Radiation Exposures of Workers and the Public associated with the Transport of Radioactive Material in Germany

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1. Introduction

Every year approximately 750.000 radioactive material packages (consumer goods excluded) are transported in Germany by all modes on land, water and in the air, i.e. by road, rail, air and sea. The transport involves many types of radioactive materials and radiation sources for applications in medicine, research, industry (e.g. process control, NDT), hydrology, geology and nuclear power production and ranges from very small amounts of radionuclides (some 10.000 Becquerel per package) to very large quantities of radioactivity of some 100.000 Tera-Becquerel. The great majority of radioactive material packages, however, contains only relatively small quantities of radiopharmaceuticals, research and industrial sources and other radioactive commodities, while large quantity shipments of radioactive material such as high level radioactive spent nuclear fuel account only for a small proportion of the total national volume of radioactive material shipments. With a total volume of approximately 750.000 radioactive material package shipments per year Germany is - together with France and Belgium - one of the largest shipper countries of radioactive materials in the enlarged European Union [1]. Road and air are the predominant modes of transport. A significant fraction of these radioactive material shipments are transboundary shipments of packaged radioactive materials.

Most radioactive material packages transported emit penetrating ionising radiation and radiation exposures of transport workers and the public may occur during their transport. The radiation exposures incurred by transport workers and members of the public can vary significantly depending on a number of factors: most important is the type of radiation emitted (primarily gamma and neutron radiation), the radiation field intensity in the surrounding of a package and conveyance and the duration of exposure to ionising radiation.

To ensure an adequate level of safety and protection of persons, property and the environment during transport the potential radiological hazards must be constrained below unacceptable levels. The packagings and containers used for the transport of radioactive material shipments are therefore designed and their transport performed in conformity with the safety standards agreed upon internationally, i.e. the "Regulations for the Safe Transport of Radioactive Material" (No. TS-R-1) developed and published by the International Atomic Energy Agency (IAEA). The performance standards of the Regulations for packages and containers prescribe inter alia maximum permissible radiation levels for packages, containers, overpacks and conveyances and require that they prevent release of significant amounts of radioactive material under normal conditions of transport and in accident situations. Experience, however, indicates that most packages, containers and conveyances have radiation levels (and radionuclide inventories) well below the regulatory limits [2, 3, 4]. In addition, the general provisions of the Regulations require (i) that periodic assessments of transport-related radiation doses to persons shall be carried out (para 304 TS-R-1) and (ii) that protection and safety in transport shall be optimized “in order that the magnitude of individual doses, the number of persons exposed, and the likelihood of incurring exposure shall be kept as low as reasonably achievable, economic and social factors being taken into account, and doses to persons shall be below the relevant dose limits" (para 320 TS-R-1). The IAEA regulatory requirements are fully reflected in the Modal Regulations, i.e. ADR, RID, IATA-DGR, IMDG-Code, which form essentially the basis of the applicable legislation in Germany in regard to the transport of hazardous materials incl. radioactive substances.

2. Objectives and scope

The nature and extent of protective measures being employed by operators to satisfy the optimization principle and the effort and resources committed for determining optimized levels of protection and safety in the transport of radioactive material are left to the discretion of the transport operators. Although the optimization requirement is appealing, its implementation and application is not always straightforward and may involve a number of difficult technical, organisational and administrative considerations. It is, however, recognised that in everyday control much can be achieved in the optimization of protection and safety in transport through the use of professional judgement by suitably qualified and experienced staff on the basis of a comparison and the application of radiologically

cally relevant performance indicators, e.g. relevant worker doses, for similar or related well-managed transport activities (cf. para 92 ICRP Publ. 75). Therefore, a broad understanding of the nature and magnitude of occupational and public exposures in various transport disciplines is of prime importance to the parties with responsibilities for the safe transport of radioactive material, i.e. the competent authorities and transport operators.

