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Severe Accidents in the Oil Chain with Emphasis on Oil Spills

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by Peter Burgherr and Stefan Hirschberg

Abstract

Accidents in the energy sector have been identified as one of the main contributors to man-made disasters. The present analysis addresses severe accident risks of the oil chain with an emphasis on oil spills. Evaluations were based on the comprehensive accident database ENSAD (**En**ergy-related **S**evere **A**ccident **D**atabase), which allows detailed comparisons of full energy chains, including various damage categories and selected technical aspects. Within the oil chain, transportation stages (i.e., “Regional Distribution” and “Transport to Refinery”) were most accident-prone in terms of fatalities, accounting for 72.4 percent of fatalities in OECD, 65.4 percent in EU 27 and 89.9 percent in non-OECD countries. Tanker accidents have the largest contribution to total volume released in oil spills from all sources. The potential influence of key factors (e.g., flag state, hull type and tanker age, among others) was also evaluated. Results showed that the total number and volume of tanker spills have significantly decreased since the 1970s. However, catastrophic events can still have devastating ecological and socio-economic impacts because the major maritime transport routes often cross the boundaries of the Large Marine Ecosystems.

Introduction

Among man-made accidents, severe accidents in the energy sector are a very controversial topic in the public perception and in energy politics. Furthermore, the growing levels of industrialization, urbanization and associated complex infrastructures are likely to result in higher damages from man-made accidents that can affect a multitude of stakeholders (Dilley et al., 2005, Munich Re, 2005, Swiss Re, 2004, UNDP, 2004) . In the past, however, such accidents have not been adequately documented, and their exposure to public scrutiny was therefore not sufficiently comprehensive (Hirschberg et al., 1998) . In response to this gap, PSI initiated in the mid-1990s a research activity to allow an objective assessment of accidents and risks to be made on the basis of comprehensive data collection. To this purpose, the database ENSAD (**En**ergy-Related **S**evere **A**ccident **D**atabase) was constructed. Since its first release, it has been continuously updated, maintained and extended (Burgherr et al., 2004, Hirschberg et al., 2003, Hirschberg et al., 1998). The database concentrates on documenting all severe, energy-related accidents, including their technical aspects. The scope of the analysis is not restricted to accidents occurring in power and heating plants, but covers the complete energy chain, since accidents can occur at every stage. Other man-made (anthropogenic) accidents and natural catastrophes are also addressed, but in a less detailed manner. ENSAD currently contains 18,706 entries, of which about 70 percent are man-made accidents, with 89 percent of the entries pertaining to the years 1969–2000. Within this period, 6,995 accidents resulted in five or more fatalities, of which 39.5 percent were natural disasters and the other 4,233 were man-made accidents. The latter can be further divided into energy-related accidents (1870, or 44.2 percent) and other man-made accidents (2,363, or 55.8 percent).

According to the reference scenario of the World Energy Outlook (IEA, 2006), oil is and will remain the single largest fuel in the primary fuel mix until year 2030. When looking at severe accidents in the various fossil energy chains (i.e. coal, oil and gas), seven out of the ten most deadly accidents are attributable to the oil chain, of which all except one occurred in non-OECD countries, where less strict safety regulations and the lack of engineered safety features in many highly exposed areas can lead to more catastrophic consequences. In the case of insured damages, six out of the ten most expensive accidents also took place in the oil chain, with five of them in OECD countries that exhibit a much higher insurance coverage than the non-OECD.

Finally, the availability of crude oil and its refined products is a key driver for all kinds of activities in modern society. This widespread use inevitably leads to accidental oil spills, which can cause major environmental and socio-economic impacts. The extent of these impacts is dependent on a variety of interrelated factors such as the amount, rate and type of oil spilled, the exact spill location, as well as subsequent clean-up strategies (e.g., Etkin, 1999, Höfer, 2003, McCay et al., 2004, Monnier, 1994, NRC, 2003, Peterson et al., 2003, Whitfield, 2003) . More than 60 percent of the oil consumed in the world is transported by tankers (NRC, 2003), whose shipping lanes often pass through sensitive ecological areas (Roberts et al., 2002) . Despite significant improvements due to international conventions and preventative measures by the International Maritime Organization (IMO), national legislation, and increased financial liabilities, accidental tanker spills are still perceived as a major threat, which is also reflected in their often exceptional coverage by the media (Anderson, 2002) .

Since the last consolidated edition of the ENSAD database (Burgherr et al., 2004), the coverage of accidental oil spills has been significantly expanded in terms of additional information sources survey, more homogenous quality and completeness of the data and extended coverage up to the year 2004. Compared to previous analyses (Burgherr, 2007), the current publication combines a general risk evaluation of the full oil chain with the specific aspects of accidental oil spills. In particular, oil spill analyses have been substantially expanded by the consideration of the effects of changes in regulations at the national and international levels, the use of predictive geostatistical methods, and Frequency-Consequence (F-N) curves to assess changes in spill frequencies over the period of observation.

