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Safe transport of radioactive materials — Leakage testing on packages

Sûreté des transports de matières radioactives — Contrôle d'étanchéité des colis

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 12807 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 5, *Nuclear fuel technology*.

Annexes A to F of this International Standard are for information only.

Introduction

The International Atomic Energy Agency (IAEA) Safety Series No. 6, Regulations for the Safe Transport of Radioactive Material (reference [1] in annex F) specify permitted release of radioactivity under normal and accidental conditions of transport, in terms of activity per unit of time, for Type B packaging used to transport radioactive materials. Generally, it is not practical to measure activity release directly. The usual method used is to relate activity release to non-radioactive fluid leakage, for which several leakage test procedures are available. The appropriate procedure will depend on its sensitivity and its application to a specific package.

This International Standard specifies gas leakage test criteria and test methods for demonstrating that packages used to transport radioactive materials comply with the package containment requirements defined in reference [1] of annex F for:

— design verification,

— fabrication verification,

— preshipment verification,

— periodic verification.

The regulations specify permissible activity release for normal and accidental conditions of transport. These activity release limits can be expressed in maximum permissible activity release rates for the radioactive material carried within a containment system.

In general, it is not feasible to demonstrate that the activity release limits are not exceeded by direct measurement of activity release. In practice, the most common method to prove that a containment system provides adequate containment is to carry out an equivalent gas leakage rate test.

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Safe transport of radioactive materials — Leakage testing on packages

1 Scope

This International Standard describes a method for relating permissible activity release rates of the radioactive contents carried within a containment system to equivalent gas leakage rates under specified test conditions. This approach is called gas leakage test methodology. However, in this International Standard it is recognized that other methodologies might be acceptable.

When other methodologies are to be used, it shall be shown that the methodology demonstrates that any release of the radioactive contents will not exceed the regulatory requirements. The use of any alternative methodology shall be by agreement with the competent authority.

This International Standard provides both overall and detailed guidance on the complex relationships between an equivalent gas leakage test and a permissible activity release rate. Whereas the overall guidance is universally agreed upon, the use of the detailed guidance shall be agreed upon with the competent authority during the Type B package certification process.

It should be noted that, for a given package, demonstration of compliance is not limited to a single methodology.

While this International Standard does not require particular gas leakage test procedures, it does present minimum requirements for any test that is to be used. It is the responsibility of the package designer or consignor to estimate or determine the maximum permissible release rate of radioactivity to the environment and to select appropriate leakage test procedures that have adequate sensitivity.

This International Standard pertains specifically to Type B packages for which the regulatory containment requirements are specified explicitly.

2 Definitions, symbols and units

2.1 Definitions

Terms defined in this International Standard have the same meaning as those used in the applicable documents mentioned in clause 3. However, some of these definitions have been adapted particularly for the purpose of this International Standard and might not conform to those in other publications.

2.1.1 accidental conditions of transport: Conditions used in the applicable documents listed in clause 3.

2.1.2 activity release rate: Loss of radioactive contents per unit time through leaks or permeable walls of a containment system.

2.1.3 A_2**:** Quantity (activity) of radioactive material, other than special-form radioactive material, as defined in the applicable documents listed in clause 3.

2.1.4 blockage mechanism: Mechanism by which radioactive material might be retained within a containment system due to blockage of potential leakage paths by solid or liquid material.

2.1.5 competent authority: Any national or international authority designated or recognized as such for any purpose in connection with the International Atomic Energy Agency's Regulations for the Safe Transport of Radioactive Material (reference [1] in annex F).

2.1.6 containment system: Assembly of components of the packaging intended to retain the radioactive material during transport.

2.1.7 gas leakage test methodology: Method of specifying a gas leakage test which relates permissible activity release rates of the radioactive contents carried within a containment system to equivalent gas leakage rates under specified test conditions.

2.1.8 leak: Any unwanted opening or openings through a containment system that could permit the escape of the contents.

2.1.9 leakage: Transfer of a material from the containment system to the environment through a leak or leaks. See also **permeation** (2.1.17).

2.1.10 leakage rate: Quantity of solid particles, liquids or gases passing through leaks per unit time.

