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Severe accidents in the energy sector: comparative perspective

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Abstract

This paper addresses one of the controversial issues in the current comparative studies of the environmental and health impacts of energy systems, i.e. the treatment of severe accidents. The work covers technical aspects of severe accidents and thus primarily reflects an engineering perspective on the energy-related risk issues, though some social implications are also touched upon. The assessment concerns fossil energy sources (coal, oil and gas), nuclear power and hydro power. The scope is not limited to the power production (conversion) step of these energy chains but, whenever applicable, also includes exploration, extraction, transports, processing, storage and waste disposal. With the exception of the nuclear chain the focus of the work has been on the evaluation of the historical experience of accidents. The basis used for this evaluation is a comprehensive database ENSAD (Energy-related Severe Accident Database), established by the Paul Scherrer Institut (PSI). For hypothetical nuclear accidents the probabilistic technique has also been employed and extended to cover the assessment of economic consequences of such accidents. The broader picture obtained by coverage of full energy chains leads on the *world-wide* basis to aggregated *immediate* fatality rates being much higher for the fossil chains than what one would expect if only power plants were considered. Generally, the immediate fatality rates are for all considered energy carriers significantly higher for the non-OECD countries than for OECD countries. In the case of hydro and nuclear the difference is in fact dramatic. The presentation of results is not limited to the aggregated values specific for each energy chain. Also frequency-consequence curves are provided. They reflect implicitly the ranking based on the aggregated values but include also such information as the observed or predicted chain-specific maximum extents of damages. This perspective on severe accidents may lead to different system rankings, depending on the individual risk aversion.

Keywords: Accidents; Energy sector; Database; Comparison; Aggregated indicators; Frequency-consequence curves

1. Introduction

The energy sector has been recognised as one of the main contributors to man-made disasters. According to the previously published data on accidents that occurred world-wide since 1970 the second (after transportation) largest group responsible for man-made disasters is the field of energy production. Fritzsche [1] concluded in an editorial in one of the issues of "Risk Analysis" that about 25% of the fatalities caused by severe accidents world-wide in the period 1970−1985 occurred in the energy field. These results were based on the statistics on the disasters, published by the world's second largest reinsurance company Swiss Re in Zurich. In the same editorial Fritzsche [1] recognised that the level of completeness and the quality of the existing data on severe accidents is not satisfactory. He urged the risk assessment community to undertake an effort of "a systematic collection and analysis of the world-wide statistics on accidents in the energy field and their correlation with the quantity of electrical energy produced". The work summarised in this paper was carried out in response to this challenge; a wide variety of data sources has been employed, much beyond previous analyses. For the full report we refer to [2]. The scope of the work is not limited to the accidents, which occurred in the past. In addition, probabilistic safety assessment (PSA) has been employed in some cases where due to several reasons the past experience is not representative. Furthermore, completeness requires that apart from power generation also other stages of the various fuel cycles are covered.

The present study was performed as a part of an integrated evaluation covering risk-related, environmental and economic aspects associated with different energy systems. The results of this work are intended to serve as a scientific support to the decision-making process concerning energy supply options for Switzerland. For this reason, significant effort has been directed towards the examination of the relevance of the world-wide accident records to the Swiss- and OECD-specific conditions, particularly in the context of nu-

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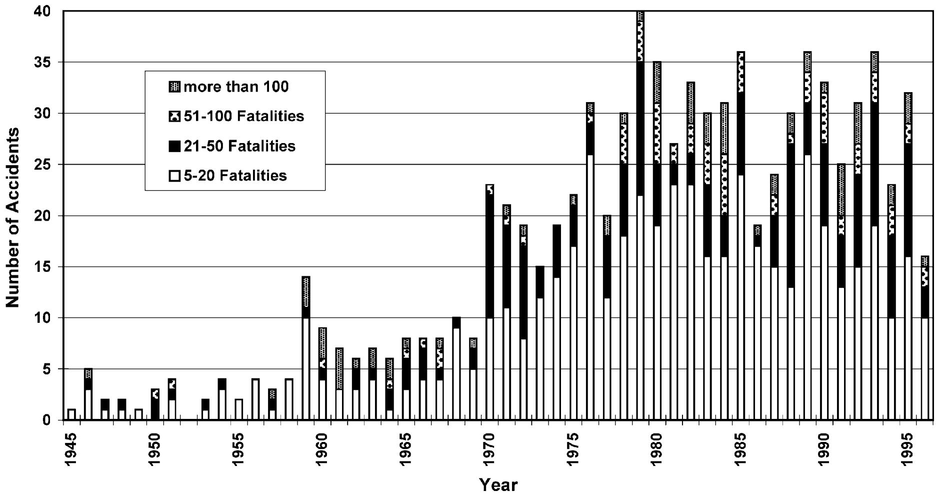

Fig. 1. Severe energy-related accidents world-wide during the period 1945–1996, with different gravity indices for fatalities.

clear and hydro power. Consequently, the results and conclusions applicable to OECD countries are emphasised.