Therefore, the objective of this publication is twofold. First, an overview of severe accidents in the oil chain is given, focusing on fatalities. Second, accidental oil releases are addressed in more detail, with a strong emphasis on tanker spills.

Approach and Methods

Severe accident database ENSAD

The compilation of a severe accident database is a complex and extremely time consuming task. Therefore, it was decided in the beginning that ENSAD should build upon existing information sources, but its unique feature is that it combines data from a large variety of primary data sources, i.e., information is verified, harmonized and integrated. In total, almost 200 primary information sources were surveyed, of which only about 20 were the most dominant contributors to ENSAD. However, many of the sources with small shares were of critical importance because they covered specific energy chains and/or countries, were useful to resolve contradicting statements, and provided supplementary information that would otherwise not be available.

The actual process of database building and implementation has been described in detail elsewhere (Burgherr et al., 2004, Hirschberg et al., 1998), thus only a brief summary of the essential steps is given here:

1. Relevant information sources are selected and surveyed.
2. Raw information is collected, consolidated, transferred to ENSAD, and subjected to a final check.
3. Energy-related accidents are assigned to an energy chain and a step within that chain.
4. Comparative evaluations are then carried out, based on customized ENSAD-queries.

Severe Accident Definition

In the literature there is no commonly accepted definition of the term *severe accident*. Differences include the actual damage types considered (e.g. fatalities, injured persons, evacuees or economic costs), the use of imprecise categories such as "people affected," and differences in damage thresholds to distinguish severe from smaller accidents.

In the ENSAD database an accident is considered to be severe if at least one of the following criteria is fulfilled (Burgherr et al., 2004, Hirschberg et al., 1998):

- at least 5 fatalities
- at least 10 injured
- at least 200 evacuees
- extensive ban on consumption of food
- release of hydrocarbons exceeding 10000 metric tons (t)
- enforced clean-up of land and water over an area of at least 25 km^2
- economic loss of at least $5 million USD (price level year 2000).

Generally, fatalities are the most reliable indicator concerning completeness and accuracy of the data; superior to injured or evacuated persons. A typical problem in case of economic damages is that sources outside the insurance sector tend to mix the various types of economic damages (e.g., insured vs. total loss) or give no specification at all what type of damage is reported.

In the current study severe oil spills and smaller ones of at least 700 t were considered. The selection of a lower threshold ensured that a larger data set was available for analysis, and where appropriate different spill size classes could be separately evaluated. At the same time, the exclusion of spills below 700 t ensured that the quality of the data set was highly consistent because information on smaller spills is often incomplete and major differences in the quality of reporting among countries as well as ports and terminals occur (Huijer, 2005, ITOPF, 2005)

Evaluation Period

Severe accidents in the oil chain were analyzed for the years 1969–2000. The starting year was chosen to reflect the distinct increase in the number of energy-related accidents at the end of the 1960s, which is primarily due to the increase in the volume of activities (Hirschberg et al., 1998), whereas data from 2001 onwards were not included because it is a well known fact that there is a time delay of up to several years for certain accidents until consolidated information and final reports become available (Burgherr et al., 2004) .

For oil spills analyses were based on the time period 1970–2004 because additional data beyond the year 2000 were available, allowing for evaluation of differences between decades (1970's to 1990's) and of how observed trends may continue (2000–2004). This is of particular interest because several important international laws and conventions were enacted at the end or beginning of a decade, such as the MARPOL 1978 Convention (IMO, 2002), the Oil Pollution Act (OPA 1990) (OPA 1990 in NRC, 2003), the International Management Code for the Safety of Ships and for Pollution Prevention (ISM 1998) (ISM 1998 in Etkin, 2000), and a revised regulation on Safety of Navigation (SOLAS Chapter V in SOLAS, 2002) .

Statistical analyses

Severe accidents in the oil chain

Temporal trends in the annual numbers of accidents and associated fatalities within the oil chain were analyzed for industrialized countries of OECD[1] and EU 27[2] as well as less developed non-OECD countries, based on the non-parametric Mann–Kendall test (Mann, 1945) . The presence of a statistically significant trend is evaluated using the Z-statistic, where a positive (negative) value of Z indicates an upward (downward) trend. Calculations were performed with the MS Excel application MAKESENS (Salmi et al. 2002). Results were considered statistically significant when the probability level (p-value) was smaller than the chosen significance level of $\alpha = 0.05$.

Frequency-consequence (F-N) curves show the relationship of the cumulative frequency (F) of events having consequences ≥ N (e.g., fatalities) which is usually presented in a diagram with double logarithmic axes. For the purpose of comparison, results were based on data normalized to the unit of electricity production. For the oil chain the thermal energy was converted to an equivalent electrical output using a generic efficiency factor of 0.35, and then expressed as Gigawatt-electric-year (GW eyr) (Burgherr et al., 2004, Hirschberg et al., 1998) .

