TANKER TRUCKS IN THE CURRENT ACCIDENT SCENE AND POTENTIALS FOR ENHANCED SAFETY

Dr.rer.nat Johann Gwehenberger GDV, Institute for Vehicle Safety, Leopoldstr. 20, 80802 Munich, Germany
Prof. Dr.-Ing. Klaus Langwieder GDV, Institute for Vehicle Safety, Leopoldstr. 20, 80802 Munich, Germany

ABSTRACT

The transport of hazardous goods, which today is governed by extremely restrictive laws, and which constitutes approximately 10% of road transport, involves great risks to people, the environment and material objects. This is especially true if flammable liquid hazardous goods are released. Large-scale damage or even disasters may be the result. Terrifying incidents in the past, such as Herborn, Germany (1987) or San Carlos de la Rapita Alfaques, Spain (1978), clearly illustrate the scale of the damage that could be involved.

Under this circumstances the development of road accidents involving vehicles carrying hazardous goods will be shown by using statistical data of Germany. In summary, due to a varity of measurements a decrease in road accidents involving dangerous substances can be recognized. Nevertheless, a risk analysis of hazardous goods transport shows that the road transport accident rate is at least seven times higher than that of rail and inland waterway transport. Furthermore, major accidents (involving the escape of more than 10,000 liters) occur most frequently on the road and least frequently by rail.

Therefore the primary sources of risk leading to hazardous substances escaping from a tank will be focused. These are mainly single accidents with rollover of the tank vehicle (roughly 60%) and collisions with other heavy vehicles, in which the rear or side of the tank are involved. Finally active and passive safety measures will be proposed which are in line with the state-of-the-art technology and which are effective to reduce the probability of accidents resulting in the release of liquid hazardous goods from protective tanks.

INTRODUCTION

In 1998, the total volume of goods transported in the European Union was 2,870 billion tonne kilometres (Eurostat, 2000). The largest proportion (1,255 billion tonne kilometres or 43.7%) was transported by truck on European roads. Road transport also had the largest growth rate in the period between 1990 and 1998 at 35%, while rail transport decreased by 6% (Figure 1). In 1988, cross-border transport accounted for 20% of the volume of goods carried by road in the EU, tri-country transport for 2%, intra-country transport for 77% and cabotage for roughly 0.2% (Hedbrand, 2001). These general statistics prove that the truck is the number one means of transportation within the EU. Moreover, forecasts predict that there will be a further increase in the volume of goods transported by road (BMVBW, 2000).

Furthermore, our modern, highly industrialized economic system is inconceivable without the use and transport of hazardous goods. Under § 2 of the German law on hazardous substances, these are "a danger to public safety or order, particularly to the general public, important public property, the life and health of people and to animals and objects".

Nevertheless, the transport of hazardous goods, which today is governed by extremely restrictive laws, and which constitutes approximately 10% of road transport (Staebler, 2001), involves great risks to people, the environment and material objects. This is especially true if flammable liquid hazardous goods are released. Large-scale damage or even disasters may be the result. The damage potential from fire (Figure 2) and explosions and the diffusion of harmful substances carried through the air and atmosphere connected with these is particularly high (Gwehenberger, 1998). Terrifying incidents in the past, such as Herborn, Germany (1987) or San Carlos de la Rapita Alfaques, Spain (1978), clearly illustrate the scale of the damage that could be involved.

ACCIDENT STATISTICS

Unfortunately, there are no detailed statistics on the number of tanker truck accidents within the EU available. However, since the German federal statistics (German Federal Statistics Office, StBA, 2000) started separately recording road accidents involving vehicles carrying hazardous substances, both with and without the release of the substances, a downward trend in the number of accidents involving injury to people and serious material damage has been seen (Figure 3). The official statistics also show that with 52 accidents in 2000, in which hazardous substances were released and which also caused injury to people or serious material damage, accidents involving hazardous substances are infrequent.

If we examine the accidents from 1999 according to the hazard class of the substances transported (Figure 4), the majority of accidents involving released substances (34 of 52 cases or approximately 65%) involved hazard class 3 ("flammable fluids"). This correlates well with the volume of goods carried which, at 66.4%, is also at its highest in this hazard class (KBA/BAG, 2000).

Most flammable fluids (usually gasoline, diesel and fuel oil, as well as other related liquid hydrocarbon compounds) are transported in tank trucks or tank trains. However, up to now, there have been no official detailed accident data statistics in this area. There are no detailed statistics on tank truck accidents available in other EU countries either, which means that other sources of information must be used.

Although it is not directly comparable with the German Federal Statistics Office data, the "hazardous substances accident database" (GUNDI, 2001) compiled by the editors of "Gefährliche Ladung" ("Hazardous Load") provides a good overview of the accident situation for tank trucks. These statistics are primarily based on an analysis of 600 German daily newspapers and additional research carried out by the editorial department with the police, fire department and local authorities. In this context, the graph at the bottom of Figure 5 shows the number of accidents involving tank trucks, and is subdivided into accidents where the tanks remained intact and accidents where hazardous substances were released. According to these statistics, in 194 of the 328 accidents and incidents recorded between 1995 and 2000 (which roughly corresponds to 60%), hazardous substances were released in varying quantities. A total of 752.6 t of hazard class 3 substances were released, the majority of these being gasoline, diesel and fuel oil (683.2 t).

