THE TRANSPORTATION OF RADIOACTIVE MATERIALS

R. W. Blackburn
Atomic Energy Control Board

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, application of, and effects on transport economics of these uniform regulations are discussed.

A paper presented to the Canadian Nuclear Association Conference '67, May 1967, Montreal, Que.
TABLE OF CONTENTS

(I) THE INTERNATIONAL ATOMIC ENERGY AGENCY REGULATIONS

1. Introduction
2. The International Atomic Energy Agency (IAEA)
3. The Basis for the IAEA Regulations
   3.1 General
   3.2 Hazard Potential of Radioactive Materials
   3.3 Material Quantity Limits for Type A Package
   3.4 Material Quantity Limits for Type B Package

CORRIGENDUM FOR
"THE TRANSPORTATION OF RADIOACTIVE MATERIALS"

This paper was prepared in advance of the 1967 Edition of the IAEA Regulations and did not anticipate an editorial change which was incorporated in that Edition. This change is the consolidation of former (1964 Edition) transport groups VII and VIII into a new group also designated VII. You will notice that in Appendix 1 of this paper, the maximum activity - per - package limits for former groups VII and VIII are identical.

R.W. Blackburn,
June 1967

1.6 All Transport
1.7 Road Transport
1.8 Postal Transport
1.9 The Role of the Atomic Energy Control Board
1.10 Emergency Procedures
2. The World
   2.1 General
   2.2 United States of America
   2.3 United Kingdom
   2.4 European Countries

(III) TRANSPORT ECONOMICS AND THE IAEA REGULATIONS

1. General
2. Formulation of the Transport Problem
3. Packaging Costs
   3.1 General
   3.2 Design
   3.3 Approval
   3.4 Fabrication
   3.5 Maintenance
4. Handling Costs
   4.1 General
   4.2 Loading the Package
   4.3 Preparation for Shipment
   4.3 Presentation to Carrier
5. Freight Costs
6. Insurance Costs

(IV) CONCLUSIONS
(V) ACKNOWLEDGEMENT
(VI) APPENDICES
(VII) LIST OF REFERENCES
(VIII) LIST OF TABLES AND FIGURES
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

\[ \text{Design Safety} = \text{Safety features provided by packaging design and material quantity limitations;} \]

\[ \text{Operational Safety} = \text{Operational and administrative controls by shipper, carrier, and regulatory authority.} \]

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 plus its radioactive contents.

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 hazard potential of a radionuclide is a function of its inherent characteristics, its physical form, and its quantity.

Inherent characteristics include type and energy of emission and internal and external effects on the human body.

Physical form may be non-dispersible (in which case there may be an exposure hazard but not a contamination hazard) or dispersible (where both exposure and contamination must be considered). Different dispersible forms (liquid, gas, and finely-divided solid) may present different degrees of contamination hazard.

The hazard potential of a radionuclide may be controlled by limiting the quantity of that radionuclide per package.

3.3 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(2), only a brief summary is given here.

The recommendations of the International Commission on Radiological Protection (ICRP)(3) are used as the basis for the development.

The pertinent ICRP recommendations are listed in Table 1 below:

TABLE 1.

<table>
<thead>
<tr>
<th>ICRP Recommended Exposures - Basis for Transport Regulations</th>
<th>ICRP Para. 52(e)</th>
<th>ICRP Para. 52(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>For the whole body and the gonads</td>
<td>3 rem</td>
<td>12 rem</td>
</tr>
<tr>
<td>For the skin, thyroid and bone</td>
<td>8 rem</td>
<td>30 rem</td>
</tr>
<tr>
<td>For other organs</td>
<td>4 rem</td>
<td>15 rem</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 2.
TABLE 2.
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><strong>Structural integrity</strong> - intact after</td>
<td>&quot;impact by</td>
</tr>
<tr>
<td></td>
<td>&quot;falling</td>
</tr>
<tr>
<td></td>
<td>&quot;billet&quot;</td>
</tr>
<tr>
<td></td>
<td>(percussion)</td>
</tr>
<tr>
<td></td>
<td>test</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dimension</strong></td>
<td>All dimensions &gt;0.5 mm or one dimension &gt;5 mm</td>
</tr>
<tr>
<td><strong>Stability in Air and Water</strong></td>
<td>Does not convert into dispersible reaction products during specified tests in 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 eight 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 eight 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.

