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SAFETY ANALYSIS FOR THE TRANSPORT OF RADIOACTIVE WASTE TO THE KONRAD REPOSITORY – PROGNOSTIC SCENARIOS FOR 2020 AND 2040 AND RESULTS

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ABSTRACT

A transport risk assessment study was conducted in 2009 for the transport of radioactive waste with negligible heat-generation (low- to medium-level) to the German repository Konrad. This study was 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 2,300 shipping units of low and medium active waste will be transported to the Konrad site starting with its expected begin of operation.

The transport risk assessment study 2009 concerned the radiological consequences from routine (incident-free) transport of radioactive material as well as from accidents. The results covered the first ten years of operation of the Konrad site based on detailed information, e.g. waste characteristics, up to the year 2008. Meanwhile the expected begin of operation of the Konrad site has been postponed. Over time the characteristics and the amount of produced radioactive waste will also change, e.g. all German nuclear power plants have to shut down until 2022 and will be decommissioned afterwards. Therefore, two additional prognostic transport scenarios for the years 2020 and 2040 have been evaluated.

These prognostic scenarios are based on the reference scenario from the transport risk assessment study (i.e. 80 % of the radioactive waste is shipped by rail and 20 % by road) and the forecasts for future waste volumes published by the Federal Office for Radiation Protection. The results show that the accident rate with release of radioactive material for 2020 and 2040 is slightly lower compared to the reference scenario from 2009. The possible consequences after an accident are in the same order of magnitude or even slightly smaller compared to the reference scenario from the transport risk assessment 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 repository. Radioactive waste shipments are subject to comprehensive safety arrangements and regulations due to their potential to cause severe health effects through ionizing radiation. There is public concern about this potential hazard in Germany, especially in the region around the Konrad repository. 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) has already released a study in an earlier planning stage (1991) and an updated version in 2009 (TSK 2009) [2]. The latest study examined the shipment of radioactive waste to the Konrad final repository for the first ten years of operation, and the results were presented at PATRAM 2010 [3]. As the composition of radioactive waste which has to be transported to the Konrad repository will change with time GRS started to examine potential radiation exposures from normal transportation as well as after incidents or accidents after the first 10 years of operation. Therefore, two prognostic scenarios for the years 2020 and 2040 were presumed for analyzing the possible transportation risk.

All results are based on present available data and best estimates which may change in future. Thus, calculated results based upon future analysis or development of prognostic scenarios may vary from presented results.

PROGNOSTIC SCENARIOS

TSK 2009

The TSK 2009 "scenario" represents the results of the safety analysis done by GRS in 2009 [2] and presented at PATRAM 2010 [3]. In TSK 2009 the radioactive waste was assigned to four different main origins:

- Research,
- Nuclear industry,
- Nuclear power plants (NPP) and
- Federal state collection depots and collection depot of German armed forces.

A database was created containing the result of a comprehensive survey of actual (up to 2008) radioactive wastes with negligible heat-generation (low- to medium-level) in interim storages. This database has detailed information about approximately 110,000 m^3 of radioactive waste, i.e. about 20,400 shipping units. This amount corresponds nearly to the transport volume for the first ten years of operation of the Konrad repository. 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 in TSK 2009. Additionally, two other – more hypothetical – scenarios were also considered: 100 % transport by rail and 100 % transport by road.

Scenario 2020

For the TSK 2009 it was assumed that the beginning of operation of the Konrad site will be in 2014. Meanwhile the expected begin of operation of the Konrad repository has been postponed. Over time the characteristics and the amount of produced radioactive waste will also change, e.g. all German nuclear power plants have to shut down until 2022 and will be decommissioned afterwards.

The scenario 2020 estimates the beginning of operation of the Konrad site to be in 2020. It takes into account the changing characteristics of the radioactive waste. Like TSK 2009 it is calculated for the first ten years of operation.

Scenario 2040

The prognostic scenario 2040 is based upon scenario 2020. It analyzes the amount and characteristics of radioactive waste which has to be transported to the Konrad repository after

20 years of operation. For this scenario it was assumed that beginning with 2020 radioactive waste with negligible heat-generation has been continuously transported to the Konrad site. Beginning in 2040 again ten years of further operation of the Konrad repository has been analyzed, assuming an overall operation time of the Konrad site for 30 years.