In order to ensure compliance with all relevant regulatory provisions and requirements with relevance to protection and safety in transport and to assist competent authorities and transport operators in the assessment and evaluation of the adequacy and effectiveness of the measures and procedures employed to control radiation exposures to levels *as low as reasonably achievable* work has been undertaken to provide up-to-date guidance material on the nature and magnitude of radiation exposures incurred by transport workers and the general public from the normal transport of radioactive material in Germany. Normal transport is used to mean transport operations which occur without unusual delay, loss of, or serious damage to a radioactive material package, or an accident involving the conveyance.

The information and guidance material on occupational exposures has primarily been derived from a survey and analysis of personal monitoring data provided by a number of commercial transport operators in Germany known as major carrier and handler organisations of fuel cycle and non-fuel cycle material (in terms of the number of pack-ages and the activity carriaged). To some extent advantage was taken of compilations of statistical transport and exposure data collated within other transport safety analysis studies including research projects funded by the European Commission [1, 2, 3]. The exposure data collected cover the time period of the last 4 - 8 years and are most representative for routine transport operations closely related to the movement phase of packaged radioactive material, i.e. receipt, vehicle loading, carriage, in-transit storage, intra-/intermodal transfer, vehicle unloading and delivery at the final destination of loads of radioactive material and packages and the related supervisory and health physics functions.

Radiation dose monitoring of members of the public, however, is generally impracticable and, consequently, the information available relies on employing dose assessment models and reflects radiation exposures incurred by hypothetical or critical group individuals of members of the public under normal conditions of transport. The exposure conditions considered in the dose assessment include, for example, members of the public living or working near to an approach road of a distribution centre/depot or a rail siding used for the transport of significant amounts of radioactive material shipments and being exposed to static and transient exposures during the transport or a stop of a radioactive material shipment. Several nationally relevant population dose assessment studies were identified in this respect and have been examined for the study purpose.

3. Survey and assessment results

The survey and assessment results in terms of occupational and public radiation exposures arising from the normal transport of radioactive material in Germany are summarised in Figure 1 and Table 1. The transport-related doses are presented for a range of transport activities and cover fuel cycle and non-fuel cycle radioactive material shipments and their predominant mode of transport including the following:

- Unirradiated nuclear fuel cycle material, e.g. uranium concentrate, uranium hexafluoride, UO_2-powder/pellets, fuel elements and pins etc.
- Irradiated nuclear fuel cycle material incl. spent nuclear fuel, vitrified high level radioactive waste, irradiated fuel pins etc. and large quantity radiation sources
- Non-nuclear radioactive waste, e.g. medical and research waste
- Supply and distribution of medical, research and industrial isotopes
- Radiography sources

Figure 1 presents radiation dose distributions and time trends in doses of transport workers (e.g. truck/van drivers, handlers, escort personal, warehouse personal) which have been physically involved in the handling, consigning, vehicle loading/unloading, in-transit storage, intra-/intermodal transfer, supervision, radiological protection, carriage and delivery of radioactive material package shipments by transport organisations with significant volumes of radioactive material shipments in Germany. The transport worker doses are from external exposure to radioactive material packages and conveyances and are derived - except for railway workers, site radiographers and sea crews - from personal monitoring data provided by operators for the study purpose (film badge data).

Table 1 summarizes up-to-date maximum observed occupational and public radiation exposures for major radioactive material transport activities and all relevant transport modes in Germany. The maximum worker doses given are most representative for road vehicle drivers, package handlers, supervisors, health physics personal, workers of marshalling yards and air terminals and crew members onboard vessels. The related operational practices and procedures are believed to reflect well-managed transport operations. The public radiation doses given in Table 1 represent upper (or conservative) dose estimates for critical group individuals being exposed to static and transient exposure during transport such as, for example, a permanent resident living or working in close proximity to the path of travel of radioactive material shipments including stops at traffic lights or at an intermodal transfer station with significant radioactive material traffic. Therefore, the doses given are unlikely to be exceeded under "real world" transport and handling conditions. The occupational and public radiation exposures are expressed as annual effective dose (mSv/yr).

