Definitions

IV. Definitions

Package (IAEA standard SSR-6 [4]) means the complete product of the packaging operation, consisting of the *packaging* and its contents, prepared for transport.

Nuclear fuel cycle (NFC) (IAEA glossary [5]) means all operations related to the production of nuclear energy, comprising:

a) the mining and processing of uranium or thorium ores;
b) uranium enrichment;
c) the manufacturing of nuclear fuel;
d) the operation of nuclear reactors (including research reactors);
e) the reprocessing of spent fuel;
f) all waste management activities (including decommissioning) relating to operations associated with the production of nuclear energy;
g) any related research and development activities.

Spent fuel (CSN IS-29 [6]): irradiated nuclear fuel permanently removed from a reactor core.

Defence in depth (CSN IS-37 [7]): consists of the hierarchical deployment, at different levels, of various structures, systems and components and procedures to prevent the escalation of planned operational events or accidents, and to maintain the effectiveness of physical barriers performing safety functions located between a radiation source or radioactive material and workers, members of the public or the environment.

Nuclear fuel element: an assembled set of nuclear fuel rods and any other associated components necessary to form a structural unit.

Packaging (IAEA standard SSR-6): means one or more receptacles and any other components or materials necessary for the receptacles to perform containment and other safety functions.

Consignor (IAEA standard SSR-6): means any person, organisation or official body preparing a consignment for transport.

Radioactive material (IAEA standard SSR-6): means any material containing radionuclides where both the activity concentration and the total activity of the consignment exceed the values specified in paragraphs 402 to 407 of IAEA SSR-6.

Mode of transport (IAEA standard SSR-6, paragraph 106): modes of transport of radioactive material by land (road, rail), water (inland waters, sea) or air.

Non-compliance (CSN IS-34): failure to satisfy a requirement regarding the transport of dangerous goods regulations, or deviation from the design of a package that may compromise its safety.

Uranium oxide: material used for the manufacturing of the rods that make up nuclear fuel elements.

Physical protection (CSN IS-26 [8]): conditioning and maintenance of facilities and activities in a secure manner by means of measures aimed at preventing, detecting and responding to unauthorised access or unauthorised actions affecting nuclear and other radioactive material or associated facilities.

Consumer products (IAEA glossary): a device, such as a smoke detector, a luminous dial or an ion-generating tube, containing a small quantity of radioactive substances.

Consignment (IAEA standard SSR-6): means any package(s) or load of radioactive material presented by a consignor for transport.

Radioactive waste (Nuclear Energy Act 15/1964 [9]): any waste material or product, for which no use is foreseen, that contains or is contaminated with radionuclides at concentrations or activity levels exceeding those established by the Ministry of Industry and Energy[1], following a report by the Nuclear Safety Council (CSN).

Event during transport of radioactive material (CSN IS-42): any incident or accident that occurs or is detected in the process of loading, transport, storage in transit or unloading and that could affect (or could have affected) the radiological safety of the packages or the shipment.

Fissile material (IAEA standard SSR-6): means a material containing any of the fissile nuclides. The following are not considered fissile substances under this definition: material containing any of the fissile nuclides. Excluded from the definition of fissile material are the following:

a) Natural uranium or depleted uranium that is unirradiated;
b) Natural uranium or depleted uranium that has been irradiated in thermal reactors only;
c) Material with fissile nuclides less than a total of 0.25 g;
d) Any combination of (a), (b) and/or (c);
e) These exclusions are only valid if there is no other material with *fissile nuclides* in the *package* or in the *consignment* if shipped unpackaged.

Transport (IAEA SSR-6, paragraph 106): Transport comprises all operations and conditions associated with, and involved in, the movement of radioactive material; these include the design, manufacture, maintenance and repair of packaging, and the preparation, consigning, loading, carriage

1. At present: Ministry for Ecological Transition and the Demographic Challenge.

including in-transit storage, shipment after storage, unloading and receipt at the final destination of loads of radioactive material and packages.

In relation to the term 'transport', it is noted that throughout the document it may be used in a general sense, considering all the phases indicated in the above definition, or in the sense of carriage or transfer, in which case it will be expressly indicated.

V. Transport of radioactive material in Spain

V. Transport of radioactive material in Spain

This chapter first identifies the regulatory framework to which the transport of radioactive material is subject. Once defined, the characteristics of the most relevant aspects of transport will be detailed, i.e. the activities in which it is carried out, the modes of transport used, the types of packages used and the types of materials transported.

V.1. Legal framework

The transport of radioactive material falls under the transport of dangerous goods but, due to its particular nature, it must also conform to the requirements that apply to any activity involving radioactive material. This section presents all the regulations establishing the requirements with which this activity must comply.

V.1.1. Transport of dangerous goods

The first publication concerning the transport of dangerous goods was produced by the United Nations: *Recommendations concerning the transport of dangerous goods.* Model Regulations, the first edition of which was published in 1957.

The provisions of this publication, which apply to the transport of radioactive material, are drawn from those contained in an IAEA document entitled *Regulations for the Safe Transport of Radioactive Material.* The first edition of this standard was published in 1961 and has been modified in successive editions up to the current edition, which was published in 2018 as SSR-6 *(Specific Safety Requirements* No. 6).

In the specific case of Spain, our national legislation on the transport of dangerous goods by road, rail and air refers to compliance with a series of international regulations based on the recommendations of the aforementioned publications, or, as in the case of maritime transport, the international regulations are applied directly. These are the following:

- Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) [10].
- The Regulations concerning the International Carriage of Dangerous Goods by Rail (RID) [11].
- Technical Instructions for the Safe Transport of Dangerous Goods by Air of the International Civil Aviation Organisation (ICAO) [12].
- International Maritime Dangerous Goods Code (IMDG Code) of the International Maritime Organisation (IMO) [13].

As well as the aforementioned standards, the CSN has published instructions (IS) which are technical standards of a binding nature, including provisions applicable to the transport of radioactive material: regarding operational aspects (IS-34); regarding package design modifications (IS-35) [14]; regarding personnel training (IS-38) [15]; regarding packaging manufacturing (IS-39) [16] and regarding criteria for reporting events to the CSN (IS-42).

The CSN ISs attempt to develop in detail those aspects that are not sufficiently specified in the regulations regarding the transport of dangerous goods for the transport of radioactive material.

V.1.2. Protection against ionising radiation

Transport of radioactive material is an activity involving a risk of exposure to ionising radiation. Consequently, it is fully covered by all the requirements of Spanish national legislation on the subject: the Regulation on Health Protection against Ionising Radiation [17][2].

Therefore, issues such as the ALARA[3] principle or dose limits to workers and the public, which apply to the use of radioactive material in nuclear and radioactive facilities, must also be complied with in its transport.

V.1.3. Physical protection

Some radioactive materials have such characteristics that the concept of security should not be limited to technological or operational security, which aims at preventing these materials or the radiation they emit from escaping the barriers containing them, but should also take into account other aspects such as the physical protection of these materials to prevent them from being sabotaged, stolen or diverted for misuse.

The physical protection requirements for the transport of radioactive material are set out in Royal Decree 1308/2011 [18].

2. At the time of preparing this document, these regulations are currently being revised due to the transposition of Directive 2013/59/EURATOM *establishing basic safety standards for protection against the dangers arising from exposure to ionising radiation and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.*

3. ALARA principle: individual doses, the number of people exposed and the likelihood of potential exposures should be kept as low as reasonably achievable, taking into account economic and social factors.

V.1.4. Authorisations for the transport of radioactive material

Apart from the approvals of package designs, radioactive material *and* the transport shipment authorisations, which are required by the Dangerous Goods Transport Regulations governing the four modes of transport, the Nuclear and Radioactive Facilities Regulations [19] require carriers of radioactive material in non-excepted packages to declare this activity by entering it in the Register of Carriers of Radioactive Material established by the Directorate General for Energy Policy *and* Mines.

The Directorate-General notifies the CSN of the register of these companies and of any variation that may occur therein, so that it may carry out its functions of monitoring and controlling their activities within its competences. At the time of writing, a total of 39 carriers are in the register: 26 Spanish firms and 13 foreign ones.

V.1.5. Event reporting

The reporting of events during transport of radioactive material by road and rail falls under the following regulations on the transport of dangerous goods:

- Spanish Royal Decree 387/1996, dated 1 March, which approves the basic guideline for Civil Protection Planning in view of the risk of accidents during the transport of dangerous goods by road and rail [20].
- Spanish Royal Decree 97/2014, dated 14 February, regulating the transport of dangerous goods by road in Spanish territory [21].

Air and sea transport have their own particular procedures for reporting accidents.

In addition, and without detriment to the above, to address the particular case of transport of radioactive material the CSN published Instruction IS-42 in 2016, aiming to:

- Identify the types of events during transport of radioactive material that must be reported to the CSN and their reporting deadlines.
- Specify the minimum information to be provided in a notification.
- Identify those responsible for the notification and subsequent reporting of the event.

The events during transport of radioactive material to be reported to the CSN and their reporting periods are listed below:

- The disappearance (misplacement or theft) of radioactive material in Excepted packages, Industrial packages or Type A packages, occurring or detected during transport, storage in

transit, intermediate passage through airports, ports, etc., as well as issues detected on receipt at the final destination. This type of event must be reported within 24 hours from the time the incident becomes known.

Before reporting any such packages missing, it should be confirmed that efforts have been made to locate the packages to no avail.

- The disappearance (misplacement or theft) of radioactive material in Type B(U) packages, Type B(M) packages, Type C packages or packages of fissile material, occurring or detected during transport, storage in transit, intermediate passage through airports, ports, etc., as well as any such issues detected on receipt at the final destination, shall be reported immediately, within one hour of knowledge of the incident.
- The breakdown of the conveyance leading to its detention, if it is realised that there has been a loss of any safety barrier of the radioactive material packages or the sufficient level of safety of the shipment cannot be guaranteed, must be notified immediately, within one hour after the incident is known.
- An accident during transport, if it is suspected or noticed that there has been a loss of any safety barrier of the radioactive material packages or the sufficient level of security of the shipment cannot be guaranteed, must be reported immediately, within one hour after the incident is known.
- An accident during transport in which there is no suspicion or warning that there has been a loss of any safety barrier of the radioactive material packages and the sufficient level of safety of the shipment can be assured must be reported within 24 hours of the occurrence becoming known.
- A fall or other incident occurring during the handling of radioactive material transport packages in loading and unloading operations, if it is suspected or noticed that there has been a loss of any safety barrier of radioactive material packages is to be reported immediately, within one hour after the incident is known.
- Threats to the physical protection of transport, such as attempted intrusion or sabotage of the conveyance, intentional degradation of physical protection, blockage of traffic lanes or a credible bomb threat, must be reported immediately, within one hour of knowledge of the incident.

Notifications should be made to the Emergency Room (SALEM) of the CSN. The initial notification must be made by telephone, but must subsequently be submitted in writing, by fax or email.

V.1.6. Notification of non-compliances

In 2012 the CSN published Instruction IS-34 concerning the actions to be taken regarding the detection and notification of non-compliances (NC), article 5 of which establishes that if the radioactive

material carrier (during transport) or the consignee of such material (on receipt) detects any of the non-compliances included below, these must be notified to the consignor and notified to the CSN once they have been detected, within the deadlines indicated:

- A breach in any of the limits of the dangerous goods transport regulations in relation to dose rate or contamination. It shall be notified no later than 24 hours after the non-compliance becomes known.
- The packages do not have the required labels indicating the radiological risks (24 hours).
- The labelling does not match the category of the package (24 hours).
- If any significant incident or damage to the packages that could compromise their safety is observed, immediately upon learning of the incident.
- The type of packaging used is not suitable for the contents transported (24 hours).

As in the case of events, notifications must be made to the CSN Emergency Room (SALEM).

V.2. Activities involving the transport of radioactive material

Radioactive material is used extensively in today's society for medical, industrial or research purposes, as well as in facilities related to the nuclear fuel cycle for energy production. This use requires transport from the suppliers to the user facilities and subsequently transport of the radioactive waste generated by the user facilities to the treatment centres.

The transport of radioactive material accounts for about 2% of the international transport of dangerous goods. Most of these transport operations contain small amounts of radioactive material, which are used for medical diagnostic purposes, in certain industrial applications or for research purposes. Other shipments relate to high-activity radioactive sources used primarily in cancer therapy.

The transport of radioactive material in Spain follows these general lines. Thus, shipments can be made to or from about 1,000 radioactive facilities[4] (about 300 for medical applications, about 600 for industrial applications and about 100 for research). Transport may also be arranged to or from 7 nuclear power plants: five in operation, one undergoing cessation of operation and one in decommissioning; one nuclear fuel fabrication facility and one temporary storage facility for low and intermediate level radioactive waste. More details on these transport operations can be found in section V.5 of this document.

4. Rounded numbers are given only to give an idea of the order of magnitude, as they may vary over time due to additions and removals of these facilities.

Figure 5.2.1. Map of Spanish nuclear facilities

V.3. Transport modes

As a consequence of the use of radioactive material in medical, industrial or research applications, as well as in nuclear fuel cycle (NFC) facilities, tens of millions of packages containing radioactive material are transported around the world each year using different modes of transport.

The choice of the mode of transport depends mainly on the characteristics of the radioactive material and the physical characteristics of the package. Most of the radioactive material is related to medical applications using small packaging and transport operations are mainly by air, as this radioactive material decays rapidly and needs to be shipped urgently. These materials are then transported by road to their final destination in medical centres.

Sea and rail transport are commonly used to move over long distances large quantities of very heavy materials or packages, usually associated with the nuclear fuel cycle: ores, concentrates, uranium hexafluoride, uranium oxide, non-irradiated nuclear fuel elements, irradiated nuclear fuel and high-level radioactive waste.

Multimodal transport operations such as air/road (a/r), especially during transport of radioactive material for medical applications, and sea/road (s/r) in the nuclear fuel cycle are also very frequent.

The transport of radioactive material in Spain follows these general lines, with road and air transport being the most widely used modes of transport, and rail transport is not currently used. Further details can be found in section V.5 of this document.

V.4. Types of packages

Transport regulations focus on packaging design requirements and on the requirements to be met by the consignor of the goods, who prepares the package for transport.

Packaging requirements follow a graded approach: they become more stringent as the risk of the contents increases. Thus, the higher the risk of the contents, the tougher the transport conditions that the packages have to overcome: routine (as is transport without incidents), normal (including minor incidents) or accident.

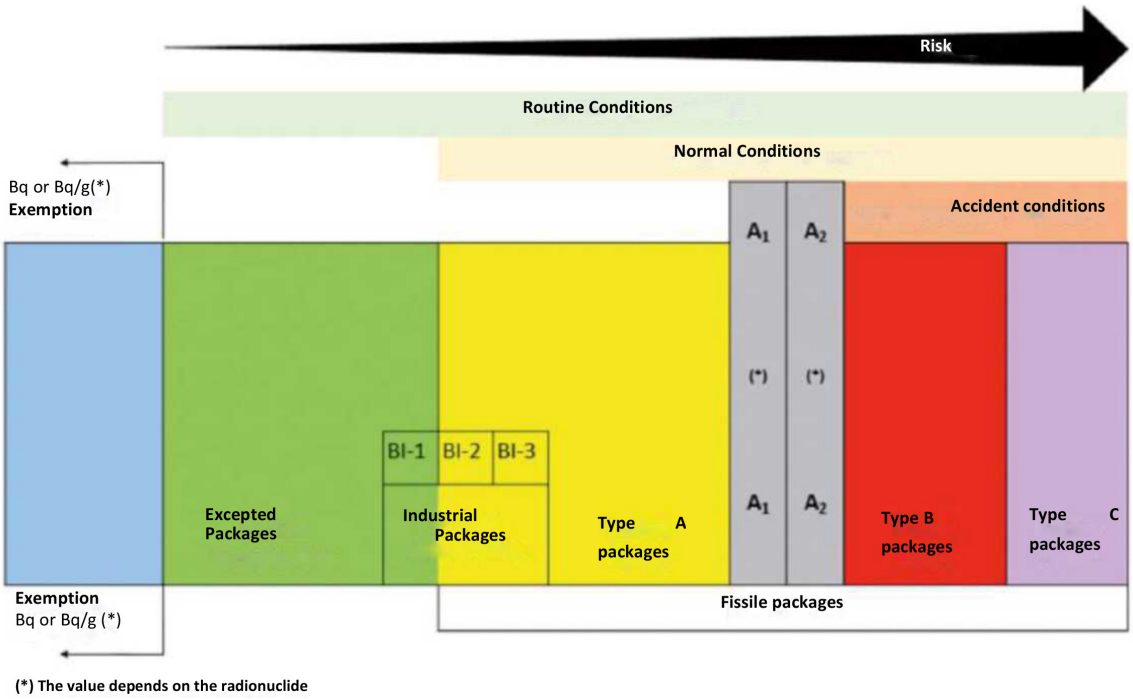
Based on this graded approach, packages are classified into five types: Excepted, Industrial, Type A, Type B and Type C.

Figure 5.4.1 describes the types of packages according to the transport conditions they have to withstand. As can be seen, above certain values for activity involving radioactive material (A_1 or A_2: parameters directly related to the risk) the package must withstand severe accident conditions, red and violet areas of the graph (packages Type B and C).

The yellow coloured area contains package types (A, Industrial type 2 and 3) designed to withstand normal transport conditions, including minor mishaps. The green zone contains packages which, because they contain very low risk materials, need only withstand routine transport conditions (Excepted and Industrial type 1 packages).

The blue area indicates that below a certain activity (Bq) or specific activity (Bq/g) of the radioactive material, its transport is exempt from regulatory requirements, and it can be transported as a non-radioactive good, as it does not carry risks (for transport purposes it is not considered radioactive material: see definition in this document).

Figure 5.4.1. Types of package. Graded approach



In addition, when the contents include fissile material, packages are generated which have to meet additional requirements related to the particular hazards of these material. Industrial Fissile (IF), Type A Fissile (AF), Type B Fissile (BF) or Type C Fissile (CF) packages are used for transport of fissile material.

However, it is important to note that the vast majority of transport operations (around 90%) involve Excepted or Type A packages, the design of which does not need to withstand severe accidents.

V.5. Summary of types of transport of radioactive material

Before making an estimate of the events occurring in Spain during the analysis period, it is advisable to identify the types of radioactive material transport operations carried out annually in the country and to estimate their volume.

As can be seen in table 5.5.1, as in the rest of the world, the vast majority of transport operations are related to the medical and industrial sectors, using Type A and Excepted packages. These transport operations are carried out either multimodally, by air and road (a/r), or only by road. There are no precise statistics on the number of transport operations of this type in Spain, however, based on information from the main transport operators handling this type of material, it is estimated that around 100,000 shipments are made annually, involving the transport of more than 200,000 packages.

Within the aforementioned industrial sector, the transport of soil density and moisture measuring equipment used in road construction and other public works is of particular note. This equipment is transported by road on its journeys to construction sites and is contained in type A packages. This activity can involve tens of thousands of transport operations per year.

The transport of radioactive waste, most of which is transported in packages classified as Industrial, accounts for around 250 transport operations per year and is mainly carried out by road from the radioactive and nuclear facilities to the temporary radioactive waste disposal facility that is located at the site that Enresa operates at El Cabril (Córdoba). In addition, the transport of waste from the Balearic and Canary Islands is carried out by multimodal means, by sea and by road (s/r).

Around ten or so transits of uranium concentrates are also made through Spanish ports each year, generally destined for Europe.

The transport of industrial gammagraphy equipment can involve some ten thousand movements per year, which are normally carried out by road using Type B packages. High activity sources for use in the medical and food sector are also transported in Type B packages, but these transport operations are sporadic and use road or multimodal air and road (a/r), as well as sea, with transits in Spanish ports.

Transport operations of uranium oxide and non-irradiated nuclear fuel elements account for approximately 70 transport operations per year and are carried out using fissile material packages.

The uranium oxide comes entirely from abroad and is destined for the nuclear fuel factory in Juzbado (Salamanca) belonging to Enusa Industrias Avanzadas (Enusa). Most of it is transported by sea to Spanish ports and from there by road to the facility. Currently, the main supplier countries are the United Kingdom and the United States of America.