The GUNDI database also shows that in the six year period examined there were 19 cases of fire and explosion and 153 cases of damage to the environment (graph at the top of Figure 5). An extract of the accidents involving fire, including details of how the accidents happened, can be found in the appendix (GUNDI, 2001). Even if, fortunately, no large-scale damage has occurred in Germany in the recent past, accidents involving fire and explosion can cause terrible damage, with a probable maximum loss (PML) of Euro 50 million to Euro 100 million (Gwehenberger, 2000). Economic damage and human suffering, which cannot be expressed in monetary terms, are not included in this estimate.

In summary, it can be said that the German federal statistics and the GUNDI hazardous substances database show that, on the whole, there has been a decrease in road accidents involving hazardous substances. According to the federal statistics, the main responsibility for accidents lies less frequently with drivers of vehicles transporting hazardous substances (excluding cars) – 513 with main responsibility per 1000 parties involved – than with drivers of goods trucks (571). One essential reason for this is the continuing improvement in the safety "chain" for transporting hazardous substances by road (Staebler, 1995, 2001). This includes the requirements that have to be fulfilled by vehicles carrying hazardous substances regarding electrical installations, the braking system, fire protection and speed limiters. In the GGVS/ADR regulations regarding the transport of dangerous goods by road, the "human" factor is also taken into account with driver training, which considerably increases the driver's awareness of the various risks and dangers involved in transporting hazardous substances and in handling the vehicles carrying them. And finally, the ADR/RID structural reform has been contributing to safety since July 01, 2001 with its call for a hazardous substance officer at the location where the goods originate, the intermediate storage facility and with the carrier.

Nevertheless, very serious accidents involving fire, explosions and damage to the environment continue to occur (see Figure 2). According to a risk analysis of hazardous goods transport (Brenck and Mondry, 1998), the road transport accident rate is at least seven times higher than that of rail and inland waterway transport. Furthermore, major accidents (involving the escape of more than 10,000 litres) occur most frequently on the road and least frequently by rail.

Official accident statistics continue to be an inadequate indicator of risk. Accidents monitored in the individual EU countries currently neither suffice to cover the entire spectrum of all possible accident scenarios, nor can the significance of changes to individual, "risk-influencing" factors (such as active safety systems or new types of transport containers) be reasonably represented with regard to the overall risk (see also Brenck and Mondry, 1998). Varying accident definitions and recording methods in the individual countries complicate the problem even more.

This is why the creation of a uniform European database is essential. It is especially important because in the area of hazardous substances, which already has restrictive regulations imposed upon it, decisions concerning safety are today only accepted if they are based on transparent risk analyses.

The particularly large damage potential means that the hypothetical risk of transporting hazardous substances must also be considered. In addition to accidents which have actually happened and which emerge from the statistics retrospectively, in a pragmatic approach, hypothetical accidents must also be considered when attempting to eliminate deficiencies. Work on eliminating the sources of risk and on improving the safety of transporting hazardous substances must be carried out step by step. Two major sources of risk are described below, together with measures for overcoming or reducing them.

PRIMARY SOURCES OF RISK AND COUNTERMEASURES

Although there are no statistics to support this, it is sufficiently well-known from accident research that the main source of risk leading to hazardous substances escaping from a protective tank is a single accident with tilting or rollover of the tank vehicle (roughly 60%). Collisions with other heavy vehicles, in which the rear or side of the tank are hit, are also critical (Podzuweit, 1990; THESEUS, 1995; Rompe and Heuser, 1996). The following types of tank stress occur:

- point load
- collision with an obstacle of the same type
- collision with a bulk object.

In order to reduce the probability of tank truck accidents involving the release of hazardous substances, it is therefore necessary first of all to reduce the risk of rollover for tank vehicles, and to increase the stability of both the protective tanks containing the hazardous substances, and their components.

Sources of Risk: Rollovers

In contrast to trucks without tanks, the centre of gravity of partly filled tank trucks during steady-state turning and with increasing speed shifts radial in the direction of the effective centrifugal force and, at the same time, upwards. The rollover axis is adversely shifted so that the rollover threshold is considerably lower. In this context, Figure 6 shows the adverse shift in the centre of gravity during a steady-state turn of a tank truck at three different speeds.

In addition to this, during an abrupt evasive manoeuvre or turning of the vehicle, the liquid surges so that the vehicle's centre of gravity is shifted even more unfavourably. The natural frequency for this lateral oscillation in a tank 8 feet in diameter and half-full is roughly 0.5 Hz (McLean and Hoffmann, 1973). This means that a stimulus caused by a manoeuvre such as changing lanes causes a dynamic shift of the liquid and also reduces the rollover threshold. Figure 7 shows the rollover threshold for a cylindrical tank depending on the load (in percent) for a steady-state turn and a transient turn during a manoeuvre with a frequency of 0.5 Hz (Winkler et al., 2000). The rollover threshold for the transient turn is reduced from 0.8 g (tank empty) to a level of only 0.3 g (tank half-full).