4. Discussion of the assessment results

The survey and assessment results are given in terms of radiation exposures incurred by transport workers and members of the public (critical group individuals) from the normal (incident-free) transport of radioactive material shipments in Germany and cover all major categories of radioactive materials (i.e. fuel cycle and non-fuel cycle material) and shipping modes.

The exposure data presented in Figure 1 and Table 1 for the recent years indicate that the occupational and public exposures (effective dose) associated with the normal transport of radioactive material have - with few exceptions - been consistently in the range of or below of 1 mSv/yr for transport workers and well below of 0,05 mSv/yr for the general public (critical group individuals) for all major transport activities and categories of radioactive material. Radiation doses in these dose ranges represent only a small fraction of the relevant regulatory dose limit for radiation workers and members of the public of 20 mSv/yr and 1 mSv/yr, respectively. However, a small fraction of transport workers (driver/handler) being routinely involved in the transport and (manual) handling of large volumes of shipments of radioisotopes for medical, scientific and industrial applications has been found to represent a notable exception by incurring maximum doses of up to 10 - 14 mSv/yr. In the recent years, however, the highest individual worker doses tended to approach the lower end of the given dose range (cf. Figure 1 bottom).

Similarly, some site radiographers have been found to become occupationally exposed to levels which represent a significant fraction of or close to the regulatory dose limit of 20 mSv/yr for radiation workers from external exposure by both the field use and the road transport of high activity radiography sources. However, analyses of typical personal exposure pattern indicate that the worker doses are generally dominated by the field use and handling of radiography sources while the transport-related worker doses are typically below 1 mSv/yr (effective dose).

5. Conclusions

The comprehensive survey and assessment results confirm that the transport-related radiation doses incurred by transport workers and member of the public are generally low for all major categories of material and transport activities under normal conditions of transport and well below the applicable regulatory dose limits (20 mSv/yr for workers and 1 mSv/yr for members of the public). A notable exception are transport worker doses resulting from the nationwide supply and distribution of medical, research and industrial isotopes where in recent years a few workers have received maximum effective doses in the range of 10 - 12 mSv/yr. The number of persons concerned is, however, very limited. This general observation is according to a European wide assessment study performed on behalf of the European Commission broadly consistent with the operational experience in other Central European EU Member States [1].

The occupational and public radiation exposures data described above are believed to reflect well-managed transport and sound management practices and may thereby serve as a reasonable basis and guidance material for the establishment of an optimised level of radiological protection and safety in transport. The radiation exposure data nationally available also indicate that the implementation and application of the international safety standards, i.e. TS-R-1, ensure an adequate level of radiological protection of both workers and members of the public for normal conditions of transport and satisfy the radiation protection principles of the International Basic Safety Standards (BSS). Nevertheless, there is no room for complacency in optimisation of protection and safety of people, property and the environment and possible developments, both in operational procedures and equipment being used for transport and handling should be considered. Sometimes, improvements in safety and protection can be achieved at very little costs and thus transport operators should establish regular reviews of their methods of work and equipment.

6. References

[1] Shaw, K.B. et al., Statistics on the transport of radioactive materials and statistical analyses, Final Report (Contract No. 4.1020/D/01.003), March 2003
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[4] Schwarz, G. et al., Erfassung, Bewertung und Fortentwicklung der sicheren Beförderung radioaktiver Stoffe - Strahlenexpositionen des Transportpersonals und der Bevölkerung beim normalen (unfallfreien) Transport in ausgewählten Anwendungsbereichen, GRS-A-3177/I, März 2004

Table 1: Maximum radiation doses incurred by transport workers and members of the public from the normal (incident-free) transport of radioactive material in Germany