The Enusa facility at Juzbado manufactures fuel assemblies for Spanish and European nuclear power plants from uranium oxide. In Spain, transport is carried out by road, while transport to other European countries is usually by road or by multimodal road and sea transport (s/ r).

As regards the transport of irradiated fuel, including spent nuclear fuel, this does not currently occur in Spain except for sporadic movements of irradiated rods as part of research programmes. Spent nuclear fuel continues to be stored in nuclear power plants, either in their fuel pools or in dry storage casks, until such time as a centralised temporary storage facility for such fuel is authorised.

Finally, it should be pointed out that railways have hardly ever been used for the transport of radioactive material in Spain during the period analysed in this document.

In short, it may be concluded that more than 100,000 transport operations involving radioactive material are performed annually in Spain, since the vast majority of these transport operations are for the medical and industrial sectors, as shown in figure 5.5.1.

Figure 5.5.1. Annual shipment volume by package type

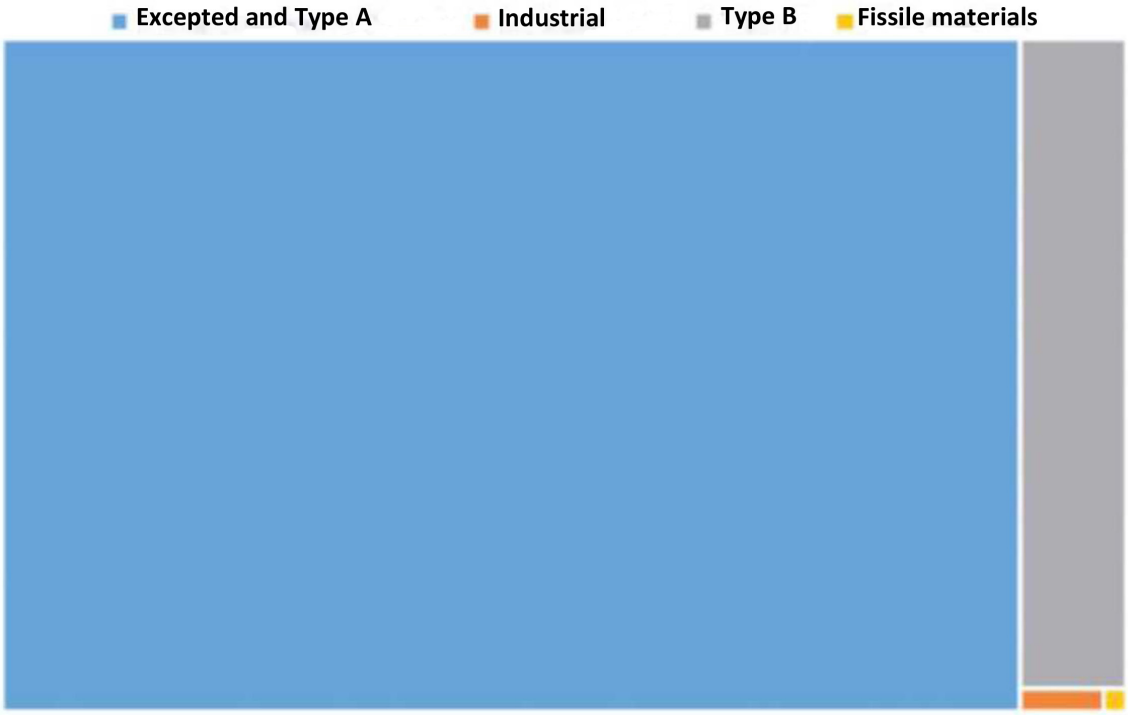


Table 5.5.1. Summary of radioactive material transport operations in Spain

Type of package	Application of radioactive material	Transport per year	Modes of transport
Excepted and Type A	Medicine, research, industry	~ 100,000 shipments ~ 200,000 packages	Road Multimodal a/r
Industrial	Radioactive waste	~ 250	Road Multimodal s/r (from Balearic and Canary Islands)
	Uranium Concentrates	~ 10	Maritime (transits in ports without unloading)
Type B	Gammagraphy equipment	~ 10,000	Road
	High activity sources	~ 5	Road Multimodal a/r Maritime (transits in ports without unloading)
Fissile materials	Uranium oxide and non-irradiated nuclear fuel elements	~ 70	Road Multimodal s/r

VI. Recording and reporting of events

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This chapter describes the methodology applied by the CSN for the recording of events occurring during transport of radioactive material. It also establishes a classification of events based on their typology, identifying in detail the characteristics of the most common ones.

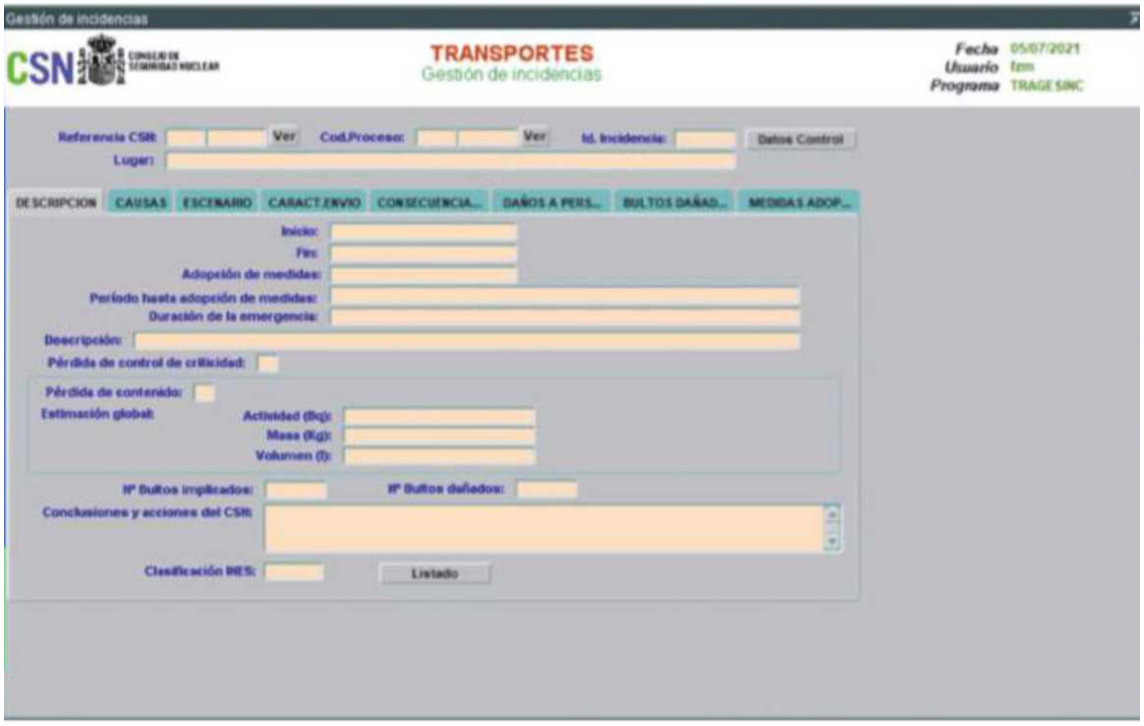
VI.1. Recording of events

Events occurring during transport of radioactive material and all associated information are recorded in the *Incident Management* database, which is included in the CSN's corporate application on *Transport Management.* This computer application, used at the CSN since the end of the 1990s to facilitate the management of regulatory activities relating to the transport of radioactive material (licensing, control and inspection and event handling processes), was considered to be a "good practice" in the conclusions of the final report of the IRRS mission conducted by the IAEA in Spain in 2018 [22].

The database on *Incident Management* has a number of sections whose purpose is to record the fundamental data of an event. For each event, a general description is thus recorded (see figure 6.1.1), including the place and date of the occurrence, its duration, the number of packages involved, their INES classification (see section VIII) and the conclusions and summary of the actions adopted by the CSN. In addition to this general description, several sections (screens) of the database include a series of fields that provide a detailed description of the main characteristics of the event:

- Causes.
- Scenario of the event, type of radioactive material and package and mode of transport.
- Characteristics of the shipment: origin, destination, consignor, carrier, conveyance and damage suffered, the phase of the transport process at which the event occurred, etc.
- Consequences. Radiological consequences for human life (the public and any workers classified as exposed), surface contamination on objects and surfaces and contamination of the environment are considered.
- Non-radiological harm to persons involved in transport and members of the public, identifying the extent of any such harm qualitatively.
- Damaged packages: the characteristics of the packaging, the details of the contents and the damage sustained in the event.
- Actions taken: these include intervention measures, treatment of persons, management of radioactive material or waste, if generated, clean-up of affected areas and actions taken with the transport vehicle.

Figure 6.1.1. Main screen of the database *Incident Management* of the application *Transport Management*



VI.2. Global information on events. Type events

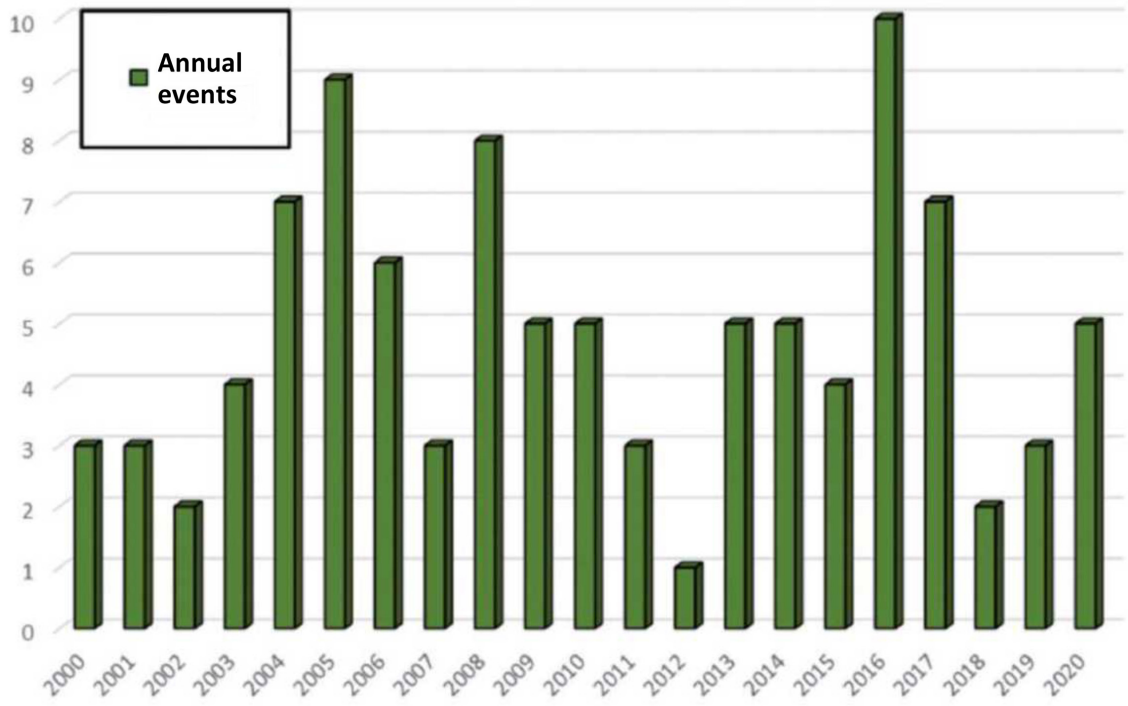
The information on events occurring annually in Spain during transport of radioactive material has been included in the annual reports of the CSN to the Congress of Deputies and the Senate.

Between 2000 and 2020, a total of 100 events have occurred, the breakdown by year of which can be seen in Figure 6.2.1. Furthermore, table 6.2.1 and figure 6.2.2 show the overall summary of the event classes in that period, and figure 6.2.3 shows the proportion of each event class in relation to the total.

Table 6.2.1. Summary of events in Spain. Period 2000-2020

TYPE OF EVENT	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	TOTAL
Packaging deficiencies	0	0	0	0	2	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	**6**
Unsuitable package content	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	**2**
Event during loading/unloading processes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	0	0	0	0	**5**
Exceedance of contamination limits (NC IS-34 CSN)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**2**
Exceedance of radiation limits (NC IS-34 CSN)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	**3**
Incidents at airport terminals	3	2	1	2	2	1	2	0	0	0	0	0	0	1	1	0	2	4	1	0	0	**22**
Traffic accident	0	0	1	1	0	5	3	2	3	1	3	1	1	4	2	1	2	1	1	0	2	**34**
Theft of packages	0	0	0	1	1	2	1	0	1	1	1	1	0	0	0	0	2	1	0	1	2	**15**
Misplacement of packages	0	1	0	0	1	1	0	0	0	2	1	1	0	0	0	1	0	1	0	1	0	**10**
Physical protection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
TOTAL	**3**	**3**	**2**	**4**	**7**	**9**	**6**	**3**	**8**	**5**	**5**	**3**	**1**	**5**	**5**	**4**	**10**	**7**	**2**	**3**	**5**	**100**

Figure. 6.2.1. Annual events in the period 2000-2020



The classes of events that have occurred and that have been recorded in the CSN database are as follows:

a) Packaging deficiencies

These are deficiencies such as damage to the packaging or missing elements of the packaging with a potential impact on safety. It also includes cases where a type of packaging has been used that does not meet the regulatory requirements for a particular content.

These deficiencies can be detected at any phase of transport, but are most often detected on receipt of the packages.

These are events of great interest, as transport safety is fundamentally based on the safety of the packaging as part of the overall package, and the regulations focus on maintaining its integrity following a graded approach: the higher the risk posed by the contents, the higher the requirements.

b) Unsuitable package content

The contents of the package do not correspond to what is stated in the package design or to the information originally described by the consignor in the transport documents and/or in the labelling and marking of the package.

c) Event during loading/unloading processes

These are incidents such as incorrect preparation of packages, damage to internal components of the package during loading, detection of internal contamination in packages during unloading, or packages falling during loading or unloading on the means of transport.

d) Exceedance of regulated contamination limits

These include detection of contamination above the regulated limits on packaging or vehicles. Since the publication of CSN IS-34, these events have been treated as non-compliances (NCs), but since they are NCs that directly affect safety, they have been included in this analysis, as indicated in the scope of the document.

e) Exceedance of regulated radiation limits

These include the detection of radiation levels above the regulated limits on the external surfaces of packages or vehicles. As in the case of contamination limit exceedance events, since the publication of the CSN's IS-34, these events have been treated as NCs, but have been included in the analysis since they directly affect safety.

f) Incidents at airport terminals

These are incidents during the handling of radioactive packages in airports: loading and unloading of aircraft and transfer of packages from aircraft to cargo terminals or vice versa and operations in terminal warehouses. Although some could have been included in the general category of *events during loading/ unloading processes,* it has been deemed appropriate to highlight them independently, given the uniqueness and frequency of these events.

g) Traffic accident

These are road transport accidents during transport (transfers). They include vehicle-to-vehicle collisions, run-offs or mechanical failures of vehicles with actual or potential risk to radiation safety.

h) Theft of packages

These are thefts of radioactive packages during some phase of transport, usually from road vehicles or directly of road vehicles.

i) Misplacement of packages

These include events where there is a temporary relocation or permanent loss of a radioactive package during one of the transport steps.

j) Physical protection

They include threats to physical transportation security, such as attempted intrusion or sabotage of the conveyance, intentional degradation of physical security, blockage of traffic routes or credible bomb threat.

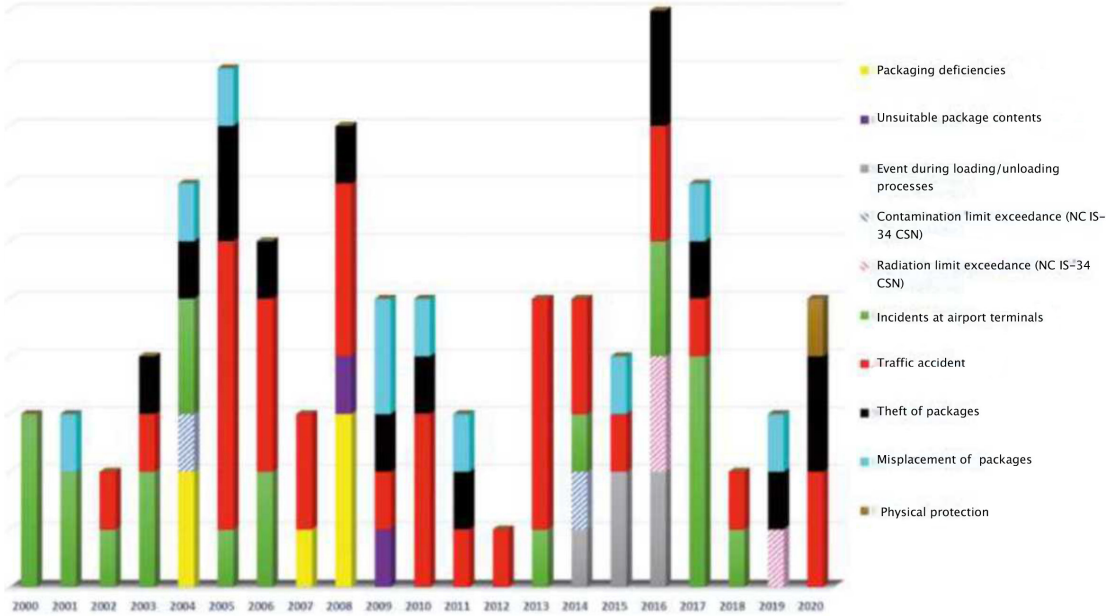
Analysing the events from 2000 to 2020, it can be seen that, within the variability, the average number of events per year is approximately 5. Considering this average number of events and the approximate annual number of radioactive material transport operations in Spain (over 100,000), this means a rate of events/number of shipments of less than 5x10-5, i.e. less than 1 event for every 20,000 transport operations.

It can also be observed that the most frequent events were traffic accidents (34%), incidents occurring at airport terminals (22%) and theft and misplacement of packages (15% and 10% respectively). For these events:

- The average number of traffic accidents is approximately 2 events/year.
- The average number of incidents at airport terminals is approximately 1 event/year.
- The average number of thefts or misplacements of packages is approximately 1 occurrence every two years.

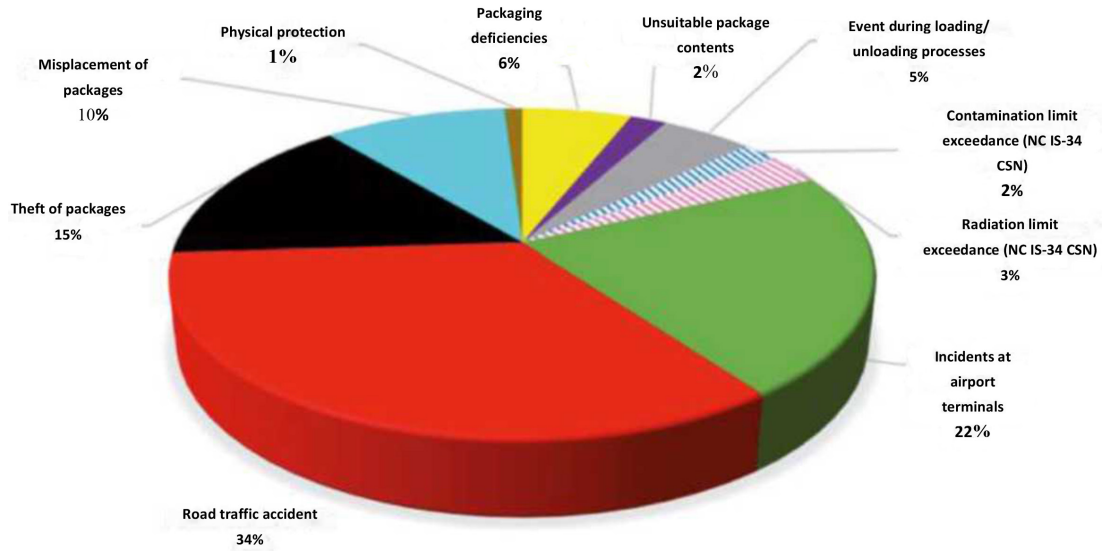
At this point it is considered of interest to compare the occurrence of events during transport of radioactive material with those involving all dangerous goods.