In summary, technical measures are already being carried out today to raise the rollover threshold and reduce the risk of rollover connected with this. Appropriate measures are the use of anti-surge plates, the subdivision of tanks into a number of chambers and lowering of the centre of gravity by using special tanks. Changing from the cylindrical tank to the rectangular tank is not a suitable measure, however. A lower centre of gravity can, of course, be achieved, but, as we describe later, the stability of a rectangular tank is far lower in the face of global and local loads on the tank.

What augurs well for the prevention of tilting/rollover accidents is ESP (Electronic Stability Program). However, in addition to the features ESP offers for cars, this system must be capable of preventing or reducing dangerous jack-knives or rollovers by means of rollover stabilisation. Fortunately, systems of this kind are about to be or have already been launched on to the market (Hecker et al., 2000; Neuhaus et al., 2000).

Sources of Risk: Protective Tanks

The tanks carried by tank trucks are subject particularly to local and global load initiation during accidents (Figure 8). In the case of local loads, where only specific points on the tank are affected, the strength properties of the material determine the failure threshold. In the case of global loads, however, failure tends to occur where abrupt transitions in rigidity, for example in the bases, bracing rings or welded bracing bands, impede distortion (THESEUS, 1995).

If we take a look at the ADR/GGVS special provision regarding the construction of tanks for transporting gasoline, diesel and fuel oil by road, the requirements are far lower than those for tanks on rail tank cars. They may

- have a low test pressure of roughly 0.4 bar, instead of 4 bar in the case of rail tank cars,
- have forms other than cylindrical forms,
- have abrupt wall transitions,
- be designed as "open tanks" (permanent source of ignition), and
- an increase in wall thickness over and above the minimum wall thickness is not required (Droste et al., 1990)mailto:droste@all).

From the point of view of accident research, this is extremely surprising, especially from the background of the far lower accident rate of rail transport and its more consistent transport conditions. In contrast to road transport, constantly changing risk situations such as volumes of traffic, routes, quality of road surface or varying bend radii are not normally expected (see also Droste et al.,1990).

Unfortunately, this special provision for tanks transporting gasoline, diesel and fuel oil has resulted in the fact that, today, rectangular tanks made of aluminum alloys (e.g. AlMg 4.5 Mn W 28) with a wall thickness of approximately 5 mm are predominantly in use, even though aluminum has a number of disadvantages as compared to austenitic steel (stainless steel) with regard to global and local stress.

The schematic stress-strain diagram in Figure 9 shows that the specific resilience of austenitic steel (which corresponds to the surface integral of the curves) is several times greater than the specific resilience of the aluminum alloy frequently used (Ludwig and Schulz-Forberg, 1998).

The German Federal Institute for Materials Research and Testing (BAM) was able to ascertain by experiment that the resilience of the aluminium alloy with a wall thickness of 5 mm is 6,900 Nm, while an austenitic steel (X6 Cr Ni Mo Ti 17 122) with a wall thickness of 3 mm has a resilience of 30,000 Nm (4.4 times greater). Stainless steel, which is highly ductile, can therefore be considered to be the better material against local stress even if the wall is thinner.

According to the THESEUS results (1995), if we consider local and global stress, a stainless steel tank with a wall thickness of 3 mm is almost twice as safe for transporting class 3 hazardous substances by road than a tank made of aluminium alloy of the conventional type. Moreover, due to the low melting point of aluminium alloys (approximately 660 °C), there is the danger, in contrast to steel, of tanks becoming damaged as a result of thermal stress from fire occurring for any reason.

In summary, it can be said that the way rectangular tanks, which are widely used for transporting petroleum, behave in an accident is not acceptable. Aluminum alloys with a minimum wall thickness of around 5 mm are normally used. For this reason, a complete switch should be made from unpressurized tanks to medium-pressure tanks with a test pressure of around 4 bar. At the same time, the dome cover and tank components must be designed with the same level of safety. Both the results of research and practical experience confirm the advantages with regard to resilience against leakage (Fath, 1996).

Rustproof, highly ductile austenitic steel should be the first choice of material, even if additional weight has to be accepted because of the higher density of stainless steel (7.85 kg/dm^3 rather than ρ_{Al} = 2.7 kg/dm^3). The additional weight is counterbalanced by a far safer tank with a high damage reduction potential as regards injury to people and material damage as well as the reduction of human suffering. A statutory load incentive for increased safety could speed up implementation.

DEMANDS AND RECOMMENDATIONS IN SUMMARY

Society's threshold of acceptance for the risks involved in transporting hazardous substances is low. This is why it is necessary to prevent accidents, or at least reduce them to a minimum. The primary and attainable objective should be to aim for safety comparable to that of rail transport.

This can be achieved by systematically analyzing accidents involving tank trucks on a European level and by overcoming the main sources of risk described above, and especially by

- introducing ESP with rollover stabilization for all new tank trucks,
- using medium-pressure tanks (test pressure of 4 bar) instead of aluminum tanks with reduced wall thickness operated at atmospheric pressure,
- installing effective collision-protection systems at the rear and sides of vehicles,
- and granting a weight incentive for vehicles with medium-pressure tanks.

