SAFETY ANALYSIS OF THE TRANSPORTATION OF RADIOACTIVE WASTE TO THE KONRAD FINAL REPOSITORY – METHODS AND RESULTS

Florence-Nathalie Sentuc **Wenzel Brücher**

Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH,
Cologne, Germany

ABSTRACT

A transport risk assessment study has been conducted for transport of radioactive waste with negligible heat-generation (low- to medium-level) to the German final repository Konrad. This study is a revision of the former Konrad Transport Study performed by GRS in 1991 implementing updated waste data among other improved methods and assumptions for the purpose of a more realistic approach to risk assessment. According to the results of the revised survey each year approximately 2300 shipping units of low and medium active waste will be transported to the Konrad site starting with its expected begin of operation in 2014.

The first part of the transport risk assessment study concerns the radiological consequences from routine (incident-free) transportation of radioactive material, i.e. the radiation exposure of transport personnel and the public (expected exposure). Based on the assessed detailed information on transport arrangements and on the average number and radiological characteristics of waste packages the maximum annual effective doses for the representative persons were estimated. The results show predicted doses far below the relevant German annual statutory dose limits.

The risk associated with transport incidents and accidents has been quantified for the area within a radius of 25 km around the repository site. The probabilistic method adopted in this study considers parameters as the frequency and severity of railway or road accidents, characteristics of radioactive waste and transport packagings and the frequency of atmospheric dispersion conditions. From a large set of parameter combinations the spectrum of potential radiological consequences and of the associated probability of occurrence was assessed. Compared to the former risk analysis of 1991 a revised set of release fractions for mechanical and thermal impact conditions and a modern Lagrangian particle dispersion model have been applied. In combination with the updated waste database and revised transport scenarios these changes result in potential radiation exposures in the repository area which are about one order of magnitude lower than predicted in the former study.

INTRODUCTION

According to the definite official approval in 2007 the Konrad site will be the final repository for all waste types of negligible heat-generation from nuclear power plants, nuclear facilities, industry, scientific research centers and medical use of radioactive nuclides in the Federal Republic of Germany. A total volume up to 303 000 m^3 of radioactive waste with negligible heat-generation will be transported to the Konrad site over the expected operational period of 30 years. Radioactive waste shipments are subject to comprehensive safety arrangements and regulations due to their potential to cause severe health effects through ionizing radiation. This potential hazard is subject of public concern in Germany, especially in the region of the Konrad site. To address this issue and to provide a sound scientific basis for the public debate on the problems of radioactive waste transportation the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Cologne, has already released a study in an earlier planning stage (1991) which examined the shipment of radioactive waste to the Konrad final repository [1]. Within that safety analysis two main topics were discussed, the assessment of potential radiation exposures from normal (accident-free) transportation and the assessment of risks associated with transport incidents and accidents. On account of the technological progress and latest developments concerning waste treatment, packaging and new/omitted waste streams this study was now revised based on the actual planning status using an updated waste database and enhanced analysis methods (e.g. a Lagrangian dispersion model).

REFERENCE TRANSPORT SCENARIO

The updated database as the result of a comprehensive survey of actual wastes in interim storage comprises detailed information (e.g. radiological characteristics and packaging) about approximately 110 000 m^3 of radioactive waste (or 20 400 shipping units with one cubic or 1-2 cylindrical containers) which corresponds nearly to the amount of the transport volume for the first operating decade of the Konrad final repository. According to the current planning status each year approximately 2300 shipping units of radioactive waste, e.g. on average 50 shipping units per week, will be transported to the Konrad site. The survey results indicate that 80 % of this waste will be shipped by rail and 20 % by road, which is used as basis assumption for the realistic reference scenario (e.g. 40 shipping units per rail and 10 per road on average per week). As a result of transport modalities and other influencing factors (e.g. dispatch capacities) it is assumed that approximately 8 rail transports with 2-3 waste wagons per regular goods train and – depending on the truck’s load capacity – at most 10 road transports per week will arrive at the Konrad final repository. Additionally, two other – more hypothetical – scenarios were also considered: 100 % transport by rail and 100 % transport by road.

