The Shipment of Radioactive Material in Type A, Exempt and LSA Packages

by M. White

Surveys of radioactive materials shipments and other reports indicate that the majority of consignments are transported in Type A, Exempt and LSA packages, as defined in the IAEA Transport Regulations Refs. [1]*, [2]. For instance, data gathered in the USA in 1975 Ref. [3] show that out of a total of some 2 500 000 or so packages shipped there during that year, approximately 1 200 000 (48%) were Type A, 700 000 (28%) were Exempt and 310 000 (12%) were LSA (Low Specific Activity). This pattern is understandable in light of the ways in which radioactive materials are employed in industry, research, medicine, consumer products and for electricity generation. Some of the radionuclides in commonplace usage are listed in Table 1; most of the Low Specific Activity materials transported comprise physical and chemical concentrates of natural uranium (as 'yellow-cake' (a diuranate salt), uranium hexafluoride and new reactor fuel) and low-level radioactive wastes (objects and materials contaminated with small amounts of various radionuclides). Many other nuclides are also used for the purposes mentioned in Table 1 and for others Ref. [4].

The maximum allowable quantities of these nuclides in Type A and Exempt category packages are presented in Table 2. In many cases where the radionuclides are to be used directly, such as pharmaceutical compounds and tracer compounds, the material is shipped in bulk form e.g. technetium-99m generators, from which individual doses are withdrawn as needed.

TYPE A PACKAGES

The Type A category provides a means for shipping intermediate quantities of radioactive materials (as compared to small quantities in Exempt category packages and large quantities in Type B packages) at moderate cost yet with a high degree of safety. The characteristics of this class, and also the regulatory prescriptions governing it, have their origins in the practices and rules of the late 1940's and 1950's, they have evolved appreciably since then, however, in both practical and theoretical respects Ref. [5]. Typical packagings in current use — comprising containment system (receptacles and absorbent), shielding, spacing elements and outer container — are shown in Figures 1 & 2, other common forms are described in Refs [6, 7, 8 and 9].

* Referred to in the remainder of this article simply as the regulations

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Table 1. Some of the radionuclides in widespread use

Radionuclide*	Use/Purpose	Amounts Employed
Americium-241	Smoke detectors	• up to 5 μCi in domestic models 15+ μCi in commercial/industrial units
(with Beryllium)	Moisture Content-Density gauges	• in the order of 50 mCi
	Oil & Gas Well Logging	• up to 15 Ci
Gold-198**	Research/tracer	• up to Ci's, depending on whether lab work or field studies
Carbon-14**	Research/tracer	• in the order of μCi
Cobalt-57, 58, 60**	Medical/diagnostic	• in the order of 1 μCi per dose
Chromium-51**	Medical/diagnostic	• in the order of 50 μCi per dose
Caesium-137	Moisture Content-Density gauges	• up to tens of mCi
	Medical/therapeutic	• up to 200 mCi or so per treatment
	Oil & Gas Well Logging	• up to 1–2 Ci
	Density & Level gauges	• up to 5 Ci
Gallium-67**	Medical/diagnostic	• in the order of 1.5 mCi per dose
Tritium	Luminescent devices	• up to 200 mCi in watches, • up to 25 Ci in exit & similar signs
Tritium**	Research/tracer	• in the order of μCi
	Oil & Gas well/tracer studies	• up to tens of Ci
Iodine-125**	Medical *in vitro* tests	• in the order of μCi
	Research/tracer	• in the order of μCi
Iodine-131**	Medical/diagnostic	• up to 50 μCi or so per dose
	Medical/therapeutic	• up to 100 mCi per dose
Iridium-192**	Oil & Gas Well Logging	• in the order of μCi
Krypton-85	Thickness gauges	• up to 1 Ci
Neodymium-147**	Research/tracer	• up to Ci's, depending on whether lab work or field studies
Polonium-210	Static eliminators	• up to 100 mCi or so in industrial units
Scandium-46**	Research/tracer	• up to Ci's, depending on whether lab work or field studies
Strontium-90	Thickness gauges	• up to 25 mCi
Technetium-^{99m}**	Medical/diagnostic	• up to 20 mCi per dose
Thallium-201	Medical/diagnostic	• in the order of 1 5 mCi per dose

* Sealed sources excepted where marked**

As is evidenced by these examples and as is generally the case, Type A packages are made up of basically lightweight, low-strength components. Thus, they are liable to be damaged in accidents. This eventuality was recognized in the development of the regulations and is reflected in the limits on the contents of packages. These are derived from the premises that, in a 'median' accident Ref. [10]:

(i) the shielding of the package is completely lost,

(ii) up to one thousandth (10^{-3}) of the radioactive material may escape from the containment system.