Accidental oil spills

The Mann-Kendall test (see previous section) was used to analyze temporal trends (1970–2004) in annual numbers and volumes of accidental tanker spills, as well as spilled volumes within Large Marine Ecosystems (LME). These are ocean regions of 200000 km^2 or greater with a distinct bathymetry, hydrography, productivity and trophically dependent populations (Sherman, 1992) .

Two-way analysis of variance (ANOVA) was used to investigate how four major factors were related to spill volume, and how they changed between decades (1970s to 1990s, 2000–2004). *Hull types* considered were restricted to Pre-MARPOL and MARPOL single hull because accidents with double sides/bottoms only and double hull constructions rarely occurred. *Tanker age* at the time of the accident was assigned to three categories, i.e. 0-9, 10-19, and 20 and more years (modified from UNCTAD, 2005) . *Accident cause* was evaluated in terms of the primary event occurring at the time of the spill. Categories considered included the dominant causes of Collision, Explosion/Fire and Grounding. *Flag state affiliations* were analyzed for FOC countries[3], and other countries assigned to OECD and non-OECD. All data were log-transformed prior to ANOVA to improve normality and homogeneity of variances (Zar, 1999) .

For analyzing spatial trends of accidental tanker spills (≥ 700 t) in the years 1970–2004, their locations were geo-referenced using ArcGIS 9 software (ESRI, 2005a) to obtain worldwide distribution patterns. Based on this a map was constructed that captured three different analytical aspects of spatial relationship: (1) Individual spill locations were drawn as graduated symbols; their size corresponding to the spilled volume. (2) It was analyzed how many spills occurred in ecologically sensitive areas because they are located within the boundaries of the Large Marine Ecosystems (LME) of the world. (3) Spatial patterns of oil spills were analyzed using the kriging technique, which is a geostatistical method to interpolate the value of a random field at an unobserved location from observations of its value at nearby locations (Krige, 1951, Matheron, 1963) . In a preliminary step, locations were assigned to a Marsden Square Chart, which divides the world into grids of 10 degrees latitude by 10 degrees longitude, because in some cases only approximate coordinates were available. Afterwards, the number of spills per Marsden Square was calculated, and coordinates set to the center of each grid cell. Ordinary point kriging was then applied to compute a prediction surface for the number of spills to be expected in a particular region, i.e. to evaluate regional differences in susceptibility to accidental tanker spills. Ordinary kriging was selected because it is the most commonly used and the simplest form of kriging, assuming that local means are not necessarily closely related to the population mean (i.e. the constant mean is unknown), and which therefore uses only the samples in the local neighborhood for the estimate (ESRI, 2005b) . All geostatistical analyses were performed using ArcGIS 9 and ArcGIS Geostatistical Analyst software (ESRI, 2005a, ESRI, 2005b) .

F-N curves (see previous section) were calculated for individual decades of accidental oil spills (≥t 700 t).

Results and Discussion

Severe accidents in the oil chain

For the period 1969–2000, PSI's database ENSAD comprises 397 oil chain accidents (165 in OECD and 232 in non-OECD countries) amounting to 20218 fatalities (3713 and 16505 fatalities, respectively) that are classified as severe because five or more fatalities occurred. For EU 27 the corresponding values are 61 severe accidents and 1,215 fatalities.

The annual number of severe (≥ 5 fatalities) accidents showed a statistically significant decrease in the years 1969–2000 in OECD (Mann-Kendall: Z-statistic = -2.32, p-value= 0.02) and non-OECD countries (Z = 4.01, p < 0.0001), but was only allusive in EU 27 (Z = -1.48, p = 0.14). For fatalities a similar pattern was found, however a significant trend only occurred in non-OECD (Z = 2.97, p = 0.003), but not in OECD (Z = -0.70, p 0.48) and EU 27 (Z = -1.15, p = 0.25) countries.

Figure 1: Percent shares of severe (≥ 5 fatalities) oil chain accidents, associated fatalities, and insured losses (≥ 5 million USD (2000)) per continent for OECD and non-OECD countries in the years 1969–2000.