NORMAL (ACCIDENT-FREE) TRANSPORT

The radiation exposure associated with normal, accident-free transportation can be attributed to situations where people find themselves regularly or by chance in the direct vicinity of passing or stationary vehicles carrying radioactive waste. Furthermore persons who are professionally required to work with such, e.g. marshaling personnel, may be exposed to the radiation field emanating form the transport packages. Exposition analysis were conducted to identify the representative persons and the potential exposure situations (e.g. duration, distance, type and magnitude of dose rate) to determine the resultant radiation exposure in the form of individual doses. The annual radiation dose of individuals is then derived from the local dose rate at the places where people are exposed and the total time they spend in these places in the course of the year. The local dose rate at different distances is based on the results of the waste data survey supplemented by additional calculations for transport configurations (e.g. see Fig. 1).
The results for maximum annual radiation exposure for the general public and the transport personnel (expected exposure) resulting from transportation of radioactive waste to the Konrad final repository are shown in Tab. 1 and Tab. 2 respectively. The predicted doses to the public (representative persons) for the reference scenario range between 0.003 (plant employees) up to 0.02 mSv/a (permanent residents at 5 m distance from main transport route). This calculated dose values are far below the relevant statutory dose limit of 1 mSv/a for the general public in Germany.

The low doses determined reflect the fact that on average only short periods of time are spent in the immediate vicinity of waste transports, since the vehicles generally pass by or stop only for a short time, or are the consequence of a longer distance between individual and waste package depending on the residence along the transport route. Therefore, even for the representative persons of the general public the additional radiation exposure as a result of the waste transports is equivalent to a small fraction of natural radiation exposure. The radiation exposure of these individuals, and consequently even more significantly of those inhabitants of the region around the final repository who do not belong to the small group of representative (most exposed) persons, remains practically unchanged by the waste shipments.
The results for the transport personnel show highest predicted doses for the truck driver of approximately 0.6 mSv/a for the reference scenario (1.1 mSv/a for the scenario 100 % transport by road assuming that a larger number of truck drivers is involved). For rail transport the highest exposure situations are associated with operations at the two marshaling yards ranging from approximately 0.08 up to 0.32 mSv/a (shunting engine driver) for the reference scenario. For all scenarios the predicted doses for the transport personnel are far below the annual statutory dose limit for occupationally exposed persons (Kat B: 6 mSv/a, and with individual dose assessment Kat A: 20 mSv/a).