Figure 6.2.2. Summary of events in Spain. Period 2000-2020



According to data provided by the Spanish Ministry of Transport, Mobility and Urban Agency [23], since 2008 there has been an average of just over 110 accidents per year for the overall movement of dangerous goods by road. In other words, considering the average number of traffic accidents involving radioactive material per year, these events do not account for even 2% of the average number of accidents involving all goods.

Figure. 6.2.3. Proportion of each type of event in the period 2000-2020



VI.2.1. Type events

For the most frequently occurring cases, it is considered of interest to show their basic typology. The "type event" for each of them is described below:

Traffic accident type event

- Mostly occurs during transport of radiopharmaceuticals involving Type A and Excepted packages.
- On RIMP (Red de Itinerarios para Mercancías Peligrosas, Dangerous Goods Route Network) roads.
- There is damage to the vehicle, but no damage to the cargo.
- The driver may be incapacitated due to physical injury.
- The transport company applies its emergency plan, notifies the CSN of the event and sends another vehicle to pick up the cargo and deliver it to the originally intended consignees.
- The traffic police (Guardia Civil) intervenes.
- Occurring at night (very early in the day).

Type event in airport terminal incidents

- Events in cargo terminal warehouses or on the airport runway.
- Dropping of Excepted and Type A packages, without release of material, in the process of handling and transfer from terminals to aircraft and vice versa or in operations within terminal warehouses. Crushing of the packages may occur when they are run over by the transfer vehicle.
- Communication from the airport operator *(handling)* to the airport (applying its internal emergency plan), to the CSN and to the consignor.
- In some cases, the airport intervention services (fire brigade, Guardia Civil) are involved.

Type event of theft and misplacement of packages

- Package thefts often occur in road vehicles parked outside premises.
- The most common thefts are of mobile radioactive equipment (soil moisture and density gauges in a Type A package or industrial gammagraphs in a Type B package). To a lesser extent, radiopharmaceuticals in Excepted and Type A packages are involved. All of them pertain to the field of radioactive facilities.
- Carriers or consignors immediately file a complaint with the police.
- Misplacements are most frequent in air transport: ramp handling (airport runway) and cargo terminal warehouses.
- Missing packages are usually Excepted and Type A packages with radiopharmaceuticals.
- In both cases (once confirmed) the CSN issues a press release to warn the population.

In addition to the most frequent occurrences, it should be noted that in the analysis period there have been very few cases where the regulated radiation and contamination limits were exceeded –they account for only 5% of the occurrences.

Although they have occurred infrequently, given the significance of the package in terms of transport safety, events related to incorrect preparation –such as detection of deficiencies in the packaging (6% of events) or loading of packaging with unsuitable contents (2%)– are noteworthy, as they could lead to an increase in the dose rates of the package during transport.

As regards events during loading and unloading processes, apart from those considered to be incidents at airports, most of them consisted of damage to the glass vial (which acts as the primary container for the liquid radioactive material) when it was being loaded into packages intended for the medical sector.

VII. Event analysis

VII. Event analysis

Having introduced the general nature of the events, this chapter will address their systematic analysis, taking as a reference several of the key transport characteristics recorded in the CSN database.

Firstly, tables 7.0.1, 7.0.2 and 7.0.3 show the relationship between the different types of events occurring during the 21 years of the study period and the classes of radioactive material transported, the sectors in which the transport operations were performed and the types of package involved, respectively.

From the perspective of the materials transported, the case study of events shows that most of them involve radiopharmaceuticals (70%) and industrial radioactive sources (16%). In the case of radiopharmaceuticals, 41% of the events were due to traffic accidents, 30% to incidents at airport terminals and 14% to misplacement of the packages themselves. As far as industrial sources are concerned, the most common event is theft of packages (69%) followed by traffic accidents (19%).

In terms of the sectors in which the transport operations take place, a large majority of the events occurred in the medical field (74%), followed by other industrial applications[5] (14%) and activities linked to the nuclear fuel cycle - NFC (7%). In the medical sector, virtually all events involved radiopharmaceuticals, and most were due to traffic accidents (39%), incidents at airport terminals (28%) and lost packages (14%). For industrial applications, package theft (71%) and traffic accidents (21%) were predominant. Finally, events within the NFC were mostly due to deficiencies in packaging (43%) and exceeding surface contamination limits (29%).

Finally, the analysis of the events according to the type of package used shows that Type A packages are the most frequent (77%), followed by Excepted packages (12%). The packages with higher risk are far below: packages of fissile materials (4%) and Type B (2%). The prevalence of the use of Type A and Excepted packages for the transport of radiopharmaceuticals in the medical sector means that they are the most frequently involved in transport events. Considering Excepted and Type A packages as a whole, it can be seen that the majority (34%) have been involved in traffic accidents, followed by incidents at airport terminals (24%) and theft (16%) and misplacement (11%).

5. Applications other than industrial gammagraphy.

7.0.1. Radioactive material involved in different types of events

Type of event	Radiopharmaceuticals	Radioactive material used in research	Medical therapy sources	Industrial sources	Uranium oxide	Irradiated fuel	Radioactive waste	SCO	Total
Packaging deficiencies	2	0	0	1	3	0	0	0	**6**
Unsuitable package contents	0	0	1	0	0	0	1	0	**2**
Loading/unloading events	5	0	0	0	0	0	0	0	**5**
Exceedance of contamination limits (NC IS-34 CSN)	0	0	0	0	0	1	0	1	**2**
Exceedance of radiation limits (NC IS-34 CSN)	0	0	3	0	0	0	0	0	**3**
Incidents at airport terminals	21	0	0	1	0	0	0	0	**22**
Traffic accident	29	0	0	3	0	0	2	0	**34**
Theft of packages	3	1	0	11	0	0	0	0	**15**
Misplacement of packages	10	0	0	0	0	0	0	0	**10**
Physical protection	0	0	0	0	1	0	0	0	**1**
Total	**70**	**1**	**4**	**16**	**4**	**1**	**3**	**1**	**100**

7.0.2. Sectors in which the radioactive material involved in the events was transported

Type of event	Medical	Research	Industrial gammagraphy	Other industrial applications	NFC[6]	Management of radioactive waste	Total
Packaging deficiencies	2	0	0	1	3	0	**6**
Unsuitable package contents	1	0	0	0	1	0	**2**
Event during loading/unloading processes	5	0	0	0	0	0	**5**
Exceedance of contamination limits (NC IS-34 CSN)	0	0	0	0	2	0	**2**
Radiation limit exceedance (NC IS-34 CSN)	3	0	0	0	0	0	**3**
Incidents at airport terminals	21	0	1	0	0	0	**22**
Traffic accident	29	0	0	3	0	2	**34**
Theft of packages	3	1	1	10	0	0	**15**
Misplacement of packages	10	0	0	0	0	0	**10**
Physical protection	0	0	0	0	1	0	**1**
Total	**74**	**1**	**2**	**14**	**7**	**2**	**100**

6. Does not include radioactive waste management.

7.0.3. Types of packages involved in occurrences

Type of event	Excepted	Industrial	A	Miscellaneous[7] NA	B(U)	B(M)	Fissile	Unpacked	Total
Packaging deficiencies	0	0	3	0	0	0	3	0	**6**
Unsuitable package contents	0	0	1	0	0	0	0	1	**2**
Event during loading/ unloading processes	0	0	5	0	0	0	0	0	**5**
Exceedance of contamination limits (NC IS-34 CSN)	0	0	1	0	0	0	1	0	**2**
Radiation limit exceedance (NC IS-34 CSN)	3	0	0	0	0	0	0	0	**3**
Incidents at airport terminals	2	0	19	0	1	0	0	0	**22**
Traffic accident	0	2	30	2	0	0	0	0	**34**
Theft of packages	3	0	11	0	1	0	0	0	**15**
Misplacement of packages	3	0	7	0	0	0	0	0	**10**
Physical protection	1	0	0	0	0	0	0	0	**1**
Total	**12**	**2**	**77**	**2**	**2**	**0**	**4**	**1**	**100**

7. Various types of packages not subject to design approval (Excepted, Industrial or Type A).

Finally, within this general analysis of the events that occurred, it is interesting to note that 35% of them took place in one of the phases of an international transport, i.e. their origin or destination was outside Spain. In these events:

- The predominant mode of transport was air (57%), together with road transport (17%) and multimodal a/r (14%).
- They mainly involved Type A (63%) and Excepted (23%) packages.
- The radioactive material involved belonged to the medical field (63% radiopharmaceuticals and 11% therapy sources) and to a lesser extent to the NFC (11% - uranium oxide transport).
- The majority of the causes of the events are distributed between incorrect handling of the packages (31%), misplacement (20%) and incorrect preparation (14%), although it should be noted that in 23% of the cases the causes could not be confirmed.

In addition to this general analysis, several sections are included below in which a detailed study is made of the interrelation of different parameters defining the scenario of the events, such as the type of radioactive material transported, the sector in which this material is used, the means of transport used, the phase of transport in which the events occurred, the area in which they occurred and the causes that gave rise to them.

VII.1. Depending on the type of radioactive material transported

As stated in the introduction to this section, most of the events have involved radiopharmaceuticals and, to a lesser extent, industrial sources.

This section will analyse the events considering the types of radioactive material transported in Spain in relation to the types of packages involved in the events, the modes of transport used, the phase of transport in which the event occurred and the causes of the events.

The types of radioactive material listed below are not defined as such in the regulations applying to the transport of radioactive material, but are simply identified in this document in order to relate the events to the main sectors in which they are used. The following types of radioactive material have thus been considered:

- Radiopharmaceuticals: radioactive material with a major application in medical diagnostics (nuclear medicine).
- Radioactive material used in research.
- Encapsulated radioactive sources used in medical therapy.
- Industrial sources: encapsulated radioactive sources used in industrial processes, such as soil density and moisture measurement and industrial gammagraphy (detection of defects in welds and structures).

- Non-nuclear mixture: transport of various radioactive materials not considered as fissile substances.
- Nuclear fuel cycle (NFC) ores and uranium concentrates.
- Uranium Hexafluoride (UF_6).
- Uranium oxide.
- Non-irradiated nuclear fuel: rods and fuel elements.
- Irradiated nuclear fuel. It may be considered as "spent fuel".
- Radioactive waste. Generated in radioactive and nuclear facilities.
- Surface contaminated objects (SCO). These are tools and equipment that are not radioactive but are contaminated on the surface and are not considered as radioactive waste.

Type of material vs. type of package used

Analysing the events that occurred by type of package and the material transported (see table 7.1.1), it can be seen that 77% of them occurred when transporting Type A packages, which in 79% of cases contained radiopharmaceuticals and 18% industrial sources (normally incorporated in soil density and humidity measuring equipment).

The remaining events involving industrial sources (2%) involved a Type B package (industrial gammagraphy equipment). In other words: 88% of industrial source events involved mobile soil moisture and density measuring equipment and only 12% involved mobile industrial gammagraphy equipment.

Type of material vs. mode of transport

From the analysis of the events according to the type of material and mode of transport, shown in table 7.1.2, it appears that most of the events occurred during road transport (61%), of which 67% involved the transport of radiopharmaceuticals and 23% industrial sources (mainly soil moisture and density measuring equipment).

Only 5% of road events were related to the transport of radioactive waste and less than 2% to the nuclear sector (a single event involving the transport of uranium oxide).

Air transport-related activities accounted for 29% of the incidents, mainly during handling activities which almost all involved the transport of radiopharmaceuticals (97%).

Type of material vs. time of event

Before analysing the events included in Table 7.1.3, which shows the relationship between the type of material transported and the transport phase or time of the event, it is important to make it clear

that transport does not only comprise the movement of radioactive material from one point to another, but covers all the operations and conditions inherent to it, such as the loading of the packaging with the contents (package preparation), loading/unloading on/from the conveyance, handling at airport cargo terminals and in ports, storage in transit, etc.

Events occurring during the actual transport (transfer) accounted for 35% of the total, 83% of which involved radiopharmaceuticals.

The percentage of events in loading/unloading operations and in the handling of packages at airport cargo terminals is also noteworthy – 22% in each case. Most of the events at cargo terminals have involved packages with radiopharmaceuticals and there was only one case involving industrial sources. In terms of loading and unloading outside air terminals, the occurrences are more spread out in terms of the material transported, but 50% occurred involving radiopharmaceuticals.

Finally, it should be noted that 14% of the events occurred when a vehicle was parked and were mostly thefts, 79% of which involved industrial sources, mainly soil moisture and density measuring equipment.

Type of material vs. causes of the event

Table 7.1.4 shows the relationship between type of material transported/causes of the event. The analysis shows, firstly, that the causes of the events in the period under study are manifold.

The most frequent are being hit by another vehicle in a road accident (21%) and incorrect handling of packages (20%), mainly during loading and unloading processes and during handling at air cargo terminals, which mainly affected the transport of radiopharmaceuticals.

Also noteworthy are thefts (15%), mostly of industrial sources; lost packages (9%), mostly affecting radiopharmaceuticals, and incorrect preparation of packages (10%), which affected the medical sector (radiopharmaceuticals and medical therapy sources) and to a lesser extent the industrial and nuclear sectors.

Considering the importance of package design for transport safety, it is noteworthy that in only two events was the cause attributed to the fact that the package used was not in accordance with the design, affecting the transport of radiopharmaceuticals and medical therapy sources.

In addition, it should be noted that in 18% of the events it was not possible to reliably determine their causes.

Table 7.1.1. Events according to the type of material and package types used

Type of material	Type of package								
	Excepted	Industrial	A	Miscellaneous[8] NA	B(U)	B(M)	Fissile	Unpacked	TOTAL Events
Radiopharmaceuticals	7	0	61	2	0	0	0	0	**70**
Radioactive material used in research	1	0	0	0	0	0	0	0	**1**
Sources for medical therapy	3	0	1	0	0	0	0	0	**4**
Industrial sources	0	0	14	0	2	0	0	0	**16**
Non-nuclear mixture	0	0	0	0	0	0	0	0	**0**
NFC Minerals and Uranium Concentrates	0	0	0	0	0	0	0	0	**0**
UF_6	0	0	0	0	0	0	0	0	**0**
Uranium oxide	1	0	0	0		0	3	0	**4**
Non-irradiated fuel	0	0	0	0	0	0	0	0	**0**
Irradiated fuel	0	0	0	0	0	0	1	0	**1**
Radioactive waste	0	2	0	0	0	0	0	1	**3**
SCO	0	0	1	0	0	0	0	0	**1**
TOTAL Events	12	2	77	2	2	0	4	1	100

8. Various types of packages not subject to design approval (Excepted, Industrial or Type A).

Table 7.1.2. Events by type of material and modes of transport

Type of material	Mode of Transport								
	Road	Air	Air (h)[9]	Maritime	Maritime (P)[10]	Railway	Multimodal a/r[11]	Multimodal s/r[12]	TOTAL events
Radiopharmaceuticals	41	8	20	0	0	0	1	0	**70**
Radioactive material used in research	1	0	0	0	0	0	0	0	**1**
Sources for medical therapy	0	0	0	0	0	0	4	0	**4**
Industrial sources	14	0	1	0	0	0	1	0	**16**
Non-nuclear mixture	0	0	0	0	0	0	0	0	**0**
NFC Minerals and Uranium Concentrates	0	0	0	0	0	0	0	0	**0**
UF_6	0	0	0	0	0	0	0	0	**0**
Uranium oxide	1	0	0	0	0	0	0	3	**4**
Non-irradiated fuel	0	0	0	0	0	0	0	0	**0**
Irradiated fuel	0	0	0	0	0	0	0	1	**1**
Radioactive waste	3	0	0	0	0	0	0	0	**3**
SCO	1	0	0	0	0	0	0	0	**1**
TOTAL Events	61	8	21	0	0	0	6	4	100

9. The event takes place during transfer, loading or unloading operations on the runway or in the cargo terminals of an airport (handling operations).
10. The event takes place during transfer, loading or unloading operations within a seaport.
11. Multimodal transport: air-road.
12. Multimodal sea-road transport.

Table 7.1.3. Events according to type of material and time of occurrence

Type of material	Time of the Event (Transport Phase)							
	Loading / Unloading[13]	Transport	Cargo terminal handling[14]	In Store	Parked vehicle	Other	Unknown	TOTAL events
Radiopharmaceuticals	11	29	21	0	2	1	6	**70**
Radioactive material used in research	0	0	0	0	1	0	0	**1**
Sources for medical therapy	4	0	0	0	0	0	0	**4**
Industrial sources	1	3	1	0	11	0	0	**16**
Non-nuclear mixture	0	0	0	0	0	0	0	**0**
NFC Minerals and Uranium Concentrates	0	0	0	0	0	0	0	**0**
UF_6	0	0	0	0	0	0	0	**0**
Uranium oxide	3	1	0	0	0	0	0	**4**
Non-irradiated fuel	0	0	0	0	0	0	0	**0**
Irradiated fuel	1	0	0	0	0	0	0	**1**
Radioactive waste	1	2	0	0	0	0	0	**3**
SCO	1	0	0	0	0	0	0	**1**
TOTAL Events	22	35	22	0	14	1	6	100

13. Not at airport cargo terminals.

14. Handling of radioactive packages at airport cargo terminals (including ramp handling operations).

Table 7.1.4. Events according to type of material and causes of the event

Type of material	Causes of the event										
	Collision with another vehicle	Mechanical vehicle failure	Theft	Incorrect preparation of the package	Incorrect handling of packages	Package not compliant with design	Other/ unknown causes	Misplacement of the package	Weather conditions	State of the road	TOTAL events
Radiopharmaceuticals	17	2	3	5	19	1	12	9	1	1	**70**
Radioactive material used in research	0	0	1	0	0	0	0	0	0	0	**1**
Sources for medical therapy	0	0	0	2	0	1	1	0	0	0	**4**
Industrial sources	3	0	11	1	1	0	0	0	0	0	**16**
Non-nuclear mixture	0	0	0	0	0	0	0	0	0	0	**0**
NFC Minerals and Uranium Concentrates	0	0	0	0	0	0	0	0	0	0	**0**
UF_6	0	0	0	0	0	0	0	0	0	0	**0**
Uranium oxide	0	0	0	2	0	0	2	0	0	0	**4**
Non-irradiated fuel	0	0	0	0	0	0	0	0	0	0	**0**
Irradiated fuel	0	0	0	0	0	0	1	0	0	0	**1**
Radioactive waste	1	1	0	0	0	0	1	0	0	0	**3**
SCO	0	0	0	0	0	0	1	0	0	0	**1**
TOTAL Events	21	3	15	10	20	2	18	9	1	1	100

Conclusions of the analysis according to the type of radioactive material transported

The main conclusions of the analysis are:

- Most events involve Type A packages carrying radiopharmaceuticals.
- Most events with industrial sources are related to the transport of soil moisture and density measuring equipment.
- Most events occur during road transport of radiopharmaceuticals.
- Transfers are the phase of transport in which most events occur, although the loading, unloading and package handling phases are also significant.
- Most of the thefts from vehicles have involved packages carrying soil moisture and density measuring equipment.
- The causes of transport incidents have been very varied, although the most prominent ones are collisions between the transport vehicle and other vehicles in road accidents and incorrect handling of packages during loading, unloading and transfer processes inside airport cargo terminals.

VII.2. According to sectors of activity

As indicated at the beginning of this section, most of the events occurred in the medical field and to a lesser extent in industrial applications and NFC-related activities.

An analysis of the events is then carried out with reference to the sectors of activity to which the radioactive material transported are directed. Several tables will correlate the events in these sectors with the time or phase of transport in which they occurred, with the cause of the events and with the modes of transport.

The sectors of activity listed below are not defined as such in the regulations applying to the transport of radioactive material, but have simply been identified in this document in order to relate the occurrences to the main sectors in which these materials are used. The following sectors have been considered:

- Medical.
- Research.
- Industrial irradiators.
- Industrial gammagraphy.
- Other industrial applications.
- Nuclear Fuel Cycle (NFC).
- Management of radioactive waste.
- Consumer products.

Sector of activity vs. time of occurrence

Table 7.2.1 lists the events that occurred in the different sectors of activity according to the phase of transport or time of the event in which they occurred.

From the analysis of the results in the table, it can be concluded that most of the events occurred during transport phase (35%) and almost all of them in the medical sector (83%).

