THE TRANSPORTATION OF RADIOACTIVE MATERIALS

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SUMMARY

Radioactive materials transport regulations which are internationally uniform for all modes of transport are being adopted by most countries including Canada. The basis for these regulations and their application in Canada are discussed.

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1. Introduction

Regulations for the transport of radioactive materials are necessary to protect the health and safety of transport workers and the general public including passengers.

Most of us are familiar with the use of radioactive materials within our own establishments where building, equipment, personnel, operational procedures, and health and safety procedures minimize radiation and contamination hazards. In addition, the surrounding area may be restricted from access by the general public.

By contrast, radioactive materials in transport are subject to climatic exposure, rough handling during loading and unloading, vibration and impacts in transport, and accidents involving severe impact and fire - all while in the custody of transport workers who are likely unaware of the potential exposure and contamination hazards. This situation occurs while the radioactive materials may be in close proximity to transport workers and to the general public as passengers, users of transport facilities, and residents of adjacent transport routes.

In addition to the basic need for protection of the health and safety of the general public, the regulations should be uniform for all modes of transport on an international basis and should also be practicable from the point of view of shipper, carrier, designer and regulator.

Transport involves four basic modes - rail, road, air and water. Many shipments involve more than one of these modes. In addition, transport is an international activity - a single shipment may cross several international boundaries between origin and destination. Since each mode of transport may be subject to the jurisdiction of a different national regulatory authority and this situation may be repeated in many nations of the world, the need for mode-of-transport and international uniformity becomes obvious - particularly for a nation whose nuclear industry anticipates export markets.

Some of the factors contributing to practicability of regulations are that they must:

1. Maintain risks below an agreed and uniform level.
2. Be related to routine transport so that radioactive materials are treated simply as another class of dangerous goods and not as something stigmatic.

3. Be inherently flexible to accommodate unusual cases, to permit use of both design safety and operational safety measures, and to accommodate continuing technological developments in packaging and transport.

4. Provide scope for ingenuity by defining the basic safety requirements and not just a method of complying with them.

5. Communicate their intent efficiently by being definitive, precise, concise, and not subject to varying interpretation.

2. The International Atomic Energy Agency (IAEA)

The task of developing regulations which are safe, uniform, and practicable was recognized early as a difficult one whose solution was essential to full realization of the potential of radioactive materials. It is not surprising that such a difficult and important task was in 1959 assigned to the IAEA by the Economic and Social Council of the United Nations.

The IAEA was established in 1957 as an autonomous member of the United Nations family of organizations with the general objective that it "shall seek to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity around the world." The IAEA, in co-operation with its approximately 90 member states and several international transport organizations, undertook to develop regulations for the safe transport of radioactive materials. Significant steps in the development of these regulations were marked by the 1961 and 1964 Editions of Safety Series No. 6. The finalized regulations are contained in the 1967 Edition of Safety Series No. 6 entitled "Regulations for the Safe Transport of Radioactive Materials." (1)

These regulations are published by IAEA with the recommendation that they be applied to all IAEA transport operations and
that they be used by all member states and international organizations as a basis for their own transport regulations.

3. The Basis for the IAEA Regulations

3.1 General

The basic consideration in the transport of radioactive materials is that they may present radiation and contamination hazards to transport workers and the general public including passengers. Similar hazards may result from criticality incidents in the transport of fissile radioactive material. In addition, radiation exposure may damage transported goods such as undeveloped photographic film.

Within the IAEA regulations, these potential hazards are controlled by considering the three basic factors of radioactive materials hazard potential, of packaging performance, and of the transport environment - all in the context of the basic safety equation which is:

\[ \text{Overall Safety} = \text{Design Safety} + \text{Operational Safety} \]

where

Design Safety = Safety features provided by packaging design and material quantity limitations;

Operational Safety = Operational and administrative controls by shipper, carrier, and regulatory authority.

The hazard potential of radioactive materials is defined by consideration of radiotoxicity and physical form and assigning each radionuclide to an appropriate "transport group." In addition, some special classes of materials (exempt, low specific activity, fissile, and large source) are considered.

**Packaging** is the assembly of components which safely contains the radioactive materials. **Package** is the
Packaging, which is the primary control over external radiation and contamination hazards, is categorized on the basis of its ability to retain shielding, containment, nuclear safety, and heat transfer capabilities under normal and accident conditions of transport. Packaging which resists normal conditions of transport is designated Type A. Packaging which resists accident conditions of transport is designated Type B. In addition, special requirements for packaging for low activity, fissile, and large radioactive source materials are considered.

In the transport environment, simple operational controls are employed to further minimize radiation exposure to personnel and film. In addition, the "normal" and "accident" conditions of transport are defined and are used as performance standards for packaging designs.

3.2 Hazard Potential of Radioactive Materials

The basic hazard of radioactive materials is that they may cause external radiation exposure to persons and cargo and internal radiation to persons who may be exposed to dispersed material.

External radiation results from radiation leakage from the package under normal and accident conditions of transport. Since the packaging reduces rather than eliminates external radiation, operational safety procedures such as limiting radiation dose rates from the package and segregating packages from persons and film are employed under normal conditions of transport. External radiation safety under accident conditions of transport is provided by limiting the quantity of material per package and/or by designing packaging to maintain its containment and shielding capability under the specified accident conditions. Control of external radiation hazards is discussed further in Section 3.3.

Internal radiation results from the uptake into the human body of radioactive material which is in a dispersible form. Since radioactive materials are normally non-dispersible by virtue of their solid form
or of their being secured in a capsule or other containment, internal radiation is usually associated with accident conditions of transport which may result in dispersion of the radioactive material. In the IAEA Regulations, internal radiation hazards are controlled by consideration of physical form and radiotoxicity of the radionuclides, by limiting the quantity of radionuclide per package and by the required ability of the packaging to retain its containment capability under normal and accident conditions of transport.

3.3 Control of External Radiation Hazards During Transport

This topic has been developed in detail in several references (2)(3), which have been summarized in this section.

The basic standards for external exposure of persons are based on the "atomic energy worker" and the "other than atomic energy worker" groups. The maximum permissible doses for these groups are defined in both the Atomic Energy Control Regulations (4) and the Recommendations of the International Commission on Radiation Protection (5).