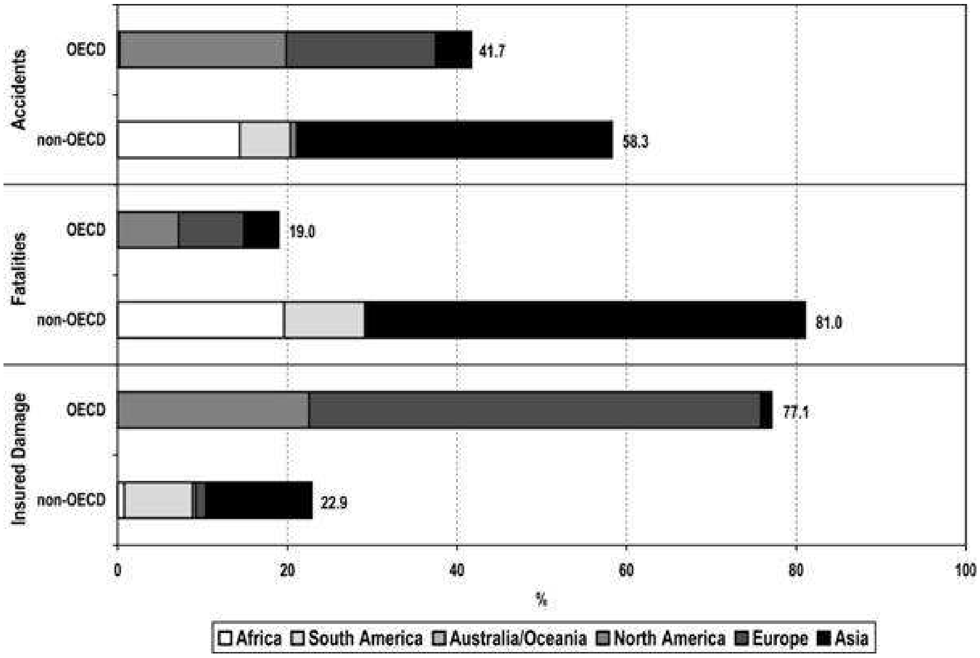
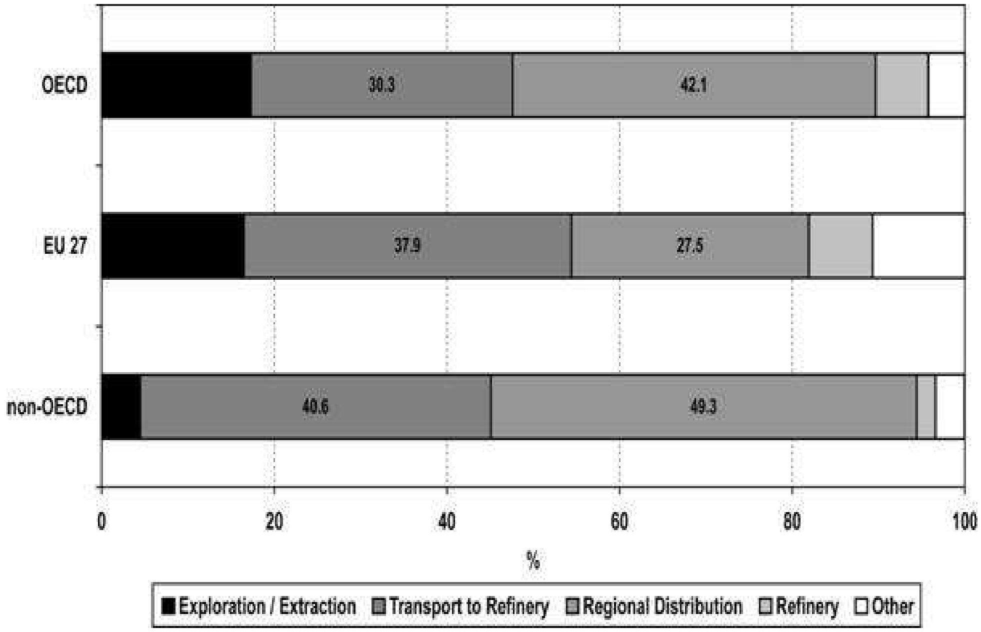


Figure 1 shows percent contributions of severe (≥ 5 fatalities) oil chain accidents, fatalities and insured losses (≥ 5 million USD (2000)) per continent for OECD and non-OECD countries in the years 1969–2000. The number of accidents and fatalities is substantially higher in non-OECD countries, with Asia being the dominant contributor.

This reflects less strict safety regulations and the lack of engineered safety features in non-OECD countries, which besides occupational safety also adversely affects many population centers neighboring or near oil chain installations. In contrast, the substantially higher insured losses in OECD can be explained by the significantly higher insurance density in these countries, the level of which also depends on national legislation.

Figure 2: Relative shares of accidental fatalities in the various stages of the oil for OECD, EU 27 and non-OECD countries in the years 1969–2000.



Within the oil chain the transportation stages “Regional Distribution” and “Transport to Refinery” were the most accident-prone chain stages in terms of fatalities (Figure 2), accounting for 72.4 percent of fatalities in OECD, 65.4 percent in EU 27 and 89.9 percent in non-OECD countries. The remaining chain stages followed distantly, including “Exploration / Extraction” and “Refinery” as well as “Heating / Power Plant” accidents together with a few accidents that due to lack of information could not be assigned to a specific chain stage.

A detailed evaluation of transportation modes revealed that maritime accidents dominated within the stage “Transport to Refinery”, whereas road accidents were most common in “Regional Distribution” (Burgherr et al., 2004) . In the former case this is primarily due to explosions and fires on tankers or collisions and groundings of them, whereas in the latter case tank trucks are overturned or collide with other vehicles.

Figure 3: Comparison of frequency-consequence curves (including 5 percent and 95 percent confidence intervals) for the oil chain, based on historical experience of severe accidents in OECD, EU 27 and non-OECD countries for the period 1969–2000.