In addition to this, the Institute for Vehicle Safety in Munich, Germany (IFM) calls for the following for all tank trucks:

- compulsory introduction of contour marking as per ECE R 104
- an electronic braking system in the truck tractor and semitrailer/trailer
- a tire pressure monitor
- Accident Data Recorder (ADR), the emphasis being on learning from accidents
- GPS systems with automatic accident warning and synchronized transmission of detailed information on the hazardous substance transported.

In a first "best case" assessment it was ascertained (Langwieder et al., 2000) that active safety systems/driver assistance systems can be of considerable advantage, provided that they include all necessary features ("fail safe"), and support the driver when at risk. The current recommendation is to equip trucks and tank trucks with adaptive cruise control systems (ACC) and lane departure warning systems.

REFERENCES

KBA and BAG (1996 – 1999): Statistische Mitteilung (Kraftfahrt-Bundesamt/Bundesamt für Güterverkehr (Hrsg.), Reihe 8: Kraftverkehr, Metzler Poeschel Verlag, Stuttgart

Brenck A., Mondry S. (1998): Risikoanalyse des Gefahrguttransportes – Unfallstatistische Risikoanalyse auf der Basis typischer Transportketten, Bericht zum Forschungsprojekt 8906/1, BASt, Bergisch Gladbach

BMVBW (2000): Bundesministerium für Verkehr, Bau und Wohnungswesen (2000) Verkehrsbericht

Droste B., Ludwig J., Schulz-Forberg B. (1990): Höherwertige Transporttechnik und ihre Konsequenzen für die Beförderung gefährlicher Güter, Forschungsbericht 173, Bundesanstalt für Materialforschung und Prüfung, Berlin

Eurostat (2000): EU Transport in Figures, Statistical Pocket Book, European Commission Directorate for Energy and Transport in co-operation with Eurostat

Fath R. (1996): "Untersuchung und Analyse tatsächlicher Tankunfälle", Vortrag im Rahmen der 12. Gefahrguttage in Hamburg, 25. - 26.

GUNDI (2001): Gefahrgutunfall-Datenbank der Redaktion Gefährliche Ladung (www.storck-verlag.de/gundi.htm), Sonderauswertung: Gefahrgutunfälle mit Tankfahrzeugen, die brennbare Flüssigkeiten der Klasse 3 transportieren für den Zeitraum 1995 bis Mai 2001, Storck Verlag

Gwehenberger J. (1998): "Schadenpotential über den Ausbreitungspfad Atmosphäre bei Unfällen mit Tankfahrzeugen zum Transport von Benzin, Diesel, Heizöl oder Flüssiggas", Bericht des Meteorologischen Institutes der Universität Freiburg Nr. 2

Gwehenberger J. (2000): Risikoanalyse und Risikoabdeckung bei Tankfahrzeugen, 16. Gefahrgut-Tage Hamburg, February

Hecker F., Schramm H., Beyer C. (2000): "ESP für Nutzfahrzeuge – ein Beitrag zu mehr Sicherheit im Straßenverkehr", VDA Technischer Kongress, Frankfurt, 28-29. September

Hedbrand A. (2001): Entwicklung des Güterkraftverkehrs 1990-1998, Verkehr, Thema 7, Eurostat Data Shop Berlin

Langwieder K., Gwehenberger J. (1999): Neueste Tendenzen der Unfallentwicklung von Lkw, GDV, Institut für Fahrzeugsicherheit, München

Langwieder K., Gwehenberger J: (2000): Anforderungen an die passive Sicherheit bei Lkw-Kollisionen – Ergebnisse einer Repräsentativuntersuchung, GDV, Institut für Fahrzeugsicherheit, München

Langwieder K., Gwehenberger J., Bende J. (2000): Der Lastkraftwagen im aktuellen Unfallgeschehen und Potentiale zur weiteren Erhöhung der aktiven und passiven Sicherheit, 17. EU-Symposium "Sicherheit von Nutzfahrzeugen", München, December

Ludwig J., Schulz-Forberg B. (1998): Sicherheitsniveaus von Transporttanks für Gefahrgut, Forschungsbericht 203, Bundesanstalt für Materialforschung und Prüfung, Berlin, 1998

McLean J. R., Hoffmann E. R. (1973): The effects of restricted preview on driver steering control and performance, Melbourne University, Department of Mechanical Engineering, Australia

Neuhaus D., Gläbe K., Koschorek R., Lindemann K., Petersen E., Reich T. (2000): Elektronische Stabilitätsregelung für schwere Nutzfahrzeugkombinationen, VDA Technischer Kongress, Frankfurt, 28-29. September

Podzuweit U. (1990): Seitenschäden an Gefahrguttanks, 7. Internationale Tagung für Straßentransport und Verkehrssicherheit, Budapest 6./7. September

Rompe K., Heuser G. (1996): THESEUS: Tankfahrzeuge mit höchst erreichbarer Sicherheit durch experimentelle Unfall-Simulation, Automobiltechnische Zeitschrift 3, pages154-161

Staebler R. (1995): "Sicherheitstechnische Anforderungen an Fahrzeuge zum Transport gefährlicher Güter", VDI Berichte Nr. 1188