The basic standards for persons are rigorous enough to be adequate for most other transported commodities (such as livestock, foodstuffs, and general goods) with the exception of undeveloped film. "Fast" types of film, such as x-ray film used in medical diagnostic radiology, are very sensitive to "fogging" damage on exposure to radiation. A maximum permissible total exposure of 10 mR of gamma radiation has been selected for film.

Consideration of these basic standards for exposure of persons and film has resulted in the maximum permissible dose rates of 200 mR/hr at the accessible surface of the package and 10 mR/hr at one meter from the center of the package (3 feet from the accessible surface of the package by North American practice) for a package transported less-than-carload under normal conditions of transport. The accessible surface dose rate limit of 200 mR/hr originated in 1947 in the U.S.A. regulations and was based on a person carrying in contact with his body, packages with this maximum permissible dose rate for a total of 30 minutes each day. This results
in an average daily exposure of 100 mRem which although in compliance with 1947 standards, is in excess of more recent standards. The 200 mR/hr limit is still in use and surveys in areas where a high volume of radioactive materials packages are handled and periodic assessments of other transport facilities indicate that current exposure standards for persons are not being exceeded. The 10 mR/hr at one meter limit was chosen on the basis of "fast" film exposure limitations.

Radiation dose rates from the package under accident conditions of transport must also be considered. For Type A packages, accidental dose rates are limited by controlling the quantity of radionuclide which may be loaded into the packaging, as described in section 3.5. For Type B packages, the radiation dose rate may not exceed 1000 mR/hr at one meter from the surface of the package following a specified severe accident. In this case, higher total exposures may be permissible and emergency procedures may be expected to minimize the accidental exposure.

Under normal conditions of transport, exposure of persons and film is controlled by limiting the dose rate contribution per package, by limiting the accumulation of packages, and by considering in terms of time and distance, the proximity between persons and/or film and the radioactive materials packages.

The upper limits of dose rate contribution per package have been described previously. To facilitate the operational control of packages, they are divided into three categories as indicated in the following table.

<table>
<thead>
<tr>
<th>TABLE I</th>
</tr>
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<tbody>
<tr>
<td>PACKAGE CATEGORIES BASED ON RADIATION DOSE RATE</td>
</tr>
<tr>
<td>CATEGORY</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>I WHITE</td>
</tr>
<tr>
<td>II YELLOW</td>
</tr>
<tr>
<td>III YELLOW</td>
</tr>
</tbody>
</table>

* North American practice is 3 feet from accessible surface of package.
Each package is labelled according to its category as shown in Figure 6. Segregation distances are specified for Category II and III Yellow packages but not for Category I White packages. The basis for the exemption of the latter is that since contact dose rates are \( \leq 0.5 \text{ mR/hr} \), an intimate exposure of film for more than 20 hours would be necessary to exceed the 10 mR threshold for significant film fogging.

The accumulation of packages is limited by the use of the "transport index" which is defined as the number expressing the maximum radiation dose rate at one meter from the center of the package (three feet from accessible surface in North America). The total number of packages which may be loaded per truck, rail car, or aircraft, is that number having a sum of transport indices not exceeding 50. The basis for this number is that it limits, under the worst case, the radiation dose rate at two meters from the outer surface of the truck, rail car, or aircraft to 10 mR/hr. Sea-going vessels are permitted to load up to 200 transport index units in four groups of 50 with each group separated by six meters.

Segregation distance tables are developed considering basic exposure standards for persons and film, maximum radiation dose rates from 50 transport index group of packages, and time in proximity to such package groups for transport facility personnel, transport vehicle crews, and passengers, for all modes of transport. The segregation distance values are developed using mathematical models - notably the inverse square law with certain assumptions relative to package size. The conservative factors of shielding by other packages, cargo, and transport vehicle structure, and the pessimistic factor of radiation scatter are not considered in establishing the basic segregation distance tables.

3.4 Control of Radioactive Contamination of Package and Transport Vehicle Surfaces

This topic is developed in greater detail in a reference document (6), and is summarized in this section.

Radioactive contamination of package and vehicle surfaces may result in health hazards caused by external radiation, airborne contamination from non-fixed material, and direct or indirect uptake by adjacent persons. These factors are considered in the derivation of the maximum permissible levels for non-fixed radioactive contamination of the surfaces of packages and vehicles.

The derivations are based on the most hazardous radionuclides for each type of emission. The maximum permissible level for alpha contamination is based on the inhalation of plutonium and radium non-fixed contamination and is \( 10^{-5} \mu \text{Ci/cm}^2 \). The maximum permissible level for beta (and gamma) contamination is based on inhalation of strontium-90 non-fixed contamination and is \( 10^{-4} \mu \text{Ci/cm}^2 \). Both limits must not be exceeded when averaged over any 300 cm\(^2\) area of any part of the package or vehicle surface.
3.5 Material Quantity Limits for Type A Package

The advantages of a low-cost limited-performance packaging for small quantities of radioactive materials have long been recognized. Such a package must fully maintain its shielding and containment capabilities in normal conditions of transport but not necessarily in accident conditions of transport. By limiting the quantity of radioactive material in the package, the hazards resulting from accidental damage to the package may be limited to a safe level. This is the principle on which the material quantity limitation for the Type A package is based.

Since the detailed development of Type A package limits is well described elsewhere(3), only a brief summary is given here.

The recommendations of the International Commission on Radiological Protection (ICRP)(7) are used as the basis for the development.

The pertinent ICRP recommendations are listed in Table 2 below:

<table>
<thead>
<tr>
<th>ICRP Recommended Exposures - Basis for Transport Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP Para. 52(e)</td>
</tr>
<tr>
<td>For the whole body and the gonads</td>
</tr>
<tr>
<td>For the skin, thyroid and bone</td>
</tr>
<tr>
<td>For other organs</td>
</tr>
</tbody>
</table>

Paragraph 52(e) gives acceptable short term exposures resulting in the given critical organ doses.

Paragraph 52(g) gives permitted deliberate emergency exposure resulting in the given critical organ doses.