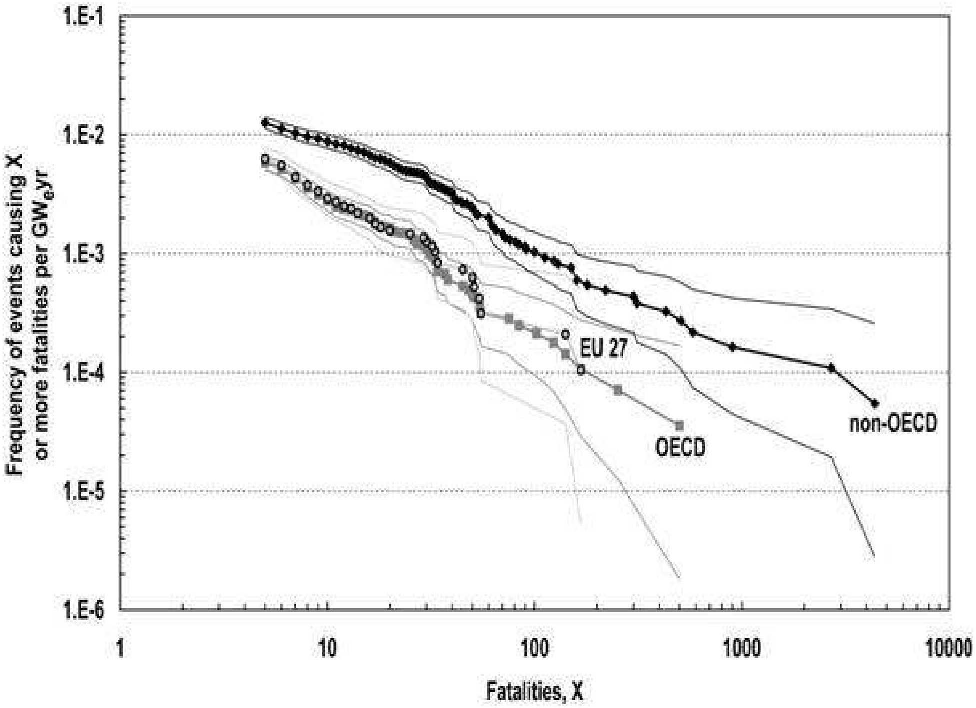


Figure 3 shows frequency-consequence curves of the oil chain for severe accidents with at least 5 fatalities in the OECD, EU 27 and non-OECD countries. The 95 percent confidence intervals indicate that frequencies of severe accidents in non-OECD countries were significantly higher than in OECD and EU 27 countries, except for a few very large accidents in these regions. No substantial differences were found between accident frequencies of OECD and EU 27 countries, however maximum consequences in OECD were about three times larger compared to EU 27. In non-OECD the most deadly accident caused more than one order of magnitude greater fatalities, i.e. the respective values were between about 9 and 26 times greater than in EU 27 and OECD.

Accidental oil spills

For the period 1970–2004, 737 accidental oil spills of at least 700 t were recorded in ENSAD, corresponding to a total volume of about 10.12 million tons (Mt). Tanker spills clearly dominated, contributing 72.0 percent (531) to the total number of spills and 63.7 percent (6.45 Mt) to the total volume spilled, whereas releases from the categories Pipeline, Platform/Well/Rig/Mobile Unit, and Storage Tank/Refinery/Other Fixed Facility followed distantly. Over the period of observation, annual numbers of oil tanker spills and associated volumes significantly decreased for severe (≥ 10000 t), smaller (700 to 9999 t) and cumulative spill values, as indicated by the Mann-Kendall tests reported in Table 1.

The influence of four key aspects on the spill volume of tanker accidents was analyzed in detail, based on two-way analysis of variance. Results reported in Table 2 show significant differences between factor levels of each aspect, whereas temporal effects, expressed as differences between decades exhibited more complex patterns.

Table 2: Results of 2-way ANOVA for spill volume of accidental tanker spills (≥ 700 t, 1970–2004), with key aspects (hull type, tanker age, accident cause, and flag state affiliation) and decade as factors. Factor levels are described in the text. F = F-statistic, p = p-value.

	F	p
Hull type		
Hull	34.69	<0.0001
Decade	1.03	0.38
Hull * Decade	13.19	<0.001
Tanker age		
Age class	3.29	0.04
Decade	0.18	0.91
Age class * Decade	4.05	0.001
Accident cause		
Cause	4.43	0.01
Decade	7.01	0.0003
Cause * Decade	1.58	0.16
Flag state affiliation		
Flag	6.66	0.002
Decade	2.42	0.07
Flag * Decade	3.78	0.002

Table 1: Results of trend analysis with the Mann-Kendall test for the annual number of accidents and spill volumes of accidental tanker spills (≥ 700 t) in the period 1970–2004 (n = 35). Z: test statistic, p: p-value.