3.4 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.

3.5 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.
3.6 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."

3.7 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.

3.8 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\(^4\).

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.

3.9 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.

3.10 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
Figure 2.

TYPICAL EXAMPLE OF A RETURNABLE TYPE "A" PACKAGING

Illustration by courtesy of USAEC
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
3.11 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 3. 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 3

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>IV1</th>
<th>IV2</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum activity leak rate per hour for all packages prior to release to carrier and during &quot;normal conditions of transport.&quot;</strong></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><strong>Maximum activity leak rate per week from multilaterally-approved package after exposure to &quot;accident conditions of transport.&quot;</strong></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 3. 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 routeing, pressure and temperature monitoring enroute, and special emergency procedures.

A more detailed discussion of irradiated fuel shipments is referenced(5).

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

3.12 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 rearrangement 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 1** 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 3.17, 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.

### 3.13 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.
Figure 5.

EXAMPLE OF FISSIONSILE PACKAGING FOR UNIRRADIATED MATERIAL

Illustration by courtesy of USAEC
3.14 **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.

3.15 **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\text{Ci/cm}^2 \text{ for beta and gamma emitters and } 10^{-5} \mu\text{Ci/cm}^2 \text{ 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.

The overall 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.

Figure 7.

PLACARD FOR VEHICLES
to rail, road, inland water craft, seagoing vessels, air and postal transport.

3.16 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.

3.17 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.
(II) APPLICATION OF THE IAEA REGULATIONS

1. Canada

1.1 General

Under the Atomic Energy Control Act(6), 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 (7) are discussed in Section 1.3 following.

1.2 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(8) and GOV/1125(9) 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.
1.3 Canadian Transport Commission

The "National Transportation Act, 34:1116-231(7), 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 1.7 following.

1.4 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 (10) 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 regulations 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.

1.5 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" (11) 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 (12).

"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.

1.6 Air Transport

The regulatory authority for air transport is the Civil Aviation Branch, Department of Transport, Ottawa. This authority, in its "Air Regulations" (13) 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"(14), 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.

1.7 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(15), 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(16) 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.
Apparently, none of the other provinces have 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(17) to the Provinces. The recent "National Transportation Act," Bill C-231(7), 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(18). 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(10), 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.

1.8 Postal Transport

The Canada Post Office does not permit the transmission of radioactive materials by post(19) 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(20).

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.

1.9 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.

1.10 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.

2. THE WORLD

2.1 General

Of the nations of the world with which Canada conducts a nuclear materials trade, the United States of America, the United Kingdom, and the European countries are among the more significant. The current regulatory situation in these countries with reference to the transportation of radioactive materials is discussed briefly in the following sections. The regulatory situation in India, Pakistan and Japan is not known at this time.

2.2 United States of America

In the past, the principal regulatory authority in the U.S.A. was the Interstate Commerce Commission (ICC) which regulated interstate road and rail traffic (21). In addition, the United States Coast Guard (USCG) was responsible for marine transport and the Federal Aviation Agency (FAA) was responsible for air transport. These regulatory organizations and the United States Post Office (USPO) co-operated closely with the ICC and adopted ICC-type regulations for their respective jurisdictions.

On April 1, 1967, the new federal Department of Transportation was formally established and assumed the regulatory responsibilities of the former Interstate Commerce Commission, United States Coast Guard and Federal Aviation Agency. The Office of Hazardous
Materials of the new department administers the regulatory requirements and the Secretary of the Department of Transportation becomes the sole competent authority in the U.S.A. The publication for public comment of revised regulations for the transportation of radioactive materials (based on the IAEA Regulations) is expected by mid-1967.

The United States Atomic Energy Commission (USAEC) is active in both the regulatory and functional aspects of radioactive materials transport, both in terms of its own and its licensees' shipments. The USAEC serves as an expert adviser to the Department of Transportation, particularly in the areas of large radioactive source and fissile packaging.

A reciprocal agreement between the former Interstate Commerce Commission and the Board of Transport Commissioners for Canada permits unrestricted movement of radioactive materials between the U.S.A. and Canada provided that the packaging and shipping procedures comply with the regulatory requirements of the country of origin\(^{(22)}\).