The accident database established by PSI in 1998 [2] is currently being significantly extended within the EU Project NewExt. This includes also implementation of accident data from recent years as well as a much improved knowledge on accidents in China, acquired by PSI within the China Energy Technology Program [3,4]. The evaluations based on this improved basis are in progress.

2. PSI's energy-related severe accident database (ENSAD)

For the purpose of this work an accident is considered to be severe if it is characterised by one or several of the following consequences: (a) at least five fatalities; (b) at least 10 injured persons; (c) at least 200 evacuees; (d) extensive ban on consumption of food; (e) releases of hydrocarbons exceeding 10,000 tonnes;[1] (f) enforced clean-up of land and water over an area of at least 25 km^2; (g) economic loss of at least 5 million 1996 US$.

2.1. ENSAD and its merits

The ENSAD (current extensions not included) covers 13,914 accidents, of which 4290 (30.8%) are energy-related; 10,064 (72.3%) accidents were classified as man-made and the remaining 3850 (27.7%) as natural.[2] The percentage of energy-related accidents among the man-made ones amounts to 42.6%. This number is, however, not fully representative (i.e. the share of energy-related accidents is overestimated) since at present ENSAD does not cover transportation accidents unless they belong to a specific fuel chain or the accident resulted due to an interaction with a fuel chain. As shown in Fig. 1, in the period 1975−1996 typically about 30 energy-related accidents with at least 5 fatalities occurred each year world-wide. Among them 1−5 accidents (per year) had consequences exceeding 100 fatalities. Nearly 93% of the energy-related accidents collected in ENSAD occurred in the time period 1945−1996. This dominance is mainly due to the larger volume of activities; however, improved reporting coverage probably also plays here an important role.

Various types of consequences are covered to different extent, depending on the availability and quality of the data. These factors differ between the various energy sources. Generally, the completeness and accuracy of the data concerning fatalities resulting from accidents is superior to the ones covering other types of consequences.

Fig. 2 shows the content of ENSAD in terms of the number of accidents of the different types and within specific consequence categories.

Applying the definition of a severe accident, established in the present work, 1943 severe energy-related accidents are stored in ENSAD. Accidents with at least five fatalities form the largest group (846 events). There is also in descending order a large number of energy-related accidents involving major releases of hydrocarbons and chemicals, injuries, large economic losses and evacuations. Nearly two-thirds of all recorded energy-related severe accidents with at least five fatalities occurred in OECD countries.

Due to the use of a variety of information sources, including databases established in various countries, ENSAD has a balanced coverage with respect to countries and regions where the accidents took place. This eliminates a problem encountered in many other accident databases driven by the local availability of information, which in turn is subject to

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[1] Other chemicals were also considered on a case-by-case basis with view to their toxicity.

[2] The name of the database reflects the focus and priorities of this work. Although the non-energy accidents in terms of numbers constitute the major part of ENSAD, as opposed to the energy-related ones no efforts were made to increase the completeness and examine the quality of these data.

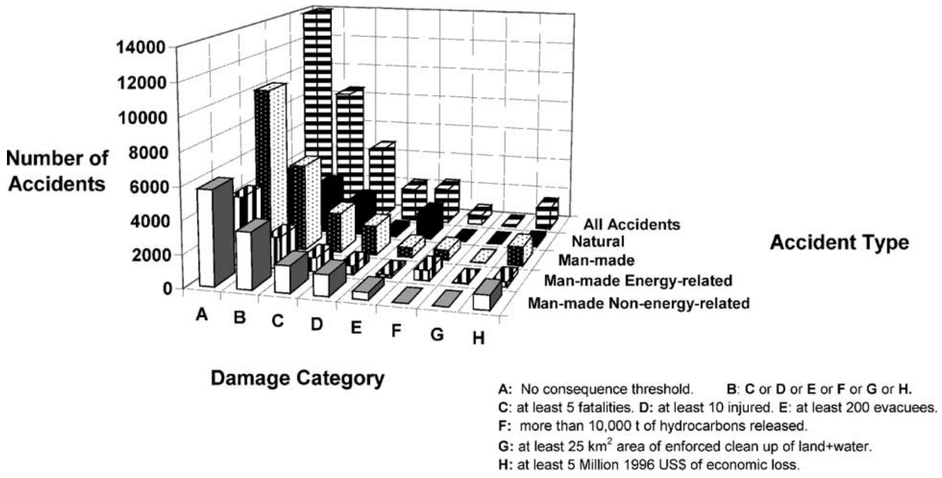

Fig. 2. Content of ENSAD—number of accidents by type and damage category.

