Transportation of Reprocessing Waste From France to Germany: Assessment of the Radiological Risks of Transport Accidents*

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SCOPE AND OBJECTIVE

The reprocessing contracts signed between COGEMA, France, and its customers include the requirement that the radioactive waste arising from reprocessing of foreign spent nuclear fuel must be returned to the customer. Accordingly, the radioactive waste generated from reprocessing of German spent nuclear fuel is expected to be returned from the COGEMA La Hague Reprocessing Plant (UP2, UP3) for interim storage in Germany in the near future. In response to safety concerns of the public related to such reprocessing waste transports a waste transport risk assessment study has been conducted on behalf of the Institut de Protection et de Sûreté Nucléaire (IPSN), France, the Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU), Germany, and the Directorate-General for Environment, Nuclear Safety and Civil Protection, (XI-A-I) of the European Commission.

The primary objective of the waste transport risk assessment study is to provide an overview of the types, quantities, and characteristics of the radioactive waste arising from reprocessing of 4,650 Mg (HM) spent nuclear fuel at the COGEMA La Hague Reprocessing Plant within the framework of the first 10-year reprocessing contracts (1985-1995) and to quantify the radiological risks associated with the transportation of reprocessing waste being returned over a time period of about 10 years from now.

The radiological risks entailed in the transport and handling operations of the reprocessing waste materials considered in the risk assessment study include the following:

- Radiation exposure of the public and transport personnel from routine (incident-free) transportation of radioactive material (public and occupational exposure).
- Transport incidents and accidents resulting in radiation exposure of the population and/or contamination of the environment and the probability of such adverse events (potential exposure).

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In this paper emphasis is placed on the radiological risks of potential transport and handling accidents and on providing an overview of the results and methods employed in the waste transport risk assessment study. The term radiological risk is used to mean throughout this paper to describe the potentially adverse effects of transport accidents in terms of the radiological dose to members of the public and the expected probability of occurrence of such accidental events. The radiation exposure of the public and transport personnel attributable to routine transport operations have been addressed in a companion paper presented at this meeting (Raffestin et al. 1995).

TYPE AND QUANTITY OF WASTE RETURN SHIPMENTS

Overall, four radioactive waste streams arising from reprocessing of German spent nuclear fuel at the COGEMA La Hague Reprocessing Plant have been identified and will ultimately be returned to the country of origin: (1) Vitrified high-level radioactive waste, (2) hulls and end caps, (3) bituminous waste (solidified sludges etc.), and (4) solid intermediate- and low-level technological waste.

However, based on current planning the waste streams expected to be returned from France over a time period of about 8 to 10 years from now, i.e., from approximately 1995 - 2003, for storage at the Interim Storage Facility Gorleben, Germany, include:

- Vitrified high-level radioactive waste
- Bituminous intermediate-level waste

The vitrified high-level radioactive waste (HAW) contains the bulk of fission products and transuranic elements - except uranium and plutonium - of the spent nuclear fuel solidified in a glass matrix which is enclosed in a 175 l stainless steel canister. The stainless steel canisters will be shipped in accordance with the relevant Transport Regulations either in heavy shielded casks of the type CASTOR HAW 20/28 CG or TS 28 V weighing up to about 113 Mg. Approximately 2,800 glass canisters are expected to be returned from France packaged in about 120 shipping casks. This corresponds on average to about 15 cask shipments per year for a projected shipping period of about 8 years (1995 - 2003).

The low- and intermediate-level radioactive liquid plant effluents of the La Hague Plant are purified by coprecipitation or evaporation and the resulting intermediate-level sludges are immobilized in a bituminous matrix and filled into a 225 l stainless steel drum. The steel drums are assumed to be placed in a cubical cast iron transport Container VII having a capacity of 5 steel drums. For the study a maximum of 3,600 drums has conservatively been assumed to be returned from France. This corresponds on average to about 50 railcars per year assuming a shipping period of 7 years (1997 - 2003) and a loading capacity of two waste transport containers per railway wagon. (According to COGEMA only 1,200 drums have been allocated to German customers from the volume of bituminous waste generated over the recent years at the La Hague plant and production of further drums will most likely be discontinued soon due to modifications in the plant process design.)

Selected characteristics of the waste product and the transport casks/containers for the vitrified and bituminous waste are given in Table 1. Both package types are multi-purpose containers and conform to the Type B package requirements of the IAEA Transport Regulations (IAEA 1990) and the waste acceptance criteria of the Interim Storage Facility Gorleben. According to currently available information the other radioactive waste streams, i.e., hulls/end caps and technological waste, are considered to be suitable for supercompaction and will most likely not be returned within the study period (1995-2003) and, thus, are not considered in the study.