2.3 **United Kingdom**

The regulatory authorities in the United Kingdom are the Ministry of Transport (for road, rail and marine transport), and the Ministry of Aviation (for air transport).

The U.K. has made a very significant contribution to the development of the IAEA Regulations and was the first Member State to adopt these Regulations as national regulations.

Further details of the United Kingdom regulations may be found in several references \((2)(23)\).

2.4 **European Countries**

The carriage of all dangerous goods by rail in Europe is regulated by the "RID" Regulations\(^{(24)}\). "RID" is an acronym for "Reglement International pour le Transport des Matières Dangereuses par Chemin de Fer." These regulations which were adopted in 1952 by 24 Western and Central European countries, are also used as a basis for the road and inland waterways regulations for these same countries.
The RID has co-operated closely with the IAEA and as a result, the RID regulations are very similar to those of the IAEA(25).
III) TRANSPORT ECONOMICS AND THE IAEA REGULATIONS

1. General

The safety-economic interface of any operation is one which can be examined to general advantage. This is particularly true of the transport of radioactive materials because a large fraction of shipment total weight and volume (on which shipping costs are normally based) is the packaging (which is also the basic safety element). For example, a 6500-pound package may be used to ship 3 pounds of cobalt isotope. The shipment of uranium products, which give much more favourable contents-to-packaging weight ratios, are significant because the same material in different forms may be shipped several times between uranium mine, reactor, and storage or reprocessing facility. The cost of each transport operation must be considered in the overall economic utilization of the material.

New regulations are sometimes criticized for being a source of increased costs. Such criticism is generally not valid in the case of the IAEA Regulations, because while providing a realistic and uniform level of safety, their consideration of mode-of-transport and international uniformity, of hazards involved with the various quantities and forms of individual radionuclides, of routine rather than special transport, and of efficient approval procedures, provides significant opportunity for the shipper to reduce costs.

The economics of the shipment of radioactive materials must be considered in the context of a total nuclear materials management or sales program. In this context, optimum shipping costs may not necessarily be minimum shipping costs. The following discussion identifies some of the economic factors involved in the transport of radioactive materials with the intention that they be applied in their proper context.

As has been previously identified in papers and reports (26)(27), radioactive materials transport costs consist of four major components as indicated in the following equation:

\[
\text{Total Transport Costs} = \text{Packaging Costs} + \text{Handling Costs} + \text{Freight Cost} + \text{Insurance Cost}
\]

The economics-safety considerations are developed on the basis of these four closely interrelated cost components as
well as some of the more general factors which are significant to formulation of the transport problem.

2. **Formulation of the Transport Problem**

To define a radioactive materials transport problem, the following factors must be considered in terms of current and future needs:

**Material:**

1. Radionuclide(s)
2. Physical and chemical forms
3. Total quantity involved
4. Quantity-limiting factors such as batch size, operational procedures, nuclear safety, shielding, decay heat
5. Value and ownership/lease costs.

**Packaging:**

1. Type required
2. Capacity, weight and size limitations
3. Potential utilization including frequency and total duration of use
4. Estimated service life
5. Estimated cost
6. Number required
7. Use for shipment and/or storage.

**Shipment:**

1. Origin and destination and distance between these points by various routes and modes of transport.
2. Modes of transport which may be used and unit freight costs for different methods of shipment such as express, freight, less-than-carload lot, full load.
3. Shipment frequency factors.
4. Duration of shipment for various modes of transport and resultant "turn-around" time for package.
5. Shipment limitations such as weight limits (vehicle, road, bridge, crane), size, capacity, route, operating restrictions (daylight hours, weekends, etc.).
6. Handling cost factors.
Regulatory Requirements:

1. Identify regulatory authorities and regulations for the various countries and modes of transport involved.
2. Define detailed regulatory requirements.
3. Define submission and approval requirements - packaging and/or shipment, unilateral or multilateral approval, contents of safety report, methods of demonstrating compliance, time required for approval action.

Equipped with the foregoing basic facts, a shipper may then proceed to a more detailed consideration of the packaging, handling, freight, and insurance cost components.

