Assessment of the radiological risks of road transport accidents involving Type A package shipments

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Introduction

This paper is an account of work performed within a multi-lateral research project on the radiological risks associated with the transportation of Type A packaged radioactive material. The research project has been performed on behalf of the European Commission (DG XVII) and various national agencies of the participating countries and involved organisations and institutes of five EU Member States, France, Germany, The Netherlands, Sweden, and the UK. The principal objectives of the research project were the assessment and appraisal of the potential radiological risks of road transport accidents involving Type A package shipments in participating EU Member States.

Background

Type A packages are intended to provide a safe and economical means for transporting moderate quantities of radioactive material (RAM) and represent an important fraction of radioactive material shipments by all modes of transport worldwide. A total activity of up to A_1 special form material, or up to A_2 non-special form material may be transported in a Type A package. An important Type A package characteristic is that they are required to maintain their integrity under normal and routine conditions of transport including minor mishaps, but may be damaged in a severe accident and that a fraction of their contents may be released into the environment. Ensuring safety against serious radiological consequences following an accident is therefore achieved by limiting the package activity inventory to A_1 and A_2. In addition, the Transport Regulations (§648, §649) require enhanced package safety standards to be applied to Type A packages designed to contain liquid or gaseous radioactive material, i.e. 9 m free drop test and 1.7 m penetration test.

Objectives

Although it is generally understood that compliance with the safety requirements of the Transport Regulations provide a suitable level of protection of people, property and the environment for (single and multiple) Type A package shipments there is very limited documentary evidence demonstrating the adequacy of the safety requirements embodied in the IAEA Transport Regulations for the Safe Transport of Radioactive Material (IAEA 1996).
The EC research project addresses the identified need of information demonstrating the efficacy (or non-efficacy) of the Transport Regulations by assessment and quantification of the potential radiological risks of road transport accidents involving Type A package shipments. For conciseness the study has been confined to transport accidents involving an atmospheric

release on publicly accessible roads and excludes from consideration accidental events by other modes of transport and from handling and loading/off-loading of Type A packages. It also does not take account of packages incorrectly prepared or labelled for transport. The individual topics to be addressed within the research project by each participating organisation included the following:

- Determination of the volume and characteristics of Type A package shipments by road in the participating EU Member States.
- Acquisition and analysis of information related to the traffic and distribution of Type A packaged radioactive material in the participating EU Member States.
- Compilation and analysis of available data on road traffic accidents involving Type A packages severe enough to cause damage/failure of the Type A structural package integrity and subsequent release of radioactive material.
- Estimation of the expected frequency of severe road accidents resulting in potential radionuclide release in the participating countries for the national volume of Type A package shipments.

The analysis results obtained in the participating EU Member States are presented and discussed below.

Volume and characteristics of Type A package shipments

The principal methods employed in the compilation of sufficiently accurate information on the volume and characteristics of Type A package shipments by road varied in the participating organisations depending on the resources available to these organisations on the national level. The resources used include, for example, analysis of existing transport statistics and questionnaire and site surveys of major national producer/carrier organisations. Most participating organisations have conducted and completed specifically designed questionnaire or site surveys. Emphasis was generally on known areas of shipping radioactive materials in Type A packages in quantities far in excess of nuclear fuel cycle related shipments, i.e. radiopharmaceutical production and distribution, radionuclides for scientific and industrial applications, and radiographic and gauging radiation sources etc. Because of the necessary representativeness of the collected shipping data, surveys have been extended over some period of time ranging broadly from about 1 week to 1 year in the participating countries.

The type of information collected on the national level by all participating organisations varied to some extent, but was generally fairly detailed and comprised, for example, the following individual data: number, weight and typical size of Type A packages transported in a specified time period, Type A package contents characteristics, e.g. radionuclide, activity inventory (in Bq and in multiples of A_2), physical form, radiologically relevant package characteristics, e.g. TI, package category, area of application/end use, type of vehicle used for carriage, loading/stowing conditions, e.g. packages per vehicle and the travel distance and type of road used. Selected characteristics of the shipment data are presented in Table 1 for each participating EU Member State. The data are for shipments of non-special form material from producer/supplier to user.

