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RADIOACTIVE MATERIAL TRANSPORT
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Introduction

All told, a considerable amount of radioactive material is being moved in Canada these days, taking into account shipments of uranium and other radionuclides for domestic use or export and transfers of radiation sources incidental to their use. There are currently 250 or so radionuclides (i.e. radioactive isotopes of one element or another) commercially available, in a variety of chemical and physical forms. Various of these are being supplied, in quantities ranging from a microcurie or less to several thousands of curies, to users in industry and in the fields of medicine, research and teaching (of which there are more than 3200, organizations and individuals licensed by the Atomic Energy Control Board to possess radionuclides) and to manufacturers for incorporation into devices and consumer products, such as luminous watches and ionizing type smoke detectors, which in turn are themselves distributed. Certain of these licensees, notably the industrial radiography companies, also transport their sources during the course of their day-to-day activities, from job-site to job-site.

Regulations - General

All such movements, regardless of the radionuclide or quantity involved, whether it is being transported by common carrier or private vehicle, by air, land or sea, are governed by a comprehensive body of regulations. These are prescribed:

1. in the "IATA* Restricted Articles Regulations" for carriage by air
 *promulgated by the International Air Transport Association
2. in the "International Maritime Dangerous Goods Code"* for carriage by sea and inland waterway
 *promulgated by the Intergovernmental Maritime Consultative Organization (IMCO)
3. in the "Regulations for the Transportation of Dangerous Goods by Rail"* for carriage by rail and road
 *issued by the Canadian Transport Commission (CTC).

These have been extended to cover transport by road by the Atomic Energy Control Board because no other agency - federal or provincial - has established appropriate requirements for this mode.

The AECB may also vary these requirements in the case of road.

Other regulations applicable to transportation by highway vehicle are:

- (1) Alberta Regulation 295/63
- (2) Manitoba Regulation H60/15
- (3) Ontario Regulation 412
- (4) Québec Regulation 75-497.

4. in the "Prohibited Mail Regulations"

Transmission of radioactive material by post is not permitted in Canada.

This listing gives the impression that requirements vary by mode and province. By and large this is not the case; other than the prohibition on mailing radioactive substances there are no significant inconsistencies or conflicts either intermodally or federally - provincially. The IATA, IMCO and CTC regulations, which define inter alia how the material shall be packaged, the criteria which packagings must satisfy, how packages must be labelled or marked and the documentation required, are virtually identical because they all derive from a common basis: a set of model provisions promulgated by the International Atomic Energy Agency (IAEA). The variances which do exist are essentially minor in nature, most of them are attributable to a difference in the generation i.e. age of the regulations: the IMDG Code and one section (the more up to date one) of the IATA Regulations (Part 2A) are based on the 1973 edition of the IAEA standard (1) whereas the alternate section of the IATA Regulations (Part 2B) and the CTC Regulations are based on an earlier version, published in 1967 (2). As for the provincial regulations, these are fundamentally compatible with the federal ones because they impose requirements on the carrier, for placarding of vehicles carrying radioactive material and avoiding certain tunnels in Montreal, whereas the CTC requirements apply mainly to the consignor.

Regulations - Basic Considerations

As is generally recognized, radioactive material is dangerous because it emits radiation. It may also be dangerous in two other ways: controlling the radiation may result in the generation of considerable heat, which may produce high temperatures or high thermal fluxes; besides this, some radionuclides, notably uranium-233 and 235 and the plutonium isotopes, can form, relatively easily, what is termed a critical system i.e. in certain circumstances they can give rise to a nuclear chain reaction, which results in the release of much more radiation.

