Analysis of German Rail Accident Statistics for Risk Assessments

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Introduction

The Federal Minister for the Environment, Nature Conservation and Reactor Safety (BMU), Bonn, commissioned the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Cologne, to conduct a study with the objective to quantify the radiological risks associated with the transportation of radioactive waste to the KONRAD final waste repository (Lange et al. 1992). Some methods and results of this investigation have been reported in (Lange et al. 1992, this conference)

As most of the transports to the repository are to be rail transports, a major aspect of the study mentioned above was the risk arising from rail accidents. In general the wagons carrying radioactive waste will run in mixed cargo trains and have to be switched repeatedly on marshalling yards between short-distance and long-distance trains. Special investigations had been conducted therefore to determine the frequency of railway accidents and the associated effects on the transport units in both goods train traffic and shunting operations (Fett and Lange 1992).

1 Data Base

Accident data from the Deutsche Bundesbahn (DB, Federal German Railways) were available as a basis for this investigation. With respect to goods train accidents these data covered the area of the former Federal Republic of Germany (West) and a period of ten years of record (1979 to 1988). A total number of 656 relevant accidents were reported in this time and a total of 1916 million goods train kilometers have been travelled.

Respecting shunting operations accidents in the marshalling yard Braunschweig were evaluated for a period of three years from 1987 to 1989. Over 2 million wagons have been handled during this period. Supplementary data from eight larger marshalling yards in Germany for the years 1985 to 1987 were also evaluated. A larger part of the shunting operations associated with the transports to the KONRAD site are actually to be performed in Braunschweig, which is situated about 15 km from the radioactive waste repository.

2 Accident Data Analysis Methods

General Proceeding

The investigation covered goods rail traffic without any restriction of the type of material transported. This meant that a sufficiently extensive and representative data base was available for the assessment of transport risks associated with radioactive waste shipments. Restricting the investigation to accidents with goods trains carrying hazardous materials seemed to be unjustified, since these are not characteristic for the transport of radioactive waste and the data base is much smaller.

The goods traffic and shunting operation sectors were dealt with separately. Different reference quantities (train-kilometers travelled in goods train traffic and number of wagons handled in shunting operations) were employed to determine the accident frequencies. This allows each type of operation to be considered separately when determining the risk from transport accidents for a specific local area.

Severity of Effects

Risk assessment requires that the expected frequency of accidents be determined as a function of the magnitude of accident consequences. The magnitude of accident consequences is characterized, on the one hand, by the **number of freight wagons affected by an accident** and, on the other hand, by the load caused by the accident. This load can either be mechanical impact, thermal impact (fire) or a combination of both. For the purposes of accident risk analysis, therefore, a model of **nine severity categories** was defined.

Three severity categories were defined for mechanical effect according to the speed of the train at the moment of the accident:

- 0 to 35 km/h,
- 36 to 80 km/h and
- above 80 km/h.

Further six severity categories were defined by combining these mechanical effects and additional fire. Two types of reference fires intended to conservatively cover the circumstances of real fires were defined in this context. These were fires with a temperature of

- 800 degrees Celsius and duration of 30 minutes and
- 800 degrees Celsius and duration of 60 minutes

When modelling the possible release from the radioactive waste containers associated with the respective severity categories it was assumed that mechanical impact was equivalent to a collision onto an unyielding surface at the upper limit of the speed range considered (110 km/h for the range of 'above 80 km/h'). Regarding thermal impact the package was assumed to be completely engulfed in flames.

In addition to these assumptions, which are believed to be overestimating in most cases, also the assignment of the observed accidents to the severity categories was done in a very conservative way. E.g. all affected wagons in an accident are assumed to suffer the same magnitude of impact and in case of fire the fact was not taken into account, that serious fires are unlikely to originate at the radioactive waste wagon itself.

