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Authors	**Philippe Bertreix, Thomas Frosio (CERN), David Viertel (CHUV), Clive Naidoo, Mikael Jensen (DTU), Ulli Köster (ILL), Thomas Elias Cocolios (KULeuven);**
Reviewer	**Jerzy Wojnarowicz (NCBJ), Pil Fredericia (DTU)**

Point of Contact	**Mikael Jensen**
Institution	**DTU**
E-mail	**kmje@dtu.dk**
Phone	**(+45) 26255890**

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Contents

Abbreviations, Participant short names

Abbreviations

ADR	Accord Dangereux Routier , the regulations concerning the transport of dangerous goods by road
IAEA	International Atomic Energy Agency, Vienna
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation

Participant short names

CERN	European organization for nuclear research
NPL	National Physical Laboratory
PSI	Paul Scherrer Institut
CEA	Commissariat à l'énergie atomique et aux énergies alternatives
IST-ID	Associação do Instituto Superior Técnico para a IST-ID Investigação e Desenvolvimento
DTU	Danmarks Tekniske Universitet
CHUV	Centre hospitalier universitaire vaudois
GANIL	Grand Accélérateur National d'Ions Lourds
SCK CEN	Studiecentrum voor Kernenergie / Centre d'étude de l'énergie nucléaire
ARRONAX	Groupement d'intérêt public ARRONAX
ESS	European spallation source ERIC
TUM	Klinikum rechts der Isar der technischen Universität München
KULeuven	Katholieke Universiteit Leuven
MedAustron	Entwicklungs- und Betriebsgesellschaft MedAustron GmbH
SCIPROM	SCIPROM Sàrl
MUI	Medizinische Universität Innsbruck
ILL	Institut Max von Laue - Paul Langevin
JRC	JRC -Joint Research Centre- European Commission
NCBJ	Narodowe Centrum Badań Jądrowych
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH
LU	Latvijas Universitāte
INFN	Istituto Nazionale di Fisica Nucleare
UiO	Universitetet i Oslo

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Definitions

A_1 and A_2	A_1 means the activity value of special form radioactive material which is listed in Table 2.2.7.7.2.1 and is used to determine the activity limits for the requirements of ADR. A_2 means the activity value of radioactive material, other than special form radioactive material, which is listed in Table 2.2.7.7.2.1 and is used to determine the activity limits for the requirements of ADR.
Consignment	Any package or packages, or load of dangerous goods, presented by a consignor for carriage.
Consignor	The enterprise, which consigns dangerous goods either on its own behalf or for a third party. If the transport operation is carried out under a contract for carriage, consignor means the consignor according to the contract for carriage.
Conveyance	A carriage by road or by air, a vehicle or an aircraft.
Dangerous goods	Those substances and articles the carriage of which is prohibited by ADR/ICAO, or authorized only under the conditions prescribed therein.
Exempted packages and excepted packages	In the transport of PRISMAP radionuclides we will often be able to use the less stringent transport requirements that allows for transport of limited amounts of radioactive material in what are called exempted or excepted packages. It is important not to confuse these words. In the context of radioactive transports special care should be taken with semantics. Words that appear like synonyms in colloquial language, e.g. exempt and excepted, may have very different meanings in radioactive transport regulations. Let us take the example of gasoline/petrol, which in large quantities is definitively a "dangerous good". During transport the containing vessel and transporting vehicle has to be marked with orange UN1203 labels, the driver has to follow a special ADR education and carry specific equipment to mitigate risks in case of an accident or incident. However, smaller quantities of the same substance contained in the tank of a car or in a portable jerrycan may be transported without special labelling, without special ADR education and without specific equipment because these smaller quantities are considered "excepted". Finally, a Zippo lighter contains really tiny amounts of gasoline/petrol and can be taken nearly everywhere (except in the hand luggage of certain airlines). Such a quantity would be considered "exempt". Similarly, for radioactivity very low activities are considered "exempt". For example, a typical banana contains about 15 Bq of K-40 activity (contained in traces in natural potassium) and it would make no sense to declare bananas as radioactive goods. The exemption limits for different radionuclides are given in the rightmost columns of Table 2 and Table 3. The next higher level is an "excepted quantity package". This one may contain more activity up to a given fraction (1E-4 to 1E-3 of A_2, depending on physical state, see Table 4). Such packages need to be labelled as UN2910 (provided the surface dose rate remains below 5 µSv/h), but can be transported with much less constraints than type A (UN2915) packages. Also, empty containers that did contain radioactivity previously are considered "excepted". They are labelled as UN2908 and may be transported with few constraints, just as UN2910 packages.
Exclusive use	The sole use, by a single consignor, of a vehicle or of a large container, in respect of which all initial, intermediate and final loading and unloading is carried out in accordance with the directions of the consignor or consignee. Exclusive use is imposed when the dose rate and/or transport index of a package exceeds certain limits, namely (> 2 mSv/h at surface) or TI (>10). We underline that "exclusive use" is a specific term of the ADR/IATA transport regulations. It should not be misunderstood in the colloquial sense. Hence, transports may well contain only one or few packages from a single conveyor to a single destination, but such a transport would NOT be called "exclusive use" in the ADR sense, unless this is IMPOSED by the dose rate (> 2 mSv/h at surface) or TI (>10).
Overpack	An enclosure used (by a single consignor in the case of radioactive material) to contain one or more packages, consolidated into a single unit easier to handle and stow during carriage.
Radioactive material	Defined in the context of transportation means any material containing radionuclides (whether natural or artificial) and where the activity and the activity concentrations exceeds some very low numerical limits depending on the specific radionuclide and defined in the IAEA publication SSR6 (rev.1). Most or all of the PRISMAP transports will be above these limits and therefore defined as containing radioactive material.

Special form radioactive material	Either an indispersible solid radioactive material or a sealed capsule containing radioactive material, fulfilling some tight regulations on minimum size and the integrity. It is mainly used to describe, “sealed radioactive sources” and the designation is not seen as relevant for any PRISMAP transports.
Transport index (TI)	A single number assigned to a package or an overpack which is used to provide control over radiation exposure. It is the maximum dose rate in µSv/hr at 1 m from the external surface of the package divided by 10 and rounded up to the first decimal place (for example, 1.13 becomes 1.2), except that a value of 0.05 or less may be considered as zero and the resulting number is the TI value.
United Nations (UN) number	A UN number that is allocated to all the different kinds of transported dangerous materials (among which radioactive materials are included). This number is frequently required to be provided on transport documents. A few of the UN numbers are listed below (others may be obtained from IAEA Safety Standards SSR-6 (Rev. 1)): UN2908 - Radioactive material - excepted packages, Empty packaging UN 2910 - Radioactive material - excepted package, Limited quantity of material. UN 2915 - Radioactive material, Type A package non-special form

Summary

This report is the first public output from the PRISMAP work package 9 (WP9, transport and logistics). The report describes in outline the existing rules and means of transport (primarily air and road) and how these rules and their implementation induce important constraints on the optimal distribution of novel radionuclides within the network. Based on input from the project partners and the analysis of the most urgent transportation needs arising from the first round of user projects, the report describes important bottlenecks for the efficient and reliable transport of novel radionuclides.

It is eventually the aim of the WP9 to work with project partners, industry and regulators to alleviate these problems, partly by exploring novel and more efficient transport solutions, partly by transfer of knowledge of transports and logistics from more experienced partners to less experienced. Future deliverables will focus on such result.

1. Introduction

The medical use of open radioactive sources (radioactive material) for diagnosis and therapy has traditionally relied heavily on transport of the radionuclide and/or the relevant radioactive compound from the point of production (typically reactors or accelerators) to the point of use (typically departments of nuclear medicine in major hospitals). The recent spread of PET imaging procedures has given some hospitals local production capacity for some diagnostic radionuclides but also expanded the need for transportation, when small hospitals with cyclotrons must supply other hospitals, typically on a daily basis. Nuclides for SPECT imaging and nuclides for therapy are still almost universally needing transportation to the user.

Such necessary transport is complicated by two facts: the radioactivity is characterized as dangerous goods, requiring special packages, carriers and documentation. The inherent physical decay of the radioactivity restricts the time available for transport. Over decades, a specialized transportation system has been developed by the radionuclide and radiopharmaceutical industry, but it has proven difficult for the specialized producers of the novel PRISMAP radionuclides to utilize such distribution channels effectively.