A shipper may acquire his own packaging and undertake the necessary operations to deliver the package to a carrier or he may contract with one of the organizations specializing in the transport of radioactive materials to provide the packaging and/or shipping service. This is a basic alternative which deserves early consideration.

3. Packaging Costs

3.1 General

Packaging costs are usually expressed as annual charges per unit of material shipped (\$ per curie or \$ per kilogram).

Annual charges include amortization and interest, and maintenance if the packaging is owned or lease charges if leased.

Since packaging costs are directly related to the amount of material shipped per year, high package capacity and maximum (and long term) utilization of packaging are immediately obvious as major economic factors.

The shipper may acquire packaging by any of the following methods:

1. Initiate design, have approved, and fabricate packaging.
2. Use a specification packaging design and fabricate packaging.
3. Acquire manufacturing rights to an approved design and fabricate packaging.
4. Purchase approved packaging.
5. Lease approved packaging.

Since each of these methods involves design, approval, fabrication and maintenance to varying degrees, all of these factors will be discussed in the following sections.

3.2 Design

The basic design objective is to achieve the most economical packaging design for the minimum design cost.

Packaging must be designed for maximum capacity, maximum contents-to-packaging weight ratio, and maximum utilization potential while complying with the regulatory requirements for shielding, containment, heat transfer, structural integrity, and nuclear safety. Although these factors are considered independently in this paper, they are in fact very closely interrelated.

The basic safety equation should be considered, carefully prior to finalizing the design specification to define to what degree the design safety and operational safety components will be employed. For example, a shipment made infrequently over a short, sparsely-populated route with radiation surveyor escort and other special arrangements may rely to a greater degree on the operational safety component and to a lesser degree on the design safety component with resultant reduced packaging costs. The flexibility of the regulations through the "special arrangements" provision permits consideration of different levels of design and operational safety provided that the overall safety level is maintained.

Packaging capacity and contents-to-packaging weight ratio are primary economic factors. The limitations on these factors should be identified and extended if possible. If packaging shape may be improved by changing the size or shape of the radioactive contents, then that should be considered.

The use of low cost, industrial-type containers as components of a packaging may have economic advantages. For example, a small steel drum centered within a large steel drum with the interspace filled with a mechanical thermal insulant, has been used successfully for low cost Type B packaging.
An essential step in the design procedure is a thorough review of the manufacturability, maintainability, and utilization potential of the packaging design.

**Shielding:**

Some of the factors which may be considered for economical shielding design are to:

1. Make accurate calculation of contact and one-meter-from-package-surface radiation dose rates to regulatory limits.
2. Use "full load" shipment which permits higher radiation dose rates from packages than does less-than-carload-lot shipment.
3. Use longer decay time of proposed contents consistent with material charges.
4. Use "space shielding" where possible. Note that regulatory limits are based on "accessible" surface which may be a "cage" around the package (which will maintain the necessary spacing under "normal conditions of transport").
5. Assure that all shield penetrations are so designed that they do not cause "hot spots" and thereby limit package contents in order to comply with regulatory limits.
6. Use shielding inserts which may be added to packaging cavity to increase shield thickness with minimum increase in weight.
7. Minimize shield total weight by using high density shielding material such as depleted uranium, by optimizing size and shape of the shielded cavity, and by shaping the outside surface of shield to avoid unnecessary shielding on square corners, etc.
8. Consider that the hazards of accumulation of packages are limited by permitting only 50 transport index units (the number representing radiation dose rate at 1 meter from the package surface in mR/hr) per package group. Therefore only five packages (having 10 mR/hr at 1 meter from the surface) may be transported per vehicle whereas 50 packages (having 1 mR/hr at 1 meter from the surface) may be transported per vehicle. Thus
the economy of transport index units may be an important factor in total transport cost.

9. Resist the temptation to "add an extra inch of shielding." Although the fabrication cost of the additional shielding may be minimal, the additional shipping cost incurred because of the additional weight may exceed its first cost each time that the package is shipped.