Non-dispersible materials may be of massive solid or encapsulated form known as "special form." Requirements for qualification as "special form" are summarized in the following Table 3.
TABLE 3.
Requirements for "Special Form" Materials

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Types of Special Form Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Massive Solid</td>
</tr>
<tr>
<td><strong>Thermal Stability</strong> - does not melt,</td>
<td>1000°F</td>
</tr>
<tr>
<td>sublime, or ignite up to</td>
<td>(538°C)</td>
</tr>
<tr>
<td></td>
<td>&quot;impact by falling billet&quot;</td>
</tr>
<tr>
<td><strong>Structural integrity</strong> - intact after</td>
<td>(percussion) test</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dimension</strong></td>
<td>All dimensions &gt; 0.5 mm or</td>
</tr>
<tr>
<td></td>
<td>one dimension &gt; 5 mm</td>
</tr>
<tr>
<td><strong>Stability in Air and Water</strong></td>
<td>Does not convert into dis-</td>
</tr>
<tr>
<td></td>
<td>persible reaction products</td>
</tr>
<tr>
<td></td>
<td>during specified tests in</td>
</tr>
<tr>
<td></td>
<td>air and in water.</td>
</tr>
</tbody>
</table>

Test and assessment methods for "special form" materials are included in the Regulations.

The Type A package limit for "special form" materials is the easier to define. An unshielded 20 curie source emitting 1 Mev gamma photons gives a radiation dose rate of about 1 R/hr at a distance of 10 feet. Since the possibility of a member of the general public remaining within 10 feet of a damaged Type A package for three hours (for a whole body dose of 3 rem) or of an accident recovery worker remaining within 10 feet of the same damaged package for 12 hours (for a whole body dose of 12 rem) is very remote, the 20 curie value was adopted as the Type A package limit for "special form" materials.
The material quantity limits for Type A package for dispersible materials were developed as follows:

1) For the accident severity assumed, $10^{-3}$ of package contents are released.

2) Only $10^{-3}$ of the released material is taken internally by any individual. This is $10^{-6}$ of the package contents.

3) The uptake of both soluble and insoluble material by the general public and the accident recovery worker are considered.

4) The permissible Type A package content for each radionuclide and each injury mode is calculated. The most restrictive quantity for each radionuclide is selected and radionuclides are listed in order of increasing quantity and divided into four basic transport groups.

5) The four basic groups are developed into the seven transport groups as indicated in Appendix 1 by consideration of the following refinements: low specific activity materials, daughter nuclides more toxic than parent, high mobility of Po-210, noble gases, tritium gas, tritium as luminous paints and as absorbed on solid carriers, and mixed fission products (MFP).

6) Since only those radionuclides listed by ICRP are considered, a method for assigning transport group numbers to unlisted radionuclides is developed. A method is also developed for limiting the quantities of mixtures of radionuclides.

7) Rather than complicate the transport grouping by consideration of different dispersible forms (especially liquids and compressed gases), additional packaging requirements are prescribed for these forms.

Thus was established the seven transport groups of radionuclides and the corresponding Type A package contents
limits. The transport groups and Type A package limits are also used as a basis for defining exempt quantities of materials and instruments and devices, low specific activity materials, and permissible release limits for large radioactive source packages.

3.6 Material Quantity Limits for Type B Package

Since a Type B package is designed to withstand a serious accident with no loss of containment and limited loss of shielding, the direct exposure and contamination criteria used to develop Type A package limits are not relevant.

The primary bases for Type B limits are the activity limit at which decay heat dissipation is not a problem, and current package capacities.

A "large radioactive source" is that quantity of material which exceeds Type B package limits.

3.7 Material Quantity Limits Exempted from Regulations

A logical extension of the "hazard potential related to material quantity" argument is that there is a small quantity of radionuclides below which regulatory safeguards are not required. A 1 mCi limit was selected from external radiation considerations. Since all contents are assumed to escape from a damaged "exempt" package, $10^{-3}$ of Type A package limits are taken for Groups I and II. Special consideration of the noble gases and various forms of tritium complete the transport group limitations for exempt packages as indicated in Appendix 1.

Exempt packages are required only to meet requirements for radiation dose rate, non-fixed surface contamination, and fissile material content.

Sheathed depleted and natural uranium used in a mass function and empty radioactive material packages are also exempted from regulatory requirements.
3.8 Material Quantity Limits for Instruments and Devices Exempted from Regulations

Many instruments and devices such as clocks, watches, instrument dials, and electronic tubes may be expected to provide better shielding and containment for the small quantities of radioactive materials which they contain than do "exempt" packages. Thus these instruments and devices are exempt from regulatory requirements provided that activity per article is limited (to approximately ten times "exempt" limits), radiation dose rate per article is limited, activity per package of articles is limited, and articles are "securely packed in a strong package."

3.9 Low Specific Activity Materials

Although the maximum permissible intake of some materials on an activity basis may be very small, the low specific activity of these materials may be such as to make the equivalent mass intake so large as to become highly improbable. If a total mass intake of greater than 10 mg is needed to arrive at the maximum permissible intake from which the Type A package limits were derived, then there is considered to be no need for a packaging containment standard exceeding that of industrial type packaging. This is the basis for the "low specific activity materials" classification which includes: uranium and thorium ores and concentrates; unirradiated natural uranium and thorium; aqueous tritium oxide with specific activity less than 5 curies per liter; items in which the activity is uniformly distributed; and externally contaminated objects.

3.10 Packaging - General

Packaging serves as the primary control over the radiation and contamination hazards of the material which it contains. Packaging is the "design safety" component of the basic safety equation.

There are five basic types of packaging envisaged in the IAEA Regulations - industrial, Type A, Type B, fissile, and large radioactive source.
Industrial packaging is used for exempt materials and instruments and devices, and for low specific activity materials. Cardboard boxes, wooden boxes, plastic containers, fibre drums, and steel drums are typical examples of industrial packaging. The specialized types of packaging (Types A and B, fissile, and large radioactive source) are required to meet the general design and construction principles as outlined in Appendix 2 and are described in the following sections.

3.11 Type A Packaging

Type A packaging may contain up to Type A quantity limits and must be capable of preventing loss or dispersal of contents and of fully retaining its shielding efficiency when subjected to the tests simulating "normal conditions of transport" as described in Appendix 3.