There were the same number of incidents during both loading/unloading operations and during the handling of packages at airport cargo terminals, 22% in both cases. In the case of events at cargo terminals, they are mostly related to the medical sector, since, as we have already seen in the previous section, the events in these operations are related to the transport of radiopharmaceuticals. In loading and unloading, 68% of the events are also linked to the medical sector, but 27% of them occurred in the NFC and the remaining 5% in other industrial applications.

In terms of events occurring while the vehicle is parked, they mainly affected the industrial sector (79%).

It should also be noted that only 2% of the events affected the waste sector, all of them occurring at the transport phase.

Finally, it should be noted that in 6% of the events it was not possible to determine the exact time of occurrence.

Sector of activity vs. causes of the event

Table 7.2.2 relates the cause of the event to the sector of activity for which the transport was performed. In view of the data in the table, the results are quite diversified.

Within the medical sector, where most of the incidents occurred, 26% were due to incorrect handling of packages, 23% as a result of collision with another vehicle in a road accident, 9% due to incorrect preparation of the package and 16% due to misplacement or stolen packages. In 18% of the events in the medical sector, the causes could not be confirmed.

The sector with the second-highest number of events (albeit considerably fewer than the previous one) was other industrial applications; the most common cause was package theft.

Sector of activity vs. mode of transport

Table 7.2.3 lists the events according to mode of transport and sector of activity.

61% of the events occurred in road transport, 67% of which were in the medical sector and 21% in the industrial applications sector. As for airborne transport, during which 29% of the occurrences took place (while in flight and during handling operations) almost all (96%) were in the medical sector.

Table 7.2.1. Events by sector of activity and time of occurrence

Sector of Activity	Time of the Event (Transport Phase)							
	Loading / Unloading	Transport	Cargo terminal handling[15]	In Store	Parked vehicle	Other	Unknown	TOTAL events
Medical	15	29	21	0	2	1	6	**74**
Research	0	0	0	0	1	0	0	**1**
Industrial irradiators	0	0	0	0	0	0	0	**0**
Industrial Gammagraphy	0	0	1	0	1	0	0	**2**
Other industrial applications	1	3	0	0	10	0	0	**14**
NFC	6	1	0	0	0	0	0	**7**
Radioactive waste Management	0	2	0	0	0	0	0	**2**
Consumer products	0	0	0	0	0	0	0	**0**
TOTAL Events	**22**	**35**	**22**	**0**	**14**	**1**	**6**	**100**

15. Handling of radioactive packages at airport cargo terminals (including ramp handling operations).

Table 7.2.2. Events according to sector of activity and causes of the event

Sector of Activity	Causes of the event										
	Collision with another vehicle	Mechanical vehicle failure	Theft	Incorrect preparation of the package	Incorrect handling of packages	Package not compliant with design	Other unknown causes	Misplacement of the package	Weather conditions	State of the road	TOTAL events
Medical	17	2	3	7	19	2	13	9	1	1	**74**
Research	0	0	1	0	0	0	0	0	0	0	**1**
Industrial irradiators	0	0	0	0	0	0	0	0	0	0	**0**
Industrial Gammagraphy	0	0	1	0	1	0	0	0	0	0	**2**
Other industrial applications	3	0	10	1	0	0	0	0	0	0	**14**
NFC	0	0	0	2	0	0	5	0	0	0	**7**
Radioactive waste management	1	1	0	0	0	0	0	0	0	0	**2**
Consumer products	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL Events	**21**	**3**	**15**	**10**	**20**	**2**	**18**	**9**	**1**	**1**	**100**

Table 7.2.3. Events by sector of activity and mode of transport

Sector of Activity	Mode of transport								
	Road	Air	Air (h)[16]	Maritime	Maritime (p)[17]	Railway	Multimodal a/r[18]	Multimodal s/r[19]	TOTAL events
Medical	41	8	20	0	0	0	5	0	74
Research	1	0	0	0	0	0	0	0	1
Industrial irradiators	0	0	0	0	0	0	0	0	0
Industrial Gammagraphy	1	0	1	0	0	0	0	0	2
Other industrial applications	13	0	0	0	0	0	1	0	14
NFC	3	0	0	0	0	0	0	4	7
Management of radioactive waste	2	0	0	0	0	0	0	0	2
Consumer products	0	0	0	0	0	0	0	0	0
TOTAL Events	61	8	21	0	0	0	6	4	100

16. The event takes place during transfer, loading or unloading operations on the runway or in the cargo terminals of an airport (handling operations).
17. The event takes place during transfer, loading or unloading operations within a seaport.
18. Multimodal transport: air-road.
19. Multimodal transport: sea-road.

Conclusions of the analysis according to sectors of activity

The main conclusions of the analysis are:

- Most of the events are related to road transport for the medical sector.
- Most of these events have occurred during the transport phase as a result of accidents of collision between road vehicles.
- The number of events in loading/unloading operations at airport cargo terminals due to incorrect handling of packages is significant, and these incidents are also mostly related to the medical sector.
- Events occurring when the transport vehicle is parked mainly affect the industrial sector (theft of packages).

VII.3. Depending on the mode of transport

An analysis of the events is then carried out taking the mode of transport as the main reference. Through various tables, events occurring on these modes of transport will be correlated with the type of population closest to the event, the conveyance used and the causes of the event.

Mode of transport vs. type of nearby population

Table 7.3.1 lists the events according to the mode of transport and the type of population in the vicinity where they occurred.

We can observe that most of the events occurred in road mode (61%), of which 34% occurred in open country (without inhabitants) and 54% in inhabited areas: in a city (28%), in its surroundings (15%) or in a village (11%).

With regard to the other mode of transport with the highest number of incidents, air transport (29%), virtually all of them occurred at airports.

Finally, it should be noted that 14% of the events occurred due to improper operation in a nuclear or radioactive facility or were detected in the facility when the cargo was received, most of them being related to road or multimodal a/r or s/r transport.

Mode of transport vs. conveyance

Table 7.3.2 lists the events by mode of transport and conveyance.

As already illustrated in previous sections, 61% of the events occurred in road mode. Of these, 74% involved vehicles with a tonnage of less than 1.5 MT, usually used for the transport of small packages of radiopharmaceuticals and mobile radioactive equipment. Only 8% of these events involved large vehicles, larger than 3.5 MT, usually used for transport during the NFC.

Of the events occurring in the air mode (29% of the total), 31% involved a forklift or forklift truck, which are commonly used in loading and unloading processes at terminals. None of the air mode events involved an aircraft accident per se or affected the aircraft, crew or passengers, and the majority occurred during handling of radioactive packages during *handling* (air-h) operations, and the remainder were misplaced packages or non-compliances detected during the air transport process.

6% occurred during multimodal a/r transport, in the road phase. Half of them occurred in road vehicles weighing less than 1.5 tonnes, and the rest in vehicles with a higher tonnage.

Finally, it should be noted that there were no events during seaport operations.

Mode of transport vs. causes of the event

Table 7.3.3 lists the events that have occurred according to the mode of transport and the causes of the event.

It can be seen that of the 61 events occurring in the road mode, 21 of them (34%) were caused by a collision between vehicles and only 5 cases (8%) were due to vehicle breakdown, weather conditions or road conditions. In second place, thefts of packages from either the vehicle or the vehicle itself significantly affect this mode of transport, accounting for 25% of the events. In 19% of the events that occurred in this mode, the causes could not be reliably determined.

In the air mode, with a total of 29 events, the majority (69%) were due to incorrect handling of packages during airport activities. It is also noteworthy that 21% of the cases involved the misplacement of packages during the air transport process: from their departure at the airport of origin to their delivery at the cargo terminal at the airport of arrival.

Table 7.3.1. Events by mode of transport and type of population nearby

Mode of transport	Type of nearby population								
	Village	City	City surroundings	Airport	Open countryside / uninhabited	Nuclear or radioactive facility[20]	Unknown	Not applicable[21]	TOTAL events
Road	7	17	9	1	21	6	0	0	**61**
Air	0	0	0	6	0	0	2	0	**8**
Air (h)[22]	0	0	0	21	0	0	0	0	**21**
Maritime	0	0	0	0	0	0	0	0	**0**
Maritime (p)[23]	0	0	0	0	0	0	0	0	**0**
Railway	0	0	0	0	0	0	0	0	**0**
Multimodal a/r	0	0	0	1	0	4	0	1	**6**
Multimodal s/r	0	0	0	0	0	4	0	0	**4**
TOTAL Events	7	17	9	29	21	14	2	1	100

20. The event occurs due to improper operation in a facility or is detected at the facility when the load is received.

21. 'Not applicable' means that it is an event that cannot be directly associated with one type of population, or that there were several types along the way. The only case identified here refers to unsuitable contents of the transport package.

22. The event takes place during transfer, loading or unloading operations on the runway or in the cargo terminals of an airport (handling operations).

23. The event takes place during transfer, loading or unloading operations within a seaport.

Table 7.3.2. Events by mode of transport and conveyance

Mode of transport	Means of transport							
	Passenger aircraft	Forklift[24]	Not specified	Other	Road vehicle < 1.5 MT	Road vehicle ≥ 1.5 MT ≤ 3.5 MT	Road vehicle > 3.5 MT	TOTAL events
Road	0	0	0	1	45	10	5	**61**
Air	4	0	3	1	0	0	0	**8**
Air (h)[25]	6	9	2	4	0	0	0	**21**
Maritime	0	0	0	0	0	0	0	**0**
Maritime (p)	0	0	0	0	0	0	0	**0**
Railway	0	0	0	0	0	0	0	**0**
Multimodal a/r	0	0	0	1	3	1	1	**6**
Multimodal s/r	0	0	0	1	0	0	3	**4**
TOTAL Events	**10**	**9**	**5**	**8**	**48**	**11**	**9**	**100**

24. Forklifts, cranes, cargo lifts and similar.

25. The event takes place during transfer, loading or unloading operations on the runway or in the cargo terminals of an airport (handling operations).

Table 7.3.3. Events by mode of transport and causes of event

Mode of transport	Causes of the event										
	Collision with another vehicle	Mechanical vehicle failure	Theft	Incorrect preparation of the package	Incorrect handling of packages	Package not compliant with design	Other unknown causes	Misplacement of the package	Weather conditions	State of the road	TOTAL events
Road	21	3	15	5	0	0	12	3	1	1	**61**
Air	0	0	0	0	2	1	0	5	0	0	**8**
Air(h)	0	0	0	0	18	0	2	1	0	0	**21**
Maritime	0	0	0	0	0	0	0	0	0	0	**0**
Maritime (p)	0	0	0	0	0	0	0	0	0	0	**0**
Railway	0	0	0	0	0	0	0	0	0	0	**0**
Multimodal a/r	0	0	0	3	0	1	2	0	0	0	**6**
Multimodal s/r	0	0	0	2	0	0	2	0	0	0	**4**
TOTAL Events	**21**	**3**	**15**	**10**	**20**	**2**	**18**	**9**	**1**	**1**	**100**

Conclusions of the analysis by mode of transport

The main conclusions of the analysis are:

- Most of the events have occurred in road mode, with the second most occurring in air mode, mainly at airports.
- Many road incidents have occurred in or around inhabited areas, but the number of events in the open countryside is also significant.
- The vast majority of events in the road mode involved vehicles weighing less than 1.5 MT, vehicles typically used for the transport of radiopharmaceuticals and mobile radioactive equipment.
- In the air transport mode, there have been frequent events involving vehicles used in one way or another in the loading and unloading processes or in the transfer of packages on the runway or in the airport warehouses.
- In the road mode, the most frequent event is due to collision between vehicles, with theft of packages, either from the vehicle or the vehicle itself being the second most frequent.
- In the air transport mode, the most prominent cases are incorrect handling of packages (loading and unloading processes and transfer on the runway) and, secondly, misplacement of packages during the air transport process.

VII.4. Depending on the transport phase

Next, an analysis of the events is carried out, taking as the main reference point the moment at which the event occurs throughout the transport process, i.e. the transport phase.

The transport phase should be understood to include not only the transport of radioactive material from one point to another (transfer), but also other activities associated with transport, such as loading and unloading of the material on or from the conveyances, operations within a storage facility in transit and events occurring while the vehicle is parked, such as theft.

In relation to loading and unloading events, as indicated above, separate data are given for the case of operations at airport cargo terminals, given the uniqueness of these events and their frequency.

Following the same mechanism as in the previous sections, several tables will be used to relate the events occurring in the different phases of transport with the type of package involved in the event and its causes.

Transport phase vs. package type

As noted at the beginning of this chapter, Type A packages have been involved in the majority of events, followed by Excepted packages, with the higher risk fissile and Type B packages far behind.

In table 7.4.1, the information on package types is crossreferenced with the phase of transport at which the event occurred.

In the case of Type A packages, 39% of the events in which they were involved occurred during transport (transfer). The remainder was split between the handling phase at airport cargo terminals (25%), loading/unloading (17%) and the parking phase of the road vehicle (13%), mainly thefts.

In the case of Excepted packages, the most notable phase was loading and unloading and handling at cargo terminals (50% of the events involving this type of package). It is also noteworthy that 25% of the total number of cases involving these packages occurred while the vehicle was parked (mainly thefts).

Finally, during transport of packages of fissile materials, only 4% of the events were involved, all of which occurred during the loading and unloading phase, none during transfer.

Transport phase vs. causes of events

With regard to the relationship between the transport phase in which the events occur and their causes, table 7.4.2 shows that:

- 60% of transport events have been caused by a collision with another vehicle,
- 90% of those due to mishandling of packages occurred at airport cargo terminals,
- 93% of the thefts took place in a vehicle, and
- with regard to most misplaced packages (55%) it is difficult to determine the phase of transport at which they occur.

The transport phases where it was hardest to determine the causes of the occurrence were transport (transfer) and loading/unloading stages, which saw the most occurrences. Numerous events have also occurred at the airport cargo terminals, however in a minority of these cases the causes could not be confirmed.

Table 7.4.1. Events according to transport phase and type of package

Time of the Event (Transport Phase)	Type of package								
	Excepted	Industrial	Type A	Various packages NA	B(U)	B(M)	Fissile	Unpacked	TOTAL events
Loading/unloading	4	0	13	0	0	0	4	1	**22**
Transport	1	2	30	2	0	0	0	0	**35**
Terminal cargo handling	2	0	19	0	1	0	0	0	**22**
In warehouses	0	0	0	0	0	0	0	0	**0**
Parked vehicle	3	0	10	0	1	0	0	0	**14**
Other	1	0	0	0	0	0	0	0	**1**
Unknown	1	0	5	0	0	0	0	0	**6**
TOTAL Events	**12**	**2**	**77**	**2**	**2**	**0**	**4**	**1**	**100**

Table 7.4.2. Events by phase of transport and their causes

Time of the Event (Transport Phase)	Causes of the event										
	Collision with another vehicle	Mechanical failure of the vehicle	Theft	Incorrect preparation of the package	Incorrect handling of packages	Package not compliant with design	Other unknown causes	Misplacement of the package	Weather conditions	State of the road	TOTAL events
Loading/ unloading	0	0	1	10	1	2	7	1	0	0	**22**
Transport	21	3	0	0	0	0	9	0	1	1	**35**
Terminal cargo handling	0	0	0	0	18	0	1	3	0	0	**22**
In warehouses	0	0	0	0	0	0	0	0	0	0	**0**
Parked vehicle	0	0	14	0	0	0	0	0	0	0	**14**
Other	0	0	0	0	0	0	1	0	0	0	**1**
Unknown	0	0	0	0	1	0	0	5	0	0	**6**
TOTAL Events	21	3	15	10	20	2	18	9	1	1	100

Conclusions of the analysis according to the transport phase

The main conclusions of the above analysis are:

- Most of the events involving Type A and Excepted packages occurred at the transport (transfer) or handling phase at airport cargo terminals or loading/unloading.
- All events involving packages of fissile material occurred during the loading and unloading phase.
- Most of the events during the transport (transfer) phase were caused by a collision with another vehicle.
- Virtually all the events caused by improper package handling occurred at airport cargo terminals.
- Practically all the thefts of packages occurred in parked road vehicles (either of the packages or from the vehicle itself).
- With many misplacements, it is very difficult to draw a conclusion as to the phase of the transport operation in which they occur.
- For events at airport cargo terminals, it is usually straightforward to determine the causes of the event.

VII.5. According to the causes of the event

The previous sections have related the causes of events to the mode of transport, to the type of material transported, to the sector of activity for which the radioactive material was intended and to the phase or point in time at which the event occurred throughout all transport-related activities. To conclude this exercise of cross-checking the parameters associated with the scenarios of the events, it was deemed worthwhile to also carry out an analysis of the relationship between the causes and the conveyance involved. The results of this analysis are presented in table 7.5.1.

As can be seen, the majority of events involved road vehicles (68%), mainly light vehicles (< 1.5 MT), accounting for 48% of the overall number of events. As indicated above, these vehicles are most commonly used for the transport of packages containing radiopharmaceuticals (generally small quantities of packages), as well as mobile industrial application equipment (soil density and moisture measuring equipments and gammagraphs). For this type of vehicle, the main causes of events were both collisions with another vehicle (29%) and theft, either of the packages transported or of the vehicle itself (29%). It should be noted that in 21% of the cases the cause of the event could not be determined with certainty.

It is also interesting to note the data for road vehicles of between 1.5 and 3.5 MT. These vehicles are also frequently used for the transport of radiopharmaceuticals, but in this case of large quantities of packages, as well as for the transport of encapsulated radioactive sources for medical therapy or industrial applications. In this case, the cause of the accident was once again the collision between vehicles (54%).

Table 7.5.1. Events by cause and means of transport involved

Causes of the event	Means of transport							
	Passenger aircraft	Forklift[26]	Not specified	Other	Road vehicle < 1.5 MT	Road vehicle ≥ 1.5 MT ≤ 3.5 MT	Road vehicle > 3.5 MT	TOTAL events
Collision with another vehicle	0	0	0	0	14	6	1	**21**
Mechanical failure of the vehicle	0	0	0	0	2	0	1	**3**
Theft	0	0	0	0	14	1	0	**15**
Incorrect preparation of the package	0	0	0	2	3	2	3	**10**
Incorrect handling of packages	5	8	3	4	0	0	0	**20**
Package not compliant with design	1	0	0	0	0	1[27]	0	**2**
Other unknown causes	0	1	0	2	10	1	4	**18**
Misplacement of the package	4	0	2	0	3	0	0	**9**
Meteorological circumstances	0	0	0	0	1	0	0	**1**
Road conditions	0	0	0	0	1	0	0	**1**
TOTAL Events	**10**	**9**	**5**	**8**	**48**	**11**	**9**	**100**

26. Forklifts, cranes, cargo lifts and similar.

27. Detected in a multimodal road-air transport (passenger aircraft).

In short, a collision between vehicles is the most common cause of accidents involving road vehicles of any type, although it should be noted that there has only been one such accident involving a large vehicle (over 3.5 MT), which is normally used in transport related to the NFC.

The other point of note in this analysis relates to air transport. 10% of the events involved transport by passenger aircraft, but none were due to an aircraft accident, but to incorrect handling of the package at some phase of the transport (50% of the cases) or misplacement of the packages during that process (40%). Likewise, in the case of forklift events (9%), the majority occurred in handling operations during air transport and almost all were due to incorrect handling of packages.

VIII. Severity of the events. Classification according to the INES scale

VIII. Severity of the events. Classification according to the INES scale

The International Nuclear and Radiological Event Scale (INES), which was developed by IAEA experts together with the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD), entered use as of 1990 to classify events in nuclear power plants and was subsequently extended and adapted for application to all facilities associated with the civil nuclear industry and radioactive material.

The 2008 edition of the INES manual [24] already fully applied to the use of radioactive sources (radioactive facilities) and to the transport of any kind of radioactive material. All events in the analysis period (2000-2020) have been classified according to the criteria of the above-mentioned edition of the INES manual.

The INES scale is used to communicate the safety significance of events associated with radiation sources to the public in a rapid and consistent manner. The scope of the scale applies to any event associated with the transport, storage and use of radioactive material and radiation sources, whether or not it occurs in a facility. The scale therefore covers a wide spectrum of practices, including industrial uses, the use of radiation sources in hospitals, activities in nuclear facilities and, of course, the transport of radioactive material.