This report summarises a number of these shortcomings.

1.1 Justification

Transport: An important aim of PRISMAP is to facilitate the European research community's access to important new medical radionuclides. Production and purification apart, it is also important to facilitate the timely and efficient exchange of radionuclides, radioactive intermediates and radiopharmaceuticals between the partners, industry and hospitals. Existing transport mechanisms need to be optimised for new, less known radionuclides often with short half-life and delivered in less regular schedule. The transport mechanisms should be disseminated as guidelines, training protocols and best practices.

PRISMAP in WP1-TNA1, WP2-TNA2, and WP3-TNA3, namely the European medical isotope programme platform, the radionuclide production and dispatch, and their radiochemical processing and use in medical research will benefit from the collaborative research developed in the four JRAs. In WP9-JRA1, transport and shipping, first the mapping of present and future needs (including the mass separation steps) and the perceived shortcomings of existing transport channels will be investigated. The aim is to establish a commonly useful transportation system for air and road transport of radioactivity between partners. For this purpose, we will investigate, train, and test for the use of small aircrafts in point-to-point transport of the radioactive material from regional airports. We will also establish a common, easily applicable set of rules and guidelines allowing the easy and swift transport within Europe of non-standard, developmental, preclinical and early clinical radionuclides. This will be accompanied with the publication of new A_1/A_2 isotope activity transport parameters defined in the UN regulation to classify packaging technologies for dangerous goods, and endorsed by IAEA. This will result in faster and more efficient shipping processes across the consortium and to the end-users of the research community.

2. IAEA rules: The guidelines for safe transport of radioactive material

The regulations are part of a complex scheme of international committees' decisions. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) provides reports on effects of exposure to ionizing radiations. Based on those reports, the International Commission on Radiological Protection (ICRP) proposes policies as recommendations ("best practices"). Those recommendations are used by the International Atomic Energy Agency to draft the Safety Standards. The safety standards are produced and reviewed by the IAEA secretariat. In particular, for radioactive shipments, the TRANSSC (TRANSport Safety Standard Committee) is responsible to oversee the redaction of the Regulations for the safe transport of radioactive material (IAEA SSR-6 [1]). IAEA member states nominate experts that are providing comments on standards documents. At the end of this chain, national regulatory authorities adopt the IAEA policy (e.g. ADR in Europe).

The IAEA regulations, drawn up by the International Atomic Energy Agency, must be adhered to at all times, as well as national regulations when radioactive material is being transported nationally or internationally. The scope of this document is not intended to be comprehensive, but aims to summarise and supplement the IAEA transport regulations.

The IAEA regulations are detailed and implemented by designated international bodies into specific rules for each transport modality (road/air/sea). For PRISMAP, the road and air transports are the most important. The hierocratic order of the different set of rules is illustrated in Figure 1.

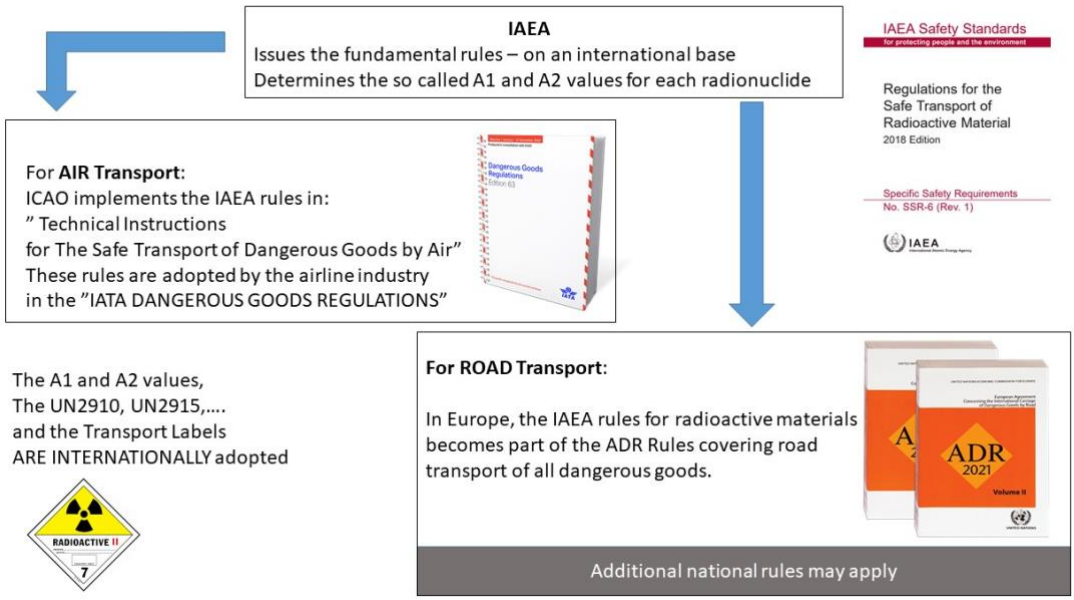

Figure 1. The most important transport rules and their relationship

2.1 The Concept of A1 and A2 limits and the implementation for PRISMAP Radionuclides

Radioactive material produced by PRISMAP shall be assigned one of the United Nations (UN) numbers as specified in Table 1. The decision flowchart is provided below in Figure 2.

Table 1. Excerpts from the list of UN numbers, proper shipping names and description

Assignment of UN numbers	Proper shipping name and description
Excepted package	
UN 2908	RADIOACTIVE MATERIAL, EXCEPTED PACKAGE — EMPTY PACKAGING
UN 2910	RADIOACTIVE MATERIAL, EXCEPTED PACKAGE — LIMITED QUANTITY OF MATERIAL
Type A package	
UN 2915	RADIOACTIVE MATERIAL, TYPE A PACKAGE, non-special form, non-fissile or fissile-excepted
Type B(U) package	
UN 2916	RADIOACTIVE MATERIAL, TYPE B(U) PACKAGE, non-fissile or fissile-excepted

We note that many more UN codes exist, e.g. for fissile materials (233U, 235U, 239Pu, 241Pu) for low-specific activity materials (e.g. radioactivity containing ores or low activity nuclear waste) or for "special form" (e.g. sealed sources for radiography or irradiators). However, these are not relevant for open radionuclides or radiopharmaceuticals employed in nuclear medicine or related research.

2.1.1 Basic Radionuclide Values

The following basic values for individual radionuclides are provided in the Table 2 (page 21 ff.) in the public and freely available IAEA Safety standard: "Regulations for the Safe Transport of Radioactive Material", SSR-6 (rev. 1)[1]:

a) A_1 and A_2 in TBq;

b) Activity concentration limits for exempt material in Bq/g; (not relevant for PRISMAP radionuclides activity concentrations)

c) Activity limits for exempt consignments in Bq.

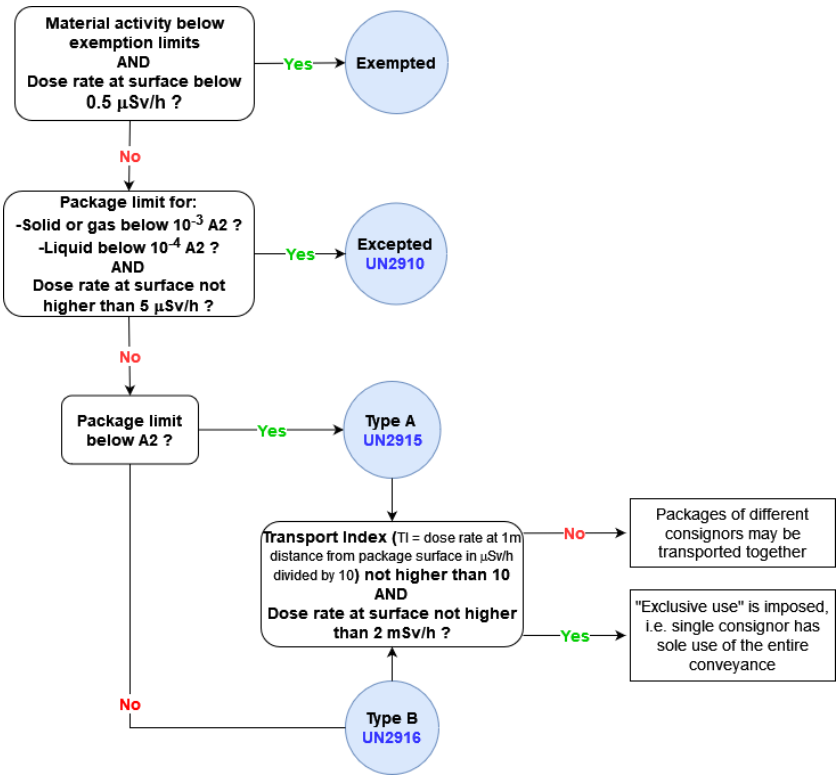

Figure 2. Simplified decision flowchart for package classification relevant for PRISMAP