Derivation of the Type A package limits assumed that $10^{-3}$ of the package contents are released from a damaged package. This assumption may be optimistic in the case of liquids and compressed gases. Rather than complicate the Type A quantity limits with material form qualifications, it was decided to impose additional requirements for Type A packagings for liquids and compressed gases.

Liquids must be within a metal containment vessel. Additionally, either the containment vessel must be surrounded by an absorbent material or the package must be capable of withstanding a 9 meter drop without leakage.

Gases must also be within a metal containment vessel. The containment capability of the vessel used for more than 20 curies of most gases must be maintained when the vessel is subjected to a 9 meter drop.

Since Type A packages are not designed to withstand fire exposure, gamma-emitting sources in excess of 3 curies whose radiation shield may be lost on fire exposure must be contained in a fire resistant metal vessel which is durably marked "RADIOACTIVE."
Typical examples of Type A packaging are shown in Figures 1 and 2. The "can-in-carton" packaging is usually non-returnable, whereas the "steel encased, lead-shielded" packaging is returnable.

Compliance with Type A packaging requirements is the responsibility of the shipper. Regulatory evaluation and approval of Type A packages is not mandatory.

3.12 Type B Packaging

Type B packaging may contain up to the Type B quantity limits of radioactive materials and must withstand tests simulating "normal conditions of transport" without reduction of containment and shielding capability. In addition, it must withstand the tests simulating "accident conditions of transport" as indicated in Appendix 4 with no loss or dispersal of radioactive contents and with limited loss of shielding.

Limited loss of shielding is defined as a radiation dose rate at one meter from surface of the package not exceeding 1 R/hr.

Type B packages are usually characterized by the type of radiation which their contents emit. Packagings for alpha and beta emitters are relatively lightly shielded and are frequently non-returnable.

Packagings for neutron and gamma sources are more heavily shielded. Shielding is generally characterized by consideration of its melting point relative to 800°C fire temperature. Commonly-used shielding materials are lead, iron and depleted uranium.

All Type B packaging designs must be approved by the competent authority of the country where they were designed. A competent authority identification mark is assigned to each approved Type B packaging design and the serial number of each packaging built to the approved design must be recorded.

Some typical examples of Type B packaging are shown in Figure 3.
Illustration by courtesy of USAEC

Figure 1.

TYPICAL EXAMPLE OF NON-RETURNABLE TYPE "A" PACKAGING
Illustration by courtesy of USAEC

Figure 2.

TYPICAL EXAMPLE OF A RETURNABLE TYPE "A" PACKAGING
Lead-shielded, steel-encased container within a fibreboard-insulated outer container

Lead-shielded, steel-encased container within an outer wooden box

Illustrations by courtesy of UKAEA

Figure 3.

TYPICAL EXAMPLES OF "TYPE B" PACKAGING
3.13 **Large Radioactive Source Packaging**

Large radioactive source packaging is required for quantities of radioactive materials in excess of the Type B package limits. The two most common types of large radioactive sources are radioisotopes and irradiated fuels.

Large radioactive source packaging is basically Type B packaging with additional consideration of decay heat and leakage of contaminated heat transfer medium and with greater dependence on operational and administrative controls to compensate for the greater hazard potential of the larger quantity of material.

Large radioactive source packaging must comply with requirements for accessible surface temperature and loss of packaging efficiency resulting from solar and decay heat loads, for internal pressure limitations as related to containment vessel stresses and pressure relief devices, for loss of heat transfer medium (with resultant loss of containment and heat transfer capability), for lifting and tiedown attachments, for securing and double sealing valves, and for design verification by certification of fabrication and by prior-to-first-use tests.

Limited leakage of contaminated heat transfer media is permitted because it is unrealistic to expect a package to contain to an absolute degree, a pressurized liquid or gaseous heat transfer medium under normal and accident conditions of transport. The permissible leakage limits are based on the development of the Type A package limits and are given in Table 4. Note that the degree of permissible leakage is related to the type of package approval. "Continuously venting" packages are not considered in this paper.
TABLE 4

PERMISSIBLE ACTIVITY RELEASED BY LEAKAGE
OF CONTAMINATED HEAT TRANSFER MEDIUM FROM
LARGE RADIOACTIVE SOURCE PACKAGES

<table>
<thead>
<tr>
<th>TRANSPORT GROUP</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum activity leak rate per hour for all packages prior to release to carrier and during &quot;normal conditions of transport.&quot;</td>
<td>.001 μCi</td>
<td>.05 μCi</td>
<td>3 μCi</td>
<td>.02 mCi</td>
<td>.02 mCi</td>
<td>1 mCi</td>
</tr>
<tr>
<td>Maximum activity leak rate per week from multilaterally-approved package after exposure to &quot;accident conditions of transport.&quot;</td>
<td>1 mCi</td>
<td>50 mCi</td>
<td>3 Ci</td>
<td>20 Ci</td>
<td>20 Ci</td>
<td>1000 Ci</td>
</tr>
</tbody>
</table>

Operational controls which are applied to all large radioactive source shipments include equilibration of pressure and temperature and leak test of closure prior to release to carrier, prior arrangements with carrier, and advance notification of shipment.

Two approval schemes are provided for large radioactive source packaging.

Unilateral approval (by competent authority of country of origin of packaging design) is available for those packaging designs which meet the eleven criteria outlined in the regulations, including permissible activity leakage following accident conditions of transport not exceeding that leakage permitted on release to carrier. Approval of shipment is not required for such packages.
Multilateral approval (by competent authorities of all countries through which the package will be shipped) is necessary for those packaging designs which do not comply with the eleven criteria. Permissible activity leakage must not exceed those values in Table 4. The competent authorities may impose additional operational controls for shipment of the multilaterally-approved packaging designs. More commonly used controls are full-load shipment, radiation surveyor escort, special routing, pressure and temperature monitoring enroute, and special emergency procedures.

A more detailed discussion of irradiated fuel shipments is referenced (9).

An example of a large radioactive source packaging is shown in Figure 4.

3.14 Fissile Packaging

Fissile radioactive materials, in addition to their normal exposure and contamination hazards, are capable under certain conditions of "going critical" and thus causing more severe exposure and contamination hazards. The fissile radionuclides are U-233, U-235, Pu-239 and Pu-241. Certain quantities and forms of fissile materials are exempt from fissile packaging requirements.