The quantities of radioactive material transports in Type A packages differ considerably on national levels and reflect to a large extent the production and/or distribution operations prevailing in each country. For instance, France, The Netherlands, and the UK export most of the RAM packages produced (64% France, 94 % Netherlands, and 70 % UK). On the other hand, Sweden has primarily distribution operations, it frequently uses rail transport (which is not considered in this study) for long distance shipments of Type A packages. The vast majority of Type A package shipments in the participating EU Member States appears to be clearly

related to radioactive material applications in medicine and research (I 131, Mo99/Tc99m-generators, Tl 201). The physical form of the radioactive contents depends on the radionuclide and manufacturer. For instance, in general the content of Mo 99/Tc 99-generators is solid but can also be present in liquid form during transport. Radionuclides like P 32, I 131 and Tl 201 are predominantly transported as liquids. Occasionally the physical form of a radionuclide is in gaseous form (Xe 133). Activity contents of the Type A packages could vary in units of fractions of A_2 from about 10^{-6} to about unity.

Table 1: Summary of national survey results on package and shipping characteristics of Type A package shipments by road

	France	Germany	Nether-lands	Sweden	UK
Population (10^6)	58	81	15.7	8.8	58
No. of Type A packages shipped per year ($x10^3$)	120	150	203	12	124
Average Type A package activity inventory (in fractions of A_2)	0,024	0,015	0,01	0,03	0,0086
Physical form of contents					
- solid	34%	45%	33%	33%	42%
- liquid	64%	54%	67%	66%	56%
- gaseous	2%	1%	0%	1%	2%
Packages per road vehicle:					
- average	17	--	71	4,3	20
- approx. range of values	1 - 350	1 - 350	1 - 300	1 - 50	1 - 320
A_2-load per vehicle (avg.)	0,4	--	0,7	0,13	0,17
Estimated annual cumulative road travel distance:					
- vehicle-km (10^6)	2,4	8,4	0,33	0,3	1,1
- package-km (10^6)	40	--	24	1,2	22

Transport and distribution of Type A packaged radioactive material

In a generalised way the movement of Type A package shipments from the consignor to the end user of a radioactive material can be thought of as a 2 or 3 stage transport and distribution process: At the early stage of the distribution process of radioactive material packages, shipments tend to be in bulk with up to about 350 packages per vehicle being carriaged, for example, to the nearest depot, airport or distribution centre. Continuation of the movement of Type A packages from such depots or distribution centres is generally in smaller quantities in van-type vehicles for delivery to the end user of the radioactive material. Loading patterns and travel distances vary considerably in the participating countries as shown in Table 1. Travel

distances depend on size of the country and transport mode for long distance shipments (Sweden frequently uses train for long distance shipments). It also reflects the structure of the nationally established supply and distribution system of radioactive material for medical, scientific and industrial applications. For example, Sweden produces radioisotopes but the radioactive material is exported for processing and packaging abroad before returned to the end user. In addition, medical use of radionuclides in Sweden is concentrated in major hospitals. The average number of packages per vehicle is low in Sweden and is high in The Netherlands because there is a major manufacturer of radiopharmaceuticals which exports most of the RAM packages. The shipping pattern also depends on the material being delivered (the very short half lives demand very short delivery times).
For transports to distribution centres and for export shipments large trucks (lorries) and truck trailers carrying up to about 350 Type A packages are primarily used, while for local delivery frequently light vehicles with a single Type A package are used. Hence, large A_2-loads per vehicle are expected for truck and trailer shipments compared to a shipment of few packages loaded into a van. From the shipment data available the average activity load of road transport vehicles was determined to be in the range from 0.1-0.7 A_2 per vehicle.

Radiological risk regarding road transport accidents: Assessment approach and results
This section outlines the principal methods and databases adopted for transport accident risk assessment by the participating organisations and briefly discusses the assessment results.
Accidents occur in all modes of transport and some of these inevitably involve packages of radioactive material (e.g., Grella 1976, Crockett and McClure 1995, Hughes and Shaw 1996, IAEA 1997). Although it is generally understood that the safety requirements of the Transport Regulations ensure a high level of protection in the transport of radioactive material, severe transport accidents representing a challenge to the structural and shielding integrity of radioactive material packages are consistently a matter of public concern. Particularly, members of the public may eventually be exposed via a number of pathways to radiation internally and externally from radioactive material releases into the environment subsequent to a transport accident.

Assessment approach: To adequately address these concerns and to be consistent with the statistical nature of transport accidents a probabilistic analysis method has been adopted for the assessment and appraisal of the radiological risk of road transport accidents involving Type A package shipments. The probabilistic method involves two components to be quantified: (1) the expected frequency of occurrence of transport accidents severe enough to cause degradation or failure of the Type A package safety functions, i.e. shielding and containment, and (2) the magnitude of the potential radiological consequences attributable to an accident event. The potential radiological accidental consequences and the related likelihood of occurrence depend on a number of factors including the volume of Type A package transports, the severity and frequency of road transport accidents, and the material and package behaviour under impact loading conditions (mechanical and/or thermal) typically encountered in road transport accidents. Both of these areas will be discussed below.
For the development of a thorough understanding of how road transport accidents occur and estimation of the frequency and severity of transport accidents there are two basic approaches available (e.g., Appleton 1988). These are:

- Use of historical accident data representative for the field of transport operations being considered or data adopted from similar transport conditions, e.g., hazardous material transport.