The use of the scale also includes the misplacement or theft of radioactive sources or packages, as well as the discovery of orphan sources, excluding events related to physical protection, malicious acts aimed at exposing people to radiation or events arising from military applications.

According to this scale, events are classified into seven levels (see figure 8.1). Occurrences at levels 1 to 3 are referred to as "incidents", while those at levels 4 to 7 are referred to as "accidents". When events are not of safety significance, they are considered to be "below scale" and are assigned a level of 0.

Figure. 8.1. INES Scale

Table 8.1. Events occurring between 2000 and 2020 and their INES[28] classification

Incident type	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Packaging deficiencies	0	0	0	0	2 (1)[29]	0	0	1 (1)[30]	3 (1/0/0)	0	0	0	0	0	0	0	0	0	0	0	0	6
Unsuitable package content	0	0	0	0	0	0	0	0	1 (1)	1 (0)	0	0	0	0	0	0	0	0	0	0	0	2
Event during loading/ unloading processes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (0)	2 (0)	2 (0) (1)	0	0	0	0	5
Exceedance of contamination limits (NC IS-34 CSN)	0	0	0	0	1 (0)	0	0	0	0	0	0	0	0	0	1 (0)	0	0	0	0	0	0	2
Exceedance of radiation limits (NC IS-34 CSN)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2 (0) (1)	0	0	1 (1)	0	3
Incidents at airport terminals	3 (0)	2 (0)	1 (0)	2 (0)	2 (0)	1 (0)	2 (0)	0	0	0	0	0	0	1 (0)	1 (0)	0	2 (0)	4 (0)	1 (0)	0	0	22
Traffic accident	0	0	1 (1)	1 (0)	0	5 (0)	3 (0)	2 (0)	3 (0)	1 (0)	3 (0)	1 (0)	1 (0)	4 (0)	2 (0)	1 (0)	2 (0)	1 (0)	1 (0)	0	2 (0)	34
Theft of packages	0	0	0	1 (1)	1 (1)	2 (1)	1 (1)	0	1 (1)	1 (1)	1 (1)	1 (1)	0	0	0	0	2 (0) (1)	1 (1)	0	1 (1)	2 (0) (1)	15
Misplacement of packages	0	1 (1)	0	0	1 (0)	1 (1)	0	0	0	2 (0)	1 (0)	1 (0)	0	0	0	1 (0)	0	1 (0)	0	1 (0)	0	10
Physical protection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (0)	1
Total	**3**	**3**	**2**	**4**	**7**	**9**	**6**	**3**	**8**	**5**	**5**	**3**	**1**	**5**	**5**	**4**	**10**	**7**	**2**	**3**	**5**	**100**

28. The INES classification of the events is indicated in brackets.

29. They were detected upon reception at Spanish facilities. INES classification in the country of origin.

30. It was detected upon reception at a Spanish facility. INES classification in the country of origin.

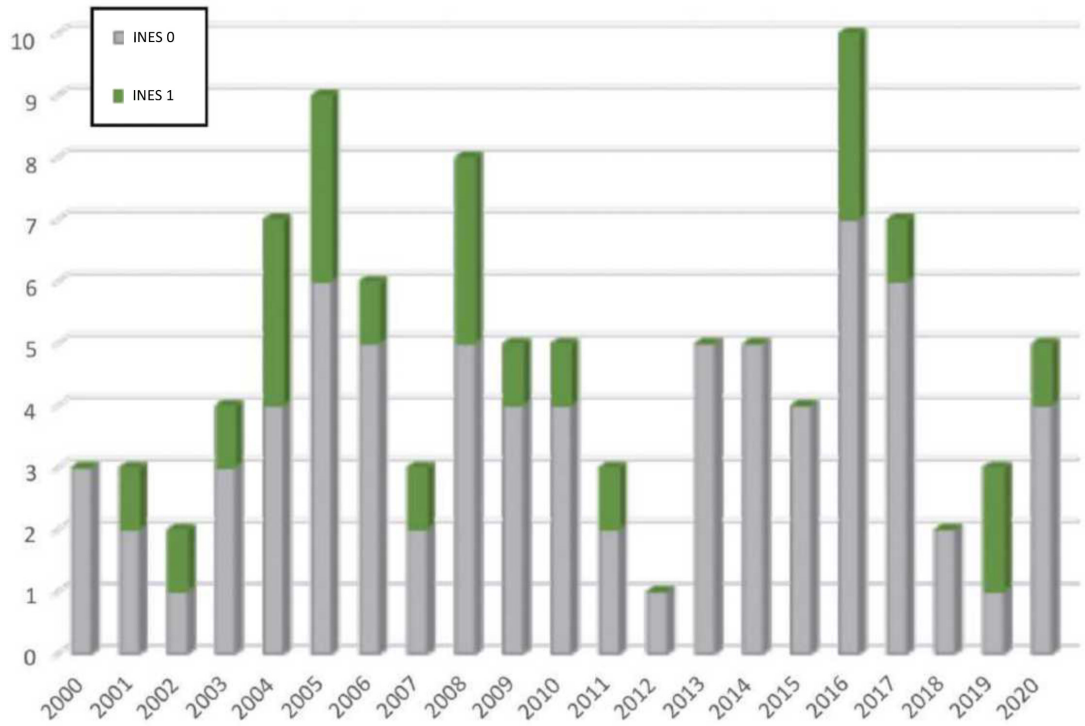
Furthermore, in order to allow the public to quickly assess the safety significance of the event, each level of the INES scale is assigned a different expression, in increasing order of severity: anomaly (1), incident (2), serious incident (3), accident with local consequences (4), accident with wider consequences (5), serious accident (6) and major accident (7).

The classification of an event at a given level is made with reference to its impact in three areas: effects on people and the environment; effects on barriers and radiological controls at facilities; and effects on defence in depth.

VIII.1. INES classification of transport events in the period 2000-2020

Figure 8.1.1 shows the INES levels assigned to the events occurring in Spain between 2000 and 2020, none of which exceeded level 1 (anomaly). Table 8.1 shows in detail the typology of the events and their INES classification for the period under analysis.

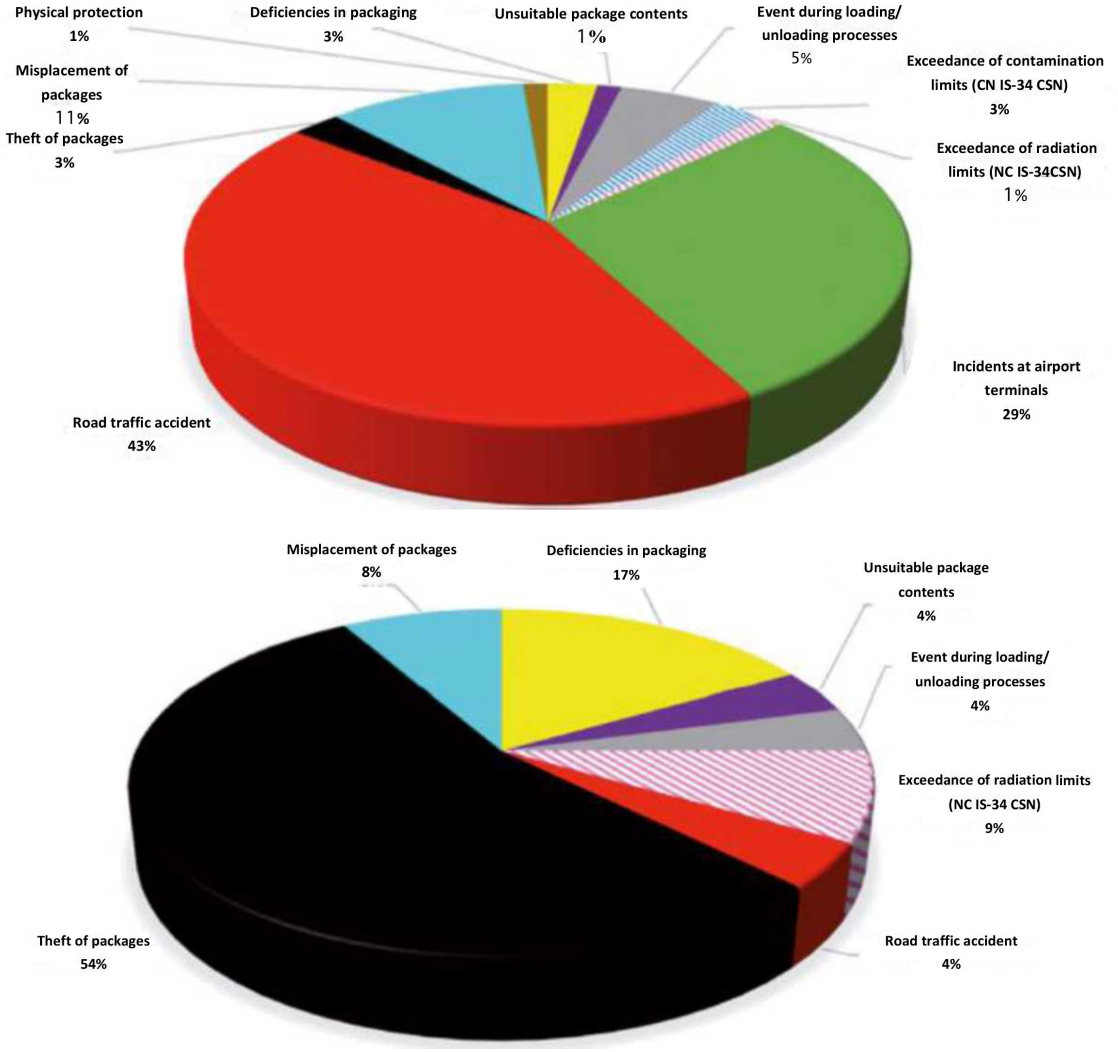
Figure 8.1.1. INES level of events occurring between 2000 and 2020



In total there have been 76 level 0 events (no safety significance / below scale) and 24 level 1 events (anomaly).

With regard to the type of event (see figure 8.1.2), approximately 43% of INES 0 events were traffic accidents, 29% were incidents at airport terminals and 11% were misplacement of packages. For events categorised as INES 1, 62% were due to theft (54%) and misplacement of packages (8%) and to a lesser extent (17%) to packaging deficiencies. It is important to bear in mind that the INES scale not only considers the risks arising from radioactive material involved in cases of package theft and misplacement; its classification also penalises events where the packages are not found.

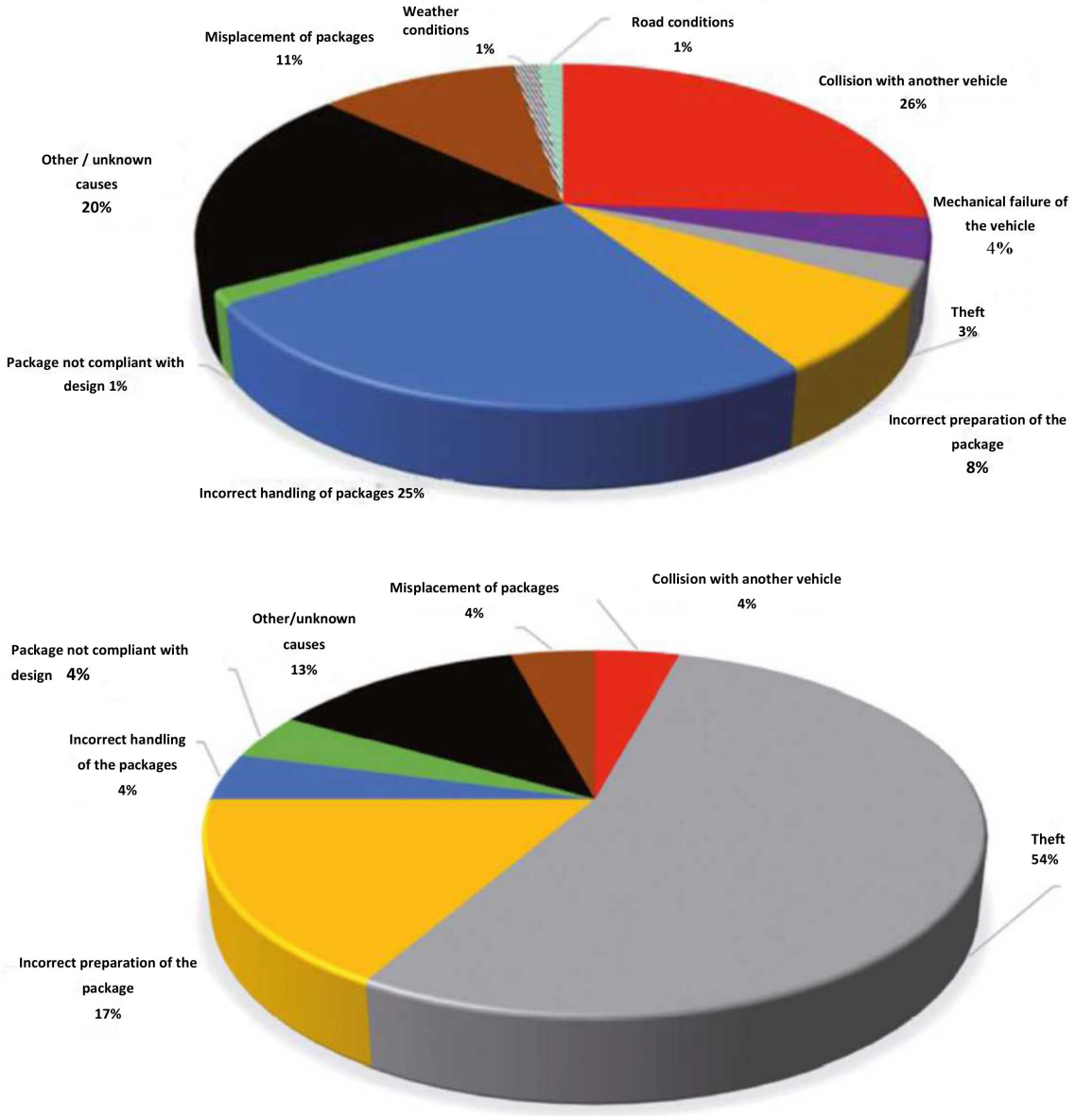
Figure. 8.1.2. Classes of events classified as INES 0 (upper) and INES 1 (lower)



From the perspective of the causes of the event (figure 8.1.3), approximately 26% of the 76 level 0 events were caused by a collision with another vehicle in a road accident, 25% by improper handling of the packages, 11% by misplacement and 8% by improper preparation. It should be noted that 20% of events were due to "other causes" which were either not envisaged in the database or could not be reliably confirmed.

On the other hand, theft is the main cause of events categorised as INES 1 (54%), followed by incorrect preparation of the package (17%). 13% of the level 1 events were due to "other causes".

Figure. 8.1.3. Causes of events classified as INES 0 (upper) and INES 1 (lower)



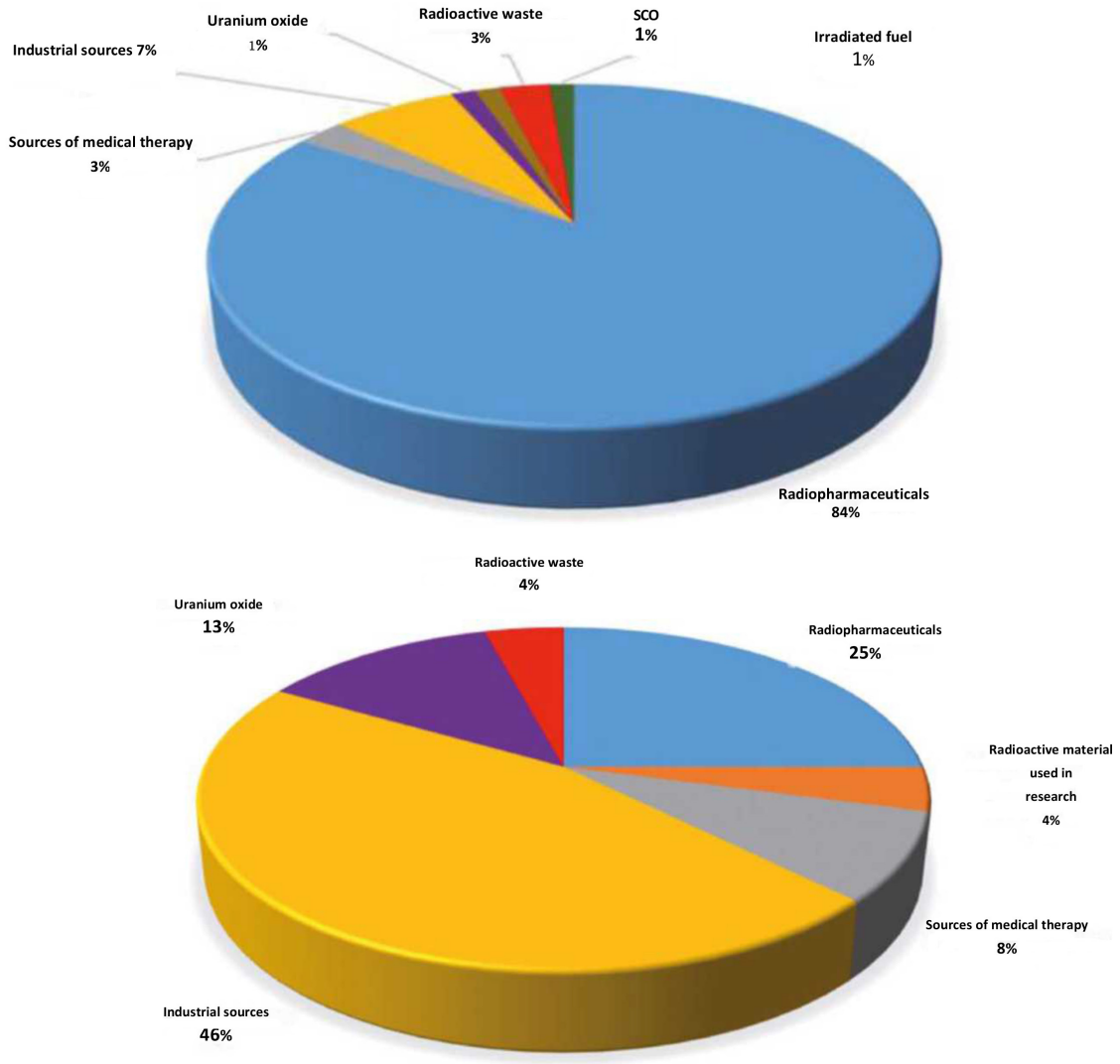
The following is an analysis of the results of the INES classification of events with respect to the different parameters associated with transport: material transported, type of package, sector of activity, mode of transport and phase of transport.

Depending on the material transported

Looking at the classification of events according to radioactive material (figure 8.1.4), as already identified in the previous chapter, radiopharmaceuticals are the material involved in the majority of events (70%), 84% of which were classified as INES 0.

On the other hand, industrial sources accounted for of the majority of events classified as INES 1 (46%), followed by radiopharmaceuticals (25%). Again it should be noted that the very high number of level 1 events in industrial sources is because they are related to thefts of mobile radioactive equipment.