TRANSPORT MODE AND SHIPPING ARRANGEMENTS

The primary mode of transport for all waste products is by rail. Road transportation will be limited to a small fraction of the journey between the La Hague Reprocessing Plant and the off-site Valognes loading terminal (road-rail transfer) and, similarly, between the Dannenberg loading terminal (rail-road transfer) and the Interim Storage Facility Gorleben. Due to logistic constraints each waste consignment is expected to be limited to a maximum of three waste wagons to be shipped in mixed cargo trains and, thus, on average two waste wagons per train were assumed for risk assessment. The rail journey of the transboundary shipments covers a distance of about 1,400 km (almost equally divided in length between France and Germany) on the network of the Société Nationale de Chemins de Fer (SNCF) and German Railways (DB AG). The average population density along the shipping route is about 358 persons/km^2.

Table 1. Selected Characteristics of the Waste Product and Transport Container for Vitrified and Bituminous Reprocessing Waste

	Vitrified Waste	**Bituminous Waste**
Cumulative Number of Waste Transport Casks/Containers to be returned:	120	720
Cumulative Number of Railcars required for Waste Transportation:	120	360
Nominal Transport Cask/Container Activity Inventory (TBq):		
• Beta/Gamma Emitters	840 000	11
• Alpha Emitters	4 000	0.13
• Cesium (Cs 134/137)	210 000	0.88
• Plutonium (incl. Pu 241)	1 100	3.9
Nominal Transport Cask/Container Dose Rate (mSv/h):		
• Surface	< 0.17	< 0.4
• at 1 m from Surface	< 0.11	---
• at 2 m from Surface	---	0.1

ASSESSMENT APPROACH

Transport and handling accidents may occur for a number of reasons posing a risk to man and his environment. Particularly, members of the public may eventually be exposed via a number of pathways to radiation from material that might be released into the environment subsequent an accident. The magnitude of such a release and the related frequency of occurrence depends on a number of factors including the type and volume of waste being returned and the severity and frequency of accidental events such as a collision, vehicle derailment, striking an object, etc. Because the occurrence of such accidents is statistical in nature a probabilistic risk assessment method (PRA) has been adopted for the study aimed at quantifying the potential radiological consequences and the expected probability of occurrence of such accidental sequences. The probabilistic assessment method adopted for the study is specifically designed to describe the broad range of shipping arrangements and the type and frequency of transport and handling accidents including low-probability, high-consequence events as well as high-probability accidents with - if at all - low radiological consequences. The method typically involves a five-step analysis approach:

- Characterization of the type and quantity of waste shipments;
- Definition and description of the type, severity, and probability of occurrence of transport and handling accidents;
- Assessment of the structural and thermal system response of the transport packaging and the waste product to specific mechanical and/or thermal impact loads and the subsequent package release (release fraction);
- Estimation of the radioactive release and frequency of occurrence taking into account the broad range of (single or multiple package) shipping patterns and accident severities (source term estimation); and
- Assessment of the potential radiological consequences for the spectrum of weather conditions encountered along the transport route.

The transport container activity inventory was generally assumed to have nominal characteristics, but for 10% of the transport containers upper-limit values were conservatively adopted for the study.

For the calculation of the accident risks a freight train accident rate of about of 0.5 per 1 million train-km or 0.026 per 1 million railcar-km has been taken for the assessment as being most representative for shipments on the French and German railway network (Fett and Lange 1992, Raffestin et al. 1994a). Nine accident severity categories representing the accidental load conditions to a waste package including three mechanical (non-fire) and six combined mechanical-thermal accident environments were adopted for rail transportation. Three severity levels were defined to describe the mechanical impact load conditions experienced by a package based on the train velocity prior to the accident event: < 35 km/h, 36-80 km/h, and > 80 km/h. The potential thermal impact loads are defined by two reference fires intended to conservatively bound real thermal accident environments. These fire environments include: a fully-engulfing 30-minute 800°C fire and a fully-engulfing 60-minute 800°C fire. Based on an analysis of a 10-year historical record of

freight train accidents provided by German Railways, the predefined severity categories were modelled assuming a relative frequency for mechanical-only accidents of about 89.4%, for combined mechanical 30 minute/800°C fire environments of about 7.03%, and for combined mechanical 60 minute/800°C fire environments of about 3.46%.

The structural and thermal response of the packaging and the waste product and subsequent fractional package release has been evaluated on the basis of experimental information including drop and penetration test experiments and engineering analysis taking into account the physical-chemical behaviour of the (vitrified and bituminous) waste product under mechanical and thermal loads (Glaser 1980, Wieser et al. 1983, Scheibel et al. 1988). For determining the fractional package release the assumption has been made that the package strikes a hard rigid target surface in the most damaging orientation with the maximum speed of the respective severity category. For the impact velocity range in excess of 80 km/h an impact velocity of 110 km/h was assumed for the assessment of the structural package response. The so-defined nine accident environments include with respect to severity mechanical and thermal load conditions within the IAEA regulatory testing requirements for Type B packages as well as beyond regulatory conditions. The assumptions made along with others represent a significant element of conservatism that has been introduced in the accident risk assessment approach.

Based on this level of information the broad range of conceivable shipping patterns and mechanical and thermal impact loads to a waste package from railway accidents has been determined using a Monte Carlo simulation approach. As much as 1000 load-shipment configurations for each severity category have been simulated for the study, each replication resulting in a radionuclide-specific source term for the simulated accidental sequence. Subsequently, the numerous different source terms have been consolidated into 10 representative release categories including five release categories representing non-fire accident environments and five release categories representing combined mechanical-thermal accidental sequences. A detailed description of the consolidation method is given elsewhere (Lange et al. 1992b).