2.1.2 The Determination of Basic Radionuclide Values

2.1.2.1 For individual radionuclides

a) That are not listed in the in the SSR6 table 2, the determination of the basic radionuclide values shall require multilateral approval. For these radionuclides, A_1, A_2, activity concentrations for exempt material and activity limits for exempt consignments shall be calculated according to the Q-System [2]. Alternatively, the radionuclide values in Table 2 may be used without obtaining competent authority approval. The current regulation contains 392 radionuclides A_1/A_2 values. For radionuclides not in the regulation, using Table 2 might be very conservative. The special Working Group of IAEA TRANSSC is responsible for the review of the new regulation. The new regulation will include a set of 1252 radionuclides A_1/A_2 values [3][4] based on ICRP-107 nuclear decay data [5] and ICPR-116 conversion coefficients [6][7][8]. In case of PRISMAP requirements for radionuclides not in the regulation, specific requests might be sent to IAEA in order to obtain A_1/A_2 values for PRISMAP's radionuclides of interest before the release of the new regulation.

[1] https://www.iaea.org/publications/12288/regulations-for-the-safe-transport-of-radioactive-material

b) In instruments or articles in which the radioactive material is enclosed in or is included as a component part of the instrument or other manufactured article, alternative basic radionuclide values to those in the SSR6 table 2 for the activity limit for an exempt consignment are permitted and shall require multilateral approval.

In the calculations of A_1 and A_2 for a radionuclide not listed in the SSR6 table 2, a single radioactive decay chain in which the radionuclides are present in their naturally occurring proportions, and in which no progeny nuclide has a half-life either longer than 10 days or longer than that of the parent nuclide, shall be considered as a single radionuclide; and the activity to be taken into account and the A_1 or A_2 value to be applied shall be that corresponding to the parent nuclide of that chain. In the case of radioactive decay chains in which any progeny nuclide has a half-life either longer than 10 days or longer than that of the parent nuclide, the parent and such progeny nuclides shall be considered as mixtures of different nuclides. For mixtures of radionuclides, the basic radionuclide values referred to may be determined as follows:

$$X_m = 1 / \sum_i \frac{f(i)}{X(i)}$$

where

f(i) is the fraction of activity or activity concentration of radionuclide in the mixture.

X(i) is the appropriate value of A_1 or A_2, or the activity concentration limit for exempt material or the activity limit for an exempt consignment as appropriate for radionuclide i.

X_m is the derived value of A_1 or A_2, or the activity concentration limit for exempt material or the activity limit for an exempt consignment in the case of a mixture.

When the identity of each radionuclide is known but the individual activities of some of the radionuclides are not known, the radionuclides may be grouped and the lowest radionuclide value, as appropriate for the radionuclides in each group, may be used in applying the aforementioned formula. Groups may be based on the total alpha activity and the total beta/gamma activity, when these are known, using the lowest radionuclide values for the alpha emitters or beta/gamma emitters, respectively. For individual radionuclides or for mixtures of radionuclides for which relevant data are not available, the values shown in Table 2 shall be used. Basic radionuclide values for some PRISMAP Day 1 Radionuclides are shown in Table 3.

Table 2. Basic radionuclide values for unknown radionuclides and mixtures

Radioactive content	A_1 (TBq)	A_2 (TBq)	Activity limit for an exempt consignment (Bq)
Only beta or gamma emitting nuclides are known to be present	0.1	0.02	1×10^4
Alpha emitting nuclides, but no neutron emitters are known to be present	0.2	9 × 10−5	1×10^3
Neutron emitting nuclides are known to be present or no relevant data are available	0.001	9 × 10−5	1×10^3

Table 3. Basic radionuclide values for some PRISMAP "Day 1"-Radionuclides

Radionuclide	A_1 (TBq)	A_2 (TBq)	Activity limit for an exempt consignment (Bq)
Ac-225	8×10^{-1}	6×10^{-3}	1×10^4
At-211	2×10^{1}	5×10^{-1}	1×10^7
Ag-111	2×10^{0}	6×10^{-1}	1×10^6
Cu-64	6×10^{0}	1×10^{0}	1×10^6
Cu-67	1×10^{1}	7×10^{-1}	1×10^6
Er-169	4×10^{1}	1×10^{0}	1×10^7
Sc-44	5×10^{-1}	5×10^{-1}	1×10^5
Sc-47	1×10^{1}	7×10^{-1}	1.0×10^6
Sm-153	9×10^{0}	6×10^{-1}	1×10^6
Tb-149	8×10^{-1}	8×10^{-1}	1×10^6
Tb-161	3×10^{1}	7×10^{-1}	1×10^6

2.1.2.2 The importance of basic radionuclide values

Radionuclides for which no individual basic radionuclide values are listed in the IAEA tables have to be transported based on the generic values for "unknown radionuclides" shown in Table 2.

In particular, today the generic A_2 value of 20 GBq applies for the following beta or gamma emitting radionuclides that are of potential medical interest: As-71, Ce-134, Er-165, La-133, La-135, Nd-140, Sc-43, Sc-44m, Tb-152, Tb-155, Tm-165, Xe-129m. The value of 20 GBq is at present sufficient for the typical activity levels exchanged between different PRISMAP facilities or between producers and hospitals in a Type A package (UN2915). However, later upscaling to larger activities might require dedicated basic radionuclide values for such nuclides to avoid unnecessary Type B transports (UN2916) that do require specific container types and a more lengthy packing and testing procedure before dispatch.

In the past no dedicated A_2 value existed for Tb-161 and the initial developments were performed with transports from high flux reactors to the radiochemical separation at Paul Scherrer Institut restricted to activities <20 GBq [9]. In 2018 a new dedicated A_2 value of 700 GBq was published by IAEA and this value entered the ADR and IATA tables in 2021. Now work on upscaling the produced batch activities can proceed without this transport restriction.

For alpha emitters the low generic A_2 value of only 90 MBq is far more penalizing in practice. Again, it was a terbium isotope where the activities initially produced at CERN had to be limited to allow shipment as Type A package (UN2915) to PSI for further processing and use: the initial works with Tb-149 used activities below

90 MBq at time of shipment from CERN [10]. In 2012 a basic radionuclide value was estimated for Tb-149 and got approval for national transports by the Swiss authorities. Later, in 2018 a new dedicated A_2 value of 800 GBq was published by IAEA and this value entered the ADR and IATA tables in 2021. Now work on upscaling the produced batch activities can proceed without this transport restriction.

Other alpha emitters that would profit of dedicated calculated A_2 values are Rn-211 that is potentially useful as At-211 generator as well as Es-254, Es-255 and Fm-255 where the former is irradiated in a high flux reactor to produce Es-255 that can serve in turn as generator for Fm-255.

We note that even before novel radionuclides are produced at activity levels exceeding the generic A_2 values, dedicated calculated A_2 values would still be useful to avoid unnecessary upgrades from UN2910 to UN2915 classification when transporting small activities (< 1E-3 A_2 in solid form or < 1E-4 A_2 in liquid form) for initial R&D purposes.

2.2 The Concept of Packages – Excepted, Type A and Type B, UN numbers

Although some of the requirements for the different types of packages are specified in the IAEA regulations, conveyors are encouraged to use approved containers wherever possible. There are rules and requirements on how to construct and test the various package types, but in most cases it can be more efficient to buy already approved transport containers a transport container supplier.