The term leakage rate can refer to the radioactive material (gas, liquid, solid or any mixture of these) or to the test fluid.

The dimensions of the rate of solid leakage are mass divided by time. The dimensions of the rate of liquid leakage can be mass divided by time or volume divided by time. The dimensions of the rate of gas leakage are the product of pressure and volume (this is a mass-like unit) divided by time at a known temperature.

2.1.11 leaktight: General term indicating that a containment system meets the required level of containment for particular contents. See clause E.6.

2.1.12 medium: Any fluid, which might or might not be radioactive itself, which could carry radioactive material through a leak or leaks.

2.1.13 molecular flow: The flow of gas through a leak under conditions such that the mean free path is greater than the largest dimension of a transverse section of the leak. The rate of molecular flow depends on the partial pressure gradient.

2.1.14 normal conditions of transport: Conditions used in the applicable documents listed in clause 3.

2.1.15 package: Packaging together with its radioactive contents as presented for transport.

2.1.16 packaging: Assembly of components necessary to enclose the radioactive contents completely.

2.1.17 permeation: Passage of a fluid through a solid permeable barrier (even if there are no leaks) by adsorption-diffusion-desorption mechanisms. Permeation should not be considered as a release of activity unless the fluid itself is radioactive. In this International Standard, permeation is applied only to gases.

2.1.18 permeation rate: Quantity of gases passing through permeable walls per unit time. The permeation rate depends on the partial pressure gradient.

2.1.19 qualitative: Refers to leakage test procedures which detect the presence of a leak but do not measure leakage rate or total leakage.

2.1.20 quantitative: Leakage test procedures which measure total leakage rate(s) from a containment system or from parts of it.

2.1.21 sensitivity

2.1.21.1 sensitivity of a leakage detector: Minimum usable response of the detector to tracer fluid leakage, that is, the leakage rate that will produce a repeatable change in the detector reading.

2.1.21.2 sensitivity of a leakage test procedure: Minimum detectable leakage rate that the test procedure is capable of detecting.

2.1.22 standardized leakage rate (SLR): Leakage rate, evaluated under known conditions, normalized to the flow of dry air at reference conditions of upstream pressure $1{,}013 \times 10^5$ Pa, downstream pressure 0 Pa and temperature of 298 K (25 °C). The units for standardized leakage rate are written as $\mathrm{Pa \cdot m^3 \cdot s^{-1}}$ SLR.

2.1.23 standardized helium leakage rate (SHeLR): Helium leakage rate, evaluated under known conditions, normalized to the flow of dry helium at reference conditions of upstream pressure $1{,}013 \times 10^5$ Pa, downstream pressure 0 Pa and temperature of 298 K (25 °C). The units for standardized helium leakage rate are written as $\mathrm{Pa \cdot m^3 \cdot s^{-1}}$ SHeLR.

2.1.24 test gas or tracer gas: Gas that is used to detect leakage or measure leakage rates.

2.1.25 Type B package: Package that is designed to meet the criteria given in the applicable documents listed in clause 3.

2.1.26 viscous flow: Continuous flow of gas through a leak under conditions such that the mean free path is very small in comparison with the smallest dimension of a transverse section of the leak. This flow may be either laminar or turbulent. Viscous flow depends upon total pressure gradient.

2.2 Symbols and units

The following symbols and units are used in this International Standard (also see clause B.2 in annex B).

Symbol	Definition	Unit
A_2	Quantity (activity) of radioactive material, other than special-form radioactive material, as defined in the applicable documents listed in clause 3	Bq
C	Average activity per unit volume; the symbol is used to simplify figure 1 and represents the use of either C_A or C_N	$\mathrm{Bq \cdot m^{-3}}$