On the other hand a **lower damage threshold** was defined, whereby damage below the threshold was considered not to constitute relevant damage for the type of transport units envisaged for carrying radioactive waste to the planned disposal site. Material damage to railway vehicles of DM 3,000 was used to determine this threshold - this limit is also used in the accident statistics of the DB to define the threshold of minor damage.

3 Goods Train Accidents

Train Accident Rate

Within the examination period a total accident rate of **34 relevant accidents per 100 million train-kilometers** travelled was determined for goods train traffic. For risk analysis purposes this number was increased to 50 accidents per 100 million train kilometers in order to account for higher accident rates of transfer trains, as determined separately. Transfer trains run in short distance traffic from the customer's own siding to the next marshalling yard. The observed trend in accident rate is a decrease of relevant accidents in the range below 80 km/h by approximately 50% over the examination period. Whereas an increasing trend is found for accidents above 80 km/h, due to the increasing use of fast goods train formations. However accidents above 80 km/h contribute only about 10% to the total accident rate.

Frequency of Severity Categories

The evaluation of the accident data with regard to accident categories resulted in the fractions presented in table 3.1:

Accident Category	Fraction (observed)
fire (no mechanical impact)	8 %
mechanical impact and subsequent fire	1 %
mechanical impact 0 to 35 km/h	37 %
mechanical impact 36 to 80 km/h	45 %
mechanical impact above 80 km/h	9 %

Table 3.1: Fractions of accident categories

When determining the frequency of severity categories the fraction of accidents with both fire and mechanical impact was increased in order to account for the low statistical relevance of the available data for this type of accident: Only two accidents of this type with three trains affected were reported within the examination period. The expected value of a Poisson distribution which allows three affected trains at the lower limit of the 95% confidence interval was therefore used for risk evaluation, resulting in a fraction of 2.8% for this accident category.

For the observed accidents with fire a separate estimate was made, considering the possible thermal energy input to a transport unit conservatively assumed to be located at an unfavorable location in the accident environment. According to this approach, the half-hour reference fire could be considered as adequately describing the equivalent energy input in two-thirds of the cases examined. In one-third of the cases the one-hour reference fire was assumed in order to ensure a conservative assignment. This ratio was used for allocating both the fire incidents with additional mechanical impact and the fire accidents without mechanical impact to the appropriate severity categories for the purpose of risk analysis.

Since a separate severity category for fire without mechanical impact has not been established, this type of accident was assigned to the severity category 'fire and mechanical impact 0 .. 35 km/h'.

The resulting frequencies of severity categories used in risk assessment are represented by the following scheme:

Impact Velocity		Relative Frequency					
		without thermal impact		thermal impact 30 min., 800°C		thermal impact 60 min., 800°C	
0 to 35	km/h	0.36	(SC 1)	5.9E-2	(SC 2)	2.9E-2	(SC 3)
36 to 80	km/h	0.45	(SC 4)	9.5E-3	(SC 5)	4.7E-3	(SC 6)
above 80	km/h	8.4E-2	(SC 7)	1.8E-3	(SC 8)	8.8E-4	(SC 9)

Table 3.2: Relative frequency of severity categories (SC)

Number of Wagons Affected

Besides the energy related severity categories the number of wagons affected in a goods train accident was introduced in this investigation to further quantify the risk from accidents for a given transport volume. From a subquantity of 196 accidents, which were documented in more detail the frequency distribution of the number of affected wagons has been determined. The documentation of the accidents was not always of the desired precision, however, so that conservative upper limits had to be set for the number of affected wagons in some cases. The empirical distribution averaged over the three velocity categories and fire without mechanical impact is shown in Fig. 3.1.

In nearly 60% of the accidents only the engine is affected ("Zero wagons affected"). The distribution decreases with increasing number of affected wagons. Accidents involving 10 or more wagons occurred in less than 1.5% of all relevant accidents. A maximum of 14 affected wagons (with damage above the relevance limit) was observed.