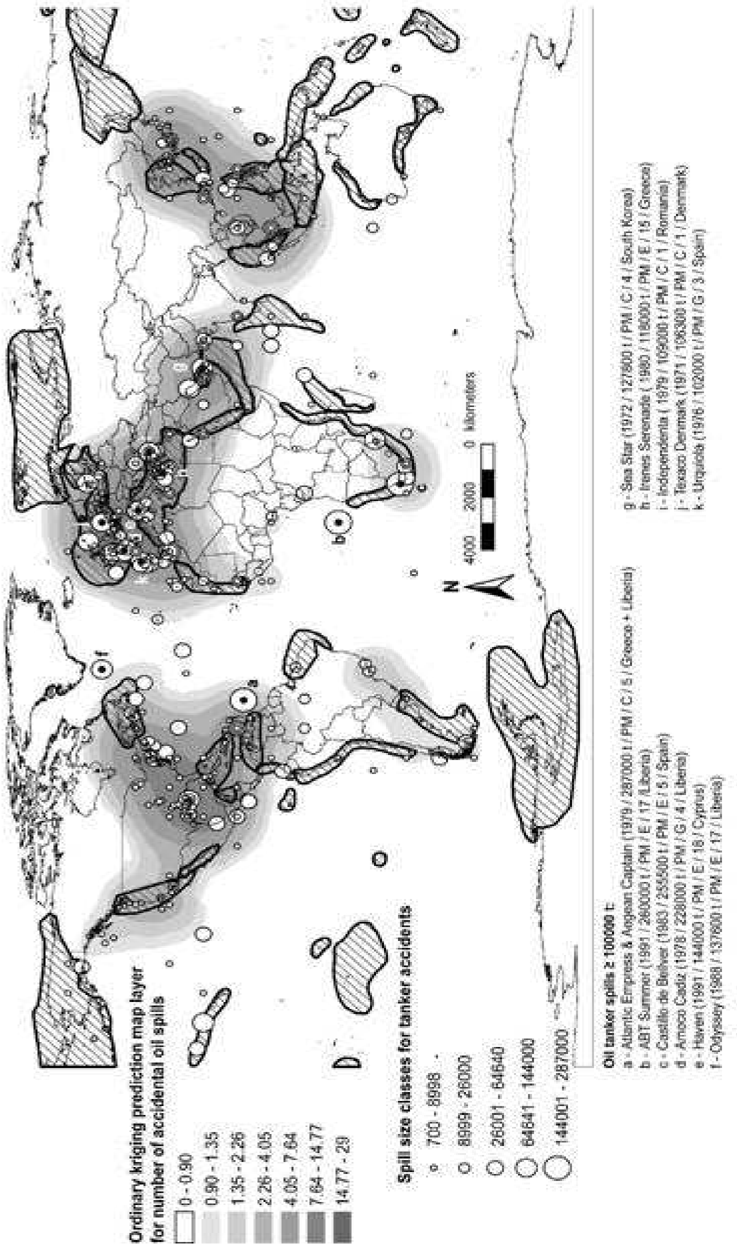
	Z	p
Number of spills		
Severe accidents (≥ 10000 t)	-3.92	<0.0001
Smaller accidents (700 - 9999 t)	-3.19	0.0014
All accidents	-3.63	0.0003
Spill volume		
Severe accidents (≥ 10000 t)	-3.40	0.0007
Smaller accidents (700 - 9999 t)	-3.38	0.0007
All accidents	-3.61	0.0003

Based on *hull type*, Pre-MARPOL single hull tankers were significantly more accident-prone than MARPOL single hull tankers. Additionally, the significant interaction effect of Hull*Decade indicates that the spilled volumes of Pre-MARPOL tankers decreased since the 1970s, whereas MARPOL tankers showed an opposite pattern, reflecting the phase-out of single hull Pre-MARPOL (2005) and MARPOL (2010) tankers, and the resulting shift of the world tanker fleet towards the substantially safer double hull construction (IMO, 1992, IMO, 2003) . Spill volumes for the three *tanker age* classes “0-9 yrs”, “10-19 yrs” and “20 and more yrs” were significantly different, and the inspection of the interaction effect revealed that spilled volumes in the first two age classes showed a decreasing tendency since the 1970s, whereas it was the opposite for tankers of 20 and more years.

This is also connected to the previous findings for hull types because old tankers are almost exclusively of single hull construction, while 80 percent of double hull tankers at the end of 2004 were 10 or less years old (American Bureau of Shipping et al., 2005) . The three most important *accident causes* were Grounding, Collision, and Explosion/Fire that cumulatively accounted for 83.8 percent of the total volume of accidents with known spill causes. Significant differences occurred between the various causes and decades, respectively. The decreasing trend in spill volume continuously intensified and was most distinct after the 1990s. For *flag state affiliations*, significant differences were found between country groups. Trends in total spill volume were opposite in OECD (down) and non-OECD (up). Decade values of FOCs varied most, but also showed a slight decrease over time. However, country group averages for the years 2000–2004 still show substantial absolute differences, ranging from roughly 24,000 t for FOC to 11000 for non-OECD and 1,200 for OECD countries.