Table 1
Ten energy-related severe accidents with the highest number of immediate fatalities in the period 1969–1996

Energy carrier	Date	Country	Energy chain stage	Immediate fatalities	Injured	Evacuees	Costs (10^6 US$ 1996)
Oil	20.12.87	Philippines	Transport to refinery	**3000**	26	0	–
Oil	01.11.82	Afghanistan	Regional distribution	**2700**	400	0	–
Hydro	11.08.79	India	Power plant	**2500**	–	150000	1024
Hydro	27.08.93	China	Power plant	**1250**	336	–	27
Hydro	18.09.80	India	Power plant	**1000**	–	–	–
LPG	04.06.89	Russia	Long distance transport	**600**	755	0	–
Oil	02.11.94	Egypt	Regional distribution	**580**	–	0	140
Oil	25.02.84	Brazil	Regional distribution	**508**	150	2500	–
Oil	29.06.95	South Korea	Regional distribution	**500**	952	0	–
LPG	19.11.84	Mexico	Regional distribution	**498**	7231	200000	2.9

constraints due to language and other cultural barriers. Access to and implementation of the very diversified input resulted also in a much more extensive coverage of man-made accidents in ENSAD in comparison with other databases.

2.2. *Most severe historical accidents*

Table 1 provides a list of 10 worst accidents in the period 1969–1996 within damage category “immediate fatalities”. Similar lists exist also for categories “injured”, “evacuees” and “costs”. While one specific indicator (shown in bold face) is in focus of the table, also other parameters characterising the consequences are provided. “Latent fatal and non-fatal cancers”, particularly relevant for the Chernobyl accident, constitute a separate category not shown in Table 1.

3. Comparative assessment

Comparisons between the different energy sources, based on the statistical evidence, were carried out for the period 1969–1996. The choice of the lower limit was guided by two factors, which imply that going too far back in time may lead to results that lack relevance for the present situation:

1. Temporal changes such as technological advancements, more rigorous safety regulations, general improvements in industrial risk management, increased hazard awareness, etc.
2. Improved reporting completeness and quality. There are clear indications that the situation has been improving along with the growing societal interest in industrial risks.

Three sets of the results are provided: for the world, OECD countries and non-OECD countries.[3] The generic results obtained for OECD are for the purpose of this report considered to be representative for Switzerland. For accidents involving fossil fuels allocation schemes were developed, taking into account the flows of these carriers between OECD and non-OECD countries.

An essential parameter used for the normalisation of the results is the total energy produced by each energy source. For comparison purposes the data in terms of number of

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[3] Few countries currently being members of OECD were within this work not included among OECD countries. The most essential comparative evaluations included in this report are based on the statistical material covering a period of nearly 30 years and stretching until the end of 1996. For this reason, countries that acceded OECD between 1994 and 1996, i.e. Mexico, Czech Republic, Hungary, Poland and Republic of Korea are here not included among the OECD countries.

Table 2
Experience-based *immediate* fatality rates associated with severe accidents within full energy chains based on the partial reallocation of damages to OECD countries [2]

Energy chain	Number of severe accidents with fatalities, world-wide (1969–1996)	Number of immediate fatalities (per GW_e year)		
		World-wide	OECD	Non-OECD
Coal	187	3.4×10^{-1}	1.4×10^{-1}	5.1×10^{-1}
Oil	334	4.2×10^{-1}	3.9×10^{-1}	4.6×10^{-1}
Natural gas	86	8.5×10^{-2}	6.6×10^{-2}	1.1×10^{-1}
Nuclear	1	8.4×10^{-3}	0	5.3×10^{-2}
Hydro	9	8.8×10^{-1}	4.0×10^{-3}	2.2

accidents, various indicators for accident consequences and cumulative frequency distribution of consequences were normalised on the basis of the unit of electricity production for the different energy sources. For nuclear and hydro power the normalisation is straight-forward since in both cases the generated product is electrical energy. In the case of coal, oil, natural gas, and liquefied petroleum gas (LPG) the thermal energy was converted to an equivalent output using a factor of 0.35.

3.1. Aggregated indicators

While a variety of damage categories were considered and analysed the conclusions cited in this summary are primarily based on fatality rates. First, the statistical records on fatalities are most complete; second, the fatalities associated with large accidents are regarded as the indicator attracting most attention on the side of the society; third, the patterns for other indicators are in some (but definitely not all) cases quite similar to that characteristic for the fatality rates.