To determine the requirements for the transport of radioactive materials the following questions must be answered sequentially:

1) What type of package/container should be used?
2) Do I have subsidiary risks, such as toxicity, biological risk or cryogen?
3) Is my container tested and certified for the physical form I have (solid / liquid / gas)
4) Will it be transported by air and/or road and what will the requirements be during transport?
5) How should the container and vehicle be marked, labelled and placard?
6) What are the consignor's responsibilities?

The three most common types of packages or containers commonly used are the "excepted" package, the Type A package, and the Type B package.

2.2.1 General requirements for all packages.

All containers or packages shall comply with the following general requirements:

(i) The package design shall be such that it can be easily handled, transported and secured during transport.

(ii) External surfaces shall be free from protruding features for easy decontamination.

(iii) The outer packaging shall prevent, as far as possible, the retention of water.

(iv) Features added to the package during transport shall not reduce its safety.

(v) The package and its closing devices shall not be affected under conditions it would most likely experience during transport.

(vi) The materials of the package shall be physically and chemically compatible with each other and with the radioactive contents.

(vii) Other dangerous properties of contents such as explosiveness, flammability, pyrophoricity, chemical toxicity and corrosiveness, shall be taken into account.

2.2.2 Requirements for excepted packages

(i) The package must meet the aforementioned general requirements for all packages.

(ii) The dose rates on the external surface of the package shall not exceed 5 µSv/h. There are specific rules for excepted packages containing “instruments and articles" but these are not relevant to PRISMAP transports.

(iii) Excepted packages may contain radioactive material in forms other than as specified in the previous paragraph, with an activity not exceeding the limits specified in column 4 of Table 3, provided that:

a) the packages retain their contents under conditions likely to be encountered in routine transport;

b) the packages bear the marking "RADIOACTIVE" on an internal surface in such a manner that a warning of the presence of radioactive material is visible on the opening of the package.

(iv) For transport by post, some countries allow that the total activity in each excepted package does not exceed one tenth of the relevant limits specified in Table 4. However, in most countries it is forbidden.

Table 4. Activity limits for excepted packages

Physical State of Contents	Package Limits
Liquids	$10^{-4}A_2$
Solids	$10^{-3}A_2$

2.2.3 Requirements for Type A packages

Radioactive material in quantities, which represent a limited radiation risk, may be carried in a Type A package, which shall be designed to withstand normal conditions of transport. The source containers incorporated in nuclear gauges are often certified as Type A containers, so that many gauges can be transported as is. Where this is not the case, the users must provide their own container. Containers that would typically meet Type A-standards are strong metal containers, hardened plastic containers, hardened cardboard boxes. Type A containers do not require the specific approval of the competent authority, but it is the responsibility of the consignor to have the proper documentation certifying the Type A package, and ensure that it uses a container which would comply with the requirements listed below and with the prescriptions edited by the designer/manufacturer for the use of the Type A package (physical form of the content, restriction in radionuclides or activity, etc.). "There are several suppliers of certified type A containers. Popular designs are made for regional transport of F-18 radiopharmaceuticals and are made with 30-40 mm tungsten or lead shielding. These containers are expensive and require return of empty package after decay and/or contamination check. For some of the PRISMAP radionuclides for therapeutic use, much less shielding is necessary and smaller, single use shields and packages may be used. Below is shown how the A_1 and A_2 values can be used to justify when a Type A Package certified for one radionuclide and activity can be used for other radionuclides. Typically, such packages are available from the well-known manufacturers of hot cell equipment for nuclear medicine and radiopharmacy.
Table 3 should be consulted when a decision must be made as to whether radioactive material may be transported in a Type A package or not, as there are limits on the activity which may be transported in such a package. If the radioactive material is in special form, up to an activity of A_1 may be transported in a Type A package, and if the material is not in special form (usual situation for nuclear medicine sources), an activity not exceeding A_2 may be transported in such a package.

Type A packages must comply with the following requirements:

(i) The package shall meet the aforementioned general requirements for all packages

(ii) The smallest overall external dimension of the Type A package shall not be less than 10 cm.

(iii) The outside of the Type A package shall incorporate a feature such as a seal, which is not readily breakable and which, while intact, will be evidence that it has not been opened.

(iv) Tie-down attachments shall under all conditions not impair the ability of the package to meet the requirements of the competent authority.

(v) Package design shall take into account temperatures ranging from -40 °C to 70 °C.

(vi) The package shall include a containment system, which cannot be opened unintentionally.

(vii) If the containment system forms a separate unit of the package, it shall be capable of being securely closed by a positive fastening device, which is independent of any other part of the packaging.

(viii) The containment system shall retain its radioactive contents under a reduction of ambient pressure to 60 kPa (for air transports a differential pressure of 95 kPa).

(ix) All openings, e.g. exit channels, valves, etc., shall be closed to retain leakage.

(x) Packages containing liquids shall:

a) have absorbent material to absorb twice the volume of the liquid material;

b) shall make provision for ullage to accommodate variations in temperature, dynamic effects and filling dynamics.

(xi) Type A packages should also be able to withstand a number of tests. These tests are well described in the IAEA Safety Series 6 and include a water spray test, a free drop test, a stacking test and a penetration test.

(xii) If the contents are special form radioactive material, and exceed the A_2 activity limit, competent authority approval of the design for the special form radioactive material is required.

(xiii) The package shall be designed in such a way that, under normal conditions of transport, it shall prevent loss or dispersal of the radioactive contents, and loss of shielding integrity, which would result in more than a 20% increase in the dose rate on any external surface.

(xiv) For air transport there may be additional tests required.

2.2.4 Requirements for Type B packages

Where Type A activity limits are exceeded, approved Type B containers/packages may be used. A Type B container is a specially designed and approved container, constructed to withstand both normal and accidental conditions of transport. The requirements and tests to which these packages are subjected, are much more severe than those for Type A packages. The limit on the total activity in a Type B package is as prescribed in the design approval certificate for that package.

2.3 Risk of spread and need for shielding

Requirements during transportation

2.3.1 Segregation during transport and during storage in transit

(i) Radioactive material shall be segregated sufficiently from transport workers and from members of the public. For the purpose only of calculating segregation distances or dose rates in regularly occupied areas, different limiting values for dose shall be required:

a) For transport workers a dose level of 5 mSv per year shall be used as the limiting value.

b) For members of the public a dose level of not more than 1 mSv per year to the critical group shall be used as the limiting value.

(ii) Radioactive material shall be segregated from undeveloped photographic film so that the radiation exposure of the film is limited to 0,1 mSv per consignment of such film.

(iii) Categories II-YELLOW or III-YELLOW packages (Table 5) shall not be carried in compartments occupied by passengers except for exclusively authorised personnel. This requirement is discussed further in the later section on the possible use of small fixed wing aircrafts.

(iv) The number of category II-YELLOW and category III-YELLOW packages, overpacks, tanks and freight containers stored in any one area shall be so limited that the total sum of the transport indices in any individual group of such packages does not exceed 50. Groups of such packages shall be stored to maintain a spacing of at least 6 m from other groups of such packages (fissile materials). There may be additional regulations for the storage of fissile material.

(v) Only articles or documents, which are necessary for the use of radioactive material, are permitted in the package provided that there is no interaction between them and the packaging or its contents that would reduce the safety of the package. Other items may not be transported in packages.

(vi) Mixing of packages of different kinds of radioactive material, including fissile material and mixing of packages with different indexes (TI's) is permitted.

(vii) Consignments shall be segregated from other dangerous goods.

2.3.2 Additional requirements related to rail and road

(i) Vehicles or railroad carriages carrying packages with category I-WHITE, II-YELLOW and III-YELLOW transport labels shall display radiation-warning signs. Vehicles carrying excepted packages need not be so marked.

(ii) No persons other than the driver and assistants shall be permitted in vehicles carrying packages bearing category II-YELLOW or III-YELLOW labels.

(iii) The dose rate at any normally occupied position shall be documented not to exceed 0,02 mSv/h unless the persons occupying such positions are provided with personal monitoring devices.

2.3.3 Additional requirements relating to transport by air

(i) There are additional restrictions for air transport of Type B containers, that are not mentioned here.

(ii) Packages having a surface dose rate greater than 2 mSv/h shall not be transported by air except by special arrangement.