The radiation hazard posed by any radioactive material is a function of many factors, some of which are related to the radionuclide, others which are fundamental and independent of the substance involved. In the first class are the type, intensity (per unit time) and energy level of the radiation emitted and the specific activity (the amount of radioactivity per unit mass), half-life and physical and chemical properties of the nuclide. In the second are distance, shielding and time; in any particular situation:

radiation intensity (per unit time) decreases as

- (i) the distance between the source and the absorber increases, in accordance with the inverse square law (i.e. doubling separation reduces intensity to one-quarter of the original level)
- (ii) shielding material is interposed between the source and the absorber (the degree of reduction depends on the nature of the radiation and the properties of the shielding, particularly its thickness)

Two types of radiation, α and β particles, can be completely stopped by comparatively thin layers of shielding.

and, radiation dose received decreases as

- (iii) the time of exposure of the absorber is reduced, in direct proportion.

It is obvious from these considerations that the worst case occurs when radioactive material is taken into an organism since then separation is minimized (in fact the substance may actually be incorporated into the structure of cells), there is essentially no shielding and the time of exposure may be long. Additionally, the nuclide may accumulate in one or other part of the body, concentrating the radiation dose on the particular organ in question. This produces what is termed an internal exposure or radiation dose; in comparison, when the source is outside the body an external exposure or radiation dose results.

Criticality, a nuclear chain reaction, occurs when the neutrons emitted from the normal radioactive decay of uranium, plutonium and several other less common nuclides cause the fissioning of other atoms in the material. This releases more neutrons which in turn cause more fissions and so on (thus the chain reaction). As a result, in a very short time, typically fractions of a second, a very large number of neutrons (which constitute a type of radiation) are emitted. Eventually, the

neutron release rate stabilizes (as happens in nuclear reactors, where conditions are closely controlled) or it reaches a peak, at which point the critical system disintegrates, and then falls off.

To produce a critical system requires:

- (i) a certain minimum quantity of the fissile material i.e. the critical mass (the amount of which depends on the radionuclide and the geometry involved)
- (ii) a particular geometry or arrangement of the material (so that neutrons strike atoms which can be fissioned and do not merely escape from the system)
- (iii) the absence of materials which absorb neutrons without fissioning, i.e. neutron "poisons" (which prevent the reaction from propagating) or the presence of other sorts of materials which reflect neutrons back into the radionuclide (thus enhancing the reaction).

Heat is produced by the radiation striking and being absorbed by other atoms of the radioactive material or of the container and/or shielding surrounding it. (The radiation is transformed into thermal energy.) This may be sufficient to cause high temperatures within the material itself or in the container or high thermal energy fluxes, which could be detrimental in various ways: by changing the chemical or physical state of the radionuclide, impairing the container, damaging nearby temperature or heat sensitive goods or harming workers who handle the package. In most cases, however, either the heat production rate is low, because little radioactive material is present or it is not highly active, or the heat is emitted over a large surface area, thus reducing flux; as a result heat is usually not a significant hazard.

Except for the chemical nature of the radionuclide, all these factors and considerations were taken into account in the development of the Regulations.

Regulations - Specific Provisions

The objects of the Regulations are:

- (i) to minimize the radiation dose received by people, members of the public and transport industry workers, (from internal and external sources) and radiation sensitive goods, such as undeveloped photographic film, during the normal course of transport operations and after accidents

- (ii) to minimize the possibility of criticality occurring in the case of fissile materials

and,

- (iii) to prevent people or heat-sensitive goods from being damaged by high surface temperatures or high thermal fluxes.

These objects are achieved by a combination of systematic precautions, requirements concerning the features, strength and external radiation levels of packages (design safety), and administrative controls, requirements pertaining to the labelling, handling and storage of packages (operational safety). Greater reliance is placed on the former rather than the latter measures, however, for several reasons, notably: first, because systematic precautions are easier to formulate and implement than administrative controls; secondly because they are also more certain and thirdly, because they obviate the need for extraordinary treatment of radioactive shipments by the transport industry, as compared to other dangerous goods. The actions for which transport workers are responsible are essentially simple and easily carried out. The implicit philosophy of the Regulations is to place the onus for safety during transport on consignors; it is assumed that they are familiar with the radioactive material involved, the dangers it presents and how it should be treated; concomitantly, the role accorded carriers is deliberately minimized (3).