Table 2 shows the fatality rates for the various energy sources. The results presented in this paper are limited to those utilising an allocation scheme when distinguishing between the results obtained for OECD and non-OECD countries. This allocation procedure considers the trade-based flows of fossil energy carriers between the non-OECD and OECD countries. The OECD countries are net importers of these energy carriers and the majority of accidents occur within the upstream stages of these chains. Consequently, the reallocation to OECD countries of the appropriate shares of accidents that physically occurred in non-OECD countries leads to smaller differences between the corresponding damage rates for these two groups of countries in comparison with the straightforward evaluation. The effect is particularly significant in the case of oil. Fig. 3 shows the set of results obtained for the normalised person-related severe accident indicators; economic losses are shown in Fig. 4. For the full set of results we refer to the main report [2].

The present work shows that significant differences exist between the aggregated, normalised damage rates assessed for the various energy carriers. One should, however, keep in mind that from the absolute point of view the fatality rates are in the case of fossil sources small when compared to the corresponding rates associated with the health impacts of normal operation.

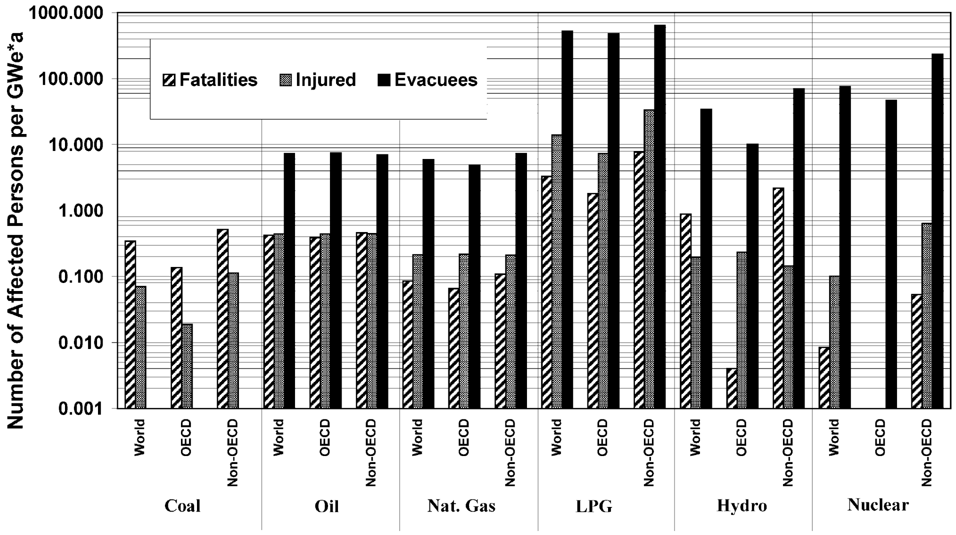

Fig. 3. Comparison of aggregated, normalised, energy-related damage rates, based on severe accidents that occurred world-wide, in OECD and in non-OECD countries in the period 1969−1996; *immediate* fatalities, injured and evacuated persons per unit of energy were estimated based on the partial reallocation of damages to OECD countries [2].

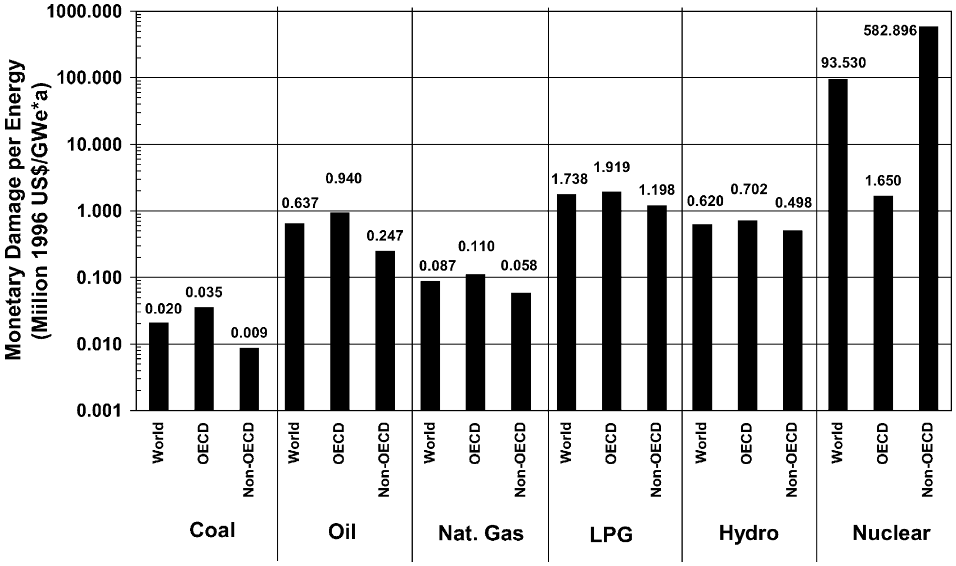

Fig. 4. Comparison of aggregated, normalised, energy-related economic losses, based on severe accidents that occurred world-wide, in OECD and in non-OECD countries in the period 1969−1996; these results are based on the full reallocation of damages to OECD countries, taking into account imports of fossil energy carriers from non-OECD countries [2].