The nuclear safety of fissile materials in transport is based on control of mass, geometry, moderation; neutron poisons, or any combination of those factors. In addition, damage to the packaging (which may cause reduced spacing, inleakage of water, escape and accumulation of fissile material, reduced efficiency of neutron moderators and poison, more reactive re-arrangement of contents, etc.), unsafe accumulation of undamaged and damaged packages, immersion in water, burial in snow, etc., must be considered.

Fissile packaging is classified by the degree of operational control needed to assure safety in transport as follows:

**Fissile Class I** includes packages which are
A steel-shielded packaging for irradiated fuel

Illustration by courtesy of UKAEA

Figure 4.

EXAMPLE OF A LARGE RADIOACTIVE SOURCE PACKAGING
nuclearly safe in any number and in any arrangement under all foreseeable circumstances of transport.

Fissile Class II includes packages which in limited number are nuclearly safe in any arrangement under all foreseeable circumstances of transport.

Fissile Class III includes packages which are nuclearly safe by reason of special arrangements (refer to section 3.19, this paper).

Detailed criteria for nuclear safety evaluation of individual packages and assemblies of packages for fissile Classes I and II are provided in the regulations.

Fissile packaging designs require the prior approval by the competent authority of each country in which they will be shipped (except certain Fissile I packages which require only the approval of the country of origin of the packaging design. This approval procedure is not used in either Canada or the U.S.A. at the present time.).

The appearance of fissile packaging varies according to its fissile class and intended use (irradiated/unirradiated and low/high enrichment material, etc.). An example of fissile packaging is shown in Figure 5.

3.15 Specification Packaging

Specification packaging is a packaging design which has broad scope for utilization, which has been approved by the competent authorities, and which is described in detail in the regulations so that it may be fabricated and used without need for further authorization.

A few specification packagings for radioactive materials currently appear in national regulations. Efforts are being made to extend the number of specification packagings available to shippers and thus reduce the requirement for individual packaging design approvals.

The IAEA Regulations make provision for inclusion of specification packages but none has been published to date.
Illustration by courtesy of USAEC

Figure 5.

EXAMPLE OF FISSION PACKAGING FOR UNIRRADIATED MATERIAL
3.16 Transport Environment

The transport environment may be defined in terms of climatic elements, normal conditions of transport, and accident conditions of transport. In addition other "foreseeable conditions of transport" may be considered in the case of fissile material shipments.

Climatic elements considered in the regulations include extremes of ambient temperature and pressure, rain, and solar radiation. Wind velocity may not be considered for heat transfer purposes.

Normal conditions of transport are defined in terms of the tests outlined in Appendix 3.

Accident conditions of transport are very difficult to define beyond the general components of impact and fire. The initial IAEA approach was to use the "maximum credible accident" concept as appeared in the 1961 Edition of the Regulations. However, in the interests of international uniformity, it was desirable to define "accident" in a quantitative way which could be applied as a packaging performance criterion. This led to the definition of the "severe" accident as described in Appendix 4. Although this definition of "accident conditions of transport" is not the worst accident imaginable, it is a realistic definition which is based on collective judgement and experience and on the consideration of both safety and economy.

3.17 Operational Controls

Certain operational controls are used for all radioactive shipments.

The shipper checks and certifies that the package complies with all relevant regulatory requirements before he releases it to the carrier. This check includes non-fixed surface contamination and radiation dose rate.

The non-fixed surface contamination on the external surface of a package must not exceed
$10^{-4}$ $\mu$Ci/cm$^2$ for beta and gamma emitters and $10^{-5}$ $\mu$Ci/cm$^2$ for alpha emitters.

The maximum permissible radiation dose rates are 200 mR/hr on contact with the accessible surface of the package and 10 mR/hr at one meter from the center of the package. Higher radiation dose rates may be permissible if the package is shipped "full load" or if other operational controls are employed. Recent North American practice is to use the accessible surface of the package as the reference for the 10 mR/hr dose rate rather than the center of the package as prescribed by the IAEA Regulations.

The total radiation dose rate from an accumulation of packages (each of which meets the 200/10 mR/hr limits) may be high enough to cause a hazardous condition. To control this hazard, the transport index (which, by North American application of the IAEA Regulations, is a number expressing the maximum radiation dose rate at 1 meter from the surface of the package) is used. The total transport index of a group of packages in storage or in a single transport vehicle (except ships) must not exceed 50. Packages may be categorized depending upon the magnitude of their transport index. The categories (I-White, II-Yellow, III-Yellow) are indicated on the label and may be used as an alternative to adding up transport indices for control of package accumulation. The transport index is also used to control unauthorized accumulation of Fissile Class II packages.

The package labels and vehicle placard recommended by the IAEA Regulations are shown in Figures 6 and 7.

Segregation distance between radioactive materials packages and areas continually occupied by persons and/or undeveloped photographic film is used to further minimize personal exposure and damage to film.

Transport practices and equipment may be different for each mode of transport. These differences are accommodated in the Regulations by specific reference
The "7" in the lower corner indicates that radioactive materials are designated as Class 7 among all dangerous goods as recommended by the United Nations Committee of Experts on Transport of Dangerous Goods.

Figure 6.
PACKAGE LABELS
PLACARD FOR VEHICLES

Figure 7.

The over-all shape of the placard may be diamond, rectangular or square as indicated by the dashed lines. Minimum dimensions are given; when larger dimensions are used the relative proportions must be maintained.
to rail, road, inland water craft, seagoing vessels, air and postal transport.

3.18 Administrative Controls

The following administrative controls contribute to the safe transport of radioactive materials.

The competent authority is responsible for assuring that packaging design and shipping procedures comply with regulatory requirements and for issuing certification of such compliance.

The shipper is responsible for providing the necessary shipment information to the carrier, for providing advance notification of shipment, and for certifying that radioactive materials are properly described and packaged and are in proper condition for transport.

The carrier may be required to certify that he is aware of and has complied with special transport requirements.

3.19 Special Arrangements

Although the IAEA Regulations were developed to accommodate a very broad scope of materials, packaging, and transport procedures, they are not intended to limit the shipper to the use of only those factors included in the Regulations. The value of flexibility in the regulations to provide for the unusual shipment was recognized and is provided under "Special Arrangements."