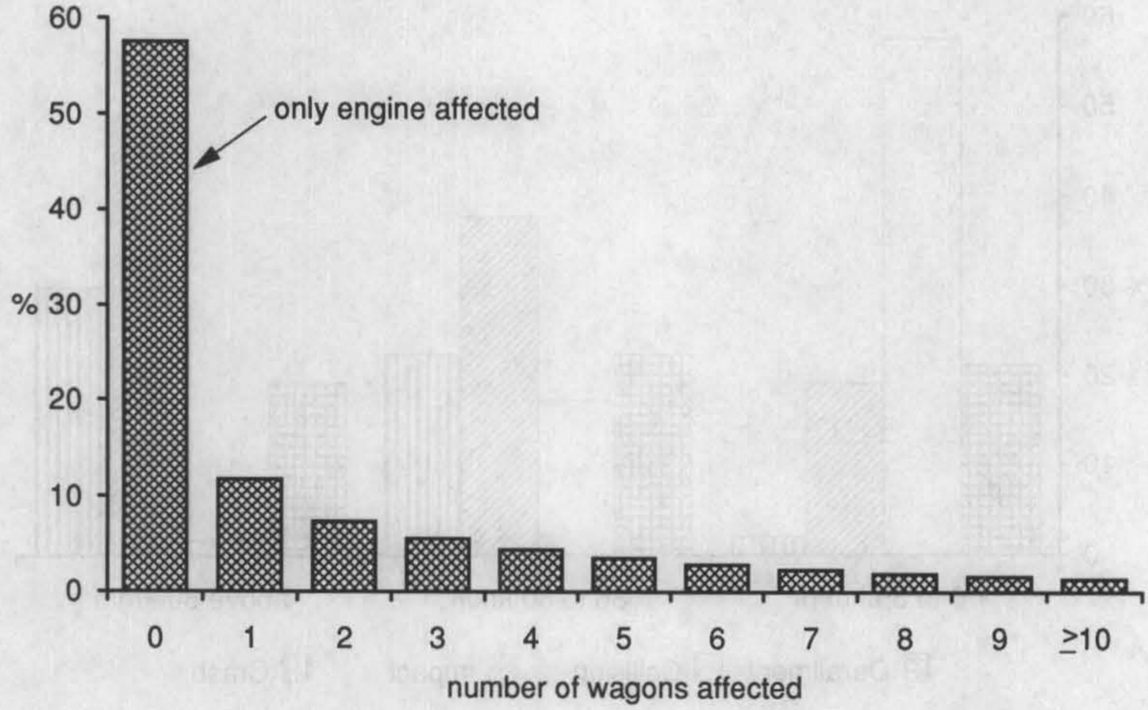

Fig. 3.1: Frequency distribution of the number of affected wagons (average over the three velocity categories and fire without mechanical impact)

In a more detailed approach characteristic tendencies for the individual accident types are discernible: Wagons are not relevantly affected in over 80% of **impact** occurrences (against obstacles, except onto vehicles at level-crossings) and in over 90% of **crash** occurrences (onto vehicles at level-crossings). In these cases engines with their large masses generally absorb the impacts of an accident. In **derailments** and **collisions** (between railway vehicles) the probability of several wagons being affected is greater. Derailment is the sole accident category in which damage only to the power unit is not the most frequent case.

In **fires without mechanical impact**, the most common incident (50%) is fire in the power unit, mostly caused by the electrical installation. Only one fire without mechanical impact was observed with two affected wagons and none with a larger number. This does surely not apply to **fires in consequence of an accident with mechanical impact**. The statistical data did not allow to generate a distribution curve analog to Fig. 3.1 for this type of accident and a uniform distribution for 0 to 10 affected wagons was conservatively assumed in these cases.