Development of the scenarios 2020 and 2040 and first results

The prognostic scenarios 2020 and 2040 mentioned above have been developed using prognostic data for the amount of radioactive waste up to 2080 continuously published by the Federal Office for Radiation Protection (BfS) [4], [5] as basis. These basic data was compared and supplemented with the data contained in the database created for TSK 2009. Afterwards the results were used for further analysis of the prognostic scenarios.

Based on the data collected several trends for changes in the characteristics of radioactive waste can be observed. The percentage of the gross volume of waste (including the container) according to the origin is changing clearly (Fig. 1). In TSK 2009 the amount of radioactive waste mainly origins from research activities (56 %) and second from nuclear power plants (31 %). In 2040 the ratio nearly switches over: Most of the volume (66 %) results from nuclear power plants while the fraction from research sector is only 28 %. The fraction from federal state collection depots and the collection depot of German armed forced is approximately the same over time (3-4 %) whereas the fraction from nuclear industry declines from 10 % to 2 %.

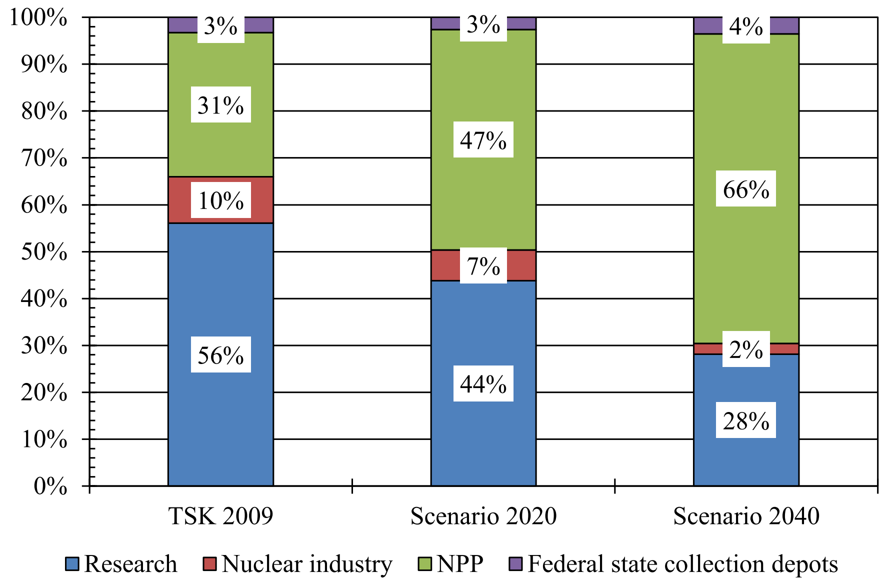

Figure 1. Estimated percentage of gross volume of radioactive waste transported to the Konrad repository for prognostic scenarios 2020 and 2040 by origin, rounded values

The changing percentage of gross volume from the origins has also an effect on many other parameters. The number of shipping units from an origin is changing according to the percentage of the volume of radioactive waste. In Fig. 2 the number of shipping units per year for each origin and each scenario is shown. According to the analysis in TSK 2009 about 2,300 shipping units per year will be transported to the Konrad site. It was assumed for all scenarios that this number corresponding with the operating regime at the Konrad repository will not change with time as long as the Konrad site will not change the operation strategy. As the volume decreases in the research sector and nuclear industry sector with ongoing time the number of shipping units also decreases accordingly. On the other hand the number of shipping units from NPPs increases.

The trend in the number of shipping units not fully corresponds with the gross volume of waste. It has to be taken into account that for the Konrad repository 11 different types of containers are allowed [6]. These 11 types with different net volume consist of three main types: cylindrical concrete containers, cylindrical cast iron containers and box-shaped containers made from steel, concrete or cast iron. In addition a shipping unit normally consists of one box-shaped container or up to two cylindrical containers depending on the characteristics, the weight and the activity of the content. Regarding the origin and the characteristic of radioactive waste different types of containers are preferred by the consignor.