Staebler R. (2001): Die Sicherheitskette bei der Beförderung von Gefahrgut auf der Straße: Pflicht oder Kür?, VDI Berichte Nr. 1617, Nutzfahrzeug-Tagung, Neu-Ulm, 2001

StBA (1992 – 1999): Fachserie 8, Reihe 7 Verkehrsunfälle, Statistisches Bundesamt, Wiesbaden

THESEUS (1995): Tankfahrzeuge mit höchst erreichbarer Sicherheit durch experimentelle Unfall-Simulation. Zusammenfassender Abschlußbericht für das Bundesministerium für Forschung und Technologie, Köln

Winkler C. B., Blower D., Ervin R. D., Chalasani R. M. (2000): Rollover of Heavy Commercial Vehicles, SAE Research Report, Warrendale, USA

TABLES & FIGURES

Mode of Transport	1990	1995	1996	1997	1998	1990-1998
Road	932	1,146	1,152	1,205	1,255	+35%
Rail	255	221	220	238	241	-6%
Inland waterways	108	114	112	118	121	+12%
Pipelines	75	83	85	85	87	+17%
Sea (intra-EU)	922	1,071	1,076	1,124	1,167	+27%
Total	**2,293**	**2,635**	**2,645**	**2,770**	**2,870**	**+25%**

Figure 1: Evolution of the total volume of goods carried in the EU by mode of transport from 1990 to 1998 in 1,000 million tkm (EUROSTAT, 2000)

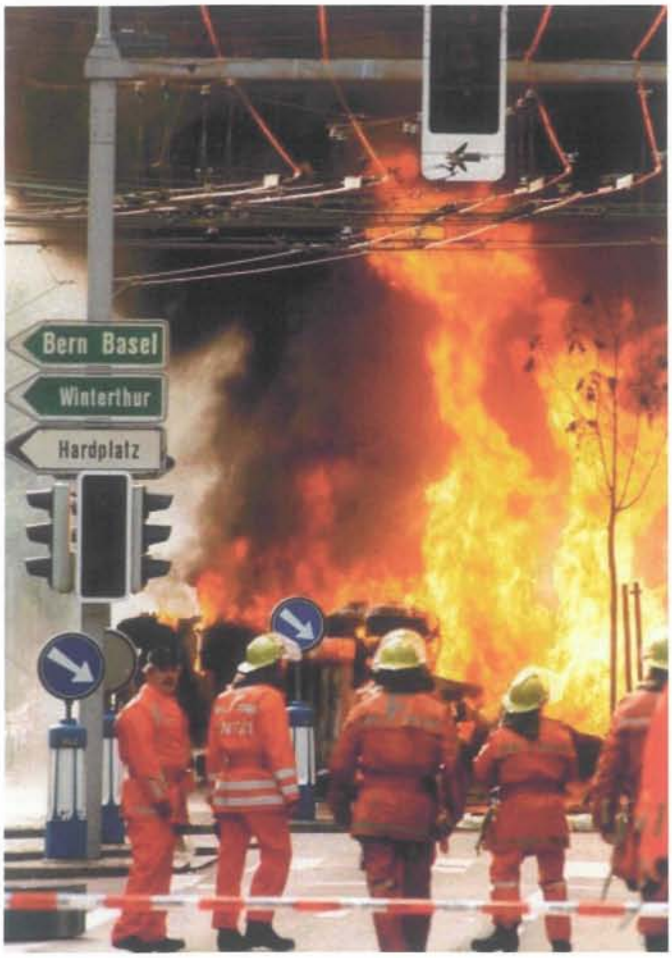

Figure 2: Tank truck accident on August 29, 1998 in Zurich, Switzerland; 23,000 l of gasoline caught fire; the driver was injured and 20 residents had to be evacuated (photo: Keystone)

Accidents involving drivers of vehicles transporting hazardous substances	1996	1997	1998	1999	2000
Accidents causing injury to people	358	338	319	291	279
with release of hazardous substances	31	44	36	38	35
Serious accidents causing material damage	157	148	118	143	98
with release of hazardous substances	17	18	17	14	17

Figure 3: Evolution of accidents involving drivers of vehicles transporting hazardous substances, broken down into personal and material damage

Hazard class		Accidents causing injury to people	With release of hazardous substances		Accidents causing material damage (serious)	With release of hazardous substances	
			Number	%		Number	%
1	Explosive materials	21	-	-	6	1	16.7 %
2	Compressed or fluidized gases or gases released under pressure	32	3	9.4 %	14	-	-
3	Flammable fluids	147	25	1.0 %	74	9	12.2 %
4.1	Flammable solid materials	3	2	6.7 %	3	-	-
4.2	Spont. combustible materials	4	-	-	4	1	25.0 %
4.3	Materials that generate flammable gases in contact with water	-	-	-	1	-	-
5.1	Mats. that promote combustion	4	1	25.0 %	2	-	-
5.2	Organic peroxide	-	-	-	-	-	-
6.1	Toxic materials	8	-	-	3	-	-
6.2	Materials causing infection	-	-	-	-	-	-
7	Radioactive materials	1	-	-	-	-	-
8	Caustic materials	16	3	18.8 %	12	2	16.7 %
9	Various dangerous materials and objects	14	1	7.1 %	5	-	-
Misc. hazardous materials and collective goods		41	3	7.3 %	19	1	5.3 %
Total		291	38	13.1 %	143	14	9.8 %