(It is acknowledged that greater releases could occur but these would be caused by accidents more severe than the notional 'median' event; the likelihood of such accidents was considered to be so small, however, that they did not need to be taken into account. Experience, thus far, has justified this policy.)

(iii) the external radiation dose received by any person as a consequence of the loss of shielding is not to exceed three rem, assuming that the individual may spend up to three hours at a distance of three metres from the source,

(In other words, for an α-emitting radionuclide, the maximum allowable radiation intensity at one metre from the bare source is nine rem per hour. The analogous criteria for α, β, neutron and X-ray emitters and those radionuclides which emit several kinds of radiation are slightly different. See Ref. [10].)

(iv) the amount of radioactive material taken into the body of any person as a consequence of the loss of containment is not to exceed half the maximum permissible annual intake for radiation workers (equivalent to a maximum radiation dose of three rem where the whole body, the gonads or the red bone marrow is the critical organ*); it is assumed that this constitutes, at the most, one thousandth (10^{-3}) of the material released.

(In other words, up to, but no more than, one millionth (10^{-6}) of a package contents may enter into someone's body as a consequence of the loss of containment of a releasable-dispersible i.e. non-special form material resulting from a median accident.)

The activity calculated on the basis of premises (i) and (iii) is called the A_1 limit; by definition this is only applicable to special form material. The figure developed from premises (ii) and (iv) for non-special form material is called the A_3 value; for most radionuclides this is greater than the A_1 limit. Premises (i) and (iii) are considered superior to (ii) and (iv), however (because, obviously, this provides an additional measure of safety); accordingly, the greatest activity of non-special form material which may be shipped in a Type A package, called the A_2 limit, is restricted to the lower of the A_1 and A_3 values. However, both limits are subject to an arbitrary, overriding maximum of 1000 curies.

Although packages of this category are not expected to survive accidents intact, they must be able to withstand, without any loss or dispersal of the radioactive contents or any increase in the maximum radiation level at the external surface of the package, what are termed the "normal conditions of transport". These comprise the ambient environments, external forces and various abuses which a shipment may experience, such as being exposed to rain, being dropped, being struck by a long, sharp object or having other packages stacked on top of them. To ensure adequate capability in such respects, the regulations prescribe that variations in temperature and pressure (respectively, from −40 to +70°C and down to nominally 0.25 atmosphere), the stresses induced during lifting (including 'snatch' lifting) and the effects of vibration and/or acceleration be taken into account in the design of packagings, and furthermore, that packages meet certain performance standards. These latter requirements are set out as tests: the water spray test; the free drop test (onto a hard, unyielding target), the penetration test (in which a slender heavy rod is dropped onto the package) and a compression test (to simulate stacking). Greater heights are specified in the

* Note the recommendations and concepts given in ICRP Publication No 26 have not yet been incorporated into the regulations.

Table 2. Maximum allowable quantities of certain radionuclides in Type A and Exempt packages* (curies)