Symbol	Definition	Unit
C_A	Average activity per unit volume of the medium that could escape from the containment system under accidental conditions of transport	Bq·m^{-3}
C_N	Average activity per unit volume of the medium that could escape from the containment system under normal conditions of transport	Bq·m^{-3}
D	Maximum permissible diameter; the symbol is used to simplify figure 1 and represents the use of either D_A or D_N	m
D_A	Maximum permissible equivalent capillary leak diameter under accidental conditions of transport	m
D_N	Maximum permissible equivalent capillary leak diameter under normal conditions of transport	m
FC_{iA}	Release fraction of radionuclide i from the radioactive contents into the containment system under accidental conditions of transport	—
FC_{iN}	Release fraction of radionuclide i from the radioactive contents into the containment system under normal conditions of transport	—
FE_{iA}	Fraction of radionuclide i which is available for release from the containment system into the environment under accidental conditions of transport	—
FE_{iN}	Fraction of radionuclide i which is available for release from the containment system into the environment under normal conditions of transport	—
I_i	Activity of radionuclide i	Bq
L	Maximum permissible volumetric leakage rate; the symbol is used to simplify figure 1 and represents the use of either L_A or L_N	m^3·s^{-1}
L_A	Maximum permissible volumetric leakage rate of the medium at pressure p_A, under accidental conditions of transport	m^3·s^{-1}
L_N	Maximum permissible volumetric leakage rate of the medium at pressure p_N, under normal conditions of transport	m^3·s^{-1}
p_A	Containment system pressure under accidental conditions of transport	Pa
p_N	Containment system pressure under normal conditions of transport	Pa
Q_{SLR}	Standardized leakage rate; the symbol is used to simplify figure 1 and represents the use of either $Q_{A(SLR)}$ or $Q_{N(SLR)}$	Pa·m^3·s^{-1}
Q_A	The permissible leakage rate of the medium under accidental conditions of transport and is calculated from L_A	Pa·m^3·s^{-1}
$Q_{A(SLR)}$	The permissible standardized leakage rate (SLR) under accidental conditions of transport	Pa·m^3·s^{-1}
Q_N	The permissible leakage rate of the medium under normal conditions of transport and is calculated from L_N	Pa·m^3·s^{-1}
$Q_{N(SLR)}$	The permissible standardized leakage rate (SLR) under normal conditions of transport	Pa·m^3·s^{-1}
Q_{TDA}	The permissible test leakage rate of the tracer or test gas that is related to accidental conditions of transport at the design verification stage and is determined from $Q_{A(SLR)}$	Pa·m^3·s^{-1}

Symbol	Definition	Unit
Q_{TDN}	The permissible test leakage rate of the tracer or test gas that is related to normal conditions of transport at the design verification stage and is determined from $Q_{N(SLR)}$	$Pa \cdot m^3 \cdot s^{-1}$
Q_{TF}	The permissible test leakage rate of the tracer gas at the fabrication verification stage	$Pa \cdot m^3 \cdot s^{-1}$
Q_{TS}	The permissible test leakage rate of the tracer gas at the preshipment verification stage	$Pa \cdot m^3 \cdot s^{-1}$
Q_{TP}	The permissible test leakage rate of the tracer gas at the periodic verification stage	$Pa \cdot m^3 \cdot s^{-1}$
R	Maximum permissible activity release rate; the symbol is used to simplify figure 1 and represents the use of either R_A or R_N	$Bq \cdot s^{-1}$
R_A	Maximum permissible activity release rate of the contents under accidental conditions of transport	$Bq \cdot s^{-1}$
R_N	Maximum permissible activity release rate of the contents under normal conditions of transport	$Bq \cdot s^{-1}$
RG	Maximum permissible activity release rate of the gas contents; the symbol is used to simplify figure 1 and represents the use of either RG_A or RG_N	$Bq \cdot s^{-1}$
RG_A	Maximum permissible activity release rate of the gas contents under accidental conditions of transport after allowing for permeation	$Bq \cdot s^{-1}$
RG_N	Maximum permissible activity release rate of the gas contents under normal conditions of transport after allowing for permeation	$Bq \cdot s^{-1}$
RI_{iA}	Releasable activity of radionuclide i under accidental conditions of transport	Bq
RI_{iN}	Releasable activity of radionuclide i under normal conditions of transport	Bq
RI_T	Total releasable activity for all radionuclides; the symbol is used to simplify figure 1 and represents the use of either RI_{TA} or RI_{TN}	Bq
RI_{TA}	Total releasable activity for all radionuclides under accidental conditions of transport	Bq
RI_{TN}	Total releasable activity for all radionuclides under normal conditions of transport	Bq
RP	Activity release rate due to permeation; the symbol is used to simplify figure 1 and represents the use of either RP_A or RP_N	$Bq \cdot s^{-1}$
RP_A	Activity release rate due to permeation under accidental conditions of transport	$Bq \cdot s^{-1}$
RP_N	Activity release rate due to permeation under normal conditions of transport	$Bq \cdot s^{-1}$
SHeLR	Standardized helium leakage rate	$Pa \cdot m^3 \cdot s^{-1}$ SHeLR
SLR	Standardized leakage rate	$Pa \cdot m^3 \cdot s^{-1}$ SLR
V_A	Medium volume under accidental conditions of transport	m^3
V_N	Medium volume under normal conditions of transport	m^3