For shipments of non-fissile radionuclides, such as iodine-131 for medical purposes, iridium-192 for industrial radiography or an organic compound containing carbon-14 for use in research, protection must be provided against radiation, the principle hazard, and possibly heat. Accordingly, the Regulations prescribe requirements for:

- (i) containment, to prevent the loss and dispersion of the material,
- (ii) the maximum allowable contamination levels i.e. radionuclide concentrations on the external surfaces of packages,

(these measures are intended to guard against the uptake of material, to minimize internal exposure)
- (iii) radiation levels, i.e. intensities at the surface of and 1 m from the package,
- (iv) labelling, related to the radiation levels at the surface of and 1 m from the package,

(these provisions control the radiation level and furnish information so that the appropriate separation distance can be determined and provided, to minimize external exposure)

- (v) separation of packages, at distances proportional to the radiation level at 1 m from the surface, from locations occupied by people, animals or sensitive goods,

(these distances are predicated on certain assumptions about exposure times, in hours per journey and journeys per year)

- (vi) stowage, to prevent certain other dangerous goods, in particular explosives, from being loaded close to radioactive materials and to keep other cargo away from packages emitting high thermal fluxes,
- (vii) placarding of rail and road vehicles and the information which must be given in shipping papers (waybills, switching orders, etc.).

Of all the requirements, the ones pertaining to containment are the most important, for the reasons mentioned earlier. These are expressed not in terms of packaging details - the type and thickness of construction material that must be used, how joints and closures shall be made, and so forth, -- as is done in the regulations which govern the transport of other dangerous goods, but rather as performance standards related to the amount, physical form and radiological properties of the intended contents. These become more severe as the magnitude of the hazard increases.

Clearly, however, the criteria cannot be varied to precisely match the hazard in each case, that is impractical; instead the Regulations prescribe a set of qualifications which define the state a material must be in to be considered non-dispersible and provide for, nominally, five categories of package. These comprise: Low Specific Activity (LSA); Low-Level Solid (LLS); Limited Quantity (also referred to as Exempt); Type A and Type B packages; there are, in addition, a number of variations of these categories.

The key element of this set is the Type A package. This category provides for relatively low-cost, limited performance containers - a "fruit-can" in a fibreboard box is a frequently used design. Such packages must be capable of withstanding the handling practices and minor mishaps which are considered normal during transport. Their adequacy in these respects must be proven, either by subjecting a specimen or specimens to certain tests or by engineering analysis to show that they are strong enough to pass these tests. Type A packages are not expected to withstand accidents, however. For this reason there are restrictions, known as A_1 and A_2 values, on the amounts of radioactive material

which may be transported in them. The basis from which these values are derived is that, in the event a package is damaged, the radiation dose received by any person - transport workers, emergency rescue or clean up crew or bystander - should not exceed 3 rem. The A_1 value pertains to non-dispensible material which gives rise to external radiation exposure; the A_2 value to material which could be taken into the body and cause internal exposure; both values depend on the radiological properties of the nuclide.

When the quantity of material to be transported exceeds the A_1 or A_2 value for the nuclide, as applicable, a Type B package must be employed. Containers of this class must be capable of withstanding accidents, including fires; thus they must be made from metals that will withstand the effects of a fire. As for Type A packages, their adequacy must be proven, again either by actually subjecting a specimen or a design model to tests (both those prescribed for Type A packages and additional, more severe ones), or by engineering analysis. In this case, however, the evidence must be submitted to the Atomic Energy Control Board for review. Two classes of Type B packages are provided for: B(U) and B(M); the requirements for the first class, particularly as regards containment, are more restrictive. Operational controls may be required for some Type B(M) packages to compensate for the differences. These must be approved (or they may be prescribed) by the AECB and if the package is to enter or pass through other countries, by the responsible authorities of those states.