(iii) This is not an exhaustive list of restrictions for air transport.

2.3.4 Post

A consignment that conforms to the requirements of excepted packages, in which the activity of the radioactive contents does not exceed one tenth of the limits prescribed in Table 4 may be accepted for domestic movement by some national postal authorities, subject to such additional requirements as those authorities may prescribe. This possibility is not generally available and is not foreseen for PRISMAP transports.

2.3.5 Maximum dose rates (with exclusive and without exclusive use)

The dose rates shall not exceed (except under exclusive use):

(i) 0.1 mSv/h at 1 m from the external surface of the package.

(ii) 2 mSv/h on the external surface of the package.

If the package is transported under exclusive use, the dose rates shall not exceed 10 mSv/h on the external surface of the package.

The dose rates may exceed 2 mSv/h but be less than 10 mSv/h on an external surface only under the following circumstances:

(i) If transported under exclusive use by road provided that:

a) the vehicle is equipped with an enclosure to prevent unauthorized access during transport;

b) the package or overpack is secured to retain its position within the enclosure during transport; c. there are no loading and unloading operations between the beginning and end of the shipment.

(ii) If transported by air provided that:

a) the package is transported under exclusive use; and

b) the transport takes place by special arrangement.

(iii) If transported by vessel (i.e. by sea) provided that:

a) the package is transported under exclusive use; or

b) the transport takes place by special arrangement.

Contamination and decontamination on packages, freight containers, tanks and overpacks

(i) Contamination levels shall be kept as low as reasonably possible and shall not exceed the values specified below

a) Beta & gamma emitters and low toxicity alpha emitters: 4 Bq/cm2

b) Alpha emitters: other than those of low toxicity: 0.4 Bq/cm2

(ii) Conveyances, equipment or parts thereof, which have become contaminated, shall be decontaminated as soon as possible and in any case before re-use.

(iii) Packages, used for the transport of radioactive material shall not be used for the storage or transport of other goods.

2.4 Typical elements of package design, approval of packages

The "excepted" package, the Type A package, and the Type B package must demonstrate compliance with the IAEA prescribed performance standards before usage. The outer cases of the packages can be made of hardened plastic containers, cardboard boxes or metal drums as shown in Figure 3.

Type A package

Type B(U) package

Figure 3. Different types of Type A and Type B packages

2.5 Need for quality system for shipping

A management system based on international, national or other standards acceptable to the competent authority shall be established and implemented for all activities within the scope of to ensure compliance with the relevant provisions as prescribed by SSR-6 [1], ADR [11], IATA [12] and IMDG[13] Certification that the design specification has been fully implemented shall be available to the competent authority. The manufacturer, consignor or user shall be prepared:

a) To provide facilities for inspection during manufacture and use; and

b) To demonstrate compliance with SSR-6, ADR, IATA and IMDG, to the competent authority.

Where competent authority approval is required, such approval shall take into account and be contingent upon the adequacy of the management system.

Special arrangement shall mean those provisions, approved by the competent authority, under which consignments which do not satisfy all the requirements of SSR-6, ADR, IATA and IMDG applicable to radioactive material may be transported.

Note: Special arrangement is not considered to be a temporary derogation.

Consignments for which conformity with any provision applicable to radioactive material is impracticable shall not be transported except under special arrangement. Provided the competent authority is satisfied that conformity with the radioactive material provisions of SSR-6, ADR, IATA and IMDG, is impracticable and that the requisite standards of safety established by SSR-6, ADR, IATA and IMDG have been demonstrated through alternative means the competent authority may approve special arrangement transport operations for single or a planned series of multiple consignments. The overall level of safety in carriage shall be at least equivalent to that which would be provided if all the applicable requirements had been met. For international consignments of this type, multilateral approval shall be required.

2.5.1 Transport documents

(iii) Approval must be obtained from the competent authority to transport radioactive materials. Normally when an application is received to possess and use radioactive materials the competent authority

automatically grants a "convey" and "cause to convey" authority. This gives the holder authority to transport the radioactive material himself, or to make use of a conveyor to transport it on his behalf.

(iv) The transport documents shall:

a) reflect all the information viz. activity, TI, type of label, type of radioactive material, etc., which appears on the labels on the package;

b) contain the words "RADIOACTIVE MATERIAL";

c) describe actions, if any, that are required from the carrier;

d) contain details of procedures to be followed in the event of an emergency.

(v) Where transport documents refer to a "class or division of dangerous goods", the class must be specified as "7". If a UN number is requested, the appropriate number must be specified.

2.5.2 Consignor's responsibility

The consignor (entity presenting package for transport) shall undertake and be responsible for the following:

(i) He shall ensure that the transport documents are correctly completed.

(ii) He shall ensure that the package is in a proper condition for transport and is in agreement with

the transport requirements specified in the latest edition of IAEA Safety Series no. 6.

2.6 Transport Labels and Transport index

Labelling and marking of packages, freight containers, tanks and overpacks (Figure 4):

Completed I-WHITE or II-YELLOW or III-YELLOW labels with the contents described (with the name of the radionuclide, or for mixtures, the names of the most restrictive nuclides) shall be affixed externally to two opposite sides of packages and to all four sides of tanks.

(i) Each label shall be marked with the maximum activity of the radioactive contents during transport.

(ii) Each II-YELLOW or III-YELLOW label shall be marked with the TI for that package.

(iii) Packages with a gross mass exceeding 50 kg shall be legibly and durably marked with their permissible gross mass on the outside.

(iv) Packages shall be legibly and durably marked on the outside with the word "TYPE A" or "TYPE B(U)", or whatever is applicable.

(v) Packages containing materials having additional dangerous properties (e.g. acids, cryogens, biohazard materials) shall also be labelled as required by other relevant transport regulations.

(i) Labels are not mandatory of UN2910 – Excepted packages. Only "UN2910" mark is mandatory for such classification.

Table 5. Categories of packages

Transport index (TI)	Maximum dose rate (H) at any point on the external surface	Category
0	5 µSv/h ≥ H	I-WHITE
0<TI≤1	5 µSv/h < H ≤ 0.5 mSv/h	II-YELLOW
1<TI≤10	0.5 mSv/h < H ≤ 2 mSv/h	III-YELLOW
TI>10	2 mSv/h < H ≤ 10 mSv/h	III-YELLOW and exclusive use

The *Transport index (TI)* is a single number assigned to a package and used to provide control over radiation exposure. It is the maximum dose rate in µSv/hr at 1 m from the external surface of the package divided by 10 and rounded up to the first decimal place (for example, 1.13 becomes 1.2), except that a value of 0.05 or less may be considered as zero and the resulting number is the TI value.

For a package, overpack or freight container, the TI and the surface dose rate conditions shall be taken into account in determining which category is appropriate. Where the TI satisfies the condition for one category, but the surface dose rate satisfies the condition for a different category, the package, overpack or freight container shall be assigned to the higher category. For this purpose, category I-WHITE shall be regarded as the lowest category.

Figure 4. Different types of radioactive labels

Placards on vehicles, freight containers and tanks

(i) Placards shall be affixed in a vertical orientation:

  a) to the two external walls of a rail vehicle;

  b) to the two external lateral walls and the external rear wall of a road vehicle; and

  c) to the two external side walls and the two external end walls of a freight container or tank; alternatively, enlarged labels may be used.

(ii) The appropriate UN Number shall be displayed on all four sides of the freight container.

(iii) Any placards that do not relate to the contents shall be removed.

(iv) Placards may be required for other dangerous properties of the contents.

(v) An emergency telephone number along with the name of a person to be contacted in the event of an accident shall be displayed on all placards.

3. Road Transport

3.1 ADR

ADR is the agreement concerning international transport of Dangerous Goods by Road (ADR) (the ADR document is referenced in this document).

The objective of ADR is to establish requirements that shall be satisfied to ensure safety and to protect persons, property and the environment from the effects of radiation in the carriage of radioactive material.

This protection is achieved by requiring:

a) Containment of the radioactive contents;

b) Control of external dose rates;

c) Prevention of criticality; and

d) Prevention of damage caused by heat.