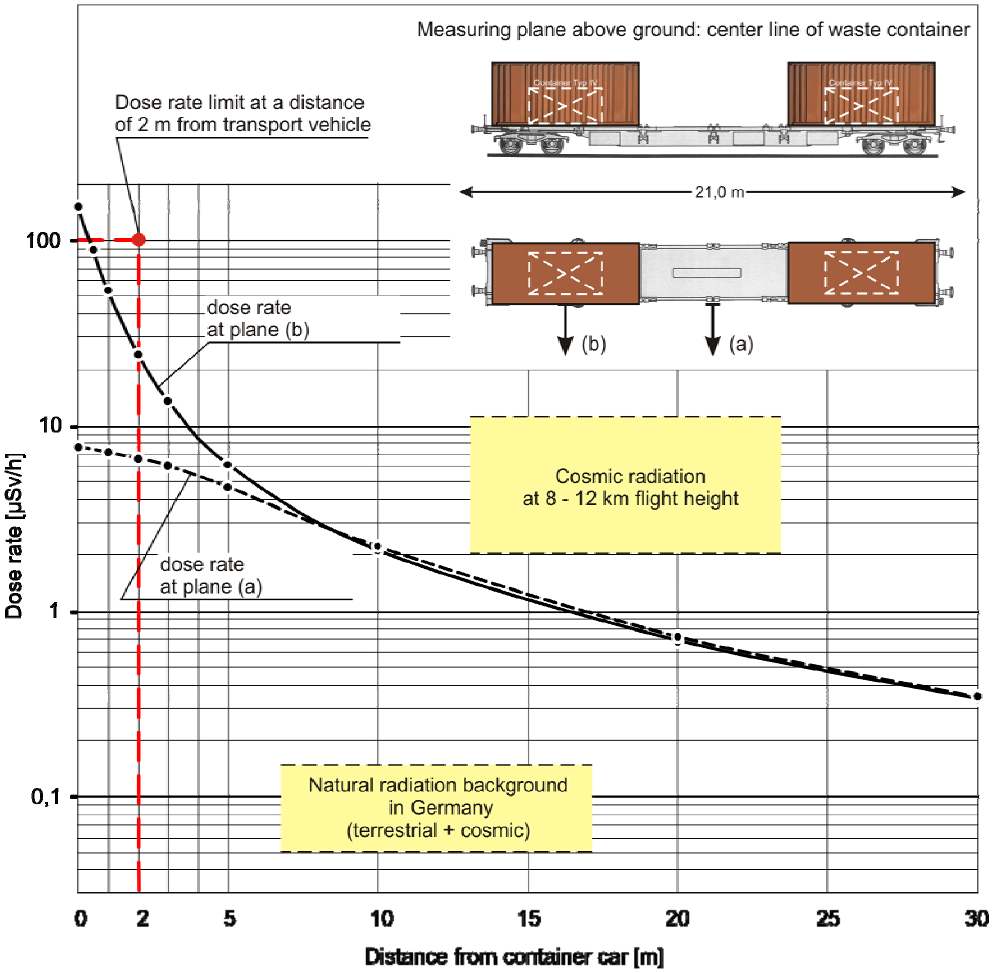

Figure 1. Typical spatial distribution of the local dose rate of a transport configuration with two radioactive waste containers (Konrad type IV) on a container car

Table 1. Estimates of the maximum annual radiation exposure of the public as a result of radioactive waste transportation to the Konrad site

Population Group/ Route	Distance	Effective Dose (mSv/a)		
		100 % rail	100 % road	80 % rail/ 20 % road
Rail transport:				
Residents, main transport route (time spent exclusively outdoors)	5 m	ca. 0.025	---	ca. 0.02
Residents, marshaling yard Beddingen (25 % outdoors/ 75 % indoors)	> 130 m	ca. 0.005	---	ca. 0.004
Residents, marshaling yard Seelze/Hannover (25 % outdoors/ 75 % indoors)	ca. 100 m	ca. 0.017	---	< 0.014
Employees of the slag reprocessing plant	> 50 m	0.004	---	ca. 0.003
Road transport:				
Residents, main transport route (time spent exclusively outdoors)	5 m		ca. 0.025	ca. 0.005
For comparison:				
Relevant annual statutory dose limit		1.0		
Natural radiation exposure		2.1		

Table 2. Estimates of the maximum annual radiation exposure of the transport personnel due to waste transportation to the Konrad site

Function/ Route	Effective Dose (mSv/a)		
	100 % rail	100 % road	80 % rail/ 20 % road
Rail transport:			
Marshaling yard Beddingen			
- Shunter	ca. 0.2	---	ca. 0.16
- Shunting engine driver	< 0.4	---	< 0.32
- Power unit driver (transfer tour to Konrad)	ca. 0.06	---	< 0.05
Marshaling yard Seelze/Hannover			
- Shunter	ca. 0.1	---	ca. 0.08
- Marshaling hump	ca. 0.2	---	ca. 0.16
Road transport:			
Truck driver/escort	---	< 1.1	ca. 0.6
For comparison:			
Relevant annual statutory dose limit	6 (Kat B)/20 (Kat A)		

TRANSPORT ACCIDENTS

General Procedure

The risk of transport accidents is determined by the frequency of accidents leading to a release of radioactive substances and by the corresponding potential radiological consequences, such as radiation exposure of persons and contamination of the biosphere. To assess the risk associated with transport accidents, the region in the proximity of the final repository Konrad is considered and defined as the zone within a radius of 25 km around the site, thus covering the area where all waste transports are converging. The frequency and magnitude of the radiological consequences for the waste transport depends on several parameters including especially:

- the frequencies of accident loads (mechanical and thermal) which may affect waste packages,
- the properties of the waste packages and the waste product contained (release behavior),
- the content of radioactive substances (activity inventory) and the number of affected packages,
- the frequency of different atmospheric dispersion conditions which influence the airborne concentration and deposition and thus, to a large extent, the radiological consequences.

Uncertainties in any parameter are treated in a conservative manner to exclude an underestimation of the potential consequences.

