PROBABILISTIC SAFETY CONSIDERATIONS FOR THE FINAL DISPOSAL OF RADIOACTIVE WASTE

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ABSTRACT

In order to demonstrate the safety-related balanced concept of the plant design with respect to the operational phase, probabilistic safety considerations were made for the planned German repository for radioactive wastes, the Konrad repository. These considerations are described with respect to the handling and transfer system in the above-ground and underground facility.

The operational sequences and the features of a repository are similar to those of conventional transportation and loading facilities and mining techniques. Hence, failure sequences and probability data were derived from these conventional areas. Incidents taken into consideration are e. g. collision of vehicles, fires, drop of waste packages due to failures of lifting equipment. The statistical data used were made available by authorities, insurance companies, and expert organizations.

These data have been converted into probability data which were used for the determination of the frequencies for all radiologically relevant incidents.

INTRODUCTION

Within the scope of safety analyses for the planned Konrad repository for radioactive wastes with negligible heat generation, an incident analysis was carried out. The possible events in the different facility areas were identified and assessed in this analysis. The events were classified as class 1 events, i. e.

- events limited in their radiological effects by the plant and/or waste package design,

and class 2 events, i. e.

- events avoided by the plant and/or waste package design.

The assessment dealt with the design of the planned Konrad repository and with the question as to whether the concept is balanced with respect to safety.

The frequency with which the events (incidents) must be expected on the basis of the planned design is one criterion for the assessment of the safety-related balanced concept. The assessment of the balanced concept is influenced by both the absolute frequency of occurrence of each single event as well as the relative frequencies of occurrence of those events which have to be clearly classified with regard to their possible radiological effects. The determination of the expected frequencies of the identified events is thus an essential task.

The possible radiological effects of the events were not dealt with in this probabilistic analysis. In this respect, this work represents a supplement to the deterministic incident analyses on a probabilistic basis rather than a risk analysis.

PROCEDURE

Basis for the Probabilistic Assessment

In a first step, the events to be considered were processed for the probabilistic assessment.

In this step, the events to be assessed with regard to their frequency of occurrence were subdivided according to the foreseen operations. Within the scope of this subdivision, the marginal conditions were determined, which could lead to a load of the waste package such that a release of radioactive substances cannot be excluded.

Data on the possible load drop, on the frequency of the single operations carried out per year as well as on the duration or transport distances covering the single operations form the basis for assessing the events. Additionally, the durations or transport distances leading to a load from an event in a facility are taken into account.

Probabilistic Assessment of Events

The determination of the expected frequencies of occurrence of the events was the goal of the probabilistic procedure. In a second step, the associated reliability data were determined. These data were derived from operational experiences. For events relating to the hoisting plant, the operational experiences of the last 35 years with ore, salt, potash and coal mining in the Federal Republic of Germany could be utilized to a large extent. Operational experiences with trackless operation and with storage on an incline (emplacement) in potash and salt mining were available for the determination of the reliability in the underground area of the facility. Operational experiences with comparable industrial enterprises as well as statistics and investigations with comparable initial questioning are the basis of reliability data for the above-ground facility area.

The derived reliability data were conservatively applied to the Konrad repository.

In a third step, the frequencies of occurrence of each incident were calculated on the basis of the determined reliability data and the marginal conditions determined in the first step. These were then combined to obtain cumulative incident frequencies in the last step. With the help of these combined values, the safety-related balanced concept of the Konrad repository was assessed.

In accordance with the criteria mentioned in (1), the following procedure was used:

The planned safety-relevant design of the Konrad repository is considered to be balanced if

- an incident classified as a class 1 design basis incident is to be expected with a frequency of once during the operational phase of the facility,
- a class 2 design basis incident is to be expected with a frequency corresponding to that of the "residual risks". This is assumed if the expected frequency of occurrence of the incident is $< 10^{-5}$/a.

Consequently, the deciding criterion for the assessment of incidents with respect to the balanced concept is the expected frequency of occurrence of the incidents. If it is assumed that an event can sufficiently be avoided by design measures (residual risk), an assessment of the consequential radiological effects of this event need not be carried out.

Events with higher frequencies of occurrence than those allowed for class 1 incidents are not permitted to lead to waste package loads with activity release. So, these events are not considered as incidents but rather as operational disturbances.

RESULTS

As an example, some results and the procedure for determining numerical values are described in the following, and the cumulative incident frequencies are listed for the components of the above-ground and subsurface facility.