The broader picture obtained by coverage of full energy chains leads on the world-wide basis to aggregated immediate fatality rates being much higher for the fossil fuels than what one would expect if only power plants were considered. The highest rates apply to LPG, followed by hydro, oil, coal, natural gas and nuclear. In the case of nuclear, the estimated *delayed* fatality rate solely associated with the only severe (in terms of fatalities) nuclear accident (Chernobyl), clearly exceeds all the above-mentioned immediate fatality rates. However, in view of the drastic differences in design, operation and emergency procedures, the Chernobyl-specific results are considered not relevant for OECD countries. In fact, this particular accident is not representative for light water reactors in general, also including the ones in non-OECD countries. Given lack of statistical data, results of state-of-the-art probabilistic safety assessments for representative plants in OECD countries may be used as the reference values.

Generally, the immediate failure rates are for all considered energy carriers significantly higher for the *non-OECD*

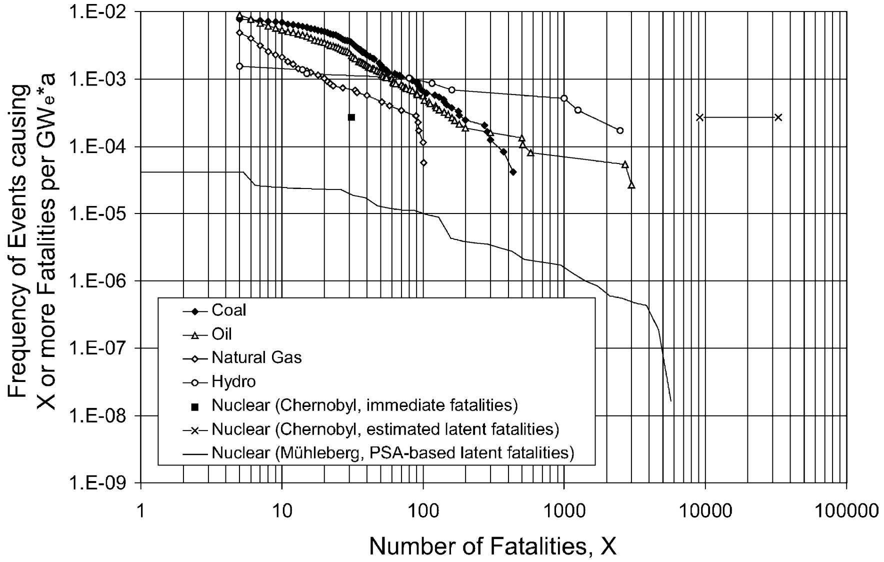

Fig. 5. Frequency-consequence curves for full energy chains *world-wide* [2]. The curves for coal, oil, natural gas and hydro chains are based on historical accidents world-wide in the period 1969−1996 and show *immediate* fatalities. For the nuclear chain the *immediate* fatalities are represented by one point (Chernobyl); for the estimated Chernobyl-specific *latent* fatalities lower and upper bound are given. The results for the Swiss nuclear power plant Mühleberg originate from the plant-specific probabilistic safety assessment (PSA) and reflect *latent* fatalities.