**Containment:**

The packaging containment must prevent loss of radioactive contents under normal and accident conditions of transport. Some of the factors which may be considered for economical containment design are:

1. The number and size of penetrations in the packaging containment should be minimized.
2. The closure should be simple, positive, and of known leaktightness capability which may be confirmed by test. Commercial type closures incorporating re-usable sealing elements are desirable.
3. The closure should be capable of being rapidly opened, closed and tested to minimize the handling time for each shipment. If necessary, operational instructions for the closure should be marked on the package adjacent to the closure.
4. Other penetrations (if necessary) such as pressure relief devices, temperature and pressure sensing elements, vent and sample ports, etc., should also satisfy the foregoing requirements.
5. The easiest heat transfer medium to contain is air at atmospheric pressure. The use of a liquid and/or pressurized heat transfer medium requires a containment vessel of greater integrity, leaktightness and cost.

**Heat Transfer:**

Heat transfer from packaging is usually significant only in the case of large radioactive source shipments. The heat transfer capability of a packaging design may be optimized by consideration of the following factors:
1. Accessible surface temperature of the packaging is limited by the regulations to prevent burn injuries to transport workers and thermal damage to companion cargo. The temperature limit is higher for "full load" shipments than for "less-than-carload-lot" shipments because of the greater operational control provided by the former. The accessible surface temperature limitation need not limit package heat transfer capacity because the "heat transfer surface" and the "accessible surface" may be separated by providing an expanded-metal or wire-mesh "cage" (whose surface temperature will not exceed the regulatory limits under normal conditions of transport) which becomes the accessible surface and satisfies the intent of the regulations. Accessible surface temperature may be further reduced by use of a solar shield which remains effective under normal conditions of transport.

2. The thermal stability limitations of radioactive and packaging materials. The use of higher-stability shielding materials should be considered—for example, steel or depleted uranium rather than lead. Thermal stress and differential thermal expansion of packaging components must also be considered.

3. The heat transfer capability of a packaging may be further increased by use of extended surfaces such as fins, or by using a more efficient (than air) heat transfer medium within the containment vessel. This medium may also be pressurized if necessary. (This approach requires careful consideration of loss-of-coolant and of leakage of contaminated heat transfer medium.)

4. Auxiliary heat transfer systems (whose reliable operation under normal and accident conditions of transport must be considered) may be advantageous.

5. Efficient heat transfer flow—especially through the shielding (where shrinkage gaps in lead shielding should be avoided), heat transfer media, and their interfaces.

6. Shipment during seasons when ambient temperatures are low may increase the heat transfer capability of a package. (This approach must consider
freezing of heat transfer medium and brittle fracture of packaging materials under impact loading.)

7. Additional storage time to reduce the decay heat load of package contents may permit shipping of larger quantities of material where packaging heat transfer capability may be limiting.

8. Establishment of a case for lower ambient temperature and solar heat load than those values prescribed in the regulations may be advantageous.

9. Since the designed heat transfer capability of a package may have to be confirmed by test on the completed package, and since the measured heat transfer capability of the package may be higher than the design value (which would normally be conservative), then the measured value should be used as the basis for approval.

10. The heat transfer capabilities of a package must be considered under both normal and accident conditions of transport, the latter of which includes fire exposure.

Structural Integrity

The structural integrity of a packaging refers to its ability to maintain shielding, containment, heat transfer, and nuclear safety capabilities under normal and accident conditions of transport.

Structural integrity in packaging design may be economically achieved by considering the following:

1. Closures should be small (for minimum inertial loads on impact and minimum sealing perimeter), should employ high performance fasteners, should be close-fitting in the packaging body (to transmit impact shear loads directly, rather than through the fasteners), and should be flush or recessed to avoid shear impacts. Where high performance fasteners are used, they should be "captive" to avoid loss and replacement with a lesser performance component.
2. Packaging structural materials should be chosen for their impact strength and should be joined with adequate and quality controlled welding.

3. Packaging should avoid areas of impact stress concentration such as corners, sudden changes of section, projecting features, notches, etc.

4. External surfaces of the package should be capable of absorbing the energy of impact through deformation while at the same time being resistant to puncture and other rupture.

5. Impact damage to the radioactive contents of the package should be considered - particularly in terms of leakage of contaminated heat transfer medium.