	Type A Packages		Exempt packages		
Radionuclide	SF	NF	SF**	NF**	Liquid-state
Americium-241	8	0 008	0 008	8×10^{-6}	8×10^{-7}
Gold-198	40	40	0 04	0.04	0 004
Carbon-14	1000	100	1	0.1	0 01
Cobalt-57	90	90	0 09	0.09	0 009
Cobalt-58	20	20	0 02	0 02	0 002
Cobalt-60	7	7	0 007	0 007	7×10^{-4}
Chromium-51	600	600	0 6	0 6	0 06
Caesium-137	30	20	0.03	0.02	0 002
Gallium-67	100	100	0 1	0.1	0.01
Tritium #	1000/20	1000/20		see note	
Iodine-125	1000	70	1	0 07	0 007
Iodine-131	40	10	0.04	0 01	0.001
Iridium-192	20	20	0.02	0 02	0.002
Krypton-85 +	20/0 6	20/0 6	$0.2/6 \times 10^{-4}$	$0.02/6 \times 10^{-4}$	–
Neodymium-147	100	100	0 1	0 1	0 01
Polonium-210	200	0 2	0 2	2×10^{-4}	2×10^{-5}
Scandium-46	8	8	0.008	0 008	8×10^{-4}
Strontium-90	10	0.4	0.01	4×10^{-4}	4×10^{-5}
Technetium-^{99m} §	100 (100)	100 (100)	0.1 (0 1)	0.1 (0 1)	0 01 (0 01)
(Molybdenum-99)					
Thallium-201	200	200	0 2	0 2	0 02

(SF refers to "special form" material as defined in the regulations Ref. [1], NF refers to "non-special form" material).

* Taken from Table VII of the regulations Ref. [1]

** If the source material is enclosed in an instrument, watch or similar device these limits are 10 times higher per item, up to 100 such items may be included in any package

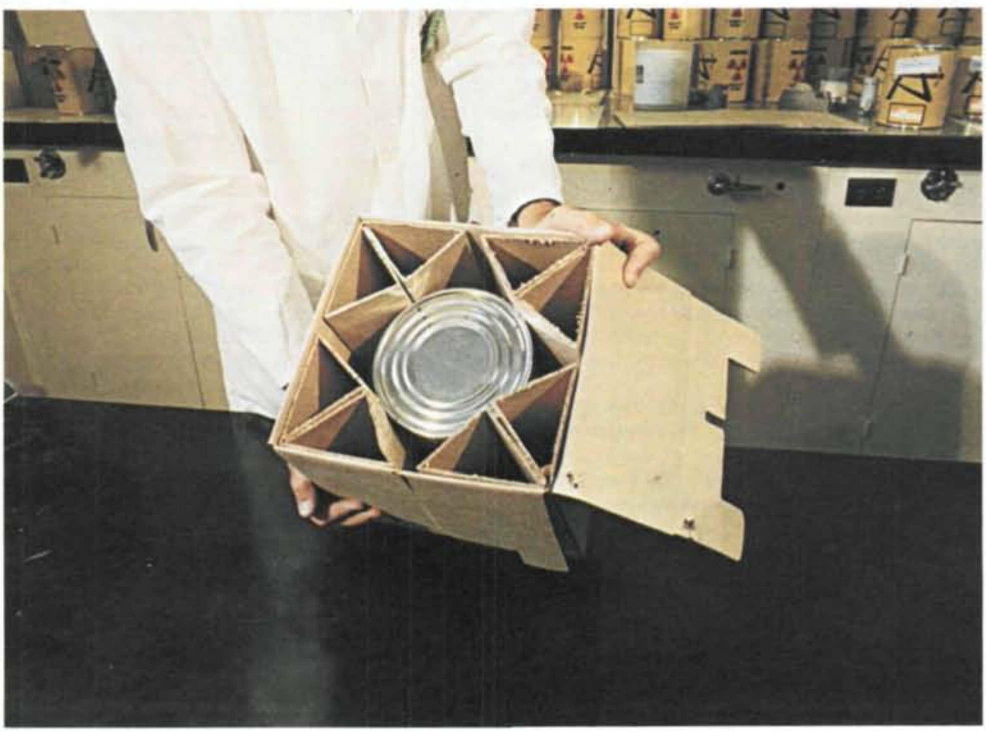
\# The upper limit pertains to tritium in the gaseous phase (uncompressed or compressed), in luminous paint, in tritiated water or absorbed on a solid carrier, the lower limit pertains to tritium in other forms. Exempt packages may contain up to 20 Ci of tritium in the gaseous phase, in luminous paint or absorbed on a solid carrier, for tritiated water up to 1000 Ci when the concentration is less than 0.1 Ci/ℓ up to 100 Ci of concentrations from 0 1 to 1 0 Ci/ℓ and 1 Ci of concentrations greater than 1 0 Ci/ℓ