Figure 4: Geo-referenced accidental oil spills (≥ 700 t) for the period 1969–2000 are represented by different circle sizes corresponding to the respective spill volume.

Regional differences in susceptibility to accidents were analyzed by ordinary kriging, resulting in a prediction map layer of filled contours. Spills of at least 100,000 t are also shown on the map (labels a–k). Additional information for them is provided in parentheses, separated by a slash: year of accident / spill volume in tons / hull type (PM = Pre-MARPOL single hull) / accident cause (C = Collision, E = Explosion/Fire, G = Grounding)/tanker age at accident in years/flag state affiliation.



Geographic locations were available for 508 out of a total of 531 tanker accidents in the years 1970–2004 that each resulted in a spill of at least 700 t.

Figure 4 shows the spatial distribution of geo-referenced spills, and the volume spilled is indicated by their circle size. It also includes a prediction map layer based on ordinary kriging that provides useful information for the identification of regional differences in susceptibility to tanker spills because it enables estimates for areas with few or no sample points.

Based on these results, the map allows the identification of several world regions that are most accident-prone to oil spills, both in terms of spill numbers and volumes:

1. the Northern European Atlantic and the Eastern Mediterranean;
2. the Gulf of Mexico, the Caribbean and parts of the Southern Atlantic;
3. the Persian Gulf and Arabian Sea;
4. the South China Sea, the Gulf of Thailand and the Strait of Malacca, and
5. around the Southern tip of Africa. Extremely large spills (≥ 100000 t) also occurred predominantly in these regions, with exception of the Odyssey spill off Nova Scotia (Canada) in 1988. (See: Figure 4).

Finally, it was analyzed which spills occurred within the boundaries of the Large Marine Ecosystems (LME) of the world that are considered areas with highly sensitive ecosystems (Figure 4).

Overall, 223 (44 percent) of the 508 spills considered occurred within LMEs, amounting to 49 percent of total spill volume. This considerable share emphasizes why many events with relatively small releases may still lead to disproportionately high ecological and socio-economic consequences.

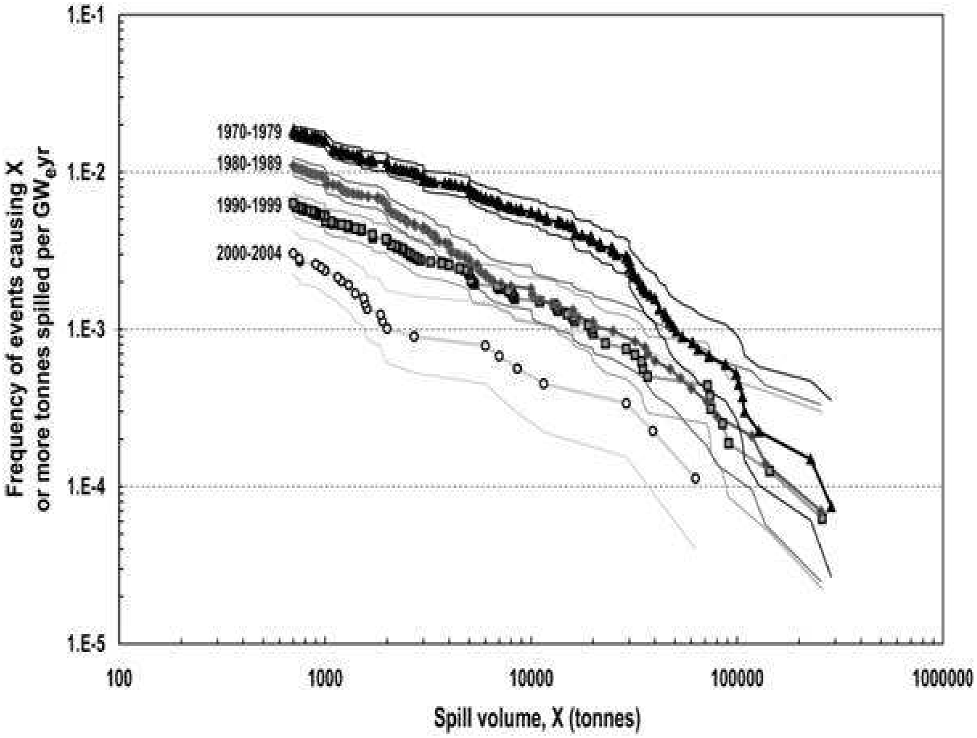
Another complicating fact is that the major shipping lanes of worldwide oil transport often intersect with LMEs (NRC, 2003) . However, the absolute contribution of the volume spilled within LMEs decreased over the period of observation (Mann-Kendall: $Z = -3.98$, $p < 0.0001$).