6. Tiedowns or other transport vehicle structure may be employed to absorb some of the impact energy.

Economically attractive protection of the packaging from fire exposure may include consideration of the following:

7. Shielding materials which are stable at fire temperatures.

8. Fire shields consisting of low combustibility materials, intumescent and ablative coatings, evaporative cooling, etc.

9. Utilization of heat capacity of shielding with intentional sacrifice of some of the shielding capability.

10. Trapping of moisture within the package should be avoided because on exposure to fire this moisture may vaporize, cause a pressure build up and result in violent failure of the packaging. The same precaution should be exercised with reference to thermally volatile packaging materials such as plastics.

One of the most economical methods of providing the necessary structural integrity for existing and new packagings is to provide a protective outer packaging made of wood, fibreboard, rigid plastic foam, or other good thermal and mechanical insulant. Usually these materials are covered by sheetmetal for additional durability. Where a packaging requires natural circulation of air for heat transfer purposes, baffled openings
may be provided in the protective outer package without loss of its effectiveness.

**Nuclear Safety**

Where nuclear safety is a consideration, the following items may be worthy of note:

1. The relative advantages of the fissile Classes I, II and III should be carefully considered in terms of packaging and shipping costs.
2. The nuclear safety evaluation of the proposed package should be made and approved before the packaging design is finalized.
3. Neutron poisons may permit increased package loadings.
4. Neutron poisons, where used, should be designed to facilitate verification and loading measurements where necessary. The performance of the neutron poisons under normal and accident conditions of transport should also be considered.
5. Containment may also be significant to prevent the leakage of water into the package.

**Design Costs**

The costs of designing a packaging may be minimized by consideration of the following factors:

1. A design specification (which is based on optimized total shipping cost and which has been reviewed by designer, shipper, carrier, and regulatory authority) should be prepared.
2. The design task should be assigned to a mature designer who has knowledge of the current regulatory requirements and of recent developments in packaging design.
3. Packaging design is well suited to calculation and optimization through utilization of a computer.
4. Standardization of packaging design will minimize design costs.
5. The alternatives to original design of packaging (purchase of manufacturing rights to an existing
approved design, specification packaging, etc.) should be thoroughly investigated.

3.3 Approval

The application for approval of packaging and shipping procedures usually consists of a safety report which documents evidence that the packaging design and the shipping procedures are in compliance with the regulatory requirements. Approval must be recognized as a step which costs money and takes time. The following considerations may minimize this cost and time expenditure.

1. Know what the packaging and shipping regulatory requirements are for the modes of transport and countries involved.

2. Define the safety report requirements through preliminary discussions with the regulatory authorities.

3. Consider carefully the relative advantages of the various methods of demonstrating regulatory compliance - theoretical analysis, full-scale testing, model testing, reference to relevant published data.

4. Make the scope of approval submission as broad as possible in order to avoid re-application for amendment to the approval when a different type or quantity of material is to be shipped or different shipping procedures are to be used.

5. Use specification packaging which does not require specific approval.

6. Consider, in the case of large radioactive source packagings (which may be used for international shipments), the relative advantages of unilateral and multilateral approval.

7. Anticipate approval requirements as early as possible in order to avoid last minute, rush applications which usually are unnecessarily conservative and result in high transport costs.
3.4 Fabrication

The fabrication cost of packaging may be minimized by the following considerations:

1. The number of packages which are built to the same design - standardized packaging designs have advantages in this respect.

2. The per-unit-capacity fabrication costs of large capacity packages are usually lower than for small capacity packages.

3. The use of a manufacturing specification to efficiently communicate fabrication requirements.

4. The simplicity and manufacturability of packaging design.

5. The capabilities, experience and work backlog of fabricator.

6. The requirements for fabrication tests and/or certification and first-use tests.

3.5 Maintenance

The maintenance costs of a packaging may be minimized by a thorough maintainability review at the design stage. Items such as closure details, vulnerable projecting features, and surface finish should receive close scrutiny. The provision of adequate and convenient handling, lifting, and tiedown attachments may minimize rough handling of the package in transport. Detachable components (especially closure bolts) should be "captive" to avoid loss during handling.

4. Handling Costs

4.1 General

Handling costs result from the loading of the package, its preparation for shipment, and its presentation to the carrier. The objectives of efficient handling are minimum
direct cost and minimum elapsed time - especially where a short "turnaround time" is necessary from a package utilization point of view. Efficient handling results from careful consideration of design of package and facilities and from effective operational procedures.