- Synthesis of the accident frequency from an analysis of the combination or sequences of events which could cause the accident, together with data for their likelihood of occurrence.

Whenever possible accident and incident data from the same type of transport operations or practices performed under similar conditions should be used for risk assessment. For comparatively rare events, however, this will not always be possible and it may be necessary to use generic data (Appleton et al. 1990). In this case eventual differences between the type of operations and practices from which the data have been gathered must be considered and evaluated very carefully. Frequently encountered difficulties are related to the fact that generally available accident data are collated for purposes other than risk analysis and are, for example, expressed in terms of human casualties and not damage to vehicle or load and, thus, not directly relevant to the problem. Even generic accident data relating directly to conceivable accidents of sufficient severity to give rise to serious consequences are often at best sparse. Thus, most risk assessments use to some extent combinations of the two principal methods. Fault and event trees are well established analysis techniques employed in the synthesis approach.

Road transport accident frequency statistics: Due to the scarcity of severe road transport accidents involving radioactive material over the last decades the Type A transport risk analysis presented herein adopted the approach to primarily rely on information on the frequency and severity of transport accident data derived from generally available road traffic statistics. Especially, the likelihood of occurrence of road transport accidents severe enough to cause structural package damage/failure resulting in a release of some fraction of its contents has been taken to correspond to the rate of road traffic accidents involving the fatality of the driver or passenger. It is recognised that the casualty rate of road traffic accidents is only loosely related to the frequency of a potential release from package but in lieu of other relevant information it is believed to be a reasonable approximation for quantifying the probability of road transport accidents with the potential to severely affect the cargo load within a vehicle, e.g. a Type A package. It is also recognised that the approach adopted does not give full credit to possible differences in the design of Type A packages for low-dispersible and light-dispersible, i.e. gases and liquids, radioactive material.

Based on nationally available driver/passenger casualty data, the likelihood of occurrence of a road transport vehicle being involved in an severe accident has been analysed and best estimates are given in Tab. 2 in terms of the expected number of vehicles experiencing a severe road transport accidents per vehicle-kilometre that will challenge the Type A package integrity. The accident rates given in Tab. 2 are most representative for transport conditions prevailing in shipping Type A packages by road in the participating countries, i.e. transportation primarily by van and truck on major roads and motorways.

The road transport accident frequency estimates presented in Tab. 2 indicate that despite substantial differences in the traffic conditions there is some consistency in the estimated frequency of occurrence of severe road transport accidents in the participating countries. The casualty-rate-based accident frequency estimates given in Tab. 2 have also be found to be broadly consistent with relevant information derived from a database of reported transport accidents involving shipments of RAM in the UK. The UK transport event database contributed by and kept at NRPB covers all types of incidents and accidents, by all modes of transport, and the total number recorded up to the end of 1995 was 538. Analysis of the UK-database found that 16 accidents involving Type A packages on public roads occurred during the 20 year study period, but non of these resulted in an atmospheric release of radioactive material. The rate of road-based accidents of all severities from general traffic statistics has

been estimated to be about 2.4×10^{-7} per veh.-km and 3.0×10^{-9} per veh.-km for accidents in which the driver or passenger was killed. For accidents severe enough to cause significant damage and release of its contents, the UK transport event database suggests that the rate of occurrence is less than 1.5×10^{-8} per veh.-km. From this and by considering the many uncertainties in the efficiency of reporting of road transport accidents in the UK, it is concluded that the closeness of the accident rate derived from the UK-database and that from national casualty data gives some confidence in the order of magnitude of the casualty-based rate of severe road transport accidents.

Type A transport risk assessment: The expected frequency of severe road transport accidents per vehicle-kilometre for each participating country can readily be related to the national volume of Type A package shipments by road for estimation of the Type A transport risk. The term transport risk is used to mean throughout this paper the expected frequency of occurrence of a severe road transport accident causing damage to a single or several Type A packages to give rise to a release of some fraction of its contents - including radiologically insignificant quantities - for the national volume of Type A packaged radioactive material transports. The analysis results are summarised in Tab. 2 in units of severe accidental events per year for each participating country.