Delivery Vehicle Fire in the Transfer Hall

The event "delivery vehicle fire" assumes that a vehicle catches fire due to technical faults. Since the associated truck-specific data are not available, the data available for cars were used for the estimation of the frequency of occurrence. The application of this frequency to trucks is conservative, since trucks are classified as being much better than cars. For trucks, fire in the carburetor, e. g., or fuel leak can be excluded as causes of fire.

Investigations on initiating car fires were carried out by the Hessisches Landeskriminalamt (Land Office of Criminal Investigation of Hesse). According to this report the frequency of initiating car fires is approximately 1.5×10^{-4} per year and car. This value corresponds to the frequency value of approximately 1×10^{-4} per car and year for initiating car fires quoted by the Deutsche Bundespost (German Federal Postal Administration) and by the Deutsche Bundesbahn (German Federal Railways Administration) for their car pool.

Therefore, the frequency of initiating truck fires is estimated to be 1×10^{-4} x vehicle.

In the planned Konrad repository, the operational staff (including truck drivers) and the public fire brigade are available in case of a fire. According to (2), the extinguishing failure probability is 5% for the operational staff and 10% for the public fire brigade. The frequency of a fully developed fire developing from initiating fires with a value of 1.0×10^{-4}/a x $0.01 = 1.0 \times 10^{-6}$/a is determined with a limited probability of 0.01 for extinguishing failure.

This frequency is valid for the case that the corresponding vehicle is available as a thermal load round the clock. Considering that

- not all waste packages are delivered by truck and that
- every truck - when loaded with a transport unit - is in the reloading area for less than 800 s,

the frequency for the incident "fire of a vehicle" during the reloading of waste packages is approximately 4×10^{-8}/a.

Prevention of a fully developed fire is effectively supported in the reloading hall by the availability of a specific truck extinguishing device which extinguishes the initiating fire and cools the transport units in order to guarantee the integrity of the waste packages until the fire brigade arrives.

Due to the low probability of occurrence, a delivery vehicle fire in the reloading hall is categorized as a class 2 incident.

Fires Inside Plants

The value of 2×10^{-6} per m^2 and year for initiating fires in industrial buildings is the basis for determining the frequency of damaging fires in the above-ground buildings at the Konrad 2 shaft.

The above-mentioned value is valid for a mean fire risk. There is a lower fire risk when there are no other buildings in the vicinity, when the building is low, when the building has a clear interior layout, when the building is constructed by using special fire protection methods, when fire loads are removed from the building, and when adequate water is available for fire fighting. Since these marginal conditions are fulfilled in the case of the planned Konrad repository, a frequency reduction for initiating fires by a factor of 10 to 2×10^{-7} per m^2 and year is permissible according to (3).

The surface areas for the individual fire areas and the associated frequency of occurrence of fires in the plant were determined. Based on this, the frequency for the fire in the reloading hall, for example, is 7.8×10^{-4}/a.

On the basis of the above-mentioned values, the frequency of a damaging fire is dependent on successful fire fighting. This needs both the operating staff and the public fire brigade to be taken into account.

During the emplacement operation, a part of the personnel is permanently present. Of these, at least three to four persons are trained in fire fighting. According to (3), the mean failure probability for direct manual fire fighting by the operating staff is 0.05 per demand, assuming a personal fire report immediately following fire fighting. According to (4), the probability of an initiating fire developing into a fire is assumed to be 0.1 in case the public fire brigade is called.

Taking fire fighting into account, the frequency of occurrence for a damaging fire in the reloading hall is about 3.9×10^{6}/a.

As there are no transport units in the reloading hall prior to and subsequent to the emplacement duration, 200 shifts with 8 hours each are taken as a basis for calculating the incidence frequency (with the exception of the buffer tunnel which is separated from the reloading hall with regard to fire protection methods and which contains only few fire loads). This results in a frequency of about 7.8×10^{-7}/a for a fire in the plant. Due to this low probability, this event is categorized as a class 2 incident.

Drop of a Waste Package during Handling with Stacking Vehicles

One stacking vehicle is used for transportation and storage in the buffer hall and two front-loading stacking vehicles are available for transportation and storage in the emplacement rooms.

Since 1970, the trade association committee of experts "Means of Transportation and Load Lifting Member" has statistically analyzed accidents with carts. The accidents considered are load drops caused by load lifting member defects (Group "Building and Equipment" of the statistics) and by defective load lifting (Group "Operation"). The results for several years of data show an approximate ratio of 1:3 for the occurrence of the two groups of stacking accidents (Building/Operation).