These requirements are satisfied firstly by applying a graded approach to content limits for packages and vehicles and to performance standards applied to package designs depending upon the hazard of the radioactive contents. Secondly, they are satisfied by imposing conditions on the design and operation of packages and on the maintenance of packaging, including a consideration of the nature of the radioactive contents. Finally, they are satisfied by requiring administrative controls including, where appropriate, approval by competent authorities.

ADR applies to the carriage of radioactive material by road including carriage which is incidental to the use of the radioactive material. Carriage 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 including in transit storage, unloading and receipt at the final destination of loads of radioactive material and packages. A graded approach is applied to the performance standards in ADR that are characterized by three general severity levels:

a) Routine conditions of carriage (incident free);

b) Normal conditions of carriage (minor mishaps);

c) Accident conditions of carriage.

3.2 Class 7 approved companies and drivers

Applications and approvals for radioactive material carriage and shipment shall include:

a) The period of time, related to the shipment, for which the approval is sought;

b) The actual radioactive contents, the expected modes of carriage, the type of vehicle, and the probable or proposed route; and

c) The details of how the precautions and administrative or operational controls, referred to in the certificate of approval for the package design are put into effect.

Drivers of vehicles carrying dangerous goods shall hold a certificate issued by the competent authority stating that they have participated in a training course and passed an examination on the particular requirements that have to be met during carriage of dangerous goods. Drivers of vehicles carrying dangerous goods of Class 7 shall attend, in addition, a specialised training course.

3.3 National rules

A transport unit loaded with dangerous goods may in no case include more than one trailer (or semi-trailer). In addition to the documents required under other regulations, the following documents shall be carried on the transport unit:

a) The transport documents prescribed in 5.4.1 (ADR), covering all the dangerous goods carried and, when appropriate, the large container or vehicle packing certificate prescribed in 5.4.2 (ADR);

b) The instructions in writing prescribed in 5.4.3 (ADR);

c) Means of identification, which include a photograph, for each member of the vehicle crew, in accordance with 1.10.1.4 (ADR).

3.4 National restrictions (restricted number of approved carriers)

The entry of dangerous goods into the territory of Contracting Parties may be subject to regulations or prohibitions imposed for reasons other than safety during carriage. Such regulations or prohibitions shall be published in an appropriate form.

Before the first shipment of any package requiring competent authority approval, the consignor shall ensure that copies of each applicable competent authority certificate applying to that package design have been submitted to the competent authority of the country of origin of the shipment and to the competent authority of each country through or into which the consignment is to be carried. The consignor is not required to send a separate notification if the required information has been included in the application for approval of shipment.

The consignors shall have in their possession a copy of a certificate required for each shipment before making any shipment.

3.5 Tunnel restrictions

Some road tunnels have specific restrictions for the passage of dangerous goods, including in some cases radioactive shipments.

The tunnel itself has a given **Tunnel Category,** ranking A to E. The E category is the most restrictive. The same tunnel may be assigned to more than one tunnel category, e.g. depending on the hours of the day, or the day of the week etc.

The dangerous goods are assigned different **Tunnel Restriction Codes,** also ranking A to E. These codes belongs to the material or goods (UN number). The sender has to provide this information on the transport certificate together with the UN number and proper shipping name. The details of how the restriction codes are derived is defined in the ADR regulations.

Tunnel restriction codes need not be added in the transport document where the carriage is known beforehand not to pass through a tunnel with restrictions for carriage of dangerous goods.

Of relevance to PRISMAP transports are mainly the UN2910 (radioactive material limited quantity) and UN2915 (radioactive material, Type A package). The tunnel restriction code for both of these types of shipments is both E. This means that tunnels with categories A,B,C and D can be passed, while tunnels category E are closed to such transports.

The list below of important road tunnels in Europe is based on available public information as per April 2022. Tunnel categories may change depending on local or national decisions.

- Øresund (Denmark-Sweden) is category B at night (19:00-06:00) and D by day (06:00-19:00), i.e. always open for UN2910 and UN2915.
- Elbtunnel (Germany, on motorway A7 around Hamburg) is category E from 05:00 to 23:00, and category C by night 23:00 to 05:00, i.e. UN2910, 2915 can only pass during night only.
- Euro Tunnel (France-England) has special restrictions and Dangerous Goods transports should be registered with the Eurotunnel first. UN2190 is then allowed, while the condition for UN2915 is stated as “only for manufactured goods”.
- Mont Blanc Tunnel (France – Italy) is category E and therefore closed for UN2910, UN2915.
- Fréjus Tunnel (France – Italy) is category C, but special escorts may be required for dangerous good transports.
- Gotthard Tunnel (Switzerland, North-South transit through the Alps) is category E, but special permits can be requested from ASTRA to traverse this tunnel with radioactive goods

3.6 Transport certificate

Each certificate of approval issued by a competent authority shall be assigned an identification mark.

The identification mark shall be of the following generalized type: *VRI/Number/Type Code*

a) Except as provided in 6.4.23.12 (ADR referenced document) (b), VRI represents the distinguishing sign used on vehicles in international road traffic 1;

b) The number shall be assigned by the competent authority, and shall be unique and specific with regard to the particular design, shipment, or alternative activity limit for exempt consignment. The identification mark of the approval of shipment shall be clearly related to the identification mark of the approval of design;

c) The following type codes shall be used in the order listed to indicate the types of certificate of approval issued:
   - B(U): Type B(U) package design
   - T: Shipment
   - X: Special arrangement
   - AL: Alternative activity limits for an exempt consignment of instruments or articles

d) For certificates of approval of package design and special form radioactive material, other than those issued under the transitional provisions of 1.6.6.2 to 1.6.6.4, and for low dispersible radioactive material, the symbols "-96" shall be added to the type code (ADR).

4. Air Transport

4.1 IATA / ICAO

The International Civil Aviation Organisation (ICAO) Technical Instructions at government level and the International Air Transport Association (IATA) Dangerous Goods Regulations (DGR) at the industry level regulate international transport of dangerous goods by air. Since IATA DGR has included all ICAO technical instructions for dangerous goods, it is generally acknowledged that compliance with the IATA Dangerous Goods Regulations will result in compliance with the ICAO Technical Instructions. If products are classified as dangerous goods and shipped by air, compliance with the provisions in the ICAO are required.

The broad principles governing the international transport of dangerous goods by air are contained in Annex 18 to the Convention on International Civil Aviation —The Safe Transport of Dangerous Goods by Air. The Technical Instructions amplify the basic provisions of Annex 18 and contain all the detailed instructions necessary for the safe international transport of dangerous goods by air.

Dangerous goods are carried regularly and routinely by air all over the world. To ensure they do not put an aircraft and its occupants at risk, there are international standard systems that ensure governmental control over the carriage of dangerous goods by air and give worldwide harmonization of safety standards.

4.2 Shippers Declaration

Under all dangerous goods regulations, the shipper has the responsibility to correctly describe dangerous goods on shipping paper. The critical shipping paper must be maintained for a given period (3 months to 2 years), depending upon the method of shipment. There are already many good guides on how to fill in dangerous goods shipping paper.

As a minimum requirement, the following information needs to appear on dangerous goods shipping paper.
- UN identification number and proper shipping name (including technical name and additional information)
- Hazard class number (including subsidiary class)
- Packing group (PG I, PG II or PG III)
- Type of packages (including the no. of packages)
- Quantity of dangerous goods in each type of package

- Shipper and consignee's name and contact info
- Emergency telephone number
- Signed declaration/certification by shipper

4.3 Dangerous Goods Management Services

DGM (Dangerous Goods Management Group) is a leading international organization acknowledged as experts in dangerous goods and hazardous materials. Founded in 1987, DGM develops comprehensive dangerous goods solutions to a large variety of customers of all sectors and industries (logistics, chemical, oil and gas, energy, freight forwarders, air, road, maritime transport companies).