Figure 4: Accidents involving drivers of vehicles transporting hazardous substances for the year 1999, broken down into the type of substances transported

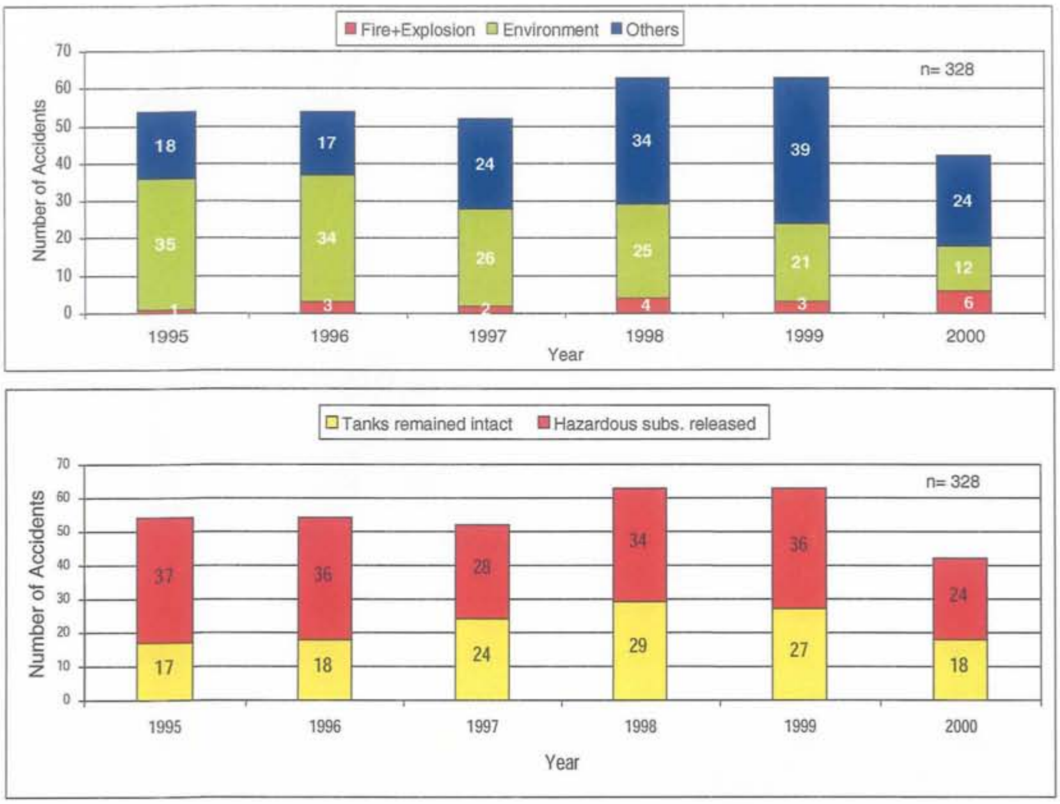

Figure 5: Accidents involving hazardous substances broken down into categories (top) and release of substances (bottom)

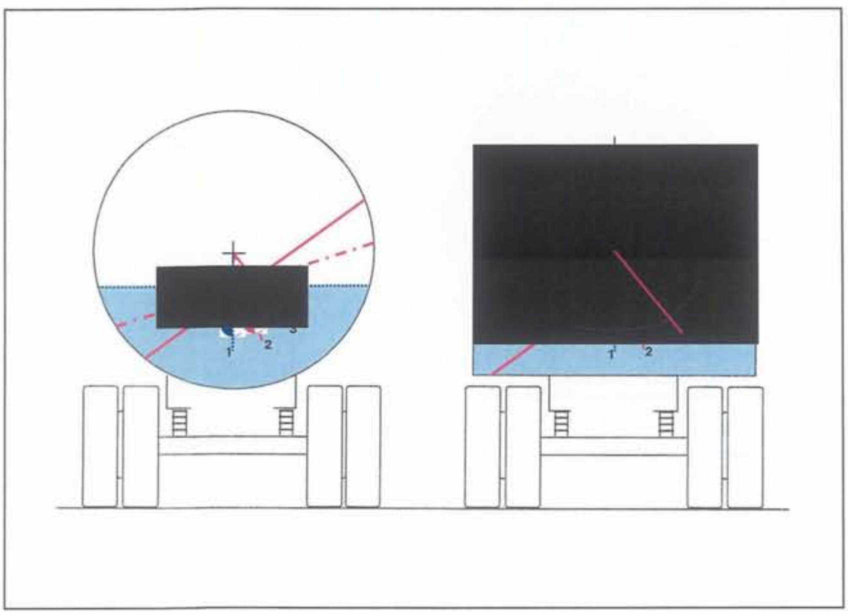

Figure 6: Liquid position and shift in the center of gravity during steady-state turning, for circular and rectangular tanks (as per Winkler et al., 2000)