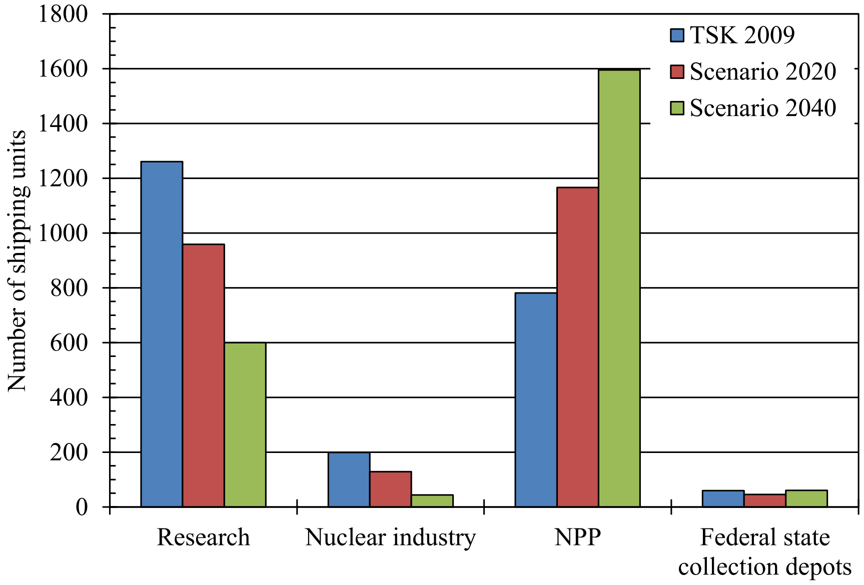

Figure 2. Estimated shipping units for prognostic scenarios 2020 and 2040, normalized to 2,300 shipping units per scenario

A rough overview of transported activities is shown in Fig. 3. A high number of shipping units will contain an average activity between 10^{11} Bq and 10^{12} Bq per shipping unit. However, the distribution is wider and reaches from 10^{7} Bq up to more than 10^{14} Bq. In this context it is to be mentioned that the activities of the radioactive waste are in many cases not corrected by radioactive decay with time. The database for TSK 2009 mainly contains activities for nuclides or containers with radioactive waste without a reference date for this activity. Hence, a correction for radioactive decay was not possible in every case which resulted in rather conservative calculations done for TSK 2009 as well as for scenarios 2020 and 2040.

Fig. 3 shows that in scenario 2020 and 2040 the number of shipping units with a lower average activity between 10^{9} Bq and 10^{11} Bq slightly increases as the number of shipping units with an activity between 10^{11} Bq and 10^{13} Bq decreases. Because of the higher percentage of gross volume of radioactive waste from NPPs there is also a slight increase of the number of shipping units with higher activities from 10^{13} Bq and above.

The change of activity percentage per origin is presented in Fig. 4. Most of the activity of radioactive waste shipped to the Konrad repository originates from NPPs. It increases from 81 % (TSK 2009) up to 96 % in scenario 2040. The fractions of activity with origin research and nuclear industry are in the same order of magnitude, even though the gross volume of radioactive waste from research is higher than from nuclear industry (compare Fig. 1). They decrease from 10 % and 8 % in 2009 to 3 % and 1 % respectively in scenario 2040. The percentage of activity from federal state collection depots and the depot of German armed forces is in all three cases about 1 %.

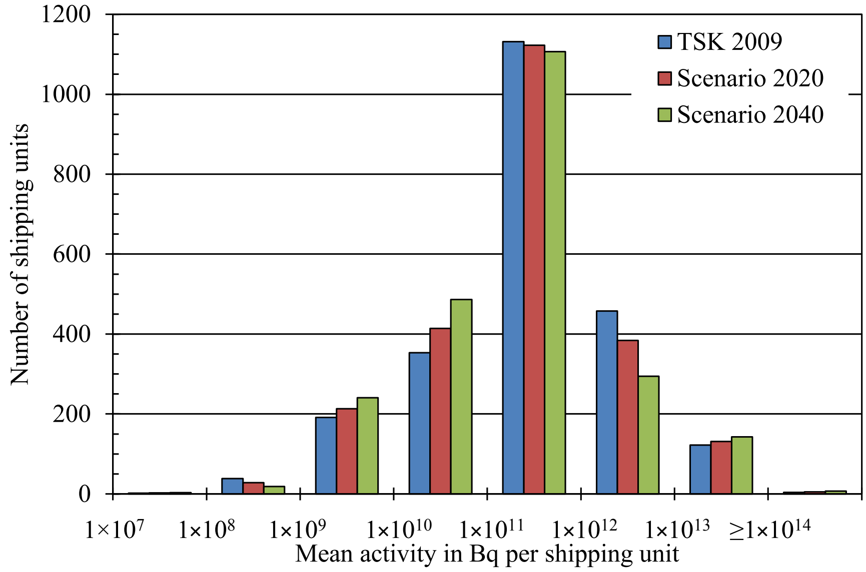

Figure 3. Estimated distribution of mean activity per shipping unit for prognostic scenarios 2020 and 2040, normalized to 2,300 shipping units per scenario