Figure. 8.1.4. Type of radioactive material involved in events classified as INES 0 (upper) and INES 1 (lower)

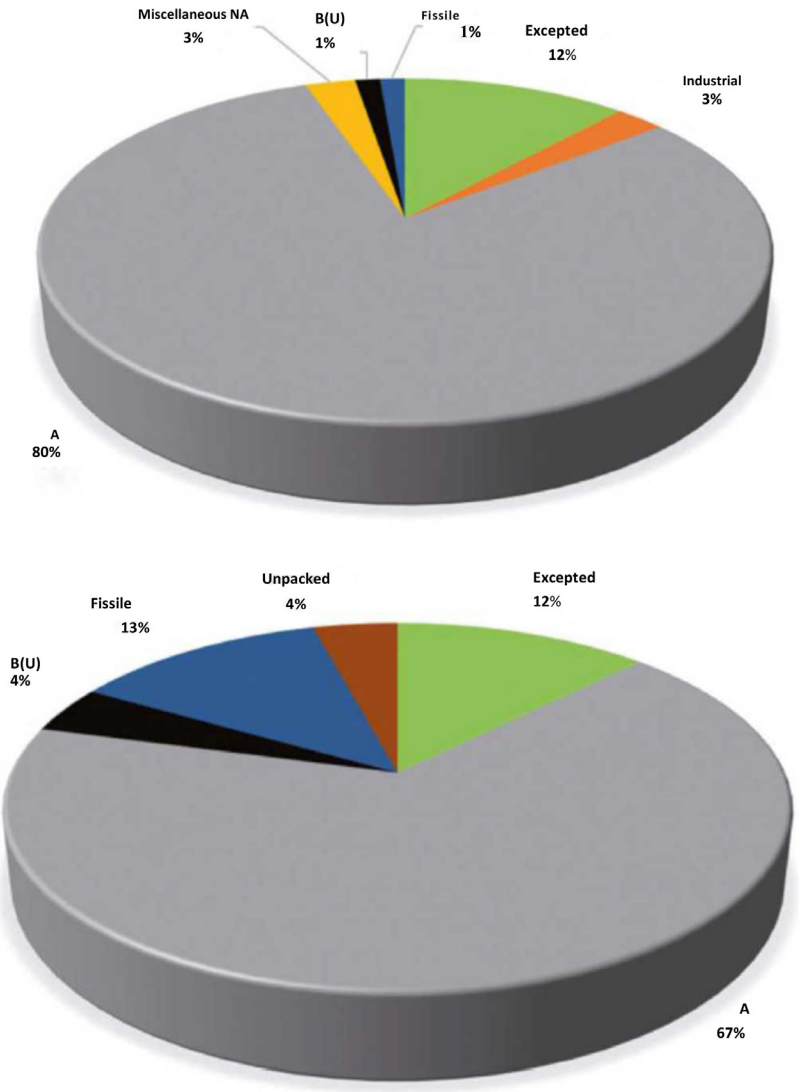


Only three events involving radioactive waste have occurred, two classified as INES 0 (3%), caused by traffic accidents, and one classified as INES 1 (4%) as a result of unsuitable package contents (metallic waste that should have been considered radioactive by a nuclear facility and packaged accordingly).

The transport of uranium oxide gave rise to four events, one classified as INES 0, linked to a physical protection event without consequences, and three classified as INES 1 (13%), resulting from deficiencies detected in the packaging on receipt of the packages.

Depending on the type of package

Figure. 8.1.5. Type of package involved in events classified as INES 0 (upper) and INES 1 (lower)



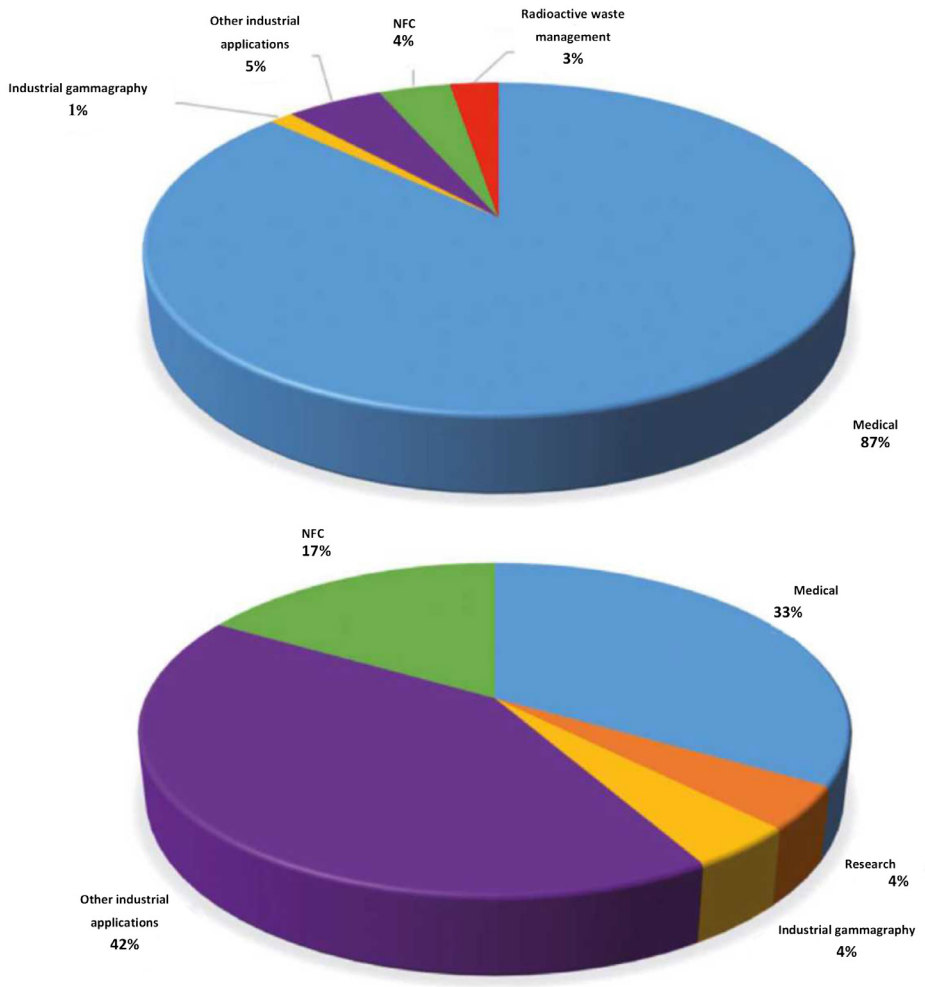
In terms of the type of package (Figure 8.1.5), as Type A packages are the most commonly used for transport of radiopharmaceuticals and industrial sources, they account for the bulk of INES 1 occurrences, with approximately 67% of the total, followed equally by Excepted and Fissile packages at 13%.

For similar reasons, Type A packages have been involved in the vast majority of level 0 events.

According to sector of activity

The INES analysis with reference to the sectors of activity involved (figure 8.1.6) shows that the majority of level 0 events occurred in the medical sector (87%), which accounted for 74% of all events in the period 2000-2020.

Figure. 8.1.6. Type of sector of activity in which events classified as INES 0 (upper) and INES 1 (lower) occur

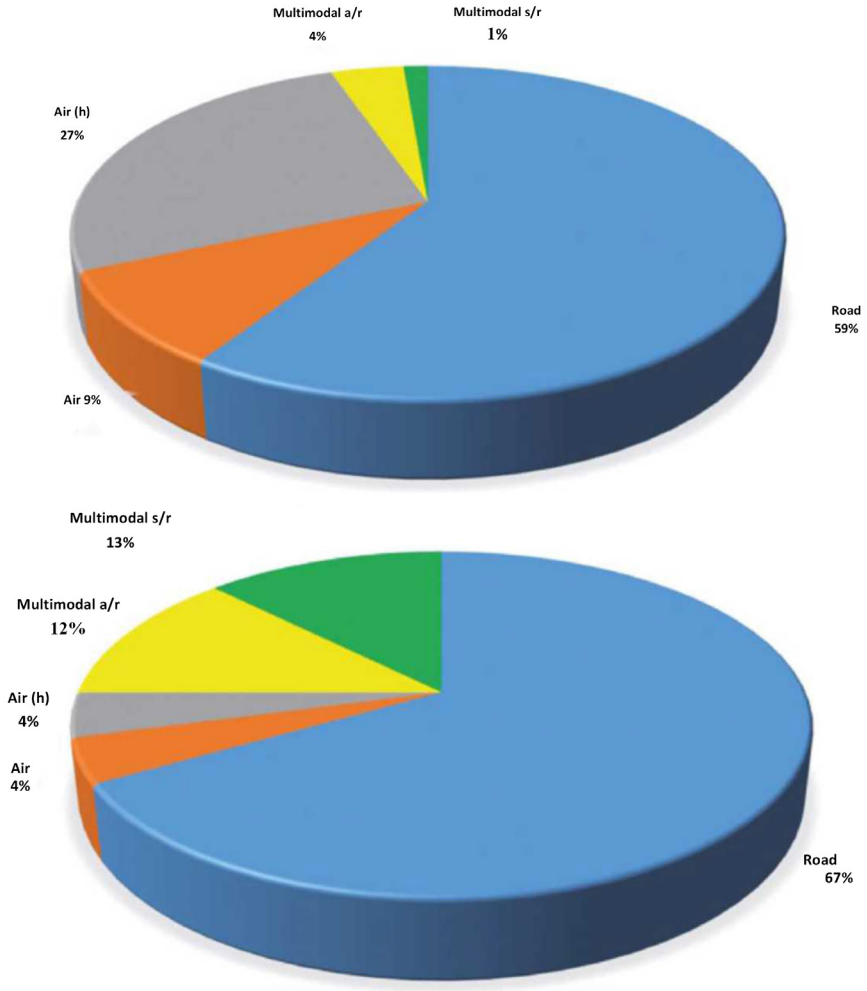


The 24 events classified as INES 1 are mostly distributed among other industrial applications (42%, all caused by package theft), medical (33%, resulting from multiple causes) and NFC (17%, half of them caused by incorrect package preparation).

Depending on the mode of transport

The distribution of cases by mode of transport (figure 8.1.7) shows that the bulk of INES 0 events are due to road transport (59%) and air transport (35%). In the context of air transport, INES 0 events mostly occurs during airport *handling* operations (26%), which, as has been observed throughout this document, are mainly related to loading and unloading processes in cargo terminals and airport runway transfers.

Figure. 8.1.7. Transport mode in which events classified as INES 0 (upper) and INES 1 (lower) occur

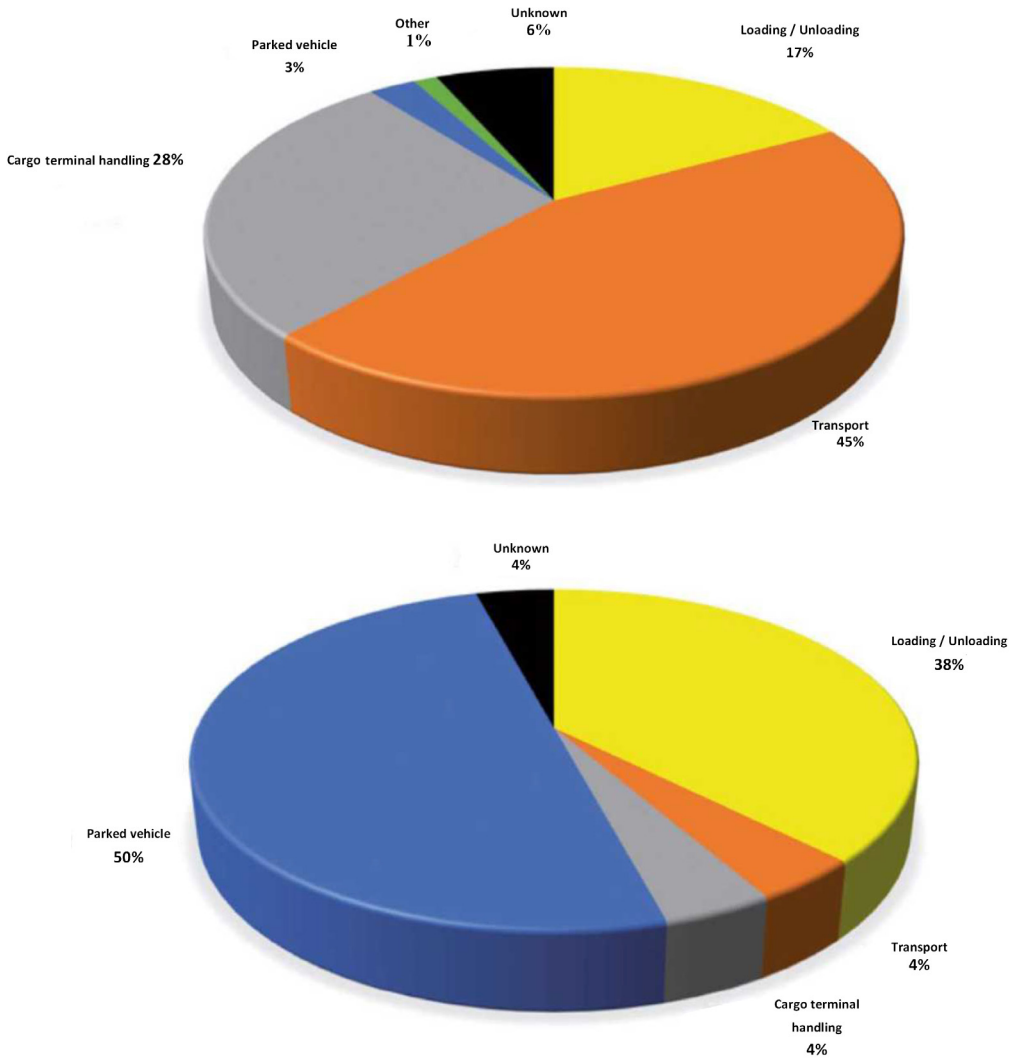


In terms of INES 1 events, road transport accumulated the highest number (67%) as a result of theft of packages in parked vehicles, followed by multimodal transport (25%), with three events for multimodal a/r and three for multimodal s/r, which were due to deficiencies in packaging or exceeding the radiation limits of packages.

In the case of air transport, there were only two events classified as INES 1, both caused by misplacement of packages.

Depending on the transport phase

Figure. 8.1.8. Transport phase when events classified as INES 0 (upper) and INES 1 (lower) occur



Analysing the data according to the phase of transport at which the event occurred (figure 8.1.8), almost all level 0 events occurred during transport (45%), handling at airport cargo terminals (28%) and loading or unloading of packages (17%).

In the case of events classified as INES 1, half of them occurred when the vehicle was parked, as a result of theft of packages, followed by the loading/unloading phase (38%) due to various causes.

VIII.2. Conclusions of the analysis of events according to their INES classification

The following conclusions can be drawn from the analysis in the previous section:

- No event has exceeded level 1 (anomaly).
- 76% of the events have been level 0 (no safety significance / below the scale).
- The majority of level 0 events occurred in road mode, and the second most occurred in air mode.
- The majority of the level 0 events were traffic accidents due to vehicle collisions and incidents in the handling process of packages during airport *handling*.
- Almost all level 0 events involved Type A packages carrying radiopharmaceuticals for the medical sector.
- The majority of the level 1 events were due to thefts of Type A packages containing industrially applied mobile radioactive equipment while the vehicle was parked in road transport.

IX. Consequences of the events

IX. Consequences of the events

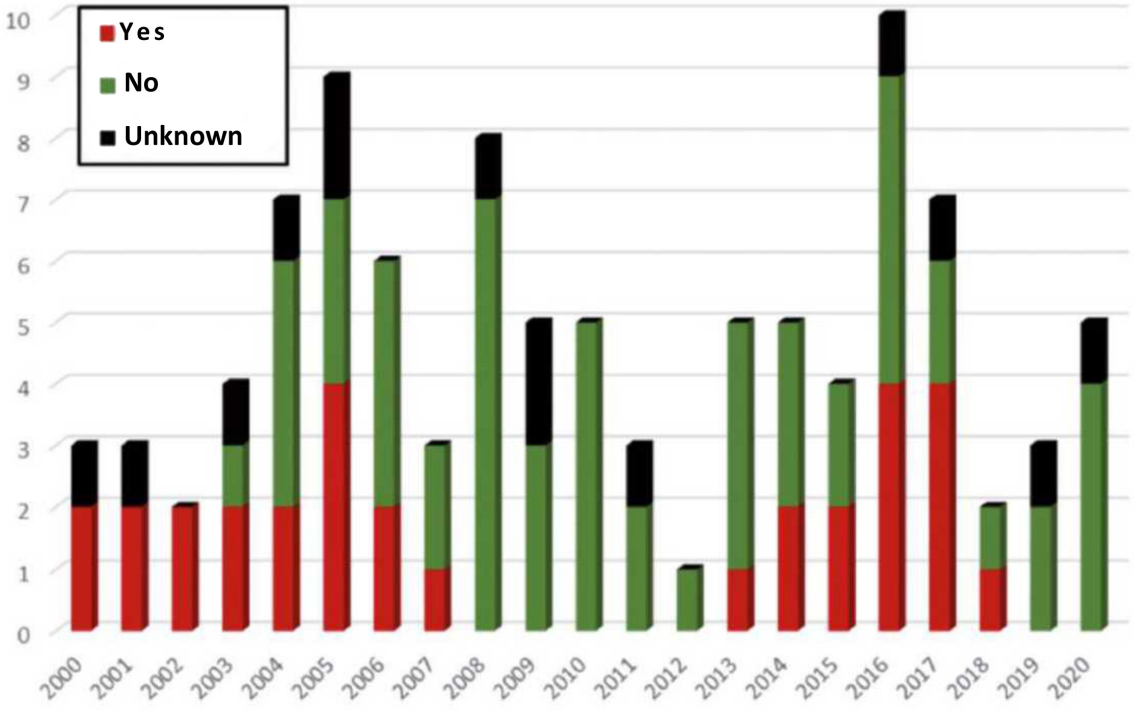
Having carried out a detailed analysis of the typology of the events that occurred during the study period, taking into account the fundamental parameters of the transport process, we will now focus on the consequences of the events, both on the cargo and on the conveyance, as well as the physical harm to human life and, of course, the radiological consequences. Finally, details of some events of the study period that are considered most significant, including lessons learned from their analysis, will be presented.

IX.1. Damage to cargo and conveyance

IX.1.1. Damage to cargo

Of the 100 events in the period under analysis, cargo damage occurred in 31 cases (see figure 9.1). Incidents where there was only minor damage, such as dents in the outer packaging of the packages, and which did not prevent the consignment from being delivered to the originally intended destination, are also considered to meet the criterion of cargo damage.

Figure 9.1. Damage to cargo



It is noted that in 15 of the events the packages were not recovered, so it could not be confirmed whether they were damaged, except one event where damage to the cargo was found as a result of the breakage of the outer packaging and subsequent loss of the inner container. Of these 14 events with unknown consequences for the cargo, the majority (10) were theft of packages and the rest were misplaced during the transport process (3) and incidents at airport terminals (1).

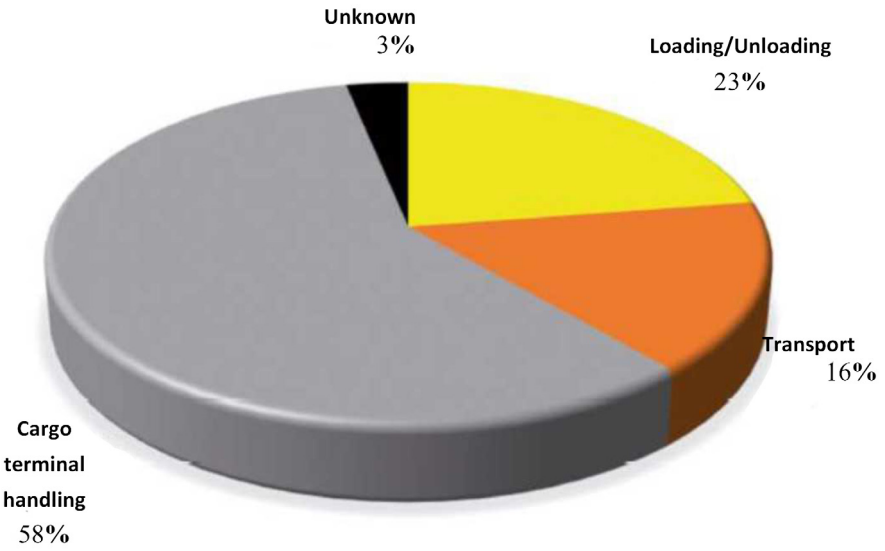
This implies that the average number of cargo damage events was approximately two per year (conservatively including events where packages were not recovered and where it could not be confirmed that no damage occurred). It is also interesting to note that of the 31 events in which cargo damage was confirmed, the majority (77%) involved a single package, with five being the maximum number of packages affected in a single event.

In addition, it is noteworthy that of those 31 events in which cargo damage was found, 64% were due to incidents at airport terminals. In second place, but in clearly lower numbers, are loading/unloading events outside these terminals and traffic accidents, which each account for about 16% of the events.

Phases of transport in which cargo damage events occurred

If we analyse the phase of transport at which cargo damage events occurred (figure 9.2), the majority occurred at the package handling phase at airport cargo terminals (58%), followed by those occurring at the loading/unloading phase (23%) and at the transport phase (16%). In 3% of the cases, the exact phase of transport at which the event occurred could not be confirmed.