If the amount of radioactive material is very small, less than one hundredth of the A_1 or A_2 value for the nuclide if it is in an enclosure such as an instrument or similar device, or less than one thousandth of the A_1 or A_2 value if not, it may be transported in a Limited Quantity or Exempt category package. Provided that the external radiation level is low, not more than 0.5 mrem/h, such packages are exempt (hence the name) from most of the provisions applicable to the Type A category, including the requirements for testing, on the grounds that since they contain so little material the hazard they present is relatively small. Even if all the contents were released from the package it is unlikely that anyone would receive a dose in excess of 3 rem.

The same consideration applies in the case of materials which have a low specific activity i.e. a low concentration of radioactivity, for example uranium and thorium. Such materials are considered inherently safe because substantial amounts of them, in the order of milligrams, would have to be taken into the body to produce a significant radiation dose. It is considered inconceivable that any event which might occur during transport would result in an uptake of that magnitude, even an accident

in which a large quantity, hundreds of thousands of kilograms, of material is spilt. Thus, only minimum containment requirements are prescribed. In Canada, LSA shipments not under the close control of the consignor must be contained in a Type A package; where the consignor is able to exert greater control, either by using his own vehicle or by agreement with the carrier, the requirements are less stringent.

Materials whose specific activity exceeds the limit for the LSA category but which are similar in nature and only moderately radioactive, such as wastes from nuclear operations and slightly contaminated objects, may be classified as Low Level Solids. Packages of this category must meet two of the test requirements applicable to Type A packages and must be transported under the direct control of the consignor. (Note: This category does not appear in the present CTC Regulations.)

As to labelling, there are three classes known as WHITE-I, YELLOW-II, and YELLOW-III. The radiation level limits applicable to these are:

WHITE-I	up to 0.5 mrem/h at the package surface
YELLOW-II	from 0.5 mrem/h up to 50 mrem/h at the package surface, and up to 1.0 mrem/h at 1 m from the surface of the package
YELLOW-III	from 50 mrem/h up to 200 mrem/h at the package surface, and up to 10 mrem/h at 1 m from the surface of the package.

(The radiation level at 1 m from the package is called the Transport Index.)

With one exception, Type A and Type B packages and LSA packages not subject to close control must fit into one of those classes and must bear two labels of the applicable design. The only exception allowed is for packages under close control which may have a radiation level of up to 1,000 mrem/h at 1 m from the package under the CTC Regulations (at the package surface under the 1973 IAEA edition), provided that certain other requirements are met.

For shipments of fissile materials, such as enriched uranium (i.e. containing more than 1% of the 235 isotope because, perhaps somewhat surprisingly, natural uranium, which has a U²³⁵ content of 0.72 wt %, is considered non-fissile) or spent fuel from a nuclear reactor, which contains plutonium, protection must be provided against radiation and criticality, either of which may be the principal hazard, and possible heat. Accordingly, the Regulations prescribe both the requirements for radiation protection and others concerning:

- (i) the geometry of packages and arrangement of the fissile material itself,
- (ii) the presence or absence of water (which may act as a neutron absorber or reflector, depending on the circumstances),
- (iii) the total mass of fissile material in an individual package or a set of packages.

Four categories of packages for fissile materials are provided for in the Regulations: Fissile-exempt, Fissile Class-I, Class-II and Class-III.

When the quantity of fissile material is small, not more than 15 grams, or the nuclide is diluted with other materials, as specifically prescribed in the Regulations, there is virtually no possibility that it could form a critical system during transport. Such shipments are, therefore, exempted from the additional requirements.

If the qualifications of the fissile-exempt category are exceeded the package must meet the requirements of either Fissile Class I, Class II or Class III. These categories differ from one another in the way that protection against criticality is provided: in Class I reliance is placed primarily on design safety, packages must be inherently safe, whereas in Class III reliance is placed on operational safety. Class II constitutes an intermediate case. The administrative controls for Class III shipments must be reviewed and approved by the Atomic Energy Control Board.