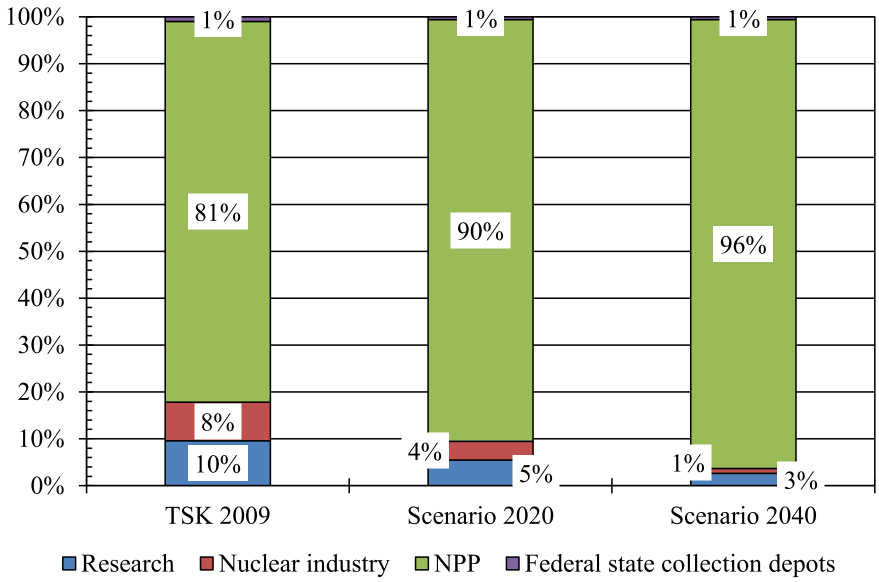

Figure 4. Estimated percentage of activity over all shipping unit for prognostic scenarios 2020 and 2040 by origin, rounded values

For the analysis of the prognostic scenarios even more parameters where taken into account. For example the radiation level of containers at surface and in a distance of 1 m and 2 m has been taken into account as well as preferred mode of transport (railway or road).

Analysis of the scenarios

The final analysis of prognostic scenarios followed mainly the tasks carried out in TSK 2009 [2], [3]. For normal (accident-free) transport and transport accidents the so called reference scenario (80 % of radioactive waste shipment to the Konrad site by rail and 20 % by road) was calculated. Additionally two hypothetical scenarios (100 % rail transport and 100 % road transport) were analyzed.

For normal transport the annual dose for an adult resident near the main transport route was calculated as this was the person of the public with the highest dose in TSK 2009. It was assumed that this person permanently stays in a distance of 5 m beside the track or road. It was further postulated that all shipping units will be shipped on this route according to the percentage of the reference scenario and the hypothetical scenarios. Additionally, in 5 % of all transports a stop next to his position for two minutes (road) and five minutes (rail) respectively is assumed. The calculations were performed according to the RADTRAN 4 method.

However, 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 converge. 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.

The potential radiological consequences of accidents, 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 years 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).

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 scenarios considered. The frequency distributions are obtained by superimposing the dispersion simulation results for each release category (see also [3]). 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.

RESULTS

Normal transport

The results for maximum annual radiation exposure of the adult resident (expected exposure) resulting from transportation of radioactive waste to the Konrad final repository are shown in Tab. 1. In comparison to TSK 2009 there is only a slight increase of the expected dose to residents near the main transport routes even though the characteristics of radioactive waste changed considerably for the prognostic scenarios shown in Fig. 1 to Fig. 4.

Table 1. Expected effective doses to permanent resident adults at the main transport routes staying outside in a distance of 5 m, rounded values

Shipping	Effective dose in mSv/a		
	TSK 2009	**Scenario 2020**	**Scenario 2040**
80 % rail transport **20 % road transport**	0.020 0.005	0.020 0.005	0.020 0.005
100 % rail transport	0.025	0.025	0.026
100 % road transport	0.025	0.026	0.026

These calculated dose values are far below the relevant statutory dose limit of 1 mSv per year 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.

Transport accidents

The results of the probabilistic risk analysis are shown in Fig. 5 (TSK 2009), Fig. 6 (scenario 2020) and Fig. 7 (scenario 2040) respectively for the realistic scenario (80 % shipment by rail, 20 % shipment by road).