Figure 9.2. Phases of transport in which cargo damage events occurred



It should be noted that the events where it was not possible to confirm damage to the cargo, being linked to theft and misplacement, mostly occurred at the transport (transfer) phase, while the vehicle was parked (64%), or at an unknown phase (29%).

Radioactive material and types of packages involved in cargo damage events

97% of the cargo damage events occurred during transport of radiopharmaceuticals and the remaining 3% during transport of industrial sources. The packages were 93% Type A and 7% Excepted.

Of the events where the consequences are unknown, 57% involved the transport of industrial sources, 36% involved radiopharmaceuticals and the remaining 7% involved radioactive material used in research. On the other hand, 86% of the types of packages were Type A, 7% were Excepted and another 7% were Type B.

Modes of transport in which cargo damage events occurred

There were two modes of transport in which cargo damage events occurred: air, 68% of the cases (mainly in airport terminals), and road, 32% (mainly traffic accidents).

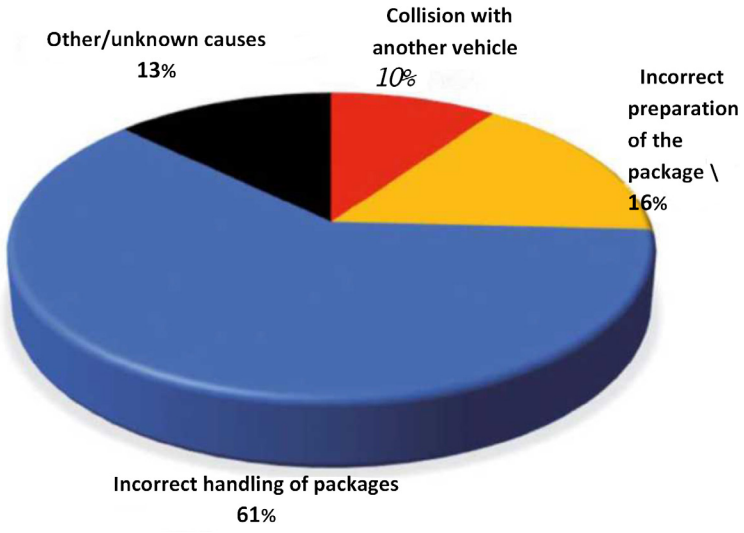
Those events with unknown consequences for the cargo are mostly linked to road transport (79%), which is where most of the package thefts occurred, while 21% occurred in air transport, which is where almost all package misplacements occurred.

Causes of cargo damage events

Finally, if we analyse the events where cargo damage was confirmed against the causes of the event (figure 9.3), incorrect handling of the package was the cause of 61% of the events, followed by incorrect preparation of the package (16%) and collision between vehicles (10%).

For events with unknown consequences, again the causes are distributed between 71% theft and 29% misplacement.

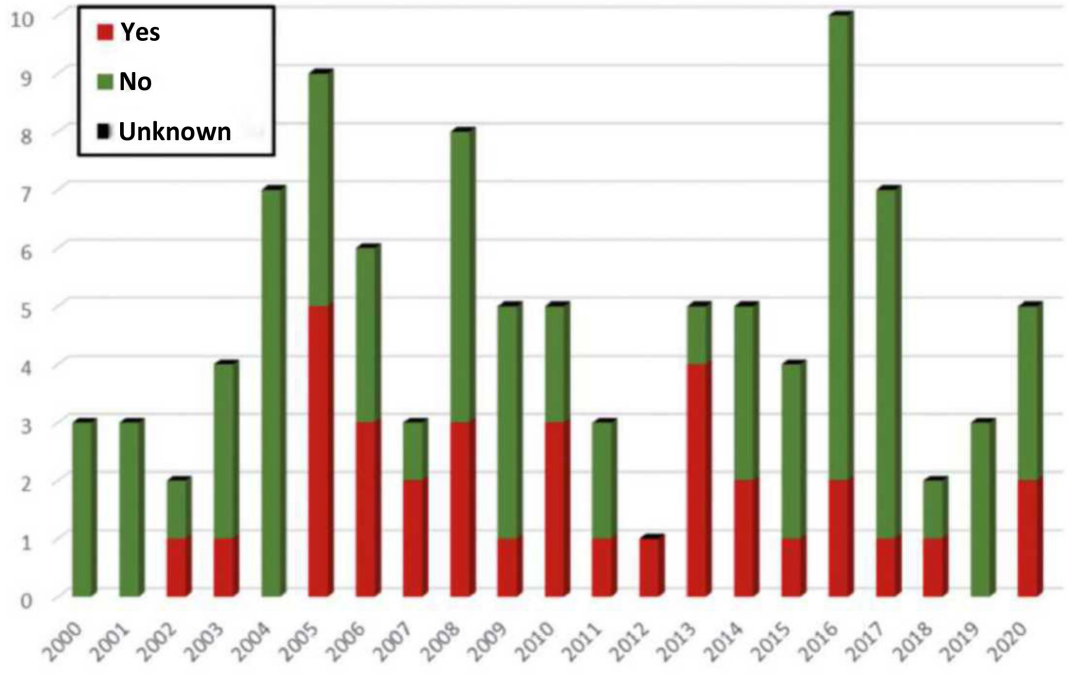
Figure 9.3. Causes of cargo damage events



IX.1.2. Damage to the conveyance

The analysis of the events according to damage to the conveyance (see figure 9.4) shows that damage occurred in 34 out of 100 cases. As expected, 100% of the damage occurred during the transport phase (transfer) and, more specifically, in road traffic accidents during road transport.

Figure 9.4. Incidents involving damage to the conveyance



In general, the damage to the transport vehicle resulted in its immobilisation, i.e. the vehicle could not continue transport and had to be replaced by another vehicle. However, in some cases, such immobilisation and subsequent replacement was carried out by the transport company on a precautionary basis, not because the vehicle could not continue to run.

73% of the damaged road vehicles weighed less than 1.5 MT, i.e. light vehicles normally used for transporting radiopharmaceuticals and mobile radioactive equipment for industrial application; 21% of the vehicles weighed between 1.5 and 3.5 MT, normally used for the transport of large quantities of radiopharmaceuticals and other radioactive sources for medical and industrial application; and the remaining 6% weighed over 3.5 MT; specifically, this was a vehicle that was transporting radioactive waste from a nuclear power plant.

If we analyse the causes of the events leading to damage to the vehicle, the majority (62%) were caused by a rear-end collision with another vehicle. And as for the location of the event, the majority occurred in open/uninhabited countryside (62%), followed by the outskirts of a city (21%), i.e. in areas where vehicles travel at higher speeds.

Finally, it should be noted that of the 34 events in which damage to the transport vehicle occurred, cargo damage occurred in only 4 of these cases.

IX.1.3. Significant aspects of events causing damage to cargo and conveyance

Considering the above, the most salient conclusions of this analysis are as follows:

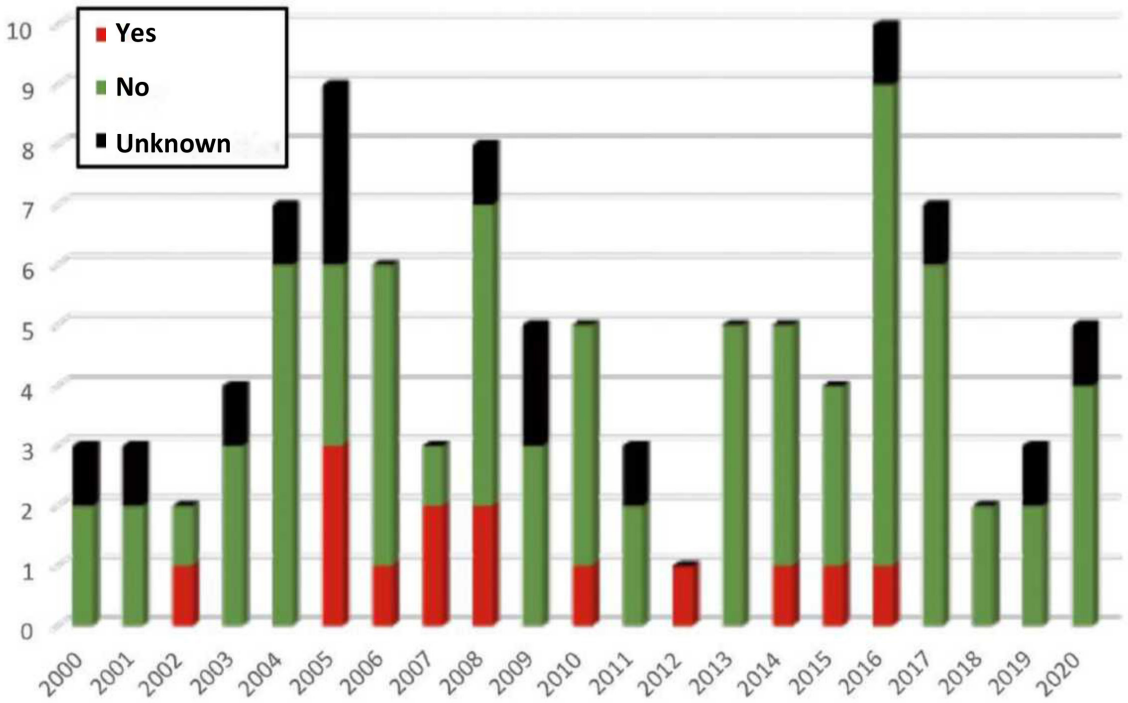
- The average number of cargo damage events was approximately two per year (including events where packages were not recovered and where damage could not be confirmed).
- In most events with confirmed cargo damage, only one package was affected.
- The majority of cargo damage events occurred in incidents at airport cargo terminals (runway transfer, loading and unloading).
- Virtually all cargo damage events occurred during transport of radiopharmaceuticals in Type A packages.
- The most affected mode of transport is air transport (events in cargo terminals caused by incorrect handling of packages) and secondly road transport, due to collisions between vehicles in traffic accidents.
- Most of the damaged road vehicles were light vehicles (<1.5 MT).
- Damage to the road vehicle usually results in its immobilisation.
- In most of the events involving damage to the transport vehicle, there was no damage to the cargo.

IX.2. Physical harm to persons

This section analyses the events from the perspective of any physical harm, unrelated to exposure to ionising radiation, suffered by the persons involved in the events. It is noteworthy that in none of the 100 events that occurred during the period under analysis were people harmed as a result of irradiation or contamination, but only strictly physical harm caused as a consequence of the event.

As shown in Figure 9.5, there were a total of 14 events where physical harm to persons –whether the driver, the crew or members of the public– could be confirmed; 71 events where there were no consequences and 15 where this information could not be confirmed (these were thefts or misplaced packages where the packages were not recovered).

Figure 9.5. Physical harm to persons



In the 14 events where there were consequences for human life, there were a total of 3 fatalities (in three different events) and 14 injuries. The most common cause (64% of events) was a collision with another vehicle in a road transport accident.

The first fatality occurred in 2002, when the driver of a vehicle carrying 26 packages of radiopharmaceutical material died as a result of a collision between vehicles on the N-IV in the province of Ciudad Real, Spain (more details on this event are given in section IX.4).

The second event involving a fatality occurred in 2005 in a traffic accident on the N-525 at Gustei (Orense). A pedestrian was killed in the accident when he was hit by a vehicle carrying 5 packages of radiopharmaceutical material. The management of the accident required the adoption of conventional measures not related to the radioactive load.

The last fatal accident occurred in 2006 on the A-45 in the province of Málaga. The driver of a vehicle carrying 22 packages of radiopharmaceutical material was killed when the vehicle collided with two trucks (see section IX.4 for more details on this event).

IX.3. Radiological consequences

Finally, the last type of consequences to be analysed are those of a radiological nature, which are considered to be the radioactive contamination of surfaces[31] or persons as a result of the release of the contents of the packages, or significant radiological exposure of persons due to damage or loss of the shielding of the packaging. Within the scope of this document, a significant exposure shall be considered to be one that that has resulted in a dose relevant to the doses received in the normal operation of a transport or is close to the annual dose limits defined for the public or workers classified as exposed.

In relation to this section, it should be pointed out that in none of the events occurring during the study period were the annual dose limits for workers classified as exposed or for the public, as established in the Regulation on health protection against ionising radiation, exceeded.

It should be noted that the analysis in this section does not consider the 15 events caused by the theft or misplacement of packages that were not found or recovered, as it could not be confirmed whether radiological consequences occurred. However, the INES classification of these events already takes into account their potential radiological consequences and in none of the cases was level 1 (anomaly) exceeded.

The overall analysis of the events according to their radiological consequences is shown in figure 9.6, where it can be seen that only three of the 100 events that occurred had consequences of this nature: in two there was significant exposure of people and in the third there was surface contamination of an area:

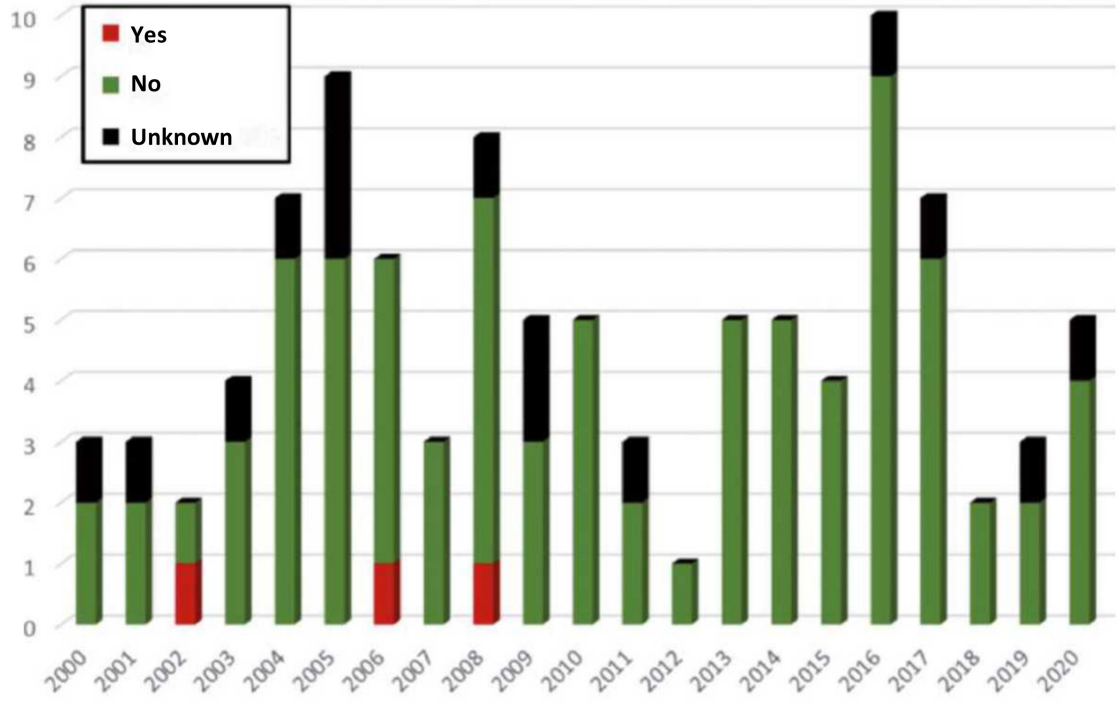
- Road accident on the N-IV in 2002, already mentioned in the previous section. Severe damage occurred to a package containing a Mo/Tc generator, causing the generator column to break out of its shielding. The person who carried out the recovery of the column –in a planned operation, by inserting it into the shielding of the generator– received a dose to the hand of about 70 mSv[32]. No significant whole-body doses were received.

31. Excluded are areas of radioactive and nuclear installations where contamination is foreseen due to their classification.

32. The equivalent dose limit for hands, forearms, feet and ankles is 500 mSv per official year for workers classified as exposed.

- Event detected in 2008 at Adolfo Suárez-Barajas airport in Madrid. During a routine inspection by the airport fire service at the cargo terminals, abnormal dose rates were detected on the outside of three packages in international transit (values not in accordance with their labelling and transport documentation).
  The packages contained two Mo/Tc generators that were being transported between Argentina and the Dominican Republic. It was found that the consignor had used insufficient shielding on the packages (deficiencies in the packaging) and had also failed to carry out adequate radiological surveillance of the packages on departure from their premises. Estimates of the doses due to the event, considering the entire route to Madrid airport and the most unfavourable conditions in the dose calculation, concluded that a dose to the public of 0.85 mSv occurred, which is below the annual dose limit for the public (1 mSv).

Figure 9.6. Radiological consequences of events



- Road accident that occurred in 2006 on the A-45, already mentioned in the previous section. In this event, three of the packages carrying radiopharmaceuticals were damaged, resulting in the release of some of its radioactive contents. This release caused surface contamination of about 400 cm^2 of land next to the road.

More details on these three cases will be given in the following section on "significant events".

IX.4. Remarkable events

This section will describe the most significant events in the period under review, pointing out the lessons learned and the most important actions that were taken following their subsequent analysis.

IX.4.1. Road accident in 2002 at Km. Marker 212 of the N-IV

The accident occurred in a rear-end collision with another vehicle at 1:30 a.m. on 17 January 2002, in open countryside (without inhabitants), in the province of Ciudad Real, Spain.

The vehicle (between 1.5 and 3.5 MT) was carrying 26 Type A and Excepted packages, with a total activity of 1 TBq and a total Transport Index (TI)[33] of 24.8.

The transport had left Madrid and was scheduled to distribute radiopharmaceutical material from various consignors to different medical centres in Andalusia.

The driver was killed in the accident and the vehicle was seriously damaged. The packages suffered various types of damage, although they all remained inside the vehicle's body. Severe damage occurred to a package containing a Mo/Tc generator, causing the generator column to break out of its shielding.

A maximum dose rate of 10 mSv/h was measured at 1 m from the vehicle. There was no radioactive contamination of people or surfaces.

The person who carried out the recovery of the column by inserting it into the generator shielding was classified as an "exposed worker" and received a dose to the hand of about 70 mSv, which is below the annual limit for this type of exposure (500 mSv).

The intervention measures required the mobilisation of the Guardia Civil traffic police, fire brigade, health services, consignors, carriers and CSN personnel.

From this event, classified as level 1 on the INES scale, several lessons were learned that led to the adoption of general actions in the field of emergency response and, in particular, during transport of radioactive material, among them:

- Systematise the reception of information on events at the CSN.
- Material improvement of the CSN's response resources and logistics.
- Increased CSN collaboration and support in the training of first responder organisations in a transport emergency.

33. Sum of the individual TIs of the packages.

- Consider immediate contact with consignors and transport companies as essential to support actions.
- Availability of regionalised CSN support units to reduce emergency response times.

IX.4.2. Incorrect handling of packages in 2004 in an airport terminal

The event occurred at around 7.45 a.m. on 20 July 2004, at Vitoria airport (Álava), and involved a consignment of five packages in transit from Brussels, bound for Seville. The transport was carried out by cargo aircraft.

The event occurred during the transfer process from the cargo terminal to the aircraft using a vehicle made up of several chained trolleys, a vehicle commonly used in the transfer of goods to and from aircraft.

Due to an excessive accumulation of goods on the trolleys, unsecured goods and the irregularities of the runway, four of the five radioactive packages fell onto the runway and were run over by the rear trolleys. The packages were scattered along about 50 metres of runway.

The four packages suffered varying degrees of damage, all of them to the outer packaging and two to the inner shielding container. In one of the packages, the innermost glass vial containing the radioactive material in liquid form was damaged. The radioactive material was released from the vial, but was absorbed by the sponge which, for this purpose, was part of the packaging and is placed between the vial and the shielding container.

All packages were of Type A, contained a maximum activity of 665 MBq of Iodine-123, were category II-Yellow and had a TI of 0.2 (a maximum of 2μSv/h at 1 metre from the surface of the package at the time of departure from the shipping facility).

The different phases of the emergency intervention involved the airport operator of the cargo airline and the Guardia Civil detachment at the airport, as well as the Technical Radiation Protection Unit of the sender of the consignment and the personnel of the CSN inspection commission in the Basque Country.

Measurements in the vicinity of the damaged packages detected a maximum of 0.5 μSv/h at a distance of 1 m from the packages.

There were no radiological consequences for people or the environment.