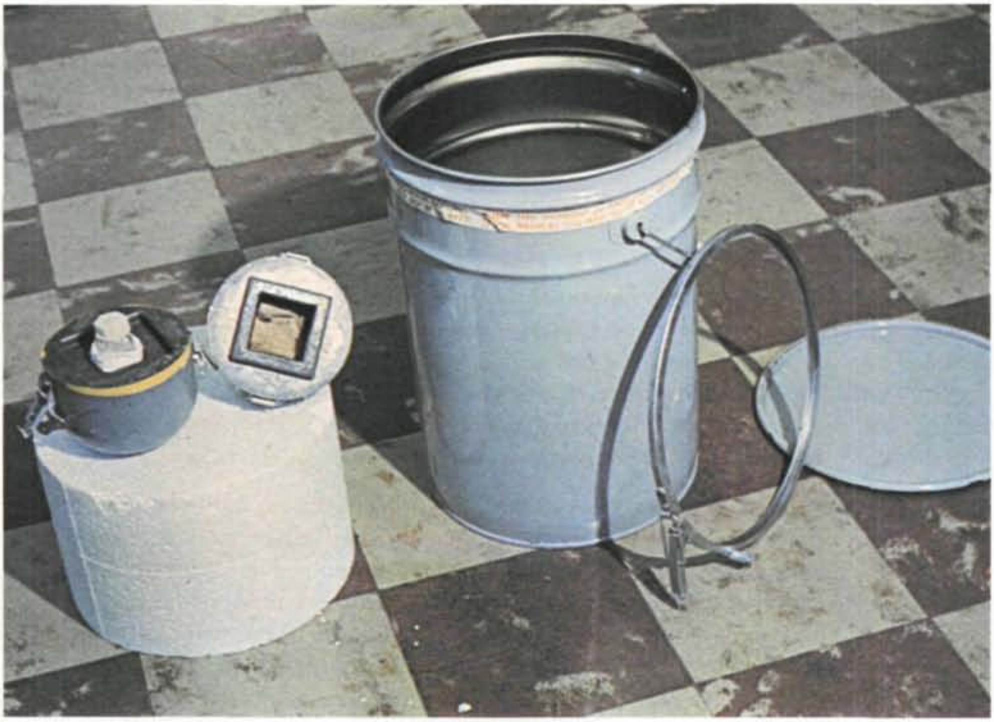
\+ The two entries refer respectively to the uncompressed (atmospheric pressure) and compressed (greater than atmospheric pressure) states

§ Technetium-99m is shipped as such and also in the form of a technetium generator containing principally molybdenum-99, the parent nuclide

free drop and penetration tests for packages containing liquid or gaseous materials as compared to solids, in recognition of, and to allow for, the differences in rheological properties and the consequent likelihood that more of the contents might escape in the case of a fluid. (The overall effect of these augmentations is to reduce the probability that a package will be damaged during normal transport operations.)

Figures 1a, 1b. Components and assembly of a Type A package.





Figures 2a, 2b. Components and assembly of a Type A package of different design.

Type A packages must also comply with a number of other requirements, with respect to minimum size (to guard against their being slipped into a pocket and thus being brought close to the body), quality of joints made by welding, brazing or similar method; security of closure of the containment system and retention of the radioactive material inside the shielding; the external features of the packaging, and the generally applicable provisions of the regulations concerning external radiation levels, non-fixed contamination and labelling.

EXEMPT PACKAGES

The Exempt* category provides a means for shipping small quantities of radioactive material at relatively low cost but with a comparable or even higher standard of safety to that provided by the Type A package. It is based, for the most part, on one of the assumptions underlying the Type A concept, namely, that of any non-special form material released as a result of damage to a shipment, no more than one thousandth, at the most, is taken into the body of any person. (This is corroborated by experience Ref. [5].)