Compared to the results of TSK 2009 the changes in prognostic scenarios are rather small, even with the variation of parameters mentioned above. 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 3.9×10^{-3} per year for TSK 2009. For prognostic scenarios it decreases to 3.3×10^{-3} per year for scenario 2020 and 3.0×10^{-3} per year for scenario 2040 respectively. This result can be explained by the increasing amount of shipping units from NPPs. Because of higher activities in this sector more resistant types of containers (e.g. made from cast iron instead of sheet steel) will be used. In the majority of accidents with activity release, the predicted effective dose is far below the annual natural radiation exposure level even without countermeasures for all scenarios. In all cases, even at a distance of 150 m and down to an expected frequency of 1×10^{-7} per year the calculated doses stay below the design guideline exposure limit of 50 mSv which is used for orientation.

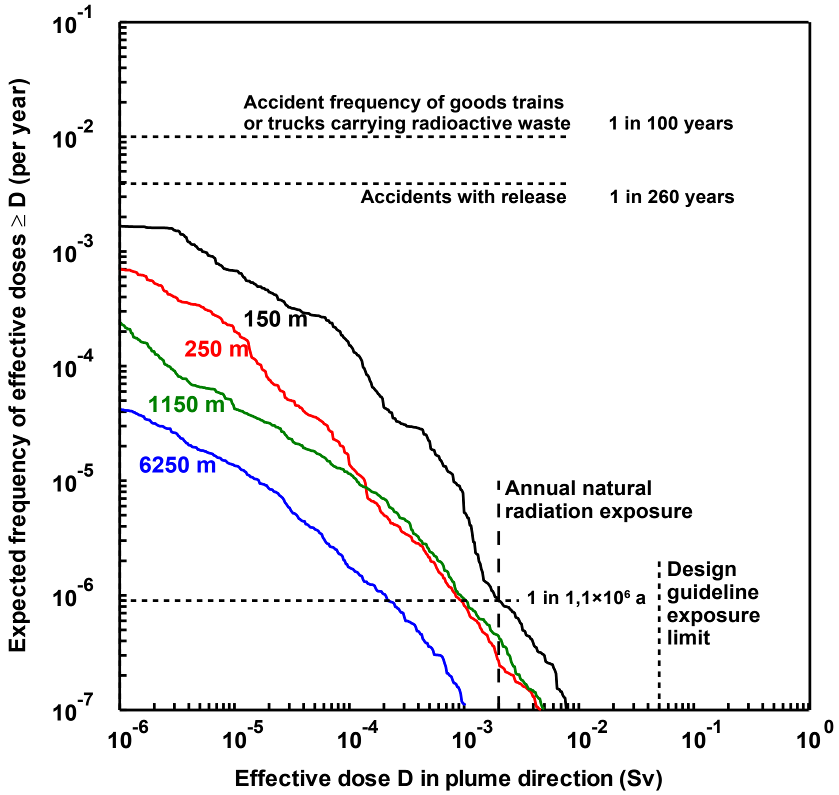

Figure 5. Frequency distribution of the effective lifetime dose from waste transport accidents in the region of the final repository (25 km zone) for the scenario TSK 2009 (80 % rail/20 % road transport) without countermeasures