Interpreting the events in which "the driver or other persons were injured by parts of the load falling down, slipping, turning over or were hit by slipping objects (staples, shelves)", leads to a load drop frequency of 4×10^{-3}/a.

This load drop frequency is based upon stacking vehicle accidents in the course of which persons were injured, since only these operational events are required to be reported to the trade association. The frequency of load drops without injury to persons can only be estimated.

Based on expert estimate, a mean factor of 10 is conservatively assumed for the probabilistic facility assessment. With this factor and with the load drop frequency of 4×10^{-3}/a for load drops with persons being injured, a load drop frequency of the stacking vehicle of 4×10^{-2} is obtained per year and vehicle.

The stacking vehicles considered in the statistics are used in one-shift working as well as in multishift working. A mean value of 900 working hours/a results from the data available.

The load drop frequency of 4×10^{-2}/a leads to 4.4×10^{-5} load drops per working hour.

It has to be taken into consideration here that the statistically recorded stacking vehicle accidents occurred in commercial operation (production facilities, dispatchers, stores) where work is performed under pressure, under partly unfavorable conditions (ramps, loading platforms, narrow lanes and curves) and often with operating staff who have very little training. This above-mentioned value can still be considered to be conservative for the conditions in the planned Konrad repository due to the clear, plane tracks (reloading hall/buffer hall as well as emplacement room), the low number of waste packages to be transported or emplaced daily and the availability of well-trained stacker drivers. A load drop frequency of 2×10^{-5}/working hour is assumed in the probabilistic assessments for Konrad.

A waste package drop during the emplacement of such containers need not be assumed for the lowest plane, since the containers are transported with the stacking vehicle at a height of 30 cm above ground. The duration during which the waste packages are lifted above a height of more than 1.2 m is relevant for the probabilistic assessments. Considering this time and the total number of containers to be expected, a frequency of occurrence of about 1.1×10^{-4}/a is obtained, i. e., the waste package drop during handling must be categorized as class 1 incidents for which radiological calculations are required.

Cumulative Frequencies of Incident Groups

The probability and reliability data were used for the determination of the frequencies for all radiologically relevant incidents. A cumulative frequency for a group of incidents was obtained by adding the frequencies of single incidents of a similar nature in various plant areas. The incident groups and their cumulative frequencies for the surface part and the underground part of the repository are shown in Tables I and II.

TABLE I

Cumulative Frequencies of Incident Groups in the Surface Part of the Repository

Incident Group	Cumulative Frequency [1/a]
Drop of waste packages	3.2×10^{-3}
Collision of vehicles with fire	3.2×10^{-6}
Fire of a vehicle	2.5×10^{-6}
Fire in the plant	7.9×10^{-6}

TABLE II

Cumulative Frequencies of Incident Groups in the Underground Part of the Repository

Incident Group	Cumulative Frequency [1/a]
Drop of waste packages	3.4×10^{-3}
Fire of a vehicle	1.4×10^{-4}
Collision of vehicles with (and without) fire	9.0×10^{-8} (6.1×10^{-6})
Drop of rocks	4.9×10^{-6}
Fire in the plant	2.0×10^{-6}
Mechanical impact while transporting	1.2×10^{-4}

CONCLUSIONS

The goal of the probabilistic incident analysis was to demonstrate that the planned Konrad repository is balanced with regard to safety. The events investigated with regard to their frequency of occurrence corresponds to the events of the safety analysis, which were obtained using a deterministic approach.

The probabilistic analysis shows that class 1 incidents occur with cumulative frequencies of $< 5 \times 10^{-3}$ per year, and that class 2 incidents occur with cumulative frequencies $< 10^{-5}$ per year.

These frequencies are upper bounds. They were statistically generated using conventional technology. The events were often chosen without considering the stringend design requirements based on the current state of the art of science an technology for the planned Konrad repository (conservative approach).

Most of the events considered for generating the reliability data occurred because of high productivity and because of shift and piece-work. The training level of the persons involved in the events could in most cases not be evaluated. Consequently, it must be assumed that the conditions are very different to those in the planned Konrad repository.

These differences resp. the stringent design requirements for the Konrad mine have mostly not been considered in determining the frequencies of occurrence. The calculated frequencies can therefore be considered as upper bounds.

The frequencies of occurrence calculated for the various groups of events show that the requirements on a balanced concept with regard to safety have been met.

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