DGM activities are performed in accordance with the global quality & safety requirements and standards:

- Health, Safety, and Quality (HSQ) Standards
- Dangerous Goods Regulations ICAO/IATA DGR, 49 CFR, IMO-IMDG, ADR and RID
- Other compliance requirements (local regulations, customers policies)

DGM has branches in many major cities in the world that are listed at www.dgm.world

These aforementioned companies can assist with the following:

- *Classification and identification of Dangerous Goods* - When dangerous goods are involved, their right classification is the first step to manage them safely. These companies can assist with Material Safety Data Sheet preparation or classification according to UN criteria.
- *Packing & Repacking of Shipments* - Most incidents or accidents in the past were caused by an inappropriate use of packing. Technical specialists can assist with ensuring that packing requirements are completely fulfilled when the package is presented to the operator for shipment.
- *Labelling & Marking of Shipments* - They take care of all labelling and marking to meet compliance requirements in accordance with the Regulations.
- *Documenting* - Technical specialists complete and sign the Dangerous Goods Declaration (DGD) for transport according to regulations (IATA-DGR, ADR, IMDG, RID or multimodal).
- *Assuming all Legal Responsibilities* - The company can assume responsibilities and liabilities related to the safe transportation of dangerous goods. In addition, the company will carry a global comprehensive liability insurance policy in case of an accident or incident.

4.4 Cargo aircraft / Passenger Aircraft

Transport index limits for radioactive freight on aircrafts are limited as shown in Table 6.

Table 6. Transport index limits for freight containers and conveyances not under exclusive use

Type of freight container or conveyance	Limit on sum of TIs in a freight container or aboard a conveyance
Aircraft: Passenger	50
Aircraft: Cargo	200

Small aircrafts (lower than 50 seaters) are used to transport radioactive consignments but these are limited by lower accumulated Transport index of <50 because of a reduced distance between passengers and radioactive consignments. The infrequency of these flights to smaller countries or remote locations is also a limiting factor and the time of the transport from radionuclide supplier to smaller countries can be a challenge.

4.5 Priority of shipment ("Urgent Medical Goods, -Do Not Delay")

Airlines and authorities work hard to balance end user needs for radioactive medicals and the medicals' short transport period with what they deem to be the maximum allowable risk for Dangerous Goods transport of

radioactive consignments by air. Not all airlines agree on what that maximum risk is. Some airlines will carry radioactive medical goods on any flight where there is space and aircraft limitations allow; others only carry radioactive cargo onboard cargo planes. Yet others will not carry them at all.

Over the years, numerous challenges of transporting medical radionuclides have been encountered:

1) Aircrafts carrying perishable fruit and vegetables or animals (cats and dogs) receives higher priority than medical radionuclides.
2) The pilot in command of a commercial aircraft always has the right to refuse any cargo or passenger for transport on his aircraft.
3) An individual airline has the option to completely refuse carriage of certain types of cargo (e.g., radioactive material); this has occurred with some air carriers.
4) An individual airline may choose to impose specific and additional requirements before it will accept radioactive material consignments.
5) Many airline pilots and other airline employees have insufficient knowledge regarding radioactive material consignments and their resulting fears may lead to their refusal to handle or carry this cargo.

4.6 Problems of carrier change (road-air-road)

It must be noted that numerous challenges can be encountered at air cargo handling areas:

1) Cargo handlers operating under the guidance of airlines implement additional requirements for radioactive consignments such as extending quarantine times before cargo is loaded onto the aircraft. This can be a problem with short-lived radionuclides.
2) Cargo handlers refuse consignments based on unauthorised package design.
3) Cargo handlers in some smaller countries are not too familiar with the regulations of dispatching/receiving radioactive cargo, which results in delays.
4) Quarantines times at cargo handling terminals require at least 2-3 hours before consignment is loaded onto aircraft, a big challenge for short-lived radionuclides.
5) Releasing the consignment at destination arrivals can take 1-2 hours before it is released to courier companies, again a challenge for short-lived radionuclides.
6) Transportation documentation is misplaced when in the possession of cargo handlers and especially when connecting flights are involved.

To counteract the above challenges:

1) Generally, pre-booking with airlines for transportation of radioactive consignments is critical.
2) Ensure duplication of transportation documentation is in place in case of connecting flights.
3) Ensure where possible connecting flights are with the same airline.
4) Ensure transportation documentation is correctly completed (use the recommended Dangerous Goods Checklist).
5) Ensure shipping containers have the required signage (labels).
6) Continued education and training of air cargo handlers and pilots on the conveyance regulations of radioactive consignments is encouraged.

4.7 Use of Courier Company

Identify a reputable courier company that can handle radioactive consignments in the network of countries of interest is critical. Generally, the competent authority in the particular country has an approved list of courier companies that are authorised to handle and convey Class 7 Radioactive Material. These companies are well equipped with transporting radioactive material by road and as well as working with the authorised airlines to transport radioactive consignments by air. They will understand the best and quickest transport routes together with frequency and related costs.

The Radionuclide Producer should have good working relationship with the courier company to ensure an efficient and effective service is possible. The Radionuclide Producer representative and the courier company representative should have 24/7 two-way communication channel to ensure any logistic eventualities are dealt with as quickly as possible. An online airline cargo tracking system should be in place. Continued education (tutorial documentation) with airlines/pilots/cargo handlers (radioactive) on the importance of medical radionuclides in healthcare is an important requirement and the courier company together with the Radionuclide Producer can play a vital role in implementing this.

4.8 Courier services / Restrictions / Door-to-door transport

It is critical to identify licenced courier companies that understand the transportation of medical radionuclides. A good understanding of the customer group that includes hospitals and radionuclide producers that require a regular and timeous delivery is a critical requirement. By virtue of the permissions of the courier company, they should transport radioactive substances according to all relevant transport regulations and in this way ensure the safe and sound transport of radionuclides at all times. The courier company should have an effective quality assurance programme to address all the regulation needs of the competent authority, which includes the safe transport, transfer of the radioactive shipment and security against theft and fire. The courier company should also ensure unauthorized persons never comes in contact with these radioactive shipments.

PRISMAP WP9 aims to develop a comprehensive list of courier companies that are able to convey radioactive material, handle customs clearances and deliver door-to-door as this is very limited across many European countries. Some of the courier companies that specialise in the transport of radioactive material may be sourced from the relevant competent authority of the particular country.

4.9 Small, fixed wing aircraft

In cases where the total transport time from production to the user becomes a limitation, alternatives to conventional air transport should be explored. It is often the time spent in road transport to and from major passenger and/or cargo airports as well as the check in/check out time that constitutes the longest part of planned air transport. It should be investigated when it is possible to find smaller airports in closer vicinity of sender and receiver sites. While such airfields are not served by regular flight services, it is possible to imagine that small, fixed wing aircraft could do the radioactive transports as point-to-point dedicated services.

This transportation scheme has been successfully tested on a number of occasions by the use of commercial business jet aircraft. As example it has been possible to routinely supply special F-18 products (half-life 110 minutes) from Hevesy Lab in Denmark to sites in Norway and southern Germany.

Several both regulatory and practical aspects of such schemes must be investigated, also by dialogue with the various regulating bodies:

1) Are there requirements to the size of the aircraft?
2) Does the aircraft always have to be certified for night/bad weather flights?
3) What Dangerous Goods training and certification will be required for pilots?

4) How can rules about transport in segregated compartment be handed for the smallest aircrafts, that often only have a single cabin, or even just the cockpit.

If the questions can be resolved, the point to point fixed wing transport scheme could become a fast alternative to the conventional transport.

5. Maritime shipments of radioactive material

Important regulations for maritime transports of radioactive material (shipments of hazardous cargo) by sea are written down in the IMDG code [13] (International Maritime code for Dangerous Goods) published by the International Maritime Organization (IMO). There are a limited number of carriers available worldwide who are willing to accept radioactive material and with the majority of carriers only accepting non-fissile material on board of vessels.

Most often, the shipment of PRISMAP radionuclides by sea transports will be too slow for the purpose. The use of ferry lines for carrying road transports is however an exception. Most ferry lines in regular schedule will under some closer defined conditions and against surcharges accept dangerous goods carried on board vans or trucks. The rules vary widely with the ferry lines, but the most often seen conditions are:

1) The shipment must comply not only with the ADR rules, but also the maritime IMDG code.
2) Radioactive material transports should be preregistered and accepted for a given crossing.
3) The transport must be checked in well before the departure.
4) It is normally only a subset of all ships and departures in operation on a given line that will handle the radioactive transports. For this reason, the total transport time involving a crossing with ferry may be much longer than the driving time.