In most cases special arrangement shipments place greater emphasis on the "operational safety" component of the basic safety equation than on the "design safety" component.

As stated in the Regulations, for special arrangement shipments, "... the competent authority or authorities shall impose conditions adequate to ensure that the
transport of the consignment shall be no less safe than if all the relevant provisions of the regulations had been complied with."

Special arrangement shipments must be approved by the competent authority of all countries through which the shipment will move.
1. General

Under the Atomic Energy Control Act\(^{(10)}\), the Atomic Energy Control Board is empowered to promulgate regulations for all aspects of atomic energy including the transport of radioactive materials. Since radioactive materials are only one type of dangerous commodity whose transport requires regulation, the Board has followed the policy that it is preferable for transport regulations for all dangerous commodities to be issued by the authority having jurisdiction over the mode of transport concerned.

Each mode of transport within Canada is regulated by a different authority at the present time. Recognizing the need for national uniformity and for representative participation by Canada in the development of the IAEA Regulations, a Technical Committee was established in 1962.

Recent developments with reference to the National Transportation Act\(^{(11)}\) are discussed in Section 3 following.

2. The Technical Committee for Uniform Regulations for the Transportation of Radioactive Materials

The Technical Committee was convened by the Minister of Transport for the purposes of examining the IAEA and other regulations to determine the feasibility of establishing uniform regulations in Canada, of considering the road transport situation (which involved multiple jurisdictions and which was essentially unregulated) and of making recommendations on these items to the Minister. Represented on the committee were the federal transport agencies, the provincial transport agencies, Departments of National Health and Welfare and of Public Works, National Research Council, Atomic Energy of Canada Limited, Canadian Nuclear Association, and Atomic Energy Control Board.

The Committee's first report was published in October 1963. It was necessary for the Committee to reconsider
this report because of subsequent development of the IAEA Regulations. The Committee was represented on the IAEA panels which were revising and further developing the IAEA Regulations.

The Committee's task was concluded in November 1966 with its second report which was approved by the Minister of Transport and which contained the following recommendations:

1) That the IAEA Regulations, 1964 Edition, and including Modification No. 1(12) and GOV/1125(13) be adopted as the basis for uniform Canadian regulations with certain exceptions for fissile materials and administrative procedures.

2) That the provinces regulate intraprovincial road transport and that a federal agency be appointed to regulate extra-provincial road transport in both cases, applying the IAEA Regulations.

3) That for both domestic and foreign shipments, all applications for packaging design and shipment approvals be directed to the Atomic Energy Control Board for evaluation and forwarding to the appropriate transport authorities with a suitability recommendation.

4) That the following target dates be set for full application of the IAEA-based regulations:

4.1 All import and export shipments with countries other than the U.S.A. shall comply by January 1, 1968.

4.2 All shipments between U.S.A. and Canada shall comply as consistent with applicable U.S.A requirements but not later than 1 January 1969.

4.3 All domestic shipments comply by 1 January 1969.

5) That the Technical Committee be succeeded by a small technical group to consider the suitability for use in Canada of future developments in the IAEA Regulations.
3. Canadian Transport Commission

The "National Transportation Act, Bill C-231(11) which at
date of writing had been approved by both House of Commons
and Senate, includes five parts which deal with (among
other things) the establishment of the Canadian Transport
Commission and the jurisdiction for extra-provincial road
transport.

The Canadian Transport Commission will incorporate
and replace the Board of Transport Commissioners for
Canada, the Canadian Maritime Commission, and the Air
Transport Board, thereby centralizing transport regulatory
authority. Details of regulatory responsibilities of the
new Commission are not known at this time.

The jurisdiction for extra-provincial road transport
is discussed in Section 7. following.

4. Rail Transport

The regulatory authority for rail transport in Canada
is the Board of Transport Commissioners for Canada (BTC),
Ottawa. This authority was the first to publish detailed
regulations(14) for the transport of radioactive materials
and as a result these regulations were used for other
modes of transport as well.

The BTC Regulations are, for reasons of North American
uniformity, similar to those regulations published by the
Interstate Commerce Commission and its successor, the
Department of Transportation, in the United States.

The BTC Regulations currently provide detailed regula-
tions for packaging and shipment of up to 2.7 curies of
most radioactive materials. This limitation corresponds
generally to the Type A package quantities described in
the IAEA Regulations. Requirements for packaging and
shipment of quantities greater than this were provided
in BTC Circular 286 "Notice to Shippers of Large Radioactive
Sources," which was published in 1961. These requirements,
especially for package performance under "accident
conditions of transport," were indicative of what was to appear later in the IAEA Regulations. Circular 286 was withdrawn in February 1967 in favour of the IAEA Regulations. It is expected that the BTC will adopt IAEA-based regulations in the near future.

5. Marine Transport

The regulatory authority for marine transport is the Chairman, Board of Steamship Inspection, Department of Transport, Ottawa. This authority in 1952 published under the "Dangerous Goods Shipping Regulations" (15) the document "The Recommended Precautions to be Taken for Safety in the Carriage of Radioactive Materials in Ships." These regulatory requirements will soon be withdrawn in favour of the "IMCO" Regulations (16).

"IMCO" is the acronym for Intergovernmental Maritime Consultative Organization which is a United Nations organization involved in the international aspects of maritime transport. This organization has published the "International Maritime Dangerous Goods Code" which includes the Class 7 section, "Radioactive Substances." These regulations were developed by IMCO in close co-operation with its sister UN organization, the IAEA, and are consistent with the IAEA Regulations.

Other federal authorities in the field of marine transport are the National Harbours Board (which has jurisdiction over the harbours of St. John's, Halifax, Saint John, Chicoutimi, Quebec, Trois-Rivières, Montreal, Churchill and Vancouver) and the St. Lawrence Seaway Authority. Although these authorities co-operate closely with the Department of Transport, they are autonomous and may impose requirements on radioactive materials shipments within their respective jurisdictions.

6. Air Transport

The regulatory authority for air transport is the Civil Aviation Branch, Department of Transport, Ottawa. This authority, in its "Air Regulations" (17) requires
that all air shipments of radioactive materials in Canada or by Canadian air carriers be subject to the approval of the Minister of Transport. In actual practice, packaging and shipping procedures in accordance with the "IATA Regulations Relating to the Carriage of Restricted Articles by Air" (18), published by the International Air Transport Association (IATA), are acceptable to this authority.