Figure 3.2 shows a breakdown into the accident types mentioned before as function of the velocity category. At higher speed, the pattern is dominated by impacts on obstacles and crashes into road-vehicles (resulting in smaller numbers of affected wagons), while at lower speeds collisions of trains (resulting in larger numbers of affected wagons) are prevail-

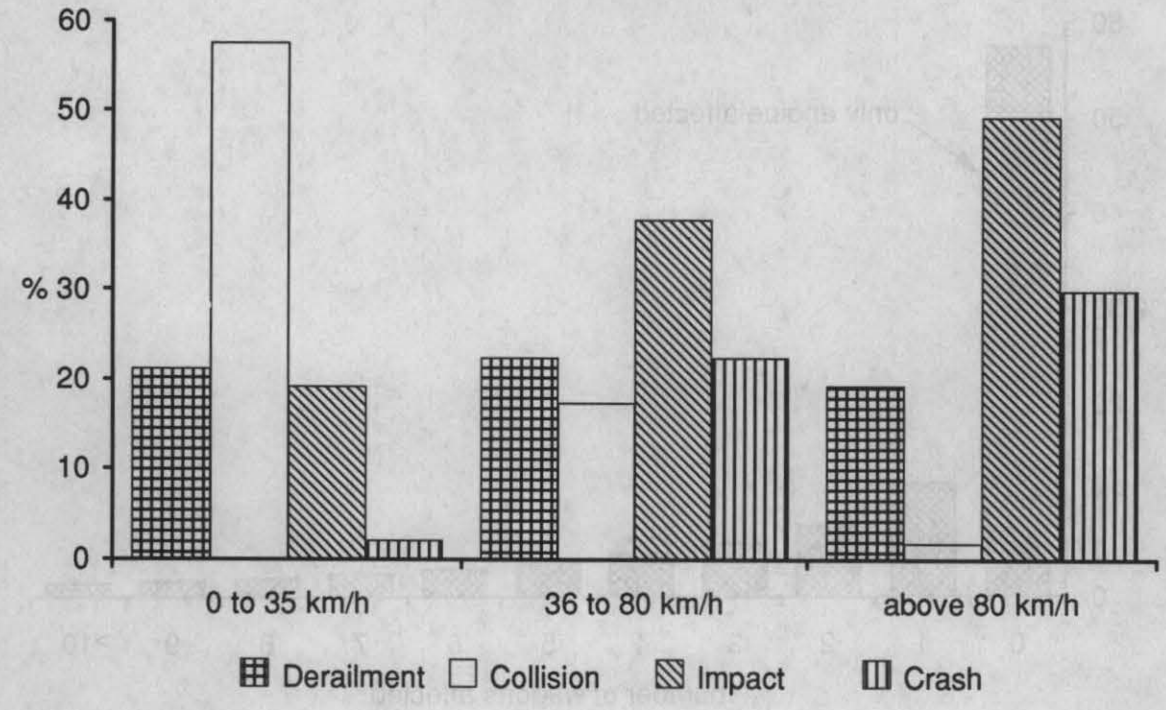

Fig. 3.2: Fractional occurrence of accidents of a particular accident type in goods train accidents

ing. This is due to the fact, that collisions of trains are more likely to occur within station areas where trains cross, while impacts on obstacles and crashes into road-vehicles will occur more frequently on the open line or on railway crossing, respectively, where trains frequently run at top speed. As result of this, the fraction of accidents in which no wagon is affected rises, as the respective speed range increases, a finding that seems somewhat surprising at the first sight.

In order to use the data in risk analysis, the empirical distributions of the numbers of affected wagons were determined separately for each velocity category and for fire and then fit with Weibull distribution curves [$F(x) = 1 - \exp(-\alpha x^{\beta})$]. The respective fractions of accidents without damage to wagons was not included in the adjustment. Estimated values for the frequency of the occurrence of an accident in each case of one to nine affected wagons, as well as for accidents with more than nine affected wagons, were determined from the calculated Weibull distributions. From this data the matrix of probability for severity categories and associated numbers of affected wagons according to table 3.3 was derived which was used as basis for the risk assessment procedure (Lange et al. 1992).