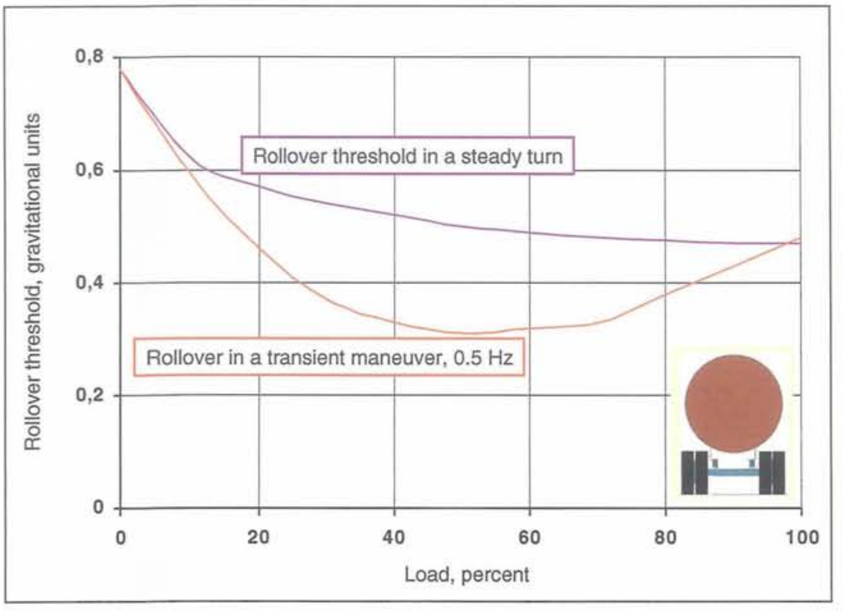

Figure 7: Rollover threshold in a steady and transient turn as a function of the percentage of unrestrained load (as per Winkler et al., 2000)

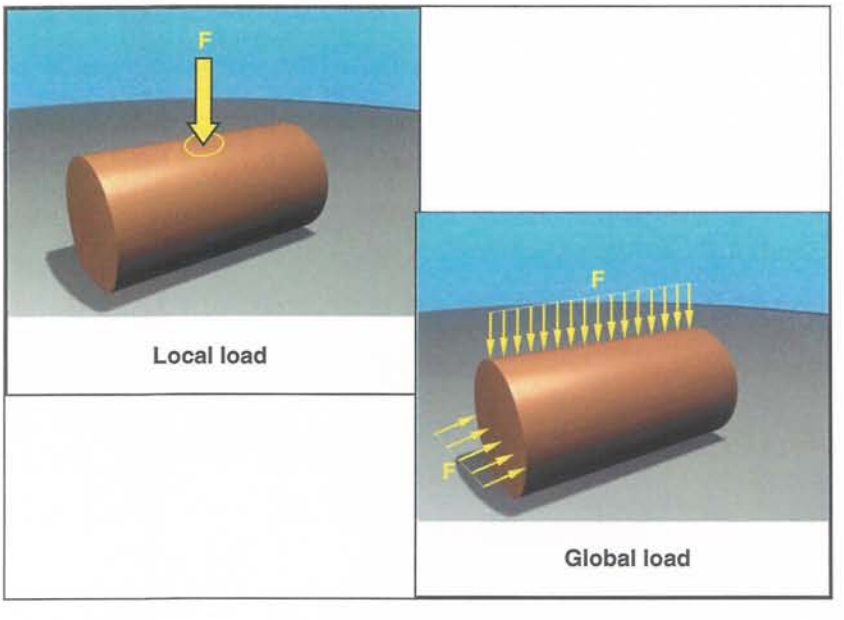

Figure 8: Schematic representation of local and global load initiation on tanks

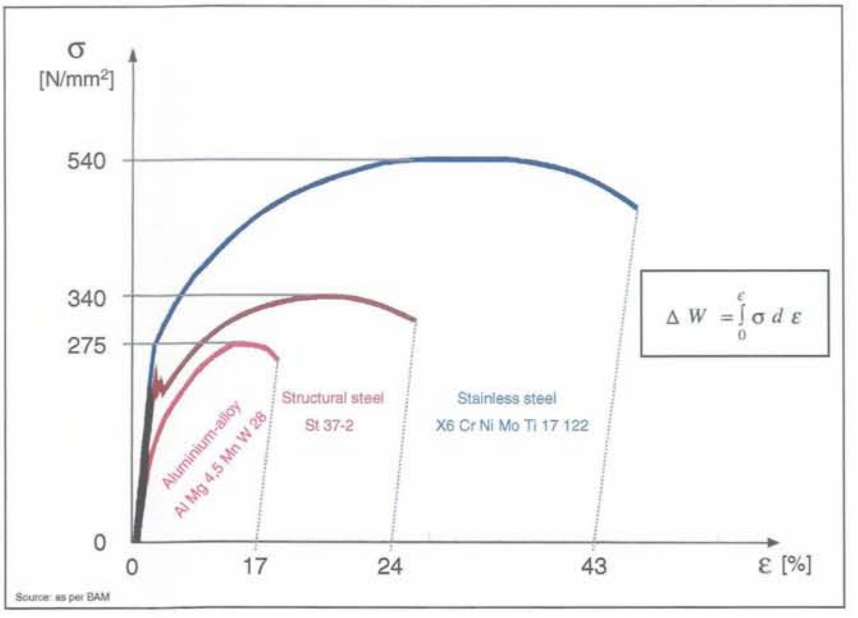

Figure 9: Schematic stress-strain diagram of aluminum alloy, structural steel and stainless steel (as per Ludwig and Schulz-Forberg, 1998)