The difference between the Class I and the Class II categories lies in the number of packages which may be put together without producing a critical system. This restricts the amount of material which may be contained in a package, less for a Class I than a Class II design. The provisions of Class I require that any number of "undamaged" i.e. whole packages or up to 250 "damaged" ones, into or from which water has leaked to the worst possible extent and which are fully surrounded by water, when stacked together in any arrangement shall be sub-critical by an adequate margin. For Class II packages these bases (of any number and 250) are lowered to five times an "allowable number" and twice the "allowable number" respectively; the number of packages which may be transported together is then limited to one "allowable number" by administrative controls. (The "allowable number" is the

smaller of either one fifth of the number of undamaged packages that forms almost a critical system - the same adequate margin must be included - or one half the number of damaged packages that forms almost a critical system. "Undamaged" means the condition in which the package was designed to be transported; "damaged" means the condition produced by the tests applicable to the Type A and Type B categories, followed by one or other additional test relevant to submersion in water, whichever is the worst combination). The design of both Class I and Class II packages and information on the damage caused by testing are subject to review and approval by the Atomic Energy Control Board.

The same labels as described earlier are used for fissile category packages except that:

- WHITE-I cannot be used on a Fissile Class II or Class III package (even if the external radiation level is less than the limit of 0.5 mrem/h)
- YELLOW-II cannot be used on a Fissile Class III package nor for a Class II package if the ratio* of $\frac{50}{\text{the design "allowable no."}}$ exceeds 1.0.

(*This ratio is also known as the Transport Index.)

After having selected the appropriate container, and verifying its adequacy, if and as necessary, including obtaining approval for the design from the Atomic Energy Control Board, and after having put the radioactive material in it, it only remains for the consignor to check the contamination concentration on the package surface, to measure the external radiation and apply the appropriate labels and to complete the shipping papers. These must show what the shipment comprises - the radionuclide, its chemical and physical state and quantity, the category of package and the labels applied.

Carriers are only required to

- (i) limit the number of packages put together in a storage area or loaded in a vehicle so that the total Transport Index does not exceed 50,
- (ii) separate packages from occupied places or undeveloped film - in accordance with the distance prescribed for the package Transport Index number,
- (iii) restrict access to damaged or suspect packages and to check for contamination in vehicles and storage areas in which radioactive material shipments are frequently placed,

- (iv) segregate radioactive material packages from shipments of other dangerous goods.

No specific requirements for tie-downs are prescribed; it is considered that the other precautions i.e. those built into the package itself, are sufficient.

Shipments and Incidents

A survey conducted by the Atomic Energy Control Board in 1977 showed that in the order of 500,000 packages of radioactive material were shipped that year. Included in this figure were (approximately):

85,000 packages of radionuclides for medical purposes

352,000 packages - instruments and devices containing radioactive material (including smoke detectors)

3,000 packages - sources for industrial uses

49,000 packages containing uranium concentrates or fuel elements for nuclear reactors

700 packages containing fissile materials

These figures refer to packages shipped by consignors, they do not include data on movements of radiography cameras or devices which were transported incidental to use nor do they show the actual number of shipments made. It is probable that some consolidation occurred i.e. a number of packages were transported together.

As to incidents, remarkably few in which surface radiation levels have increased or material has been released have occurred and none of those which have happened have resulted in anyone receiving a significant radiation dose, as far as can be ascertained. The average frequency of all kinds of incidents over the past five and a half years is 13 per year. The majority of these, 38 out of the 73 reported, occurred during road transport operations, and another 23 related to packages being shipped by air (many of these involved incorrect shipping papers). Further details are given in the attached table.

Emergency Measures

In the event that a package is damaged and material is released from containment, or even if leakage is only suspected, expert help should be obtained as soon as possible.