3 Regulatory requirements

3.1 General

The word "shall" denotes a requirement; the word "should" denotes a recommendation; and the word "may" denotes permission, neither a requirement nor a recommendation. Imperative statements also denote requirements. To conform with this International Standard, all operations shall be performed in accordance with its requirements, but not necessarily with its recommendations.

The words "can", "could" and "might" denote possibility rather than permission.

The word "will" denotes that an event is certain to occur rather than a requirement.

3.2 Relevant regulations

The main applicable document is IAEA Safety Series No. 6, Regulations for the Safe Transport of Radioactive Material, 1985 Edition (as amended 1990) (reference [1] in annex F). The following sections are particularly relevant:

1) Section I, paragraphs 110, 121, 132, 134, 135, 142 and 147.

2) Section II, paragraph 209.

3) Section III, paragraphs 301 to 306 and 313.

4) Section IV, paragraphs 401 and 402.

5) Section V, paragraphs 543, 548 and 556.

6) Section VI, paragraphs 601, 602, 614 to 624 and 626 to 629.

Explanatory and advisory material is provided in Safety Series No. 7 and No. 37 (references [2] and [3] in annex F) (see also annex E).

Other relevant national or international regulations should also be considered to ensure that any differences with the IAEA regulations are taken into account.

3.3 Regulatory containment requirements

The Type B package containment requirements are given in table 1.

Table 1 — Containment requirements for Type B packages

Condition	Containment requirement
Normal conditions of transport	$A_2 \times 10^{-6}$ per hour
Accidental conditions of transport	$10\ A_2$ in one week for ^{85}Kr A_2 in one week for all other radionuclides

Values of A_2 are specified in table 1, or are determined in accordance to paragraphs 302 and 303 and table 2 of reference [1] in annex F for individual radionuclides, and in paragraphs 304 and 548 for mixtures of radionuclides.

For the calculation of values of A_2 for mixtures of radionuclides, the assumptions made for the releasable radioactive material shall be acceptable to the competent authority.

4 Procedure for meeting the requirements of this International Standard

4.1 General

Compliance with package containment requirements may be demonstrated either by measurement of the radioactive-contents release rate of by other methods. This International Standard shows how the package containment requirements can be demonstrated by an equivalent gas leakage test. All measured test leakage rates shall be correlated to the potential release of the contained material by performance of tests on prototypes or models, reference to previous demonstrations, calculations or reasoned arguments.

This International Standard is based on the following premises.

a) The radioactive material which could be released from the package could be in any one or any combination of the following forms:

- liquid,
- gas,
- solid,
- liquids with solids in suspension,
- particulate solids in a gas (aerosols).

The maximum permissible activity release rate can be expressed in terms of a maximum permissible leak diameter when the physical form and properties of the radioactive contents are taken into account.

b) Gas leakage test procedure can be used to measure gas flow rates. These rates can be related mathematically to the diameter of a single straight capillary which in most cases is considered to conservatively represent a leak or leaks.

c) Gas leakage test procedures can be used to demonstrate compliance with regulatory containment requirements when the diameter of the single straight capillary associated with the leakage test from 4.1 b) is equal to or smaller than the maximum permissible leak diameter from 4.1 a).