The International Air Transport Association is an air carrier association representing approximately 90 member airlines and 60 participating airlines. Current IATA Regulations (10th Edition) are based primarily on earlier regulations developed for the Interstate Commerce Commission. IATA is expected soon to publish the 11th Edition of its regulations, which for radioactive materials, which will be based on the IAEA Regulations and which will be applied to virtually all national and international air transport.

7. Road Transport

The road transport of radioactive materials has been troubled by the question of federal and provincial jurisdictions and this question has not been fully resolved to date.

Intraprovincial transport (that is, transport solely within a single province) is clearly a provincial jurisdiction, although little action has been taken by the provinces to regulate intraprovincial road transport of dangerous commodities. The Province of Ontario, in regulations made under the Highway Traffic Act (19), requires every commercial motor vehicle and trailer transporting radioactive materials within the Province to be placarded in a prescribed manner with the words "RADIOACTIVE MATERIALS." The Province of Alberta, in regulations made under the Public Service Vehicles Act (20) requires that persons transporting radioactive materials in public service vehicles obtain a permit from the provincial Highway Traffic Board. Prerequisites of permit issuance include compliance with applicable Federal and Department of Public Health of Alberta requirements and filing of evidence of insurance satisfactory to the Highway Traffic Board.
Apparentely, none of the other provinces has legislation dealing specifically with the intraprovincial transport of radioactive materials.

Some responsibility for extra-provincial transport (that is, crossing provincial or international boundaries) was assigned under the Motor Vehicles Transport Act(21) to the Provinces. The recent "National Transportation Act," Bill C-231(11), makes provision for the federal government to assume the regulatory responsibility for extra-provincial road transport but when federal action in this area may be expected, is unknown.

The Atomic Energy Control Board, recognizing the jurisdictional problem and its potential hazards, in 1963 issued as an interim measure, the Shipping Containers Order(22). This Order requires that shippers of radioactive materials provide packaging, shielding, and labelling as prescribed by the appropriate transportation authority, or for modes of transport where detailed regulations have not been prescribed, the BTC Regulations(14), or such requirements as the Atomic Energy Control Board may prescribe. In this latter respect the Atomic Energy Control Board uses the IAEA Regulations, including the "Special Arrangement" provision.

8. Postal Transport

The Canada Post Office does not permit the transmission of radioactive materials by post(23) except in very unusual circumstances where prior approval is given.

The Universal Postal Union in 1966 recommended that exempt quantities of radioactive materials (as per IAEA Regulations) may be transmitted by first class post by authorized consignees provided that the package was suitably addressed and labelled(24).

Both the United States Post Office and H.M. Post Office (U.K.) permit transmission of radioactive materials through the mails generally in accordance with the Universal Postal Union recommendations.

9. The Role of the Atomic Energy Control Board

As described previously, the role of the Atomic Energy Control Board is to serve as an adviser to the transport
regulatory authorities and to serve in the interim as the competent authority for road transport.

As recommended by the Technical Committee and as agreed by the transport agencies, all applications for approval of packaging designs and shipping procedures should be submitted to the Atomic Energy Control Board, which will evaluate the submission and forward it together with a recommendation of suitability to the transport regulatory authorities involved.

In this respect, it must be clearly understood that satisfactory demonstration of compliance of the packaging and shipping procedures with the regulatory requirements is the responsibility of the applicant and not of the Atomic Energy Control Board, whose role is to judge the suitability of the proposed packaging design and shipping procedures on the basis of the evidence which the applicant has presented.

The Atomic Energy Control Board is willing to discuss regulatory requirements and to provide related technical advice to packaging designers, shippers and carriers on all aspects of national and international radioactive materials transport at any time.

10. Emergency Procedures

Although the regulations anticipate and require packaging to withstand a serious accident, they do not intend to be an absolute preventative against unusual or ultra-severe accidents which realistically must be expected to occur (albeit with extremely low frequency). Thus to provide the highest level of safety, for the full spectrum of accidents, it is necessary to consider emergency procedures to cope with transport accidents involving radioactive materials.

Emergency procedures for transport accidents must first identify any hazards resulting from the presence of radioactive materials and follow up with the necessary corrective action to minimize exposure and contamination hazards. To develop this further, let us examine the emergency procedures for road transport.

Among the first people on the scene of a road accident are the police who have at their disposal, an excellent
communications system. Although a police officer is not expected to possess expert knowledge of radioactive materials, he can identify the presence of radioactive materials at the scene of an accident (by vehicle placard or package label) and radio for expert advice and assistance from the closest source. The police officer may also apply simple controls to minimize exposure and contamination hazards at the scene of the accident until the expert assistance confirms that no hazard is present or until the accident recovery operation is completed.

Advance notification of large or unusual shipments is forwarded to the police and to the regulatory authorities.

III CONCLUSION

Radioactive materials transport regulations which are based on health physics principles and which are internationally uniform for all modes of transport, have been created by the International Atomic Energy Agency to permit the safe and economic transport of radioactive materials. These regulations are being adopted by the regulatory authorities of the various modes of transport in Canada at the present time.

IV ACKNOWLEDGEMENT

The author acknowledges with sincere gratitude the cooperation and assistance of the many persons who contributed both directly and indirectly to this paper, including colleagues, secretarial staff, authors of references; members of national and international regulatory bodies, organizations, and transport associations; packaging designers, shippers, carriers, and the Technical Committee for Uniform Regulations for the Transportation of Radioactive Materials.
### APPENDIX 1 - Radionuclide Transport Groups and Package Limits