Examples of ferries that have been used for carrying road transports across important water-way shortcuts is the crossing between Sweden and Finland and some of the crossings between Denmark and Sweden and Denmark and Germany. Also ferry transport across the English Channel of vehicles with radioactive UN2915 and UN2910 parcels is possible, but again with time restrictions.

6. Additional Risks

In addition to the radioactive and fissile properties, any other dangerous properties of the contents of the package, such as explosiveness, flammability, pyrophoricity, chemical toxicity and corrosiveness, shall be taken into account in the packing, labelling, marking, placarding, storage and transport in order to be in compliance with the relevant transport regulations for dangerous goods of each of the countries through or into which the materials will be transported, and, where applicable, with the regulations of the cognizant transport organizations, as well as these Regulations.

7. Customs Documents - value of shipment-delivery terms

Customs operations involving the inspection of the radioactive contents of a package shall be carried out only in a place where adequate means of controlling radiation exposure are provided and in the presence of competent authority. Any package opened on customs instructions shall, before being forwarded to the consignee, be restored to its original condition. Where a consignment is undeliverable, it shall be placed in a safe location and the appropriate competent authority shall be informed as soon as possible and a request made for instructions on further action.

Retention and availability of transport documents by carriers.

A carrier shall not accept a consignment for transport unless:

a) A copy of the transport document and other documents or information as required by these Regulations are provided; or

b) The information applicable to the consignment is provided in electronic form.

The information applicable to the consignment shall accompany the consignment to its final destination. This information may be on the transport document or may be on another document. This information shall be given to the consignee when the consignment is delivered.

When the information applicable to the consignment is given to the carrier in electronic form, the information shall be available to the carrier at all times during transport to the consignment's final destination.

The information shall be able to be produced without delay in a printed form. The carrier shall retain a copy of the transport document and additional information and documentation, as specified in these Regulations, for a minimum period of three months.

When the documents are kept electronically or in a computer system, the carrier shall be capable of reproducing them in a printed form.

When international shipments are made, it is mandatory to submit a copy of an invoice together with the shipment. This invoice is necessary to process customs formalities, and may be submitted well in advance of actual transport. However, such invoice must state the value of the product shipped.

We remind that PRISMAP will mainly supply research isotopes, which do not have a countable commercial value. It is proposed that the PRISMAP shipments will state only the elemental costs of contents, not the sum of all preparatory operations. As example, a shipment of mass-separated radioactive ions -implanted into a gold foil could be made just stating the weight of gold and the gold commercial market value, but not the cost of running a mass separator for the purpose.

An important mission of the PRISMAP WP9 is also to clarify some of the more technical terms used in shipping documents. A universally used set of trading conditions is outlined in the so-called INCOTERMS that describe in great detail the responsibilities of supplier and receiver of a given delivery. For PRISMAP it is important to notice the difference between the often-used terms DDU and DDP.

DDU Stands for "delivered, duty unpaid". In this scheme some handling agent capable of taking over the customs and duty liability must be available at the first import point in the receiving country (typically a major airline hub). If no such agent is clearly identified beforehand, serious delays can occur.

DDP stands for "delivered, duty paid". This scheme will put mores costs and require more detailed knowledge of customs formalities in the country of destiny from the sender.

8. Example of transport schemes in place for "Day-1" radionuclides from PSI-DTU-ILL-CERN

Based on the first PRISMAP user project requests received we analysed challenges and solutions to provide the required radionuclides in a timely manner. The requested radionuclides are listed in Table 7 with their half-life, the producing PRISMAP-WP2 facility and the requested country of use (user lab or PRISMAP-WP3 facility respectively). The typical duration of road transport is compared with the half-life and durations exceeding one half-life, i.e. that would lead to more than 50% loss of the initial activity, are highlighted in red.

Bi-213 is extremely short-lived and cannot be transported efficiently over large distances. Instead, the shipment of a Ac-225/Bi-213 generator should be considered where the required Bi-213 can be eluted on-site from the longer-lived mother nuclide.

Although planes are faster than cars it appears that often road transport will be overall faster. A specific example is transport of At-211 from ARRONAX (Nantes) to Belgium. At present Nantes airport (NTE) does not handle radioactive parcels and there are no direct scheduled flights from Nantes (NTE) to Brussels (BRU), hence an additional delay during stopover would need to be considered. Air transport from Paris (CDG) to Brussels (BRU) would be slower than direct road transport to Belgium

Table 7. Radionuclides requested in the first call for PRISMAP user projects (March 2022)

Nuclide	$T_{1/2}$ (d)	Producer	Country of use or *WP3 lab*	Road transport (d)	Transport	Airports for scheduled air transport
Bi-213	0.02	JRC	BE	0.2	Road	
Tb-149	0.2	CERN	*TUM*	0.3	Road (or small plane)	
Tb-149	0.2	CERN	DE	0.3	Road (or small plane)	
At-211	0.3	Arronax	BE	0.3	Road	
At-211	0.3	Arronax	BE	0.3	Road (or small plane)	
Er-165	0.4	DTU	FR	0.3	Road	
Tb-152	0.7	CERN	*TUM*	0.3	Road	
Tm-165	1.3	CERN	FR	0.2	Road	
Pt-195m	4	ILL	PL	0.7	Road or scheduled plane	CDG-WAW
Tb-155	5	CERN	FR	0.2	Road	
Tb-155	5	CERN	DE	0.3	Road	
Tb-161	7	PSI/SCK/NCBJ	TR	No	Plane	ZRH-IST, BRU-IST, WAW-IST
Tb-161	7	PSI	IT	0.2	Road	
Tb-161	7	PSI	*TUM*	0.2	Road	
Tb-161	7	PSI/SCK/NCBJ	FR	0.2 / 0.3 / 0.7	Road or scheduled plane (only NCBJ)	WAW-CDG
Tb-161	7	PSI	DE	0.2	Road	
Tb-161	7	PSI	DE	0.2	Road	
Ac-225	10	JRC	BE	0.2	Road	
Pd-103	17	ILL	PL	0.7	Road or scheduled plane	CDG-WAW

The transport of short-lived Tb-149 from CERN (Geneva) to the PRISMAP-WP3 lab TUM (Munich) or other remote locations is inherently challenging and so is the production of higher activities of Tb-149. Thus, large

decay losses during transport cannot be compensated by producing initially more. Wherever possible experiments with Tb-149 should rather be performed at the PRISMAP-WP3 facility AGORA in Lausanne that can be reached from CERN in less than 1 hour per road.

Transport of Tb-161 from PSI towards Italy will most likely pass through a major tunnel (at least during winter, when the mountain passes are closed) and might require special permits.

9. Conclusions

All the Day-1 radionuclide production facilities already have experience with transport of radioactive materials, and they can by existing methods reach WP3 facilities more or less rapidly.

The problems at present mainly lie with the short half-life isotopes with half-lives less than 1 day. Here, even conventional air transport will lead to significant, perhaps even prohibitive decay losses, because of the combined delays in the connecting road transports and the now necessary check-in / check-out procedures. An additional problem arises from the vulnerability of such transports to delay far beyond the planned time. Reasons can be many: road congestion, airport congestion, delays in dangerous goods clearing, denied or delayed boarding of the radioactive transports to passenger planes (where airlines will often prioritize different from our PRISMAP needs), cancelled flights and bad weather.

Some of the delays can to some part be prevented by better procedures and better contact and understanding between the shipping laboratories and the carriers. It is the intention during PRISMAP WP9 to develop as set of simple-to-use packaging and shipping instructions that can help prevent common errors in preparing packages and shipping documents.

Additional gains may be made through a dialogue with selected airlines that can commit to priority handling of our PRISMAP shipments. Similar, it will be tried to make existing international courier services interested in serving our needs. This will however both require high-level business decisions in the courier sectors as well as time for implementation. If such schemes are to work, many drivers, handlers and cargo agents will need to be additionally trained in radioactive transports.

However, none of the above proposals can solve all the time-and reliability issues. Under this background, that the possible use of small fixed-wing aircrafts for point-to-point services between local airports/airfields shall be further investigated. This will require a further clarification of rules and procedures for such small aircraft transports.

Some of these steps will require help from both national and international regulators. One of the important points is the assignment of official A_1 and A_2 values to several potential PRISMAP radionuclides that have at present only the low and perhaps limiting default A_1 and A_2 values.

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