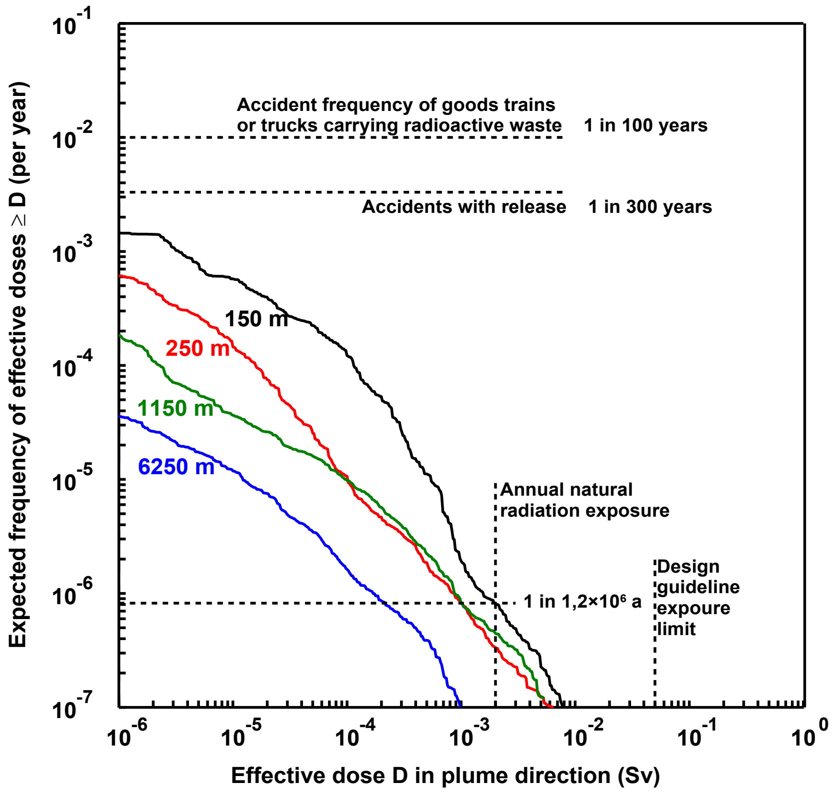

Figure 6. Frequency distribution of the effective lifetime dose from waste transport accidents in the region of the final repository (25 km zone) for the scenario 2020 (80 % rail/20 % road transport) without countermeasures

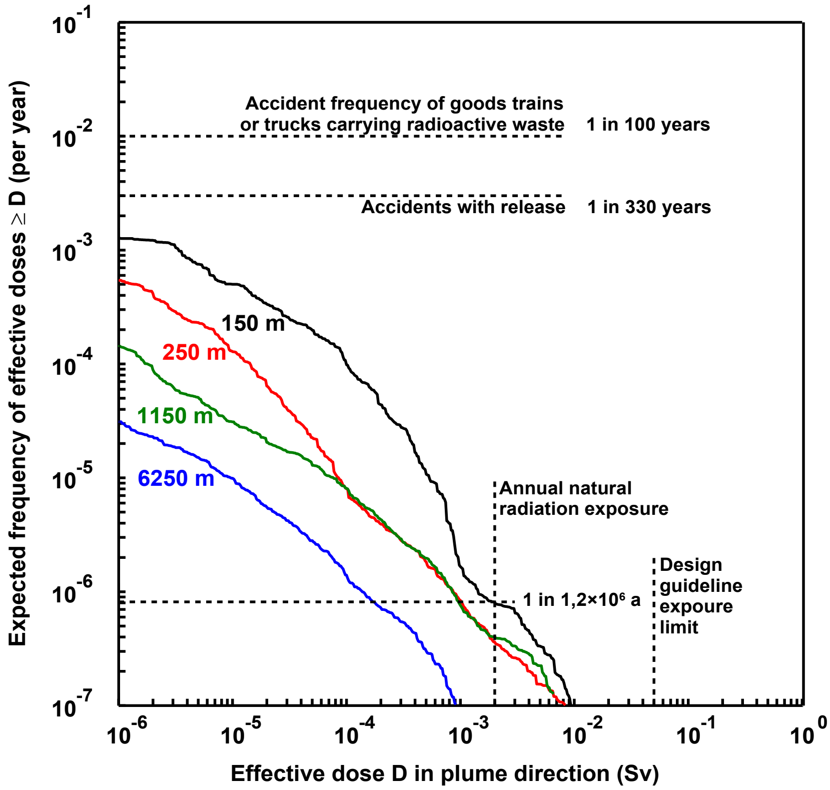

Figure 7. Frequency distribution of the effective lifetime dose from waste transport accidents in the region of the final repository (25 km zone) for the scenario 2040 (80 % rail/20 % road transport) without countermeasures

CONCLUSIONS

The results of the analysis for normal transport are based upon the prognostic scenarios 2020 and 2040, which take into account the changes of the radioactive waste characteristics. In TSK 2009 an amount of 56 % of the gross volume of radioactive waste has its origin in research, whereas in the scenario 2040 66 % of the waste has its origin in NPPs. This leads to further shifts in parameters like the number of shipping units, the mean activity per shipping unit and many others. Nevertheless, the changes of resulting consequences for the expected radiation doses of residents near the main routes for delivering the radioactive waste are small. The doses calculated on the basis of the prognostic scenarios are only slightly higher than the doses for an adult resident near main transport routes presented in TSK 2009 [2]. Regarding the prognostic scenarios for the years 2020 and 2040 the accident rate with release of radioactive material is slightly lower compared to the realistic scenario (80 % shipment by rail, 20 % shipment by road) of TSK 2009.

Overall, the results of the prognostic scenarios 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, even when the characteristic of radioactive waste will change. This applies to both normal transport and transport accidents.

ACKNOWLEDGEMENTS

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