The following sections identify some of the factors which are significant to handling costs and which should be examined thoroughly. Although these factors are presented in the context of a shipping operation, they may also be applicable to a receiving operation.

4.2 **Loading the Package**

Loading may take place in a shielded cell, water filled bay or other loading area which is serviced by lifting and handling equipment. The following factors may be involved in a loading operation:

1. A knowledge of loading limitations for which the package has been approved.
2. "Pre-packaging" of material for operational or safety reasons.
3. Tests during loading - especially for some types of fissile materials.
4. Preliminary closure of package (remote handling of closure components may be necessary).
5. Drainage of package (following wet loading).
6. Preliminary decontamination.

4.3 **Preparation for Shipment**

This operation normally includes the following steps:

1. Secure closure, leak test (if necessary), and apply security seal.
2. Check that non-fixed surface contamination is within regulatory limits. Decontaminate if necessary.
3. Check that radiation dose rates at the surface and at one meter from the surface of the package are within regulatory limits.

4. Apply labels and include contents, name and activity, and transport index units as applicable.

5. Sample heat transfer medium of large radioactive source shipments to determine contamination level. Employ a holding period to permit equilibration and measurement of temperatures and pressures.

6. Make arrangements with carrier.

7. Prepare shipping documents including consignor's certification.

8. Provide advance notification to consignee and regulatory authority as necessary.

4.4 Presentation to Carrier

This step may include loading onto the transport vehicle and advising the carrier of routine and special instructions and requirements.

The question of package tiedowns is sometimes raised at this stage. If a package complies with the regulatory requirements in all respects without being dependent upon tiedowns or other blocking or bracing structures, then the only requirements for securing the package to the vehicle are those which are normally applied to other types of large or heavy cargo. These tiedowns need consider only conditions normally encountered in transport—"panic stop" braking forces, acceleration and vibration, centrifugal forces, bumps as caused by driving over curbs or backing into loading docks, "humping" impacts for rail cars, etc.

If the use of a tiedown system is a condition of regulatory approval, then the primary responsibility for its proper installation and use rests with the shipper.
5. Freight Costs

Freight costs may be FOB or prepaid by either consignee or consignor or may be any combination of these factors.

Freight rates may be influenced by commodity classification, declared release value, size of shipment, mode of transport, distance of shipment, "full load" (FL) or "less-than-full load" (LFL) shipment, and may be based on either the weight or the volume of the package. Freight rates are published for most modes of transport.

Freight rates for radioactive material shipments may be strongly influenced by the commodity rate classification. Thus, care must be taken in establishing such commodity classifications and the IAEA Regulations may be of some assistance in this respect with the general material classifications of exempt, low specific activity, Type A, Type B, large radioactive source, and fissile.

The shipper's "declared release value" of the shipment (which limits the carrier's liability for damage to or loss of the shipment) also affects the freight rate significantly. Since "declared release value" includes the value of the packaging and its contents, an additional advantage of low cost packaging becomes apparent. It may also be advantageous for the shipper to ship on a "no declared value" basis (in which case the carrier is liable only for a set minimum value) and independently provide insurance to cover damage or loss.

In most cases, it is possible for the shipper to negotiate with the carrier on freight costs, either on the basis of specific commodity classification or freight rate. In this respect, the carrier may be influenced by a knowledge of the IAEA Regulations' provisions for safe packaging of the various classes of radioactive materials and of the excellent safety record in the transport of radioactive materials.

Since a significant part of freight costs may be the cost of returning the empty packaging (which may or may not receive a lower freight rate than the loaded package), the use of non-returnable packagings should be considered where
applicable. Again, low cost packagings exhibit a distinct advantage. Where the sum of return freight cost and packaging return overhead and administrative costs exceed the cost of the packaging, or where suitable terms can be arranged with the consignee, non-returnable packaging should be used.

Freight costs may also be influenced by the transport index units of package or shipment, depending upon the type and number of packages involved and their method of shipment.

Containerization (the collection of a number of smaller packages into a larger, standardized package) may result in reduced freight costs. The outer container may also incorporate impact and fire resistance features as required by the regulations. It may be possible to qualify specification packagings (which meet the carrier's containerization requirements) for lower freight rates.