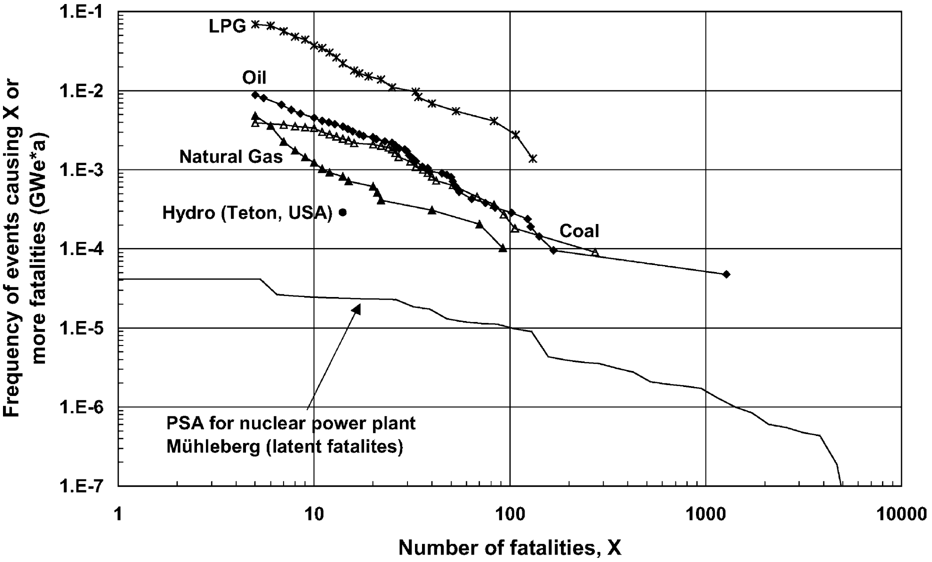

Fig. 6. Frequency-consequence curves for severe accidents in various energy chains that occurred in *OECD countries* using full reallocation; based on historical data for the period 1969–1996.

countries than for *OECD* countries. In the case of hydro and nuclear the difference is in fact dramatic. The recent experience with hydro in OECD countries points to very low fatality rates, comparable to the representative PSA-based results obtained for nuclear power plants in Switzerland and in USA. With the important exception of hydro in OECD countries, and coal and oil occasionally switching positions, the internal ranking based on the *immediate* fatality rates remains the same within OECD and non-OECD countries as the above-cited results based on the world-wide evidence. This is valid both for the straightforward assessment as well as for the estimates employing allocation schemes. Accounting for *delayed* fatalities along with the immediate ones preserves this ranking when OECD countries are considered but due to the Chernobyl accident nuclear compares unfavourably to the other chains when the experience base is considered for non-OECD countries only. For comparison, the PSA-based estimate for the rate of latent fatalities associated with the Swiss nuclear power plant Mühleberg is 0.02 latent fatalities per GW_e year.

The comparison of economic damages is limited by incompleteness and some serious inconsistencies. First, the estimates of monetary losses are not available for a major part of non-nuclear accidents. Second, the cost elements covered, i.e. the boundaries of the calculation, are normally not documented and may vary widely from case to case. Third, the

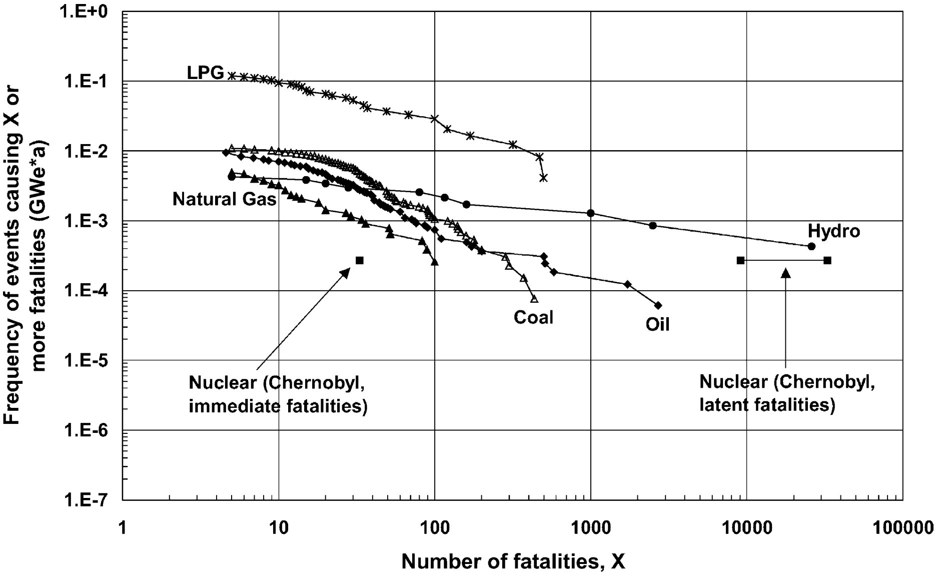

Fig. 7. Frequency-consequence curves for severe accidents in various energy chains that occurred in *non-OECD countries* using full reallocation; based on historical data for the period 1969–1996. Latent Chernobyl fatalities estimated over a period of 70 years.

nature of the reported costs may be different—there is normally a large discrepancy between the compensation paid by insurance companies, claimed damages, real damages, direct costs and indirect costs. In the nuclear case the costs of two accidents have been included, namely Three Mile Island (TMI) and Chernobyl. They are dominated by the latter accident with more than one order of magnitude discrepancy between the lower and higher bound of this estimate. Due to the devastating damages associated with the Chernobyl accident the normalised monetary damages are clearly highest for the nuclear chain, followed by LPG, oil, hydro, natural gas and coal. Consideration of the regional distribution of accidents leads to a somewhat different ranking for OECD countries.