Container Failure and Release Behavior

To take the various influencing parameters into account, possible accident loads to transport vehicles and transport containers were divided into 9 severity categories (BK, see Tab. 3). The associated relative probabilities of occurrence were determined by evaluation of accident statistics for railway goods traffic and heavy goods road traffic.

Because of the wide ranging differences in the behavior of the various container types (concrete, cast iron and steel plate containers) and of the different waste products (e.g. cement/concrete), under accident loads, the transport volume was classified into various container groups. The major criterion for this classification is the release behavior of the package. For each pre-defined severity category and waste container group a release fraction of the activity inventory was then determined. In contrast to the first transport study [1], the release fractions were updated according to recent experimental results showing lower release fractions for mechanical impact than formerly assumed. The release fractions for different nuclide groups determine – in combination with the activity inventory of shipping units affected by an accident – the released activities of individual radionuclides in particle size classes from respirable up to 100 µm aerodynamic diameter, i.e. the source term.

Table 3. Definition of the nine severity categories

Impact Velocity	Fire Duration and Temperature		
	without thermal impact	thermal impact 30 min, 800 °C	thermal impact 60 min, 800 °C
0 to 35 km/h	BK 1	BK 2	BK 3
36 to 80 km/h	BK 4	BK 5	BK 6
above 80 km/h	BK 7	BK 8	BK 9

Transport Accident Simulation - Source Term Definition

The potential radiological accidental consequences, such as radiation exposure of persons and contamination of soil and vegetation, are calculated using the COSYMA accident consequence program. To account for a more realistic approach of dispersion modeling (considering e.g. turbulence profiles, unsteady atmospheric conditions and near to ground release), the originally integrated dispersion model MUSEMET has been replaced by the advanced Lagrangian particle model LASAT®.

For the calculation of radiation exposure in terms of effective dose and committed effective dose over 50 yrs integration time, respectively, the following exposure paths are taken into account: cloudshine, groundshine, inhalation, ingestion and resuspension with subsequent inhalation. The probabilistic calculations take into account the relative frequency of the atmospheric dispersion conditions at the final repository, which were derived from on-site measurements of meteorological data of the German Meteorological Service (DWD).

A Monte-Carlo accident simulation program was used in order to cover the spectrum of possible accident sequences including the potential release of radioactive substances. This program considers the transport volume under investigation (153 types of reference waste and their relative frequency), different transport constellations, such as the number of waste wagons in the goods trains and possible accident loads (9 severity categories). Depending on the individual accident probability a large number of source terms is generated, which in total are representative of the potential releases of radionuclides caused by accidents.

In a further step the large number of generated source terms are ranked by increasing radiological relevance and then subdivided into 20 source term groups. By taking into account the conditional probabilities of the individual source terms belonging to a source term group a representative weighted source term – a so-called release category – is determined for each source term group. These release categories are representative with respect to the radionuclide composition and the released activities of individual radionuclides for calculating the radiological consequences. Twenty release categories have been generated by the simulation program for each transport scenario with the associated frequency of occurrence. 10 of them are representative of accidents with purely mechanical impact on shipping units, and 10 release categories cover accidents with mechanical impact and subsequent fire (see example in Fig. 2).

