PAUL SCHERRER INSTITUT

PSI Bericht Nr. 03-04
March 2003
ISSN 1019-0643

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EXECUTIVE SUMMARY

Within the China Energy Technology Program (CETP), sponsored and coordinated by ABB in conjunction with the Alliance for Global Sustainability (AGS), PSI, together with American (MIT), numerous Chinese, Japanese (Tokyo University) and Swiss (ETHZ and EPFL) partners, has investigated how the future electricity supply in China could be made more sustainable. Representatives of major Chinese Stakeholders participated in this program. PSI has been responsible for a major part of the program, including Energy-Economy Modeling (EEM), Life Cycle Assessment (LCA), Environmental Impact and External Cost Assessment (EIA), Risk Assessment (RA), Development of CETP Visualization Software, and parts of Analysis Integration.

This report deals with the comparative assessment of accidents risks characteristic for the various electricity supply options. A reasonably complete picture of the wide spectrum of health, environmental and economic effects associated with various energy systems can only be obtained by considering damages due to normal operation as well as due to accidents. The focus of the present work is on severe accidents, as these are considered controversial. By severe accidents we understand potential or actual accidents that represent a significant risk to people, property and the environment and may lead to large consequences.

The overall goal for this activity within the CETP was to provide a balanced perspective on the severe accident risks specific for China. The assessment addressed fossil energy sources (coal, oil and gas), nuclear power and on a lower level of detail also hydro power. This limitation is partially due to the focus of CETP on the Shandong Province, which lacks hydro resources, and partially due to the scarcity of relevant hydro data. There are strong indications that severe accidents at Chinese dams are subject to substantial underreporting.

The focus of the work was on historical experience of accidents and their applicability to China. Apart from power production (conversion) stage, whenever applicable also exploration, extraction, transports, processing, storage and waste disposal were considered. The comprehensive database on energy-related severe accidents (ENSAD), recently established by PSI, was expanded by implementation of additional Chinese records. This showed to be highly important for the Chinese coal energy chain, which exhibits very high accident fatality rates in comparison with other countries having large coal resources. For the nuclear chain the methodology of Probabilistic Safety Assessment (PSA) was employed in view of the extreme scarcity of historical severe accident events. Offsite consequences were assessed for two sites in Shandong on the basis of a simplified approach employing extrapolation from known results, one from a European site with relatively large population density, and one from a US site. As reference designs two representative western operating plants as well as two advanced/evolutionary designs, were used. It should be noted that the results obtained for the nuclear chain reflect the design features and the site characteristics; possible differences between western and Chinese operational environment (safety culture) were not considered.

The data presented in the table below summarize the available information on severe accidents in various Chinese energy chains. Severe accidents in the coal chain are largely underestimated before 1994 due to restrictive reporting by Chinese authorities. The situation improved a lot with the official release of data and their annual publication in the China Coal Industry Yearbook. Therefore coal accident statistics in the CETP-framework are based on the period 1994-1999. In contrast, the China-specific database on severe

accidents for oil, natural gas, Liquefied Petroleum Gas (LPG) and especially hydro power is much less extensive. As a consequence, Chinese data for these energy chains were pooled with those for non-OECD countries for comparative analysis purposes.

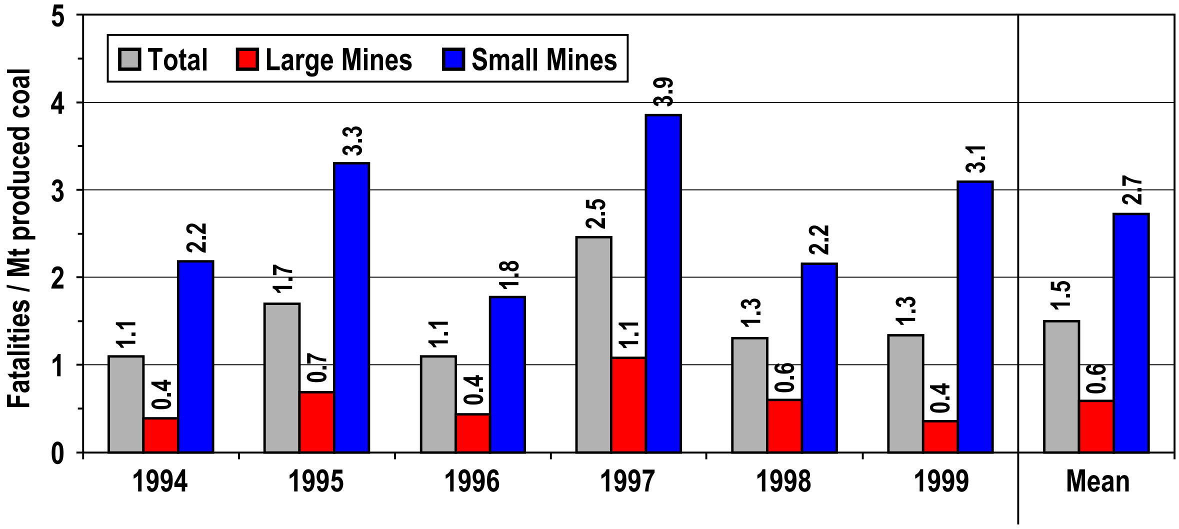
Summary of the severe accident database used for CETP. Time periods considered are 1969-1999 for China and 1969-1996 for non-OECD w/o China and for OECD.