The fundamental characteristic of this category is that the packaging must conform to only a few regulatory requirements which are general in nature; the design considerations and performance standards prescribed for Type A packages, as outlined in the previous section, are not applied (thus the designation "Exempt"). Along with this relaxation it is assumed that all instead of 1/1000 of the contents of the package would be released in a median accident; then according to the earlier stated premise (iv), the maximum activity of non-special form material allowable in an Exempt package must be restricted to one thousandth A_2. This limit is applied for solid and gaseous contents; it is further reduced to one ten-thousandth A_2 for liquids, however, to allow for the possibility that the intake of such material might exceed one thousandth of that spilled. To be consistent, the limit for special form material in a package is set at one thousandth A_1; this, in effect, produces a higher level of safety than that provided by a Type A package containing A_1 curies since the radiation level at three metres from the two sources following total loss of shielding, as is assumed to occur in a median accident, would be respectively 1 mrem/h and 1 rem/h. The amounts of tritium, in elemental or compounded forms, permitted in Exempt category packages were developed using slightly different models. (See Ref [10].)

Where the radionuclide container forms a component of a manufactured article, such as a gauge, a watch or similar device, allowance is made for the additional strength given by the structure and the limits are raised to one hundredth A_1 or A_2 curies per package, i.e. 100 (or more) items may be packed together.

All the foregoing provisions are subject to one or both of two overriding constraints, however: the radiation level must be no greater than 10 mrem/h at any point 10 cm above the surface of the unpacked device nor greater than 0.5 mrem/h on the surface of the package. If either of these restrictions is contravened then a Type A package must be used. Exempt category packages are not subject to the generally applicable labelling requirements of the regulations but they must include a label inside to warn that the contents are radioactive. They must also conform to the limits on non-fixed radioactive contamination on the external surface.

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* Also called the Limited Quantity category in some regulations

There is essentially no information about packages of this category in the literature, thus it is not possible to describe typical forms.

LSA PACKAGES

The LSA category provides for the shipping of substances of low specific activity: uranium and thorium, in the form of ores, physical and chemical concentrates or as the metal (provided that the material has not been enriched or irradiated), water containing up to 10 Ci/ℓ of tritium and materials and objects with slight radioactive contamination (subject to certain qualifications). These present minimal hazard if accidentially spilled because the amount which must be taken in to produce a significant radiation dose is so great, in comparison with other radioactive materials (in the order of milligrams rather than nanograms Ref. [11]). It is considered inconceivable that such an intake would result from any circumstances which might occur during transport, even a severe accident. Thus, for this class of material, the regulatory requirements vis-a-vis containment are much less stringent, consignments may be shipped in bulk i.e. contained only by the structure of the vehicle (except for carriage by air) or in virtually any kind of package; no performance standards are prescribed.

Two forms of container are commonly employed, however: 210 litre (55 US gallon) capacity steel drums and steel cylinders of various capacities, up to approximately 4 cubic metres. The drums are typically fabricated from 1 2 mm thick, low-carbon steel; removable lid types are used for shipping solids, such as yellowcake, uranium oxide powder and low-level radioactive wastes, with closed-head types used for tritiated water and other liquids. The cylinders are generally used for transporting uranium hexafluoride (as a solid); in most cases they are actually pressure vessels and conform to the prescriptions of the relevant code of the country of origin, e.g. ASME (American Society of Mechanical Engineers), Section VIII. The largest and probably the commonest model in service, designated the 48Y, has nominal dimensions of 1.22 m diameter by 3.81 m long with 15.8 mm wall thickness and is rated to carry 12,500 kg of uranium hexafluoride Ref. [12]. This is illustrated in Figure 3. Monazite sand, a mineral containing from six to seven percent thorium oxide, is shipped in hessian bags, with a plastic or paper liner, which weigh about 45 kg when filled Ref. [13].

When shipped as a "full-load", that is to say where all loading, unloading and handling operations are controlled by the consigner, consignee or their agent, LSA packages are exempted from the generally applicable labelling and non-fixed contamination requirements of the regulations. In other circumstances, when the package is shipped in accordance with usual practices, the requirements must be satisfied