3.2. Frequency-consequence curves

The comparison of results is not limited to the aggregated values obtained for specific energy chains. Also frequency-consequence curves are provided. They reflect implicitly the above ranking but provide also such information as the observed or predicted chain-specific maximum extents of damages. This perspective on severe accidents may lead to different system rankings, depending on the individual risk aversion. Fig. 5 shows the curves based on the historical experience as represented in ENSAD and on PSA for the Swiss nuclear power plant Mühleberg.

Among the fossil chains natural gas has the lowest frequency of severe accidents involving fatalities. Apart from LPG, coal and oil exhibit the highest frequencies of accidents up to the level of about 70 fatalities while hydro has the lowest. For higher levels of consequences the situation becomes reversed.

As with aggregated indicators reallocation of accidents was carried out to obtain frequency-consequence curves for OECD and non-OECD countries. These curves are provided in Figs. 6 and 7. For the evaluation period used there is only one severe (with respect to fatalities) hydro accident in OECD countries.

4. Conclusions

As a result of recent efforts the basis for the technical comparison of severe accident risks associated with different energy chains has been significantly improved. This applies in particular to the completeness of historical records, quality and consistency of the information, and coverage of various types of damages.

The following conclusions apply to the various energy chains.

4.1. Coal chain

1. The overall number of severe ($\geq$5 fatalities) accidents in the coal chain decreased slightly in OECD countries in the last two decades as opposed to non-OECD countries.
2. The number of fatalities in OECD countries decreased significantly. While the coal production was increased there has been a simultaneous reduction of severe accidents due to legislation, research findings concerning the prevention of gas and coal-dust explosions, fires and inundations, as well as closure of old unsafe mines.
3. The coal chain stage with by far most fatalities is "Extraction". The "Heating Plant" and "Power Plant" stages are currently relatively small contributors to severe accidents. In the industrialised world some smog catastrophes, which have features of severe accidents occurred in the 50s and 60s and have not been repeated since.
4. The main cause for world-wide severe coal accidents are methane gas explosions in underground mining. Their relative contribution in OECD countries is, however, three times lower than in non-OECD countries.

4.2. Oil chain

1. Along with higher oil consumption there has been a trend of increasing number of severe accidents resulting in fatalities within the oil chain.
2. The most risk prone stages in the oil chain are "Regional Distribution" and "Transport to Refinery". Slightly more than 75% of all severe accidents in the oil chain occurred in these two stages.
3. Maritime accidents are the most frequent accidents during the stage "Transport to Refinery" while road accidents are the most frequent accidents during the stage "Regional Distribution". In the latter mentioned stage petrol is the primary oil product involved.
4. The North Sea is the most unfriendly environment for offshore activities and consequently has a high share of severe offshore accidents.
5. In the period of 1969−1996 more than 40 refinery accidents occurred. None of them caused more than 40 fatalities per accident.
6. In terms of the quantities released oil spills as a consequence of shipping and platform accidents are less significant than oil spills caused by industrial river runoff discharges, tanker operational discharges, sewage disposal, and non-tanker maritime transportation. However, factors other than the quantity released (distance from the coast, weather and current conditions, time profile of the discharges and sensitivity of the areas exposed to oil pollution), contribute to and may in fact be decisive in the context of the ecological disasters caused by some tanker and platform accidents.

4.3. Gas chain

1. The yearly number of LPG and natural gas severe accidents significantly increased after 1970. However, since 1985 there is a decreasing trend in the number of severe

gas accidents. At the same time there is a large scatter in the number of accidents from year to year.

2. The stages in which most of the severe (≥5 fatalities) accidents occurred are "Long Distance Transport", "Local Distribution" and "Regional Distribution" for natural gas and "Regional Distribution" for LPG.
3. Nearly 72% of 288 natural gas accidents (not all are severe ones), which are collected in ENSAD, occurred in 1969–1996 during the transport by pipelines, nearly 15% in a process plant or in an area of a process plant and only 6% in a storage plant. About 21% of all natural gas accidents involving pipelines were caused by mechanical failures and 24% by impact failures.
4. Nearly 53% of 165 LPG accidents (not all are severe ones), which are collected in ENSAD, occurred in 1969–1996 during the transport by road- or rail-tankers, pipelines or by ship. The dominant cause was impact failure.