	China		**Non-OECD w/o China**		**OECD**	
Energy chain	**accidents**	**fatalities**	**accidents**	**fatalities**	**accidents**	**fatalities**
Coal Coal CETP (a)	1016 816	17’241 11’321	103	5023	43	1410
Oil	32	613	183	12’737	143	2627
Natural gas	8	201	38	920	45	536
LPG	11	291	27	2308	47	790
Hydro (b)	3	26’028	8	3896	1	14

(a) Coal CETP covers the period 1994-1999, used for statistical evaluations of the Chinese coal chain

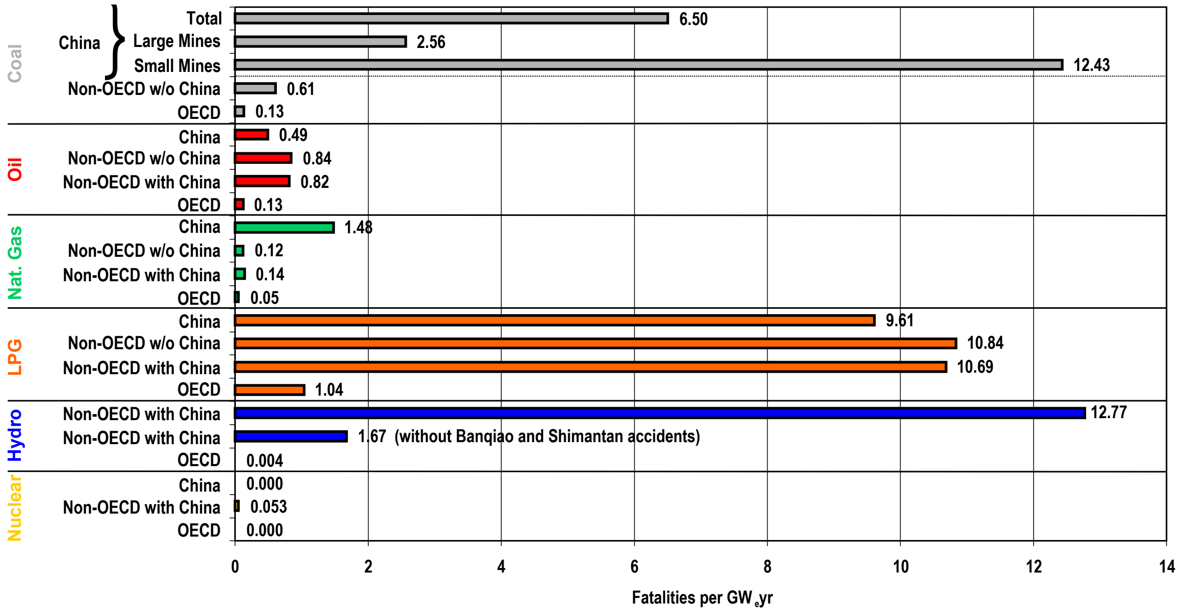
(b) Banqiao and Shimantan dam failures in China caused 26’000 fatalities

The figure below shows the number of severe accident fatalities per Mt of produced coal, according to mine type. On average, fatality rates for small mines were about five times higher than for large mines. Therefore, closing small mines with unacceptably low safety standards could significantly reduce accident risks.



Fatalities per Mt of produced coal in severe accidents according to mine type for years 1994-1999. The average value for this period is also given.