But, as in all radiation emergencies, the procedure that should be followed is

1. Take care of any victims
2. Prevent the spread of radioactive material
3. Decontaminate persons
4. Clean-up contamination

remembering during such operations to:

minimize TIME spent in proximity to the source

maximize DISTANCE from the source, to the extent possible

and to interpose SHIELDING

to reduce the radiation dose received.

References

- (1) IAEA Safety Series No. 6, Regulations for the Safe Transport of Radioactive Material, 1973 Revised Edition.
- (2) IAEA Safety Series No. 6, Regulations for the Safe Transport of Radioactive Material, 1967 Edition.
- (3) IAEA Safety Series No. 37, Advisory Material for the Application of the IAEA Transport Regulations.

SUMMARY OF INCIDENTS - RADIOACTIVE MATERIAL IN TRANSIT 1974 - 1978

Year	Total No.	Mode of Transport					Terminal	Type of Package				Class of Incident ⁽⁵⁾					Remarks
		Road	Rail	Air	Marine			LSA	LQ	A	B	I	II	III	IV	V	
1974 ⁽¹⁾	7	3	1	-	1		2	1	-	3	3	2	3	1	1	-	Class III involved 22 Ci Ir-192 Class IV involved drum of LSA material
1975 ⁽²⁾	11	6	-	1	1		3	3	1	5	2	9	-	1	1	-	Class III involved LSA-MFP 0.6 Ci Class IV involved drum of Yellowcake
1976 ⁽³⁾	14	11	-	3	-		-	2	1	6	5	9	4	-	1	-	Class IV involved loss of LSA material from ENL truck en route to waste management site
1977 ⁽⁴⁾	16	5	-	6	-		5	2	2	7	5	11	3	-	1	1	Class IV involved 36 Ci Ir-192 IRIS camera breached, capsule exposed Class V involved leakage 4 kg tritiated Heavy Water - 1 drum in shipment of 28
1978	17	6	1	8	1		1	3	2	8	4	10	2	4	-	1	Class V involved 2 x 4 µCi I-125 in 737 crash at Cranbrook
1979 to date	8	7	1	-	-		-	-	2	4	2	5	2	1	-	-	
Totals	73	38	3	18	3		11	11	8	33	21	46	14	7	4	2	

- Note: (1) 2 occurred beyond Canada, involved Canadian packages.
 (2) 1 occurred beyond Canada, involved Canadian packages.
 (3) 2 resulted from improper action by U.S. consignor.
 (4) 1 resulted from improper handling in the U.S.

(5) See overleaf for explanation of categories.

CLASSIFICATION OF INCIDENTS

The classification scheme is intended to provide a measure of severity of transportation incidents, and is described below.

Class I - No loss of Integrity

Damage to the package is suspected because the package was in a vehicle involved in a collision, it had fallen from a vehicle, or it had been hit in some other way. The shipment is delayed or stopped. No radioactive material is released and there is no loss of package integrity.

Class II - Package breached; no material released

The package integrity is breached. There is no release of radioactive material but some increase in exposure dose (up to 1 rem/h at one metre from the surface of the package) may have occurred.

Class III - Package breached; contents remain within package or vehicle

Radioactive material is released but is retained within the packaging or vehicle. This includes cases where the radioactive material is held within the containment system, but the exposure dose rate has increased to a value greater than 1 rem/h at a distance of one metre from the surface of the package.

Class IV - Materials released to ground

Radioactive material is released to the ground in a manner which results in negligible run-off or aerial dispersal.

Class V - Material released to atmosphere

Radioactive material is released in a manner which results mainly in aerial dispersal.

Class VI - Material released to watercourse

Radioactive material is released in a manner which results in the bulk of the radioactive material entering either directly or indirectly, into a watercourse.

Unclassified

Incidents, such as loss or theft, which do not fit the above classification scheme.