Particularly in the case of large and/or very heavy shipments, there may be an economic advantage in shipping "full load" (FL) rather than "less-than-full load" (LFL).

The cost of "special arrangements" such as full load, radiation surveyor escort, special shipment itinerary, etc., should also be included in freight cost.

The choice of a carrier may directly or indirectly influence the shipper's costs depending upon the limits of the carrier's franchise, the frequency of scheduled trips, and the efficiency of the carrier's follow-up services such as tracing, billing, rate classification, and claims.

Participation of the Canadian Nuclear Association in the recently organized Canadian Shipper's Council may benefit shippers of radioactive materials.

6. Insurance Costs

There are two components of insurance costs - insurance to cover damage to or loss of the radioactive materials and packaging and third party insurance.

The former item has been discussed in the previous section. The latter item will not be discussed beyond mentioning that it
is a very difficult subject and that there are some references available on the subject\(^{(28)}\).

The use of packaging to the IAEA standards may result in lower insurance costs.
IV CONCLUSION

Uniform national and international regulations based on the IAEA Regulations provide safe transport and offer significant scope for more economic transport of radioactive materials. In order to take advantage of the economic potential inherent in these regulations, the packaging designer, shipper, and carrier must be fully aware of the basis for and application of the regulations and of the technical and economic factors relating to packaging and shipment.

The CNA Sub-Committee on the Safe Transport of Radioactive Materials has made excellent progress in promoting a greater awareness of the IAEA Regulations within the Canadian nuclear industry. The Atomic Energy Control Board is also very interested in developing a greater knowledge of the requirements for safe and economic transport of radioactive materials.

The advantages of standardized and specification packaging to the Canadian nuclear industry have been mentioned several times in this paper. Coordinated action by the whole nuclear industry in this area should result in significantly improved transport economics as would a more creative approach to packaging design and development of shipping procedures.

V ACKNOWLEDGEMENT

The author acknowledges with sincere gratitude the co-operation 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 CNA Sub-Committee (of the Safety Committee) on the Safe Transport of Radioactive Materials.
## APPENDIX I - Radionuclide Transport Groups and Package Limits

<table>
<thead>
<tr>
<th>Material Form</th>
<th>Dispersible Form</th>
<th>Special Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Group</td>
<td>I</td>
<td>II</td>
</tr>
<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(a23)</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-233</td>
<td>Th(nat)</td>
</tr>
<tr>
<td>Th-230</td>
<td>Ra-224</td>
<td>U(nat)</td>
</tr>
<tr>
<td>Th-233</td>
<td>Sr-90</td>
<td>U-235</td>
</tr>
<tr>
<td>U-232</td>
<td>U-233</td>
<td></td>
</tr>
<tr>
<td>Type of Packaging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exempt material</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01 mCi</td>
<td>0.1 mCi</td>
</tr>
<tr>
<td>Exempt instruments and articles:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per item</td>
<td>0.1 mCi</td>
<td>1 mCi</td>
</tr>
<tr>
<td>Per package</td>
<td>1 mCi</td>
<td>50 mCi</td>
</tr>
<tr>
<td>Type A</td>
<td>1 mCi</td>
<td>50 mCi</td>
</tr>
<tr>
<td>Type B</td>
<td>20 Ci</td>
<td>20 Ci</td>
</tr>
<tr>
<td>Large Radioactive Source</td>
<td>No prescribed quantity limits per package</td>
<td></td>
</tr>
</tbody>
</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"

1. **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 3 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.
VII  LIST OF REFERENCES


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VII - Page 2.

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POWER COST-EVALUATION PURPOSES, ORNL-3943, March 1966

(28) Refer Chapters 18 and 19, Reference 2.
VIII - LIST OF TABLES AND FIGURES

Table

1. ICRP Recommended Exposures - Basis for Transport Regulations
2. Requirements for "Special Form" Materials
3. Permissible Activity Release by Leakage of Contaminated Heat Transfer Medium from Large Radioactive Source Packages

Figure

1. Typical Example of Non-returnable Type A Packaging
2. Typical Example of Returnable Type A Packaging
3. Typical Examples of Type B Packaging
4. Example of a Large Radioactive Source Packaging
5. Example of Fissile Packaging for Unirradiated Material
6. Package Labels
7. Placard for Vehicles