This is primarily attributable to the general decrease in annual spill numbers and volumes that are a result of the continuously more rigorous regulations at national and international levels, which enhance safety in general and when crossing LMEs. Safer passage through LMEs is essential because they are predominantly on the continental shelf and so cannot be avoided when accessing coastal harbors.

Figure 5 shows F-N curves for accidental oil spills of at least 700 t. Spill frequencies were highest in the 1970s, dropped substantially in the next two decades, and data for the years 2000–2004 suggest that this trend could continue and even increase.

The figure also illustrates that extremely large spills (≥ 100000t) could be reduced from six in the 1970s (with two of them even greater than 200000 t) to 3 and 2 in the 1980s and 1990s, respectively (one greater than 200000 tin each decade), whereas since 2000 the largest spill of the tanker Prestige (Galician coast of Spain in November 2002) resulted in a release of only 63000 t.

Figure 5: Frequency-consequence curves (including 5 percent and 95 percent confidence intervals) per decade for accidental oil spills (≥ 700 t) in the period 1970–2004.



Conclusions

The ENSAD database contains a comprehensive historical record of severe accidents in the oil chain, which provides a sound basis for the assessment of accident risk, detailed analyses of complex and multi-faceted topical areas such as accidental spills, quantification of various damage categories, and the identification of weak points in the energy infrastructure.

Accident risks in the oil chain were significantly higher in non-OECD than OECD and EU 27 countries. Regional Distribution and Transport to Refinery were the two chain stages with the largest contributions to total fatalities.

Accidental tanker spills account for 72.0 percent of total number and 63.7 percent of total volume from all sources in the period 1970–2004. The significant reduction in the total number and volume of tanker spills during the last decades is the result of continuous efforts towards increased safety of maritime oil transportation, including measures ashore, onboard and along shipping lanes, as well as spill management and contingency programs. The potential effects of these efforts were demonstrated by specific analyses of several key aspects including hull type, tanker age, accident causes, and flag state affiliation. Finally, the coupling of the ENSAD database with Geographic Information systems (ArcGIS) allows the analysis of spatially discontinuous distributions, visualization of associated spatial patterns, and identification of accidental spill hotspots based on predictive geostatistical methods.

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About the Author

Peter Burgherr took his doctoral degree in Natural Sciences at the Swiss Federal Institute of Technology in Zurich (ETHZ). From 1996 to 2000, he conducted research leading to his Ph.D. at the Swiss Federal Institute of Environmental Science and Technology (EAWAG). In 2001 he joined the Paul Scherrer Institut as a risk analyst. As a member of the Laboratory for Energy Systems Analysis he is the primarily responsible for the comparative assessment of severe accident risks, largely based on the PSI database ENSAD (Energy-Related Severe Accident Database). His recent project involvements include the “China Energy Technology Program” (CETP), contributions to various research programs of European Union (e.g., NewExt, NEEDS), and projects for industry, business organizations and the Swiss Federal Office of Energy. His academic record includes lectures at ETHZ, presentations at international conferences, numerous publications in peer-reviewed scientific journals, contributions to books, and various other publications.

Stefan Hirschberg is the head of the Laboratory for Energy Systems Analysis at PSI. He obtained his MSc in Engineering Physics from the Chalmers University of Technology, Gothenburg, Sweden in 1975, and his PhD in Reactor Physics from the same university in 1981. From 1982 to 1990 he worked for ABB Atom (Västeras, Sweden) with responsibility for the field of reliability and risk assessment for nuclear and non-nuclear facilities. Between 1990 and 1992, he served as First Officer in the International Atomic Energy Agency (IAEA; Vienna, Austria), responsible for the IAEA’s activities in probabilistic safety assessment (PSA). Since 1992, he has coordinated PSI’s inter-disciplinary project on Comprehensive Assessment of Energy Systems, addressing environmental, risk and economic aspects of current and future energy systems. As a part of these activities he manages a number of projects for the Swiss energy and environmental authorities, for the Swiss utilities and for international organizations.

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1. The Organization for Economic Co-operation and Development (OECD) was established in 1961 and currently consists of 30 member countries, which are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, The Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

2. The European Union currently comprises 27 member states. The former EU 15 countries include Belgium, Germany, France, Italy, Luxembourg, The Netherlands, Denmark, United Kingdom, Ireland, Greece, Portugal, Spain, Austria, Finland, Sweden. With the extension to EU 25, Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia and Slovak Republic joined. Bulgaria and Romania became member states as of 2007.

3. For oil spills, the consideration of so-called flag of convenience states (i.e., a ship that flies the flag of a country other than the country of ownership) is of crucial importance. Cheap registration fees, low or no taxes and freedom to employ cheap labor are the motivating factors behind a ship

owner's decision to “flag out.” The International Transport Workers’ Federation lists 32 FOC countries (ITF, 2005) with Panama, Liberia and the Bahamas among the top five countries by flag registration in terms of tonnage (dwt, deadweight tons) of their oil tanker merchant fleets (UNCTAD, 2005).

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