In this International Standard it is recognized that the activity release, or the absence of activity release (leaktight), can occur in one or more of the following ways:

- viscous flow,
- molecular flow,
- permeation,
- blockage.

4.2 Procedure

Using the flow chart in figure 1 as a guide, the procedure below shall be used. The text within each box in the flow chart indicates the result of the particular step.

Steps 1 to 8 in figure 1 pertain to containment of the radioactive contents, while Steps 10 to 12 pertain to leakage of a test gas. Step 9 is a reference step which links containment of the radioactive contents to the leakage of a test gas.

Because the releasable radioactive material might be in the form of gas, liquid or solid, or a combination of these, it is necessary to follow the appropriate part of the procedure below, as applicable to the form of the radioactive material, to obtain the permissible standardized leakage rates.

Figure 1 has been prepared for the general case. In some cases, it does not need to be necessary to complete all the steps, for example, in the case of a single radionuclide in liquid form. In other cases, such as a mixture of radioactive materials that are in different forms, it might be necessary to repeat some steps in a reiterative fashion. However, for any of these cases it will be necessary to complete the appropriate steps in figure 1 for both normal and accidental conditions of transport.

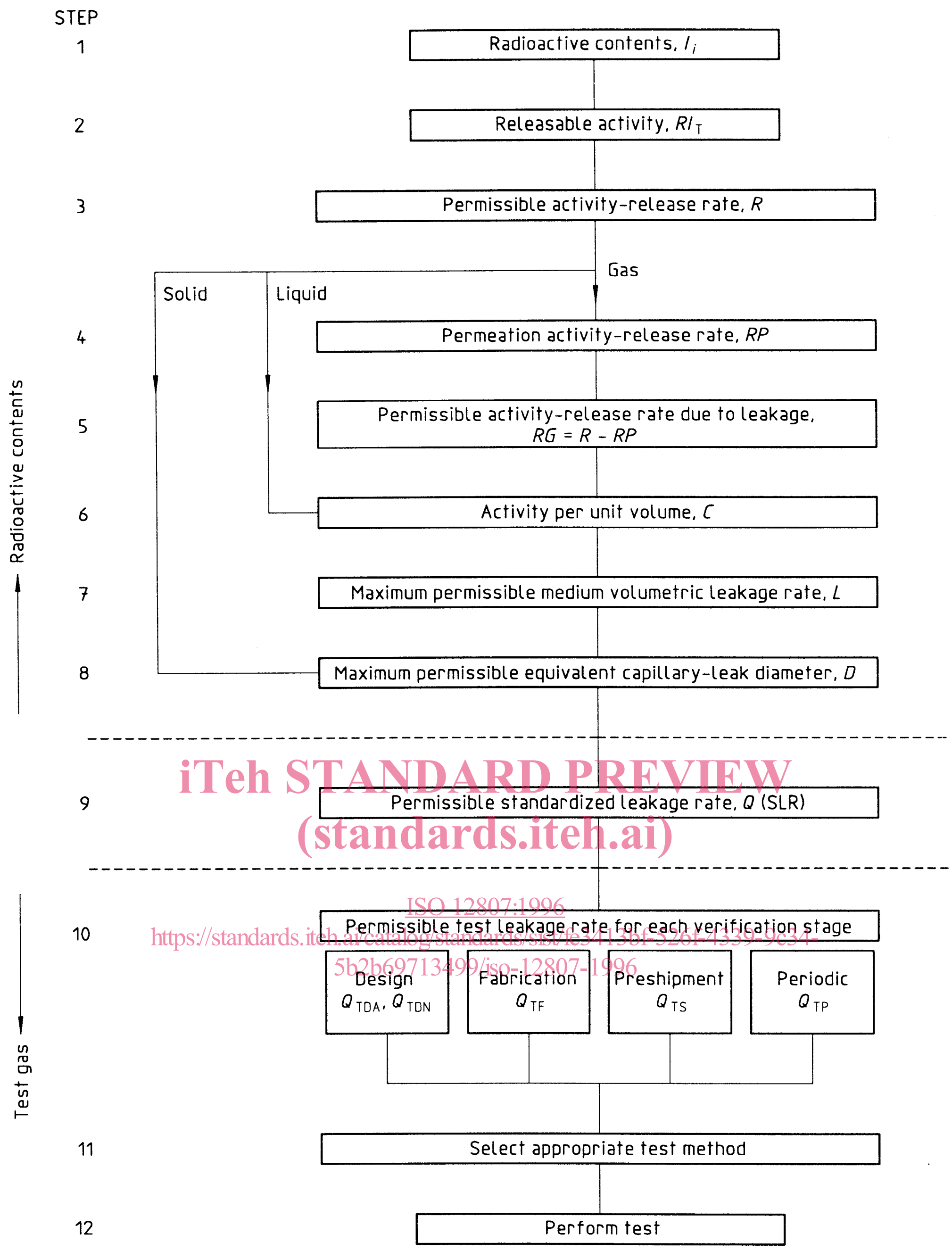

Figure 1 — Flow chart for gas leakage test methodology

4.2.1 Determination of permissible activity release rates

The inventory of the releasable radioactive contents shall be identified and the releasable contents shall be compared to the regulatory containment requirements. See Steps 1 to 3 in figure 1 and clause 5.

4.2.2 Determination of standardized leakage rates

The permissible activity release rates shall be converted to equivalent standardized leakage rates. See Steps 4 to 9 in figure 1 and clause 6.

4.2.3 Determination of permissible test leakage rates for each verification stage

The appropriate gas leakage rates shall be determined for the design, fabrication, preshipment and periodic verification stages. See Step 10 in figure 1 and clause 7.2.

4.2.4 Selection of appropriate test methods

The appropriate gas leakage test methods shall be selected for the design, fabrication, preshipment and periodic verification stages. See Step 11 in figure 1 and clause 7.2.

4.2.5 Performance of tests and record of results

The required tests shall be performed and the results shall be recorded. See Step 12 in figure 1 and clause 8.