The damaged packages were conditioned and transferred to the radioactive facility of the consignor of the packages, where they were treated as waste after decay of the radioactive material.

The event was classified as level 0 on the INES scale. This event has been chosen as representative of the most common incidents occurring in airport terminals, as it is one of the most significant from the perspective of damage to packages.

Apart from the specific improvement actions taken by the airport operator following this event, including better conditioning of the cargo in the ramp transfer vehicles, considering the frequency of this type of event until 2004, the CSN took a number of general actions aimed at reducing this type of occurrence:

- Contacts were held with airport officials in order to analyse the usual conditions for the transfer of radioactive packages on the runway and to optimise the emergency measures foreseen at the airports to deal with this type of event.
- Inspections of the main airport operators were systematised, both on the ramp (ramp transfer) and in the cargo terminal warehouses. The main checks carried out in these inspections focus on:
  - The operational procedures followed in the handling of radioactive packages, including their transfer on the runway.
  - The Radiation Protection Programme of these entities, which, among other issues, should include a specific section on emergency response.
  - Staff training.

IX.4.3. Road accident in 2006 at Km. Marker 142 of the A-45

The accident was caused by a rear-end collision with other vehicles at around 6:00 a.m. on 12 July 2006, in an open field (without inhabitants) in a mountainous area of the province of Málaga.

The vehicle (between 1.5 and 3.5 MT) was carrying 22 Type A (categories II and III-Yellow) and Excepted packages containing different radioactive material, with a total activity of 0.25 TBq and a total TI of 8.8.

The transport had left Madrid and was scheduled to distribute radiopharmaceutical material from various consignors to different medical centres in Granada, Málaga and Almeria.

The driver was killed in the accident and the vehicle was seriously damaged. The packages suffered various types of damage and several of them escaped the confines of the vehicle.

There was significant damage to 3 packages, but no loss of shielding. Radioactive material was released from one of them, which contained a Mo/Tc generator, causing a very localised contamination

of about 400 cm^2 of roadside land. The maximum contamination[34] found was 60.1 Bq/cm^2, which was allowed to decay until the soil sample could be treated as conventional waste. There was no contamination of any person.

The intervention measures required the intervention of the Guardia Civil traffic police, health services, fire brigade, dispatchers, transporters and personnel from the CSN and its regional radiological intervention unit.

The packages and contaminated land were moved to a radioactive facility in Málaga which offered its support. There, a detailed inventory of the cargo was made and two packages were found to be missing. They returned to the scene of the incident and found the packages in the vicinity of the accident, hidden in the vegetation.

There was no radiological risk to human life. The only thing of note from a radiological perspective was the minor contamination of the ground.

The damaged packages were returned to the original facility for waste management.

From this event, classified as level 0 on the INES Scale, several lessons were learned that led to the adoption of general actions in the field of monitoring and control of radioactive material transport activities, including:

- Increased inspection and control actions related to subcontracting of transport companies.
- The vehicle used was a rental vehicle. It was identified that this practice, while not prevented by regulation, could lead to regulatory non-compliance. Consequently, checks were included in the CSN inspection procedure of the transport companies to analyse the extent of this practice and how the companies act in these cases to fully comply with regulatory requirements.
- It was determined that the emergency response organisation should prioritise the rapid inventory of transported packages to avoid losses at the scene of the event.
- Inclusion in CSN Instruction IS-34 of requirements for transport companies regarding the availability of persons and resources to provide assistance in the event of incidents during the transport of radioactive material.

IX.4.4. Deficiencies detected in 2008 in the packaging of various packages in transit at an airport

The event was detected on 7 November 2008 at Adolfo Suárez-Barajas airport in Madrid during a routine inspection by the airport's fire service at the cargo terminals.

34. Contamination is considered to be present if the value exceeds 0.4 Bq/cm2 for beta/gamma emitting radionuclides (paragraph 214 of IAEA SSR-6).

Abnormal dose rates were detected on the outside of three packages in international transit at the airport (values not in accordance with their labelling and transport documentation). The packages contained two Mo/Tc generators for medical applications, which were being transported between Argentina and the Dominican Republic.

Dose rates measured on the surface of the packages ranged from 1.3 to 1.9 mSv/h.

On the basis of the analysis performed following inspections by CSN personnel, it was confirmed that the consignor had used insufficient shielding on the packages and had not carried out adequate radiological surveillance on departure from its facilities.

Estimates of the doses due to the event, considering the entire route to Madrid airport and the most unfavourable conditions in the dose calculation, concluded that a dose to the public of 0.85 mSv occurred, which is below the annual dose limit for the public (1 mSv).

The CSN brought the event and the actions taken to the attention of the regulatory authority of Argentina, the country of origin of the shipment, with which it maintained close contact in monitoring the event.

The packages were transferred to an authorised Spanish radioactive facility and, after decay of the radioactive material, were sent to the consignor as Excepted packages.

This event, classified as level 1 on the INES scale, confirmed the importance of the coordination of the various national regulatory authorities in events occurring during the international transport of radioactive material. This early coordination has proven to be key in other events in the period under review, even if they were of lesser importance in terms of their causes and consequences.

According to the information provided by the consignor, the following measures were implemented as a result of the incident:

- Modification of training criteria for operational staff and an increase in the number of hours dedicated to training.
- Exclusive use of oversized shielding in Mo/Tc generators.
- Decrease of the transport index (TI) of the packages, increasing the time between the preparation of the package and its dispatch.

X. Trend analysis

X. Trend analysis

This chapter will analyse trends in the period between 2000 and 2020 for the events that have been identified in the previous chapters as most significant.

Firstly, it has been identified that the types of events with the highest incidence are due to traffic accidents (34%), incidents in airport terminals (22%), theft of packages (15%) and misplacement of packages (10%). In order to observe the trend of these events over the study period, figure 10.1 shows their 5-year moving average[3535] together with the trend associated with the overall trend of the 100 events occurring in that period.

The evolution of the overall trend shows an initial phase of continuous increase until 2008, when it reversed and began to decline. This decrease in the moving average was halted in 2016, which represents the year with the highest incidence in the study period, with 10 cases, double the average for the total period of analysis (5 events/year). This can be considered an isolated event and not representative of the trend, as the sudden increase was followed by a stabilisation at an average of 5 events/year.

The trend in road accident events behaves similarly to the overall trend during the first phase of growth, reaching a moving average of close to 3 events/year in the first decade of the 2000s. After this peak, there is a decrease and stabilisation around 1-2 events/year. The increase in traffic accidents in the first decade of the 2000s is due to a clear increase in the transport of diagnostic single doses from radiopharmacies and PET products from cyclotrons. The increase in this type of events, in addition to the operational doses associated with the transport of radiopharmaceuticals, was one of the reasons why the CSN considered inspections of this type of transport to be a priority, developing a systematic plan of periodic inspections of the main senders and carriers. Inspection action is considered to have contributed to the improvement in the development of these transport operations and thus to the reduction of road accidents despite the increase in radiopharmacy activities and the supply of PET products in the second decade of the 2000s.

The trend for events at airport terminals shows a clear decrease from 2005 onwards, from a moving average of 2-3 events/year to practically no cases in the first five years of the second decade of the 2000s. After this period, there was a one-off change in the trend with an increase in the moving average until 2017, at which point it decreased again and stabilised at 1 event/year. The clear decrease in the number of incidents at airport terminals as of the first five years from 2000 onwards is foreseeably due to the measures adopted by the airport operators as a result of the contacts maintained by the CSN with the airport authorities and to the increase in its inspection activities in relation to these activities.

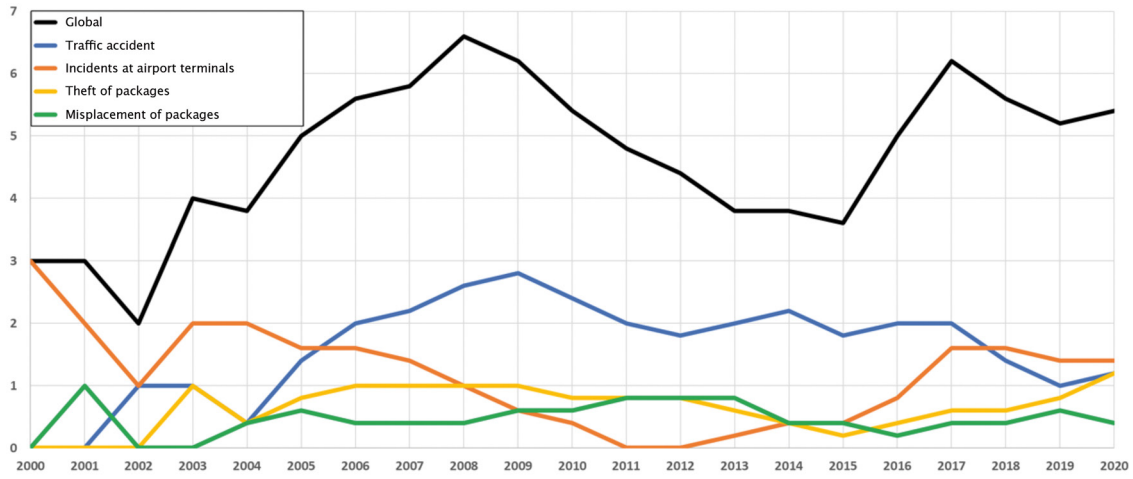
35. Moving average: an indicator that provides the average of a subset of data of a numerical series, in this case the number of annual events in 5-year subsets. Used to obtain a trend line, it has the advantage of being able to accommodate sharp variations in the values of the series without significantly impacting the evolution of the trend line.

With regard to theft and misplacement of packages, the trend has been stable, with a maximum in the moving average of 1 event/year.

From an overall perspective, besides the CSN's increased inspection activities regarding the activities during which most events occur, we may conclude that the CSN's development of specific regulatory standards has driven an improvement regarding not only the reduction of events, but also in relation to their management. In particular, it is worth noting:

- IS-34, published in 2012, which defines requirements in relation to the surveillance of cargo and vehicles during loading and unloading operations to try to prevent theft of radioactive packages, and to the availability of persons and means to assist in incidents during the transport of radioactive material.
- IS-42, regarding the criteria for reporting events during the transport of radioactive material to the CSN.

Figure 10.1. Trends of the most significant events in the period 2000-2020. 5-year moving average.



XI. Comparison with the international context

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To make this comparison, we will focus on a number of highly comprehensive studies carried out in two European countries, the UK and France, which may be considered to be good benchmarks since they undertake radioactive material transport activities similar to those conducted in Spain.

The larger population and the greater weight of the industrial sector in these countries leads to a higher volume of transport in the medical and industrial sector. In addition, the further development of its nuclear programme means an increased number of transport operations of fissile materials.

Although the total number of transport operations is higher in these countries and, consequently, the number of events, it is considered interesting to make the comparison not in terms of the number but in terms of the main characteristics of these events.

The studies to be used as a reference are:

- The one conducted by the UK Health Protection Agency (HPA) in 2006 [25], covering 46 years of activity (1958-2004). Although the data over this long period may be influenced by the evolution of the event reporting procedure and the development of the regulatory framework, the study provides very interesting global data and trends, which have been largely confirmed by analyses carried out in other countries.
- The one carried out by the Institut de Radioprotection et de Súreté Nucléaire (IRSN) in France [26], covering the period 1999-2011.

Regardless of the difference in the number of events between the two studies, which may be due to the total volume of transport operations in each country, the reporting procedures applied and the criteria for considering what is or is not an event, many of the findings of the IRSN study are in line with those of the HPA and confirm the trends.

The most salient findings of both studies are set out below:

- Most of the events occurred in transport related to the medical and industrial sectors.
- The majority of the events involved Excepted, Industrial and Type A packages. This is also consistent with the medical and industrial sector being the sector where these types of packages are most commonly used.
- Many events occurred during package handling processes, such as loading and unloading. In both studies, the number of events in cargo/unloading operations at airports is significant. Most of these incidents concern packages from the medical sector, which frequently uses the air mode for imports and exports of radiopharmaceuticals.

In the UK these events were prominent in the 1970s, but the trend was drastically reduced in subsequent years with the improvement of working procedures.

- The most affected mode of transport was road. This is also consistent with it being the most commonly used means of transport for the distribution of packages in the medical and industrial sector.
- In France, the vast majority of events were classified as level 0 on the INES scale (no safety significance), while 11% of reported events were classified as level 1 (anomaly) and only one event was classified as level 3 (serious incident).
- Of the 142 events classified in France at INES level 1 or higher, 97 occurred in the medical and industrial sectors and 44 in nuclear fuel cycle transport (only 6% of all events occurring in this sector). Most of the packages involved in level 1 and above events were Type A packages destined for the medical sector.
- In France, most of the INES level 1 or higher events were theft or misplacement of packages destined for the medical and industrial sector and damage to packages during loading/unloading operations (mainly at airports). In the UK, up to 14% of incidents involved misplaced or stolen packages.
- Although the UK study does not include the INES classification, the radiological consequences of the events are analysed:
  - In 63% the packages were not significantly damaged and in 90% there was no loss of shielding or containment. As a result, the radiological consequences were not appreciable (66% of events had no radiological consequences and 30% had very low radiological consequences).
  - The events with the greatest consequences occurred in the industrial gammagraphy sector (mainly around the 1970s), but in most cases the transport event is actually a consequence of a previous event in the gammagraphy operation (incorrect retraction of the radioactive source to the equipment).

In addition to these two detailed studies carried out in the UK and France, at the European level there is the study carried out by the European Commission in 1990, which covers the period from 1975 to 1986 [27]. Although the study itself acknowledges a great variability in the information provided by the different countries that participated in the analysis, the most significant conclusions coincide with those highlighted above in the HPA and IRSN analyses, with the following general ones standing out:

- Most of the events concern the transport of Excepted, Industrial and Type A packages destined for the medical and industrial sectors, which use the road mode.
- None of the reported events resulted in serious consequences for people due to the radioactive nature of the transported material.
- In none of the events was there evidence that the packages meeting the requirements of the transport regulations did not provide sufficient protection in the accident conditions.
- The number of events is low compared to the number of transport operations carried out.

In view of the conclusions of these international studies and the results of the analyses contained in this document for the events occurring in Spain between 2000 and 2020, it can be seen that the overall picture is similar, i.e. there is a clear similarity in the type of frequent events, the type of materials and packages involved and the sectors most affected, as well as in the severity of these events, whether based on their INES classification or on their consequences.

All in all, the number of events and their severity is low compared to the number of shipments, confirming that the international regulatory framework for the transport of radioactive material functions adequately and sufficiently ensures the safety of the activity.

XII. Conclusions

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As a result of the analysis of events occurring during transport of radioactive material in Spain between 2000 and 2020, the following general conclusions can be drawn:

- Over 100,000 radioactive material transport operations are carried out annually in Spain, most of them for the medical and industrial sector, using Type A and Excepted packages, in line with the international context.

- The most commonly used modes of transport are road, air and multimodal air/road.

- A total of 100 events have occurred, giving an overall average of about 5 events per year in the analysis period.

- Considering the estimated annual shipments of radioactive material in Spain, the incidence of events is less than 1 event per 20,000 transport operations.

- The transfer (movement from one location to another) is the transport phase in which most events occur, although the loading, unloading and package (cargo) handling phase are also noteworthy.

- The most frequent events are traffic accidents (34%), with an average value of about 2 events/year. They are followed by incidents occurring during the handling of radioactive packages in airport terminals (22%), around 1 event/year, and thefts (15%) and misplaced packages (10%), which between them also represent an average of approximately one per year.

- Most of the events involve Type A packages carrying radiopharmaceuticals. This means that the medical sector suffers the highest incidence, with the predominance of events during the road transport phase as a result of rear-end accidents between vehicles.

- In the air mode, loading, unloading, transfer on the runway and handling of packages in the warehouses of airport cargo terminals are the processes where most events occur due to incorrect handling or misplacement of packages. Normally, the affected packages are also destined for the medical sector.

- The vast majority of road mode events involve light vehicles (less than 1.5 MT), usually used for the transport of radiopharmaceuticals and mobile radioactive equipment for industrial application. There are hardly any events involving large vehicles (over 3.5 MT), usually used in nuclear fuel cycle related transport operations.

- Almost all package thefts occur in parked road vehicles, either by the theft of the packages or of the vehicle itself, and usually involve radioactive equipment used in industrial activities, mainly density and soil moisture measuring equipment.

- The number of events in the nuclear fuel cycle and in radioactive waste management is very small, less than 10% of the total in the analysis period.

- In the entire period under review, there was only one event linked to physical protection.

- 35% of the events occurred during one of the phases of international transport (departure from, destination or transit in Spain).

- No event has exceeded level 1 (anomaly) according to the IAEA INES scale criteria, 76% being classified as level 0 (no safety significance/below scale).

- Most of the events classified as level 1 in INES are thefts during road transport of industrially applied radioactive equipment and misplacements during airport handling, with no subsequent recovery of the packages.

- Most traffic accidents and airport terminal incidents have been classified as level 0 on the INES scale.

- The average number of events involving damage to cargo was two per year (conservatively including those in which the packages were not recovered after theft or misplacement and it could not be verified whether damage had actually occurred). In most of them, only a single package has been affected.

- Virtually all cargo damage events involved packages (Type A and Excepted) carrying radiopharmaceuticals.

- The majority of cargo damage events occur in cargo terminal incidents at airports and in traffic accidents involving light road vehicles.

- The conveyance (a road vehicle in every case) was damaged in 34% of the events. Of these, 73% were light vehicles, typically used for the transport of radiopharmaceuticals and mobile radioactive equipment for industrial applications.

- In most of the events involving damage to the transport vehicle, there was no damage to the cargo.

- For packages not subject to design approval (Excepted, Industrial, Type A), for which the regulations do not require tests simulating accident conditions to be passed, their performance in a severe accident often exceeds regulatory expectations. This implies that the graded approach to packaging requirements is proving effective as a tool for ensuring the safety of package contents.

- In none of the events was there any harm to persons as a result of irradiation or contamination, and the values of doses received remained below the annual dose limits for workers classified as exposed or for the public, as established in the Regulation on health protection against ionising radiation.

- Only two of the 100 events involved a significant exposure of people (always with doses below the regulatory limits) and a third one involved a slight contamination of an area outside a nuclear or radioactive facility.

- A comparison of the results of the analysis of the events in Spain with other relevant studies carried out at the international level shows a similar scenario, both in terms of the characteristics and the consequences of the events. These studies show that the number of events and their seriousness is low compared to the number of shipments, which confirms that the international regulatory framework for the transport of radioactive material, which is applied in Spain, functions adequately and sufficiently guarantees the safety of the activity

As regards the regulatory action carried out by the CSN during the period under analysis, the following may be underlined:

- The analysis of the events has made it possible to draw lessons learned from which the CSN and the main players involved in transport have implemented improvement actions in areas such as emergency response, personnel training, inspection and control tasks and regulatory development.

- The increase in traffic accidents in the first decade of the 2000s, due to the increase of the transport of diagnostic single doses from radiopharmacies and PET products from cyclotrons, in addition to the operational doses associated with the transport of radiopharmaceuticals, has led the CSN to consider the monitoring and control of this type of transport to be a priority. Despite the increase in radiopharmacy activities and supply of PET products, there has been a reduction in events in the second decade of the 2000s.

- A clear decrease in incidents at airport terminals was observed as from 2005, when the airport operators began to adopt specific measures as a result of the contacts maintained by the CSN with the airport authorities. Likewise, the decrease coincides with the increase in the CSN's inspection activities in relation to these activities.

- From an overall perspective, besides the CSN's increased inspection activities regarding the activities during which most events occur, we may conclude that the CSN's development of specific regulatory standards has led to a reduction in events and improved their management.

- The *Transport Management* database used at the CSN, considered a good practice in the final report of the IRRS mission carried out by the IAEA in Spain in 2018, constitutes a vital tool for the management of all regulatory activities related to the transport of radioactive material, including the management of events.

- Ultimately, the systematic analysis of events and the implementation of regulatory actions in the field of supervision, control and regulatory development, based on the lessons learned from these analyses, have clearly helped to safeguard safety in the radioactive material transport sector.

XIII. References

XIII. References

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Analysis of events occurring during transport of radioactive material in Spain from 2000 to 2020

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