APPENDIX

Examples of actual tank truck accidents involving fire from 1996 through 2000 (GUNDI, 2001)

Location of accident (in Germany)	Date of accident	Details of accident
A 44 freeway, near Geseke	Nov. 04, 1996	A tank truck combination skidded, tipped over and remained lying across the freeway. A car was unable to brake in time and collided with the trailer. Leaking gasoline ignited on the car engine. A large proportion of the load ran out and burned; the driver of the car died in the flames. The police suspects that the driver of the tank truck combination had fallen asleep at the steering wheel for a few seconds and came off the road on the right. When steered back in the opposite direction, the vehicle lost its stability due to the surging gasoline in the chambers of the tank.
A 19 freeway, near Röbel	Jan. 21, 1997	A truck drove into a tank truck combination in a roadworks area. The gas/air mixture in the empty chambers of the tank ignited, and there was an explosion. The tank truck combination and two other vehicles were gutted. The driver responsible for the accident and a car driver were killed.
Scharpzow, B 104	Jan. 16, 1998	At traffic lights by roadworks, an empty tank truck combination drove into a line of traffic and pushed two cars into a truck. The tank truck combination than skidded past the vehicles. The tank ripped open and the tank truck combination and front car caught fire. One of the occupants of the car was killed, two others were seriously injured.
A 81 freeway, near Zuffenhausen	Mar. 26, 1998	Due to the negligence of the driver, a tank truck combination crashed into a truck, skidded another 100 meters or so and came to a standstill across the road. At impact the tank ripped open and the truck tractor and leaking diesel caught fire. The vehicle was completely gutted. Part of the load seeped into the ground.

A 8 freeway, near Pforz-heim	Oct. 07, 1999	Within a roadworks area with two very narrow lanes, a tank truck combination came off the road on the right on to the grass verge and drove into the end of a concrete barrier at the right-hand edge of the road, all due to the negligence of the driver. The tank truck combination then crashed into the concrete barrier dividing the road from the oncoming traffic on the left. The momentum of the crash pushed in part of the wall. The tank truck, the central chamber of which contained around 1,000 liters of light fuel oil, overturned and remained lying on the left. The empty tank trailer, which had not been cleaned, came to a standstill, jutting out into the oncoming traffic lane. Leaking fuel, igniting on the hot engine which could not be switched off, set the tank truck on fire and it was completely gutted. The light fuel oil contained in the tank created a jet flame. The driver was able to get out of his cab through the shattered windscreen and tried to put out the fire with a fire extinguisher.
A 73 freeway, near Bamberg	Dec. 07, 1999	For unknown reasons, a tank truck combination loaded with roughly 28 tonnes of distilled grain spirit came off the road on the right. The tank trailer tore away from the truck tractor, damaged the fuel tank and fell over in the ditch on the right. Around 500 liters of its load escaped. The truck tractor caught fire.
A 5 freeway, near Freiburg-Süd	Mar. 10, 2000	Coming from a parking lot, the driver of an articulated truck cut right into the inside lane with his vehicle, presumably without using the full length of the acceleration lane and without sufficient speed. A tank truck combination, which was overtaken by a car on a level with the parking lot, crashed, probably without braking, head-on into the articulated truck which skidded into the central crash barrier. The tank truck combination, loaded with around 30 tonnes of gasoline and diesel, skidded and came off the road on the right. The vehicle knocked over some trees, and the load immediately went up in flames. It is still unclear why the driver of the tank truck combination did not react on time and brake.
way, near Öhringen	Apr. 19, 2000	For unknown reasons, a tank truck combination loaded with roughly 35 cubic meters of gasoline and diesel drove into a slower truck driving in front of it. After the collision, the cab of the tank truck combination caught fire. The driver was able to get out and tried in vain to put out the fire. The fire spread to the tank trailer and the tank truck combination was completely gutted.
A 9 freeway, near Hormers-dorf	Aug. 02, 2000	Presumably due to a burst tire, a tank truck combination loaded with 30 cubic meters of diesel skidded, overturned and slid right over the three lanes. The load leaked and caught fire. A large proportion of the diesel which escaped – around 25 cubic meters and some of it burning – ran into the drains and a rainwater collecting tank. The driver escaped from the vehicle and ran over the highway with his clothes on fire. Other road users were able to smother these flames with a blanket. Two days after the accident he died from his serious injuries.
A 1 freeway, near Hamm/Bergkamen	Oct. 10, 2000	For unknown reasons, a tank truck combination loaded with 28 cubic meters of gasoline and five cubic meters of diesel drove on to the left-hand lane while being overtaken by a van. It is possible that the driver had fallen asleep at the steering wheel. After colliding, both vehicles skidded. The six-chamber tank truck combination broke through the right-hand crash barrier, drove on to the embankment and tipped over. The vehicle caught fire and was completely gutted. Part of the load which escaped seeped into the ground and ran into the drains. The 41-year old driver was killed in his cab by the fire.