Table 2: Estimated transport risk for the annual volume of shipments of Type A packaged non-special form radioactive material in EU Member States

Country	Estimated rate of severe road transport accidents based on driver/ passenger casualty data	Expected frequency[1] of occurrence of severe road transport accidents involving Type A packaged non-special form radioactive material	
	(per 100 mill. veh.-km)	(events per year)	
France	1.2	0.03	1 in 35 yrs
Germany	1.0	0.08	1 in 12 yrs
Netherlands	0.5	0.002	1 in 500 yrs
Sweden	0.5	0.002	1 in 500 yrs
United Kingdom	0.3	0.003	1 in 300 yrs

1) All values rounded

Radiological consequence assessment: In addition to the frequency of occurrence of accidental events the credible range of potential radiological consequences following an accident according to severity is a key factor in transport risk assessment. Generally the potential radiological consequences of road transport accidents involving Type A package shipments can vary significantly depending, for example, on the type and severity of the accidental event, the shipping load conditions (single or multiple package shipment), the response of a packaging and its contents under (mechanical/thermal) accidental impact loading, and the protective countermeasures taken at the scene of the accident. Typically impact, crush, puncture, and fire environments (or sequential combinations of these) are conceivable in transport accidents and must be properly understood for estimating the potential radiological consequences. It is important to note that generally some test data are available for frequently encountered acciden-

tal loading conditions such as impact and fire (e.g., Hadjiantoniou et al.1980, Lohmann 1980, Taylor 1980), while others may require substantial extrapolation and engineering judgement. It is also recognised that the environmental consequences following a transport accident can be expressed in various ways, e.g., in terms of the environmental radionuclide release, the individual or collective dose to the population living close to the postulated site of the accident, or the associated health effects. The principal information required regarding the radiological consequences of Type A package transport accidents, however, has not yet been developed to the extent to fully support a quantitative and reliable analysis of radionuclide releases or doses for the broad range of conceivable shipping loads and potential impact loading conditions typically encountered in Type A package transport. The preliminary information available, however, indicates that the expected environmental radionuclide releases following a severe transport accident are generally limited to very low values by the nature of the package and material characteristics for all types of (single and multiple) Type A package shipments. Although difficult to quantify at the current stage of analysis, higher environmental releases can not be excluded to occur following a road transport accident involving a severe fire for multiple Type A package shipments (most likely less than A_2). No attempts were made to quantify adequately the radiological consequences of Type A package releases in terms of the individual or collective dose to the population in close proximity to the postulated site of the transport accident. Estimation of dose would require application of prediction models simulating the dispersal and distribution of the released radioactive material in the atmosphere, the magnitude, duration and routes of exposure and estimation of the subsequent individual and collective radiation dose to persons.

Risk measures, risk presentation, and risk comparison: There is a general understanding that transport risk assessment involves two components to be quantified: (1) the frequency of occurrence of some adverse impact and (2) the type and severity of the undesired accidental consequences. In addition to the quantified transport risks referred to above other risk measures are conceivable and may be evaluated and compared with relevant criteria and levels of acceptance (HSE 1992):

- the individual risk, i.e. the frequency at which an individual member of the population in close proximity to the accident site may be expected to be subject to the adverse consequences of an accident or incident associated with the transport of a specified volume of Type A package shipments.
- the societal risk, i.e. the frequency and number of people suffering a specified level of harm or consequences of a potential transport accident.

Selection of the individual risk approach may have the distinct advantage of comparing the estimated radiological transport risk with everyday risks of human beings which are generally expressed and presented in terms of the individual risk. Quantification of the societal risk has some relevance to decision makers for measuring the risk acceptability and risk aversion. The transport risk analysis results presented above form, in line with other relevant information, e.g., population distribution data, the principal information required for estimation of individual and societal risk measures.

Discussion and conclusions

The data collected within the research project include harmonised sets of information related to the type, quantity and characteristics of Type A package shipments by road for five EU Member States. Such databases were basically non-existent until recently. The results are expected to be valuable to both national agencies and international organisations, e.g., the IAEA, with responsibilities for the safe transport of radioactive material by providing some insight in

the carriage of radioactive materials by road making up a major fraction of radioactive material transports. Similarly, a wide body of information has been collected and compiled on road transport accidents in terms of the frequency of occurrence and the severity of accidental impact loads potentially experienced by a Type A package. In addition, the results will facilitate judgement of the adequacy of the IAEA Transport Regulations as far as Type A packages are concerned (e.g., accidents involving multiple Type A package shipments).

Concluding remarks

The type of information addressed within the EC research project is considered to greatly enhance the general understanding of the potential radiological risks associated with (single and multiple) Type A package shipments by road and has resulted in very valuable transport databases describing the type and magnitude of Type A package shipments in the participating EU Member States. The estimated radiological risks may be compared with other everyday risks and used for judging the adequacy of the level of protection provided by the Transport Regulations.

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