There are several kinds of operations contributing to the overall radiation risk: rail transport, road transport, marshalling yard operations and rail-road transfer activities. From the information available, however, it has been concluded that transportation by rail over a distance of about 1400 km represents the most dominant risk contributor and, thus, the full-scale probabilistic risk analysis has been limited to quantifying the risks from rail transportation.

The potential radiological consequences, expressed in terms of the 50-year committed effective dose of the population (critical group individuals) under the condition of absent mitigative actions, have been calculated using the probabilistic accident consequence assessment code COSYMA developed under the auspices of the European Commission (Hasemann and Jones 1993). The relevant exposure pathways considered in the estimation of dose include: cloudshine, groundshine, inhalation, and ingestion. The results of the COSYMA code can be presented in various ways and are expressed throughout this paper in terms of the probability of characteristic outcomes attributable to transport accidents, e.g. the probability of occurrence of a given dose to critical group individuals at a given distance from the scene of the accident.

ASSESSMENT RESULTS

The risk assessment results presented in this section refer to the total volume of waste transports of about 120 railcars of vitrified waste and 360 railcars each carrying two transport containers with bituminous waste. The assumed shipping mode is by mixed cargo trains traveling from Valognes (near Cape La Hague) to Dannenberg (near Gorleben) over a distance of about 1,400 km within the projected shipping period from about 1995 - 2003. The 50-year committed effective dose has been calculated for a hypothetical individual being permanently located at the specified receptor point below the plume centerline during the passage of the radioactive cloud (inhalation, cloudshine) and from exposure to ground deposits and the intake of contaminated foodstuffs under absent mitigative actions. The following conclusions can be drawn from the accident analysis results:

- Based on the accident rate of regular freight trains on the French and German railway network, the probability of a waste wagon to experience some level of material damage in a railway accident is about 0.016, i.e., a chance of 1 in 64 for the total volume of vitrified and bituminous waste transports to be returned from France over a projected time period from 1995 to 2003. In other words, by shipping a waste volume 64 times larger than the volume considered in this study, one railway accident is expected to occur somewhere on the 1,400-km shipping route resulting in material damage to (at least) one waste wagon being carried in a mixed cargo train.

- Most of the railway accidents referred to above, however, will not compromise the structural waste package integrity and, consequently, do not result in a package release. Accidents with the potential to affect the integrity of Type B waste transport casks or containers as considered in this study require some level of intensity of the mechanical and thermal accidental impact loads. The available railway accident data for France and Germany, however, indicate that such high-intensity railway accidents are rarely expected to occur. Based on a conservative approach to describe the structural package response (impaction on a hard rigid target surface) it has been found that 1 out of 16 railway accidents resulting in material damage to a waste wagon give rise to a package release of radioactive material for the total transport volume of vitrified and bituminous wastes. Consequently, the conservatively estimated chance for an accident-related radioactive package release is less than 1 in 1010 for all waste transports being returned within the projected 8-year shipping campaign.

- For a large fraction of accident events giving rise to a package release, however, the quantity of radionuclides escaping from the waste transport cask or container is low, if not insignificant. For example, in more than 90% of railway accidents resulting in an environmental release the below-plume-centerline 50-year committed effective dose to members of the public under the condition of absent mitigative actions has been predicted of not exceeding a value of 1 mSv even in close proximity (250 m) to the accident site.

- Radioactive releases and the associated below-plume-centerline 50-year committed effective doses in excess of 50 mSv are not expected to occur in close proximity of the accident site (250 m) at a probability level as low as 10^{-7}, i.e., a chance of 1 in

10 million for the total volume of vitrified and bituminous waste. If expressed as probability per year, the corresponding value would be well below 10^{-8} per year.

- The potential radiological consequences decline rapidly with distance from the accident site, and consequently, the potentially adverse consequences of transport accidents are generally limited to the area in close proximity of the accident site.
- The radiological risks are dominated by accidental sequences involving bituminous waste transports. Even with the quite conservative approach of this risk analysis, railway accidents which could result in some release from casks with vitrified waste are much rarer, and releases in those cases are much lower than for bituminous waste.

The results of the risk assessment study presented herein are broadly consistent with previous transport risk assessment studies, which have, for example, been conducted for projected waste transports to the Centre de l'Aube, France (Raffestin et al. 1994), or the designated Konrad Waste Repository in Germany (Lange et al. 1992), if differences in the waste volume and other characteristic factors are appropriately taken into account.

CONCLUDING STATEMENT

The results of the comprehensive transport risk assessment study for reprocessing waste shipments to be returned from France indicate that considering the magnitude of the radiological consequences of potential transport and handling accidents, and the likelihood of occurrence of such accidental events, waste transport accidents do not pose a significant risk to man and the environment. The risk assessment results reflect the appropriate level of protection provided and embodied in the national, international and IAEA Transport Regulations.

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