Material Category/Transport Activity	**Transport Mode**	**Maximum Effective Dose** (mSv/a)	
		Workers	**Public**[a)]
Unirradiated fuel cycle material, e.g. U_3O_8, UF_6, UO_2-powder/pellets, fuel pins & fuel assemblies, radiation sources	road/rail	< 1	< 0,01
	sea	<< 1[b)]	---[c)]
Unirradiated/irradiated nuclear fuel cycle material and large quantity radiation sources, e.g. activated /contaminated equipment and components, radioactive waste, spent nuclear fuel, high level radioactive waste etc.	road	1 - 3	approx. 0,01
	rail	< 1	approx. 0,01
Non-nuclear radioactive waste, e.g. medical and research waste	road	< 1	---
Supply and distribution of medical, research and industrial isotopes	road	10 - 12	< 0,02
	air	< 1	---
Radiography sources	road	< 1[d)]	---
Regulatory dose limits		**20**	**1**

a) Relevant to critical group individuals, e.g. permanent residents/bystanders
b) Value preliminary, derived from the general literature
c) “---“ = Data currently unavailable
d) Transport-related worker dose without the extra dose received from the field use of radiation sources

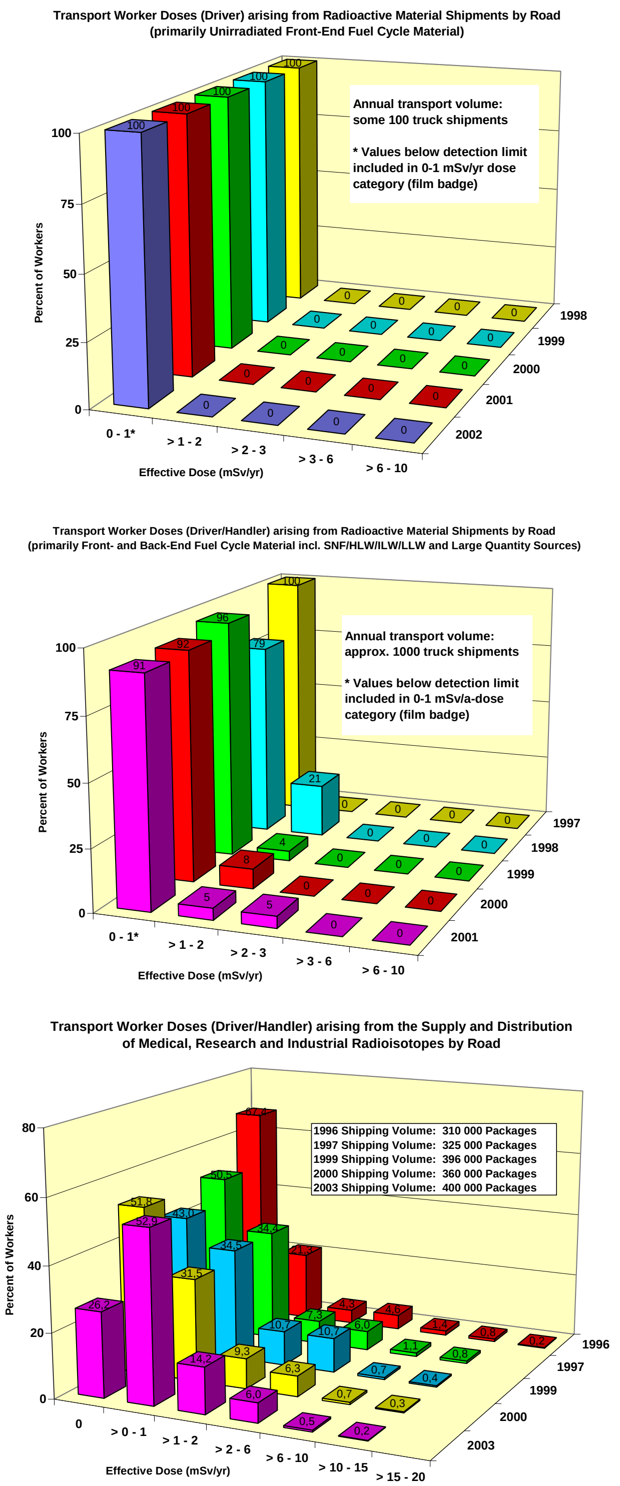

Figure 1: Frequency distribution and time trends in transport worker doses for selected transport activities in Germany: Front-end fuel cycle material (top); Front- and back-end fuel cycle material & large quantity radiation sources (middle); Supply and distribution of medical, research and industrial radioisotopes (bottom)