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<th>Special Form</th>
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<td>Transport Group</td>
<td>I</td>
<td>II</td>
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<tr>
<td>Examples of radionuclides in each group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Po-210</td>
<td>Bi-210</td>
<td>Co-60</td>
</tr>
<tr>
<td>Pu(All)</td>
<td>Pb-210</td>
<td>I-131</td>
</tr>
<tr>
<td>Ra-226</td>
<td>Pb-212</td>
<td>Ir-192</td>
</tr>
<tr>
<td>Th-228</td>
<td>Ra-223</td>
<td>Th(nat)</td>
</tr>
<tr>
<td>Th-230</td>
<td>Ra-224</td>
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<tr>
<td>Th-231</td>
<td>Sr-90</td>
<td>U-235</td>
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<tr>
<td>U-232</td>
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<th>Exempt material</th>
<th>Exempt instruments and articles: Per item</th>
<th>Per package</th>
<th>Type A</th>
<th>Type B</th>
<th>Large Radioactive Source</th>
</tr>
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<tbody>
<tr>
<td>Exempt material</td>
<td>0.1 mCi</td>
<td>0.1 mCi</td>
<td>1 mCi</td>
<td>1 mCi</td>
<td>1 mCi</td>
<td>25 Ci</td>
</tr>
<tr>
<td>Exempt instruments and articles: Per item</td>
<td>0.1 mCi</td>
<td>1 mCi</td>
<td>10 mCi</td>
<td>50 mCi</td>
<td>1 Ci</td>
<td>1 Ci</td>
</tr>
<tr>
<td>Per package</td>
<td>1 mCi</td>
<td>50 mCi</td>
<td>3 Ci</td>
<td>3 Ci</td>
<td>1 Ci</td>
<td>1 Ci</td>
</tr>
<tr>
<td>Type A</td>
<td>1 mCi</td>
<td>50 mCi</td>
<td>3 Ci</td>
<td>20 Ci</td>
<td>20 Ci</td>
<td>1000 Ci</td>
</tr>
<tr>
<td>Type B</td>
<td>20 Ci</td>
<td>20 Ci</td>
<td>200 Ci</td>
<td>200 Ci</td>
<td>5000 Ci</td>
<td>50 KCi</td>
</tr>
<tr>
<td>Large Radioactive Source</td>
<td>No prescribed quantity limits per package</td>
<td></td>
<td></td>
<td></td>
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</table>
GENERAL DESIGN AND CONSTRUCTION PRINCIPLES FOR PACKAGING

1. All external dimensions greater than 4 inches
2. Security seal to indicate unauthorized opening.
3. Marking - weight, type, trefoil, owner, approval identification.
4. Provision of handling, lifting, stowage features.
5. No protruding features.
6. No pockets to retain rain or other water.
7. Easy decontamination of external surfaces.
8. Material properties consistent with ambient temperature extremes.
9. Able to withstand transport acceleration and vibration.
10. Containment vessel must have positive closure which is leak-tight at internal and external pressure extremes, and must consider corrosion and radiolytic decomposition.
11. Shield must retain containment vessel positively and must maintain full efficiency.
TESTS SIMULATING "NORMAL CONDITIONS OF TRANSPORT"

1. Drop

The package must be subjected to a 1.2 meter (4 feet approx.) drop onto a flat target. Packages whose outer surfaces are permeable to water must be subjected to water spray before this test.

This test simulates the dropping of a water-soaked package from a transport vehicle onto a hard surface.

2. Compression

The package in its shipping attitude must support a compressive load which is the greater of 1300 kg/m² (266 psf) or five times the package weight.

This test simulates the loading resulting from overstowage of other transported goods.

3. Penetration

The package must not sustain significant damage when struck by a 3.2 cm (1.26 in.) diameter, 6 kg (13.2 lb.), hemisphere-ended non-deformable bar dropped from a height of 1 meter.

This test simulates impaction by or against protruding features of vehicle, handling equipment, and other cargo.

Each package design must withstand all tests. A single package must withstand two tests applied consecutively.
TESTS SIMULATING "ACCIDENT CONDITIONS OF TRANSPORT"

Package Drop onto Flat Target

The package must be subjected to a 9 meter (30 feet approx.) drop onto an immovable, flat target.

This test simulates the severe impact loading which the package may experience in an accident. The impact velocity is about 30 mph, which is less than the usual speed of most transport vehicles. However, the immovable target means that full energy absorption and deformation occur in the package, whereas in an actual accident one could reasonably expect the impact surface to be less than immovable, thereby absorbing a significant part of the energy and deformation.

2. Package Drop onto Penetrator

The package must be subjected to a 1 meter drop onto a 15 cm (6 inches) diameter upright steel cylinder which is of sufficient length to cause maximum damage and which is mounted on an immovable surface.

This test simulates the concentrated impact loading which may puncture the packaging. Since penetrating objects in transport accidents (bent rails, steel beams, companion cargo) are likely to be relatively flexible and not capable of immovable resistance (and resultant large deceleration forces), a 1 meter drop height is used.

3. Fire Exposure

The package (with an absorption coefficient taken as 0.8) is exposed to a 800°C thermal environment (with emissivity coefficient taken as 0.9) for 30 minutes. Following this exposure, packaging must not be cooled until peak internal temperatures are attained.

This test simulates a transport fire whose fuel supply may be derived from the ruptured fuel tanks of a transport vehicle.

4. Immersion in Water

The package is immersed under a 0.9 meter head of water for 8 hours.
This test simulates water immersion which may be caused by fire control measures or by dropping of package into a body of water. This test is applied only to fissile packagings where water inleakage may moderate and/or reflect neutrons, resulting in a more reactive system.

All tests must be applied consecutively to the same sample package.
VI  LIST OF REFERENCES


(10) ATOMIC ENERGY CONTROL ACT, Revised Statutes of Canada, Ch. 11(1952) as amended by Ch. 47(1953-54).

(11) NATIONAL TRANSPORTATION ACT, Bill C-231, 29 August,1966.


(14) Board of Transport Commissioners for Canada, REGULATIONS FOR THE TRANSPORTATION OF DANGEROUS COMMODITIES BY RAIL, Queen's Printer, Ottawa.


(17) AIR REGULATIONS, SECTION 800, Civil Aviation Branch, Department of Transport, Ottawa.

(18) IATA REGULATIONS RELATING TO THE CARRIAGE OF RESTRICTED ARTICLES BY AIR, 10th EDITION, International Air Transport Association, Montreal.


(21) 2-3 Elizabeth II, Chap. 59 (1954) MOTOR VEHICLES TRANSPORT ACT

(22) SOR/63-65 SHIPPING CONTAINERS ORDER 1/200/63, made under the Atomic Energy Control Act, 7 February 1963.

(23) CANADA OFFICIAL POSTAL GUIDE, SECTION 335.

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