5 Determination of permissible activity release rates

Permissible activity release rates shall be determined by following Steps 1 to 3 for both normal and accidental conditions of transport.

5.1 Step 1: List the radioactive contents, I_i

This gives an inventory of the radioactive contents and includes the activity and physical characteristics for each radionuclide. It could be necessary to consider the contents as separate phases, i.e. liquids, gases and solids. Aerosols can be considered as gases. Fine particles in solution can be considered as a liquid.

5.2 Step 2: Determine the total releasable activity, RI_T

In some cases, the radioactive contents might be contained by more than one container in the containment system. An irradiated fuel rod assembly in a transport packaging is an example of this situation. Then, for either normal or accidental conditions of transport, only a fraction of the radioactive contents might be released from the innermost container into the containment system FC_{iN}, FC_{iA} and, of this fraction, only another fraction may be available for release from the containment system to the environment, FE_{iN}, FE_{iA}. The numerical value of any release fraction will depend on the specific radionuclide and, if the radioactive contents consist of a mixture of radionuclides, many release fraction values could result. Also, release fraction values for normal conditions of transport might differ from those for accidental conditions of transport, even for the same radionuclide.

The releasable fractions depend upon such factors as:

1) the chemical and physical forms of the materials within the containment system, for normal and accidental conditions of transport;

2) the possible release modes, such as permeation of gases, mobility of aerosols or particulates, reactions with water or other materials present in the system, and solubility;

3) the maximum temperature, pressure, vibration, mechanical strains or distortions, and the like, to which the contained material would be subjected for normal and accidental conditions of transport. These shall be determined by the performance of tests on prototypes or models, by reference to previous demonstrations, calculations, or a reasoned argument.

Where a release fraction cannot be quantified, a value of 1,0 shall be assumed. The values of the release fractions normally require agreement with the competent authority.

For normal conditions of transport, the releasable activity of radionuclide i, RI_{iN}, in becquerels, is:

$$RI_{iN} = FC_{iN} \times FE_{iN} \times I_i \qquad \dots (1)$$

and for the total inventory

$$RI_{TN} = \sum_i RI_{iN} \qquad \dots (2)$$