Severity categories	Number of affected wagons 0*)	1	2	3	4	5	6	7	8	9		Line totals
SC 1	17,09	5,12	3,80	2,82	2,09	1,55	1,15	0,86	0,64	0,47	0,35	36,0
SC 2	2,92	2,02	0,35	0,11	0,07	0,07	0,07	0,07	0,07	0,07	0,07	5,9
SC 3	1,46	1,01	0,17	0,05	0,04	0,03	0,03	0,03	0,03	0,03	0,03	2,9
SC 4	29,77	3,15	2,60	2,14	1,77	1,46	1,20	0,99	0,82	0,68	0,55	45,1
SC 5	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,9
SC 6	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,5
SC 7	6,16	0,28	0,26	0,25	0,24	0,23	0,22	0,21	0,20	0,19	0,18	8,4
SC 8	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,2
SC 9	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,1
Column totals	57,55	11,74	7,34	5,53	4,36	3,50	2,83	2,31	1,91	1,59	1,34	100

*) e.g. only power unit affected

SC 1 0 to 35 km/h	SC 4 36 to 80 km/h	SC 7 Above 80 km/h
SC 2 0 to 35 km/h 800°C 30'	SC 5 36 to 80 km/h 800°C	SC 8 Above 80 km/h 800°C
SC 3 0 to 35 km/h 800°C 60'	SC 6 36 to 80 km/h 800°C	SC 9 Above 80 km/h 800°C

Table 3.3: Matrix of the probability of occurrence of a certain severity category and a specific number of affected wagons in goods train accidents (in %)

4 Accidents in Shunting Operations

General Remarks

On the basis of the data referred to in chapter 1 the shunting accidents were evaluated by similar methods as those described for goods train traffic above. In the Braunschweig marshalling yard, which was used as a reference because it is situated in the vicinity of the waste repository, shunting operations are generally performed on a hump and a gradient present over the entire yard is used to move even larger groups of wagons without a shunting power unit. From these methods additional risks arise resulting in a somewhat higher accident rate at this yard, compared with other large marshalling yards. It should be noticed, however, that in case of dangerous-cargo wagons (some 100 wagons per day, 70% of them carrying flammable or explosive material) gravity marshalling is generally not performed and special safety measures may be applied.

Marshalling Accident Rate

A total accident rate of 7.5 relevant accidents (with damage above the relevance limit) per 1 million wagons handled was determined. Relevant accidents in shunting operations turned out to be mainly caused by collisions and forceful bumping into stationary sets of wagons (75%) and more rarely by derailment or other causes . No relevant case of fire has been reported during the examination period and the personnel was not aware of any accident in which a fire resulted from a mechanical effect of an accident, even prior to the period under investigation. Accidents in which only the power unit is affected are rare, according to the above mentioned operating procedures.

Frequency of Severity Categories and Number of Affected Wagons

Due to the lower speeds in shunting operations, regarding the mechanical impact, all accidents are assigned to the lowest speed range between 0 and 35 km/h. The accident velocities had to be assessed, however, since speed recorder plots are not available for shunting operations without power unit. The distribution of the number of affected wagons is considerably narrower. A maximum of five affected wagons was found. Since relevant fires were not reported, conservatively the respective fractions of this accident type as determined for goods traffic were also used for shunting operations, though some causes of fire that occur with goods traffic are not or less significant in shunting operations.

For the purpose of risk assessment, as a result, for shunting operations the reduced matrix of probability as given in Table 4.1 was evaluated, using the empirical values (no exponential fit performed).

Severity categories	Number of Affected Wagons					Line Totals
	1	2	3	4	5	
0 to 35 km/h	52,6	21,1	0,0	10,5	5,3	89,5
0 to 35 km/h 800°C 30'	4,8	1,0	0,5	0,4	0,4	7,1
0 to 35 km/h 800°C 60'	2,4	0,5	0,2	0,2	0,1	3,4
Column Totals	59,8	22,6	0,7	11,1	5,8	100,0

Tab. 4.1: Matrix of the probability of occurrence of a certain severity category and a specific number of affected wagons in shunting accidents (in %)

References

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