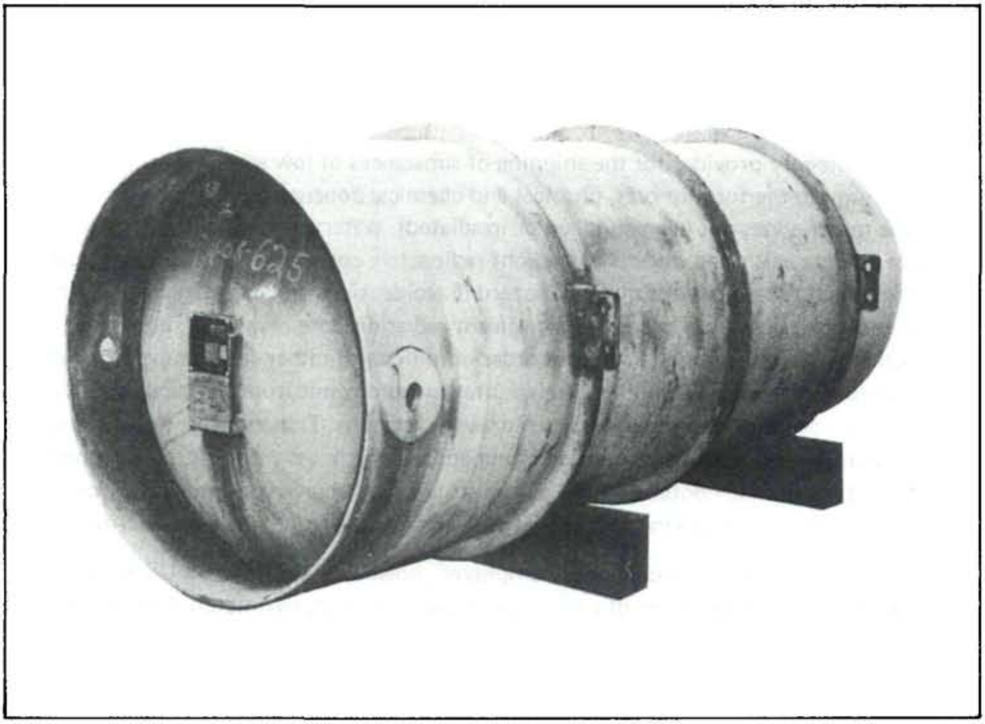

Figure 3. A Type 48Y shipping cylinder for uranium hexafluoride (UF_6).

References

[1] International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition, Safety Series No. 6, IAEA, Vienna (1973)

[2] International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Material, 1967 Edition, Safety Series No. 6, IAEA, Vienna (1967)

[3] Nuclear Regulatory Commission NUREG-0073, Transport of Radioactive Material in the US (A Detailed Summary of "Survey of Radioactive Material Shipments in the United States", BNWL – 1972), Washington, D.C. (May 1976)

[4] Amiel, S., "Production and Utilization of Radioisotopes Some General Aspects", Radioisotope *Production and Quality Control, Technical Reports Series No* 128, IAEA, *Vienna (1971)* 7.

[5] Fairbairn, A., "The Development of the IAEA Regulations for the Safe Transport of Radioactive Materials", Atomic Energy Review, II (1973) 873.

[6] Domanus, J C., "Analysis of design and test requirements and procedures for Type A packaging", IAEA-SM-147/35 (Proc Symp , Vienna, 1971), IAEA, Vienna (1971) 65.

[7] Prasad, A.N., et al., "Experience with packaging for the transport of radioactive materials". IAEA-SM-147/36 (Proc Symp., Vienna, 1971), IAEA, Vienna (1971) 129

[8] Edling, D.A , "Analysis of type A packaging systems based on greater than 400 individual packaging tests", IAEA-SR-10/2 (Proc Symp. Vienna, 1976), IAEA, Vienna (1976) 113

[9] Taylor, C B G., "Packaging and transport of radioisotopes", IAEA-SR-10/45 (Proc Symp. Vienna, 1976), IAEA, Vienna (1976) 71.

[10] International Atomic Energy Agency, Advisory Material for the Application of the IAEA Transport Regulations, Safety Series No. 37, IAEA, Vienna (1973).

[11] International Atomic Energy Agency, "A Basic Toxicity Classification of Radionuclides", Technical Reports Series No. 15, IAEA, Vienna (1963)

[12] United States Energy, Research and Development Administration, "Uranium Hexafluoride Handling Procedures and Container Criteria", ORO-651, Rev. 5, Oak Ridge Operations Office, Oak Ridge, Tennessee (April 1977).

[13] Gibson, R., Ed , "The Safe Transport of Radioactive Materials", Pergamon Press, London (1966)