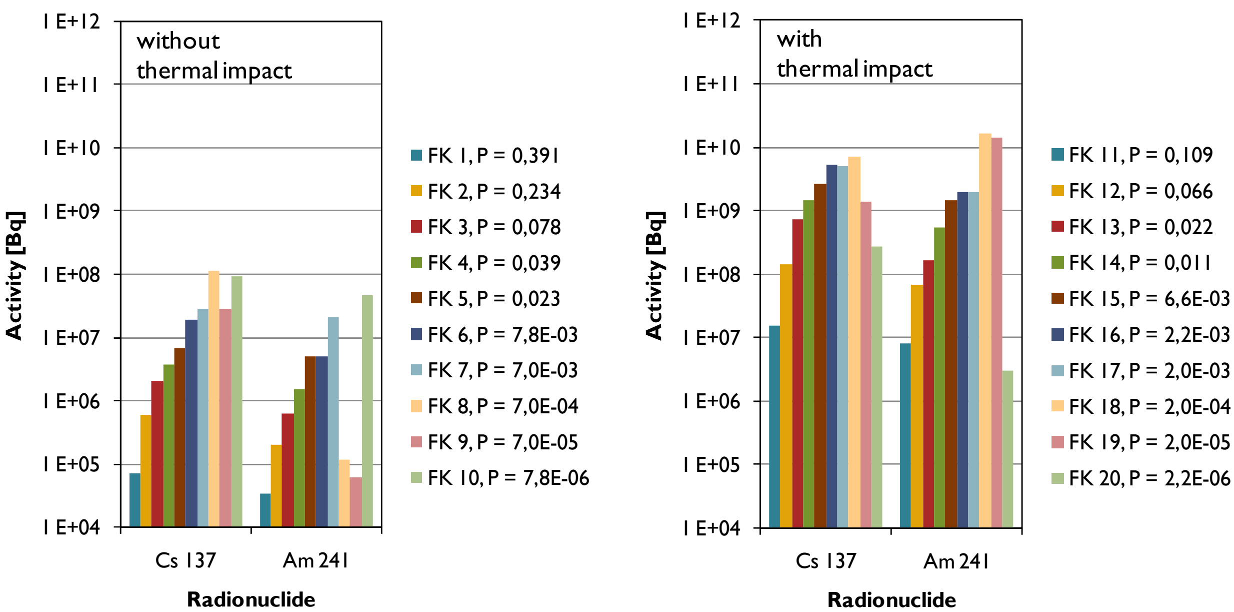

Figure 2. Example of release categories (FK) for two radionuclides with associated conditional probabilities of occurrence (P) for the scenario 100 % transport by rail

Results of Transport Risk Analysis

The results of the probabilistic risk analysis of transport accidents in the region of the final repository are expressed as cumulative complementary frequency distribution (CCFD) for the three scenarios considered. The frequency distributions are obtained by superimposing the dispersion simulation results for each of the 20 release categories. These CCFDs depict the frequencies of exceedance of specific radiological consequences in the region of the final repository for different distances from the accident location. In this context, the radiological consequences are represented as radiation exposure in the form of effective doses in the direction of dispersion without assuming any countermeasures. The main results of the transport risk analysis for the realistic scenario can be summarized as follows (see Fig. 3):

- Referred to the waste transport volume for one year, the predicted accident frequency involving the release of radioactive substances in the region of the final repository is about $3.9 \cdot 10^{-3}$ per year.
- In the majority of accidents with activity release, the predicted effective dose is far below the annual natural radiation exposure level even without countermeasures. At a distance of 150 m 9 out of 10 accidents with a release of radioactive material result in effective doses below 0.02 mSv and 99 out of 100 are below 0.3 mSv.
- In all cases, even at a distance of 150 m and down to an expected frequency of 10^{-7} per year the calculated doses stay below the design guideline exposure limit of 50 mSv which is used for orientation. The maximum effective dose calculated for this low frequency level is about 8 mSv at a distance of 150 m and decreases for larger distances to approximately 5 mSv at 1 km.
- The risk of an individual person from transport accidents is reduced by at least one order of magnitude compared to the risk for the entire population in the region of the final repository considered in this study. This is due to the fact, that the combined likelihood of an individual being situated at a certain distance from the accident and exactly in the direction of the dispersing plume is low.

CONCLUSIONS

The results of the actual transport risk analysis [2] for potential exposures and occurrence probabilities respectively, are more than one order of magnitude below the results of the previous study from 1991. This can be attributed to the reduction of the waste amount shipped per year, the missing waste stream from reprocessing, the updated and enhanced waste database and a more realistic methodical approach.

For normal transport conditions the expected exposure for the transport personnel is comparable to the values calculated in 1991 (0.2 to 0.7 mSv/a). However, the predicted maximum exposures for the general public show a considerable reduction, to some extent by more than one order of magnitude. Besides the different local conditions at the now considered marshaling yard (e.g. longer distance to the nearest residents) this is due to the more realistic assumptions in terms of annual waste shipping volume, stop periods of transport vehicles and the radiological characteristics of waste packages.

Overall, the results of the revised transport study confirm that no major associated risks would result from the converging waste transports destined for the final repository Konrad for the region around the site. This applies to both normal transport and transport accidents.