4.4. Nuclear chain

1. In the historical experience of nuclear reactor accidents two events are clearly dominant, namely the TMI-2 and Chernobyl accidents. While the first mentioned accident had practically negligible health and environmental consequences, the latter resulted in disastrous impacts. Preliminary estimates of these impacts are provided in the present work. Having in mind their partially latent nature the definite assessment cannot be made at this stage.
2. Due to the radical differences in the plant design and operational environment the Chernobyl accident is essentially irrelevant for the evaluation of the safety level of the Swiss (and most other) nuclear power plants.
3. Use of a plant-specific PSA, if available, is the most rationale basis for the estimate of the hypothetical consequences of severe accidents and the associated monetised damages. The results obtained from such an approach are by definition representative for the case being studied. In addition, it enables treatment of uncertainties in a transparent and disciplined way. In case this approach is not feasible, any extrapolation of results obtained for a specific plant in a specific environment must be done with great care and the reference case should be carefully selected with view to similarities in the design philosophy and in the operating environment. Some earlier published assessments do not exhibit such a care.
4. Estimates of external costs (i.e. of monetised damages not included in the price of electricity) of severe nuclear accidents show the largest discrepancies in the past studies and are considered controversial. Use of the Chernobyl accident as the only reference for the assessment of environmental consequences is more than questionable. Generally, state-of-the-art, rational and defensible methodological approaches, such as the one based on full scope PSAs, have not been used extensively in this context.
5. The results obtained for plants using predominantly PSA-based approaches show low (quantifiable) contributions of severe accidents to external costs of nuclear power. This contrasts with some estimates based on simplistic, limited in scope and arbitrary approaches discussed in this work. Low (absolute) contributions are to be expected as a reflection of the defence in depth design philosophy. In the particular case of Mühleberg the early offsite risks are negligible due to relatively low radionuclide inventory and low population density in the immediate proximity of the plant. The extensive backfitting has been generally efficient in terms of reduction of the applicable risk measures. Generalisations should, however, be avoided—the indication is applicable to plants with good safety standards and within the limited boundaries of the analyses performed. The relative differences between the various applications can still be large since the risks are expected to be strongly plant- and site-specific.

4.5. Hydro chain

1. Depending on the evaluation time period and the related boundary conditions the variation between the failure rates (mean values) obtained for the different dam types corresponds to a factor of 6–23.
2. With only few exceptions, the dam failure rates have decreased significantly in time. This is due to a combined effect of technological developments (including replacement of masonry by concrete as the primary construction material around 1930 and on) and the impact of regulatory requirements. In most cases there is a significant decrease in failure rates when the first 5 years of operation after filling the dam are excluded from the evaluation. This observation is important since a majority of current dams have long operating history, far beyond 5 years.
3. The Swiss dams exhibit a number of favourable safety-related features. Of particular importance is the typically relatively low capacity of earth dams, which is a positive factor for the mitigation of accidents and for the limitation of the extent of potential damages. The failure rates (mean values) based on generic estimates show a variation by a factor of at most 4.3 between the various dam types. The lowest estimate was obtained for gravity dams. For gravity, arch, buttress and rockfill dams the mean values are close to the estimated upper bounds, while lower bands are up to two orders of magnitude lower. The available statistical material is most comprehensive for earth dams.
4. Dam failure rates are not only subject to variation with respect to the type of dam but depend also to some extent on the purpose of the dam. This may partially reflect the different safety standards within the various areas of dam applications but is also a result of the differences in the distributions of dam types within these diverse applications. In this context flood control and hydro power

dams appear on average to be the best performers. The water supply dams have the highest average failure rates.

From the comparative analysis the following conclusions can be drawn:

1. The evaluation of historical experience demonstrates numerical differences between the aggregated risk indicators obtained for the various energy chains, as well as between the corresponding frequency-consequence curves. Regional differences have been shown to be of utmost importance for the nuclear and hydro chains. The expectation values for fatality rates due to severe accidents are lowest for hydro and nuclear power in OECD countries. This is also reflected in low external costs associated with severe accidents estimated using state-of-the-art methods. At the same time the extent of consequences of hypothetical extreme accidents is largest in the case of hydro and nuclear. Valuation of this aspect depends on stakeholder preferences, can be addressed in multi-criteria analysis and along with the issue of wastes affects in particular the ranking of nuclear power in the sustainability context [5].
2. PSA perspective on severe accident risks is particularly important for energy chains whose risks are dominated by power plants; since the historical experience of accidents is scarce or/and its applicability is highly restricted to a particular type of plant. Thus, PSA studies are expected to provide most representative results for hydro and nuclear power plants.
3. The upstream stages within the fossil energy chains are most prone to severe accidents.
4. Total damages due to severe accidents in the energy sector are very small in comparison with natural catastrophes but also when compared with the impacts of air pollution originating from the energy sector.

Further improvements of the current state-of-the-art are feasible and are partially being pursued. They include: continued extensions of the database, broader applications of probabilistic analysis, extended and more in-depth analysis of the economic consequences of severe accidents, and co-operation with social scientists to better reflect sociological and psychological aspects of risks.

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