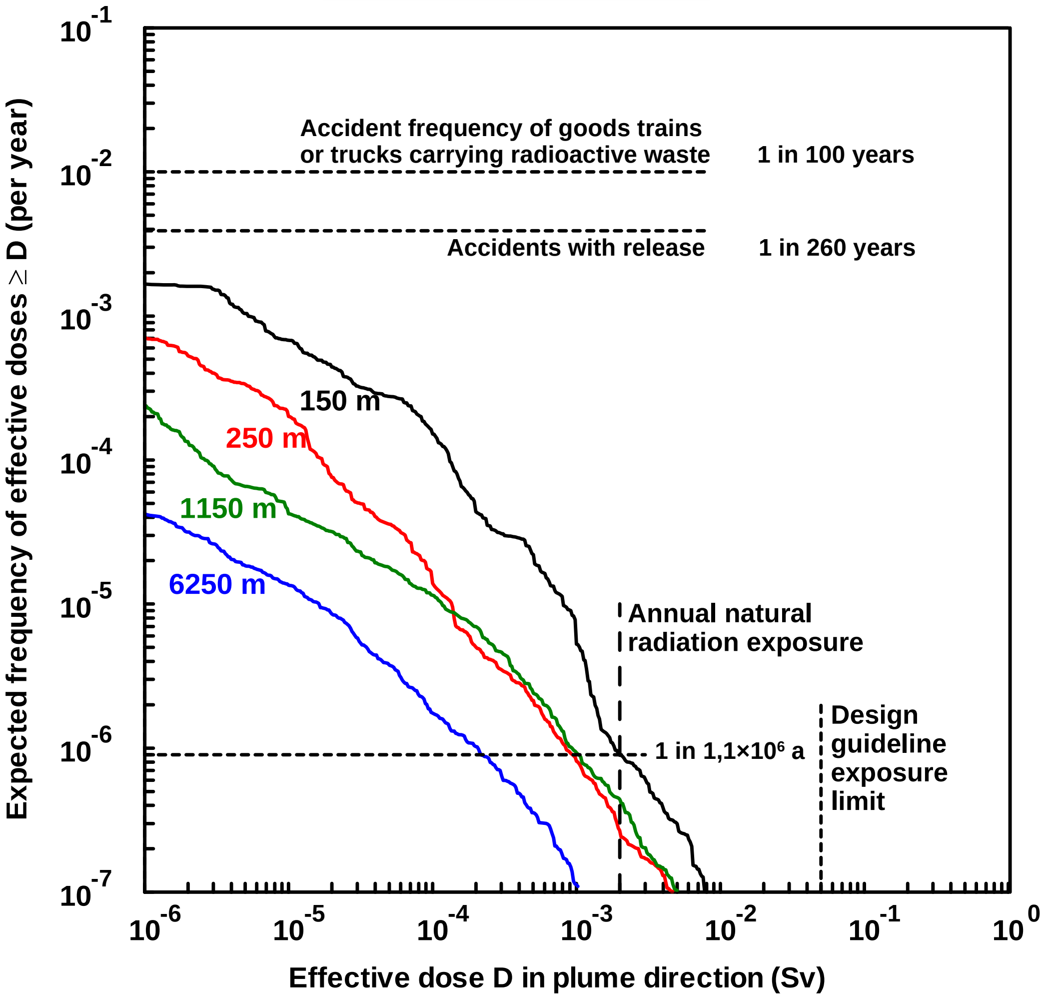

Figure 3. Frequency distribution of the effective lifetime dose from waste transport accidents in the region of the final repository (25 km zone) for the reference scenario (80 %rail/ 20 % road transport) without countermeasures

ACKNOWLEDGMENTS

This work was performed by GRS within a research project granted by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Office for Radiation Protection (BfS).

REFERENCES

[1] Lange, F., D. Gründler, G. Schwarz: Konrad Transport Study: Safety Analysis of the Transportation of Radioactive Waste to the Konrad Waste Disposal Site, GRS-91, May 1992 (Original German version: GRS-84, July 1991)

[2] Sentuc, F.-N. et al.: Transportstudie Konrad 2009, Sicherheitsanalyse zur Beförderung radioaktiver Abfälle zum Endlager Konrad, GRS - 256, Dezember 2009 mit Corrigendum vom April 2010