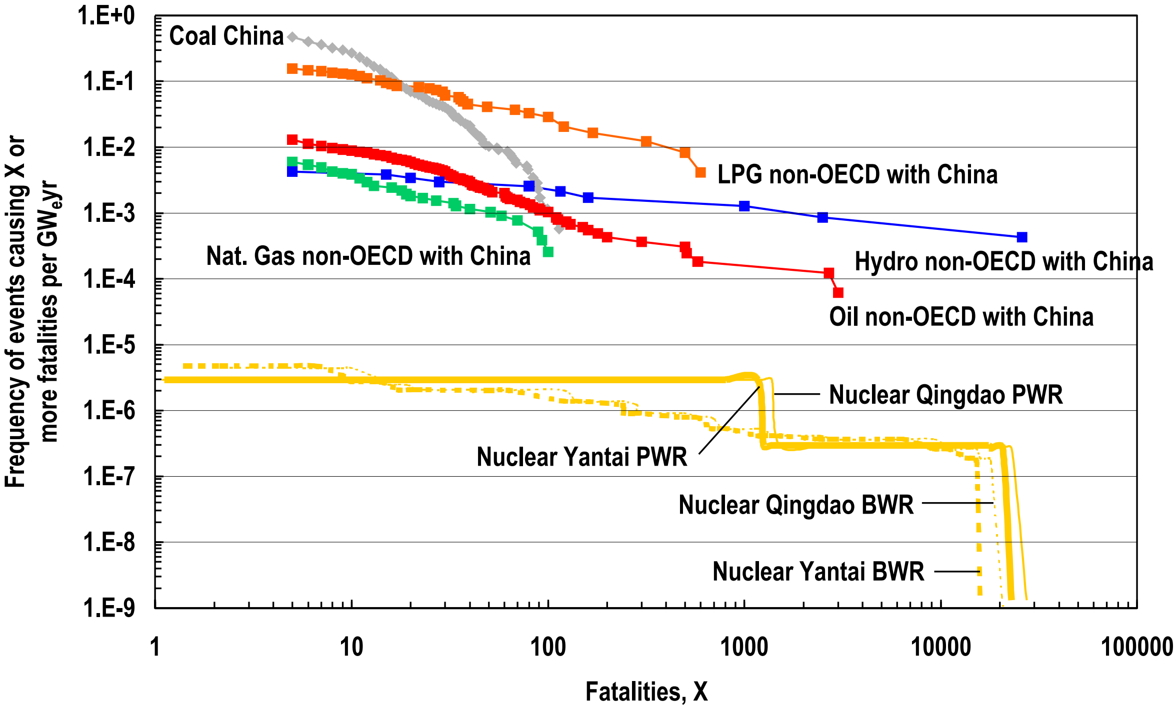
In the next figure severe accident fatality rates in major energy chains are compared, showing aggregated indicators for China, non-OECD countries without China, non-OECD countries with China, and for the OECD countries themselves. The Chinese severe accident fatality rate for the coal chain is about 6.5 per GW$_e$yr, about ten times higher than in non-OECD countries, and about 50 times higher than in OECD countries. The Chinese fatality rate for the oil chain is about 40% lower compared to non-OECD countries. This difference is primarily attributable to two very large accidents with 2700 (Afghanistan) and 3000 (Philippines) fatalities. If these two accidents were excluded, the non-OECD fatality rate would decrease to 0.47, similar to that of China. Natural gas, LPG and hydro chains all exhibited distinctly lower fatality rates for OECD countries compared to non-OECD countries (including China). The non-OECD fatality rate for the hydro chain is driven by the world’s worst hydro accident that occurred at Banqiao and Shimantan dams in 1975 in China, if included.



Severe accident immediate fatality rates in major energy chains for China (1994-1999), non-OECD countries without China (1969-1996), non-OECD countries with China (1969-1999), and OECD countries (1969-1996).

The last figure shows the final selection of frequency-consequence curves for comparison of the different Chinese energy chains. Among Chinese energy chains, coal exhibits the highest accident frequencies. However, the vast majority of coal accidents in China results in less than 100 fatalities. The natural gas chain shows a relatively good performance with regard to accident frequencies and maximum fatalities, but natural gas is currently only of minor importance in China's electricity mix. Accident frequencies of the oil and hydro chains are also much lower than for the coal chain. However, maximum numbers of fatalities within the oil or hydro chains are one to two magnitudes higher than for the coal and natural gas chains. Finally, expected fatality rates associated with hypothetical nuclear accidents are lowest among the relevant energy chains. However, the maximum credible consequences are very large.

Comparison of severe accident records based on frequency-consequence curves for different energy chains in the period 1969-1999, except for coal (1994-1999). The results for the nuclear chain are based on Probabilistic Safety Assessment and represent latent fatalities, whereas the other chains are based on historical accidents and represent immediate fatalities.



The results of the comparison of electricity supply options illustrate the various dimensions of the severe accident issue:

The experience-based evaluation focused on coal as the dominant energy chain in China. Every year about 6000 fatalities occur in Chinese mines due to small (~2/3) and severe (~1/3) accidents. This number is shockingly high when compared to the current OECD accident statistics. On the other hand, the number of accident-related fatalities is quite insignificant when compared to health damages caused by air pollution.

The Chinese severe accident fatality rate for the coal chain is about 6.5 fatalities per GW_eyr. On average, this is about 50 times higher than in OECD countries and ten times higher than in other non-OECD countries.

Small mines in China exhibit on average five times higher severe accident fatality rates compared to large mines. Closing small mines with unacceptably low safety standards could significantly reduce accident risks.

For oil and gas chains in China, accident risk estimates based on experience in other non-OECD countries is fully representative.

Hydro power accident risk was not studied in detail due to low hydro resources in Shandong province. Between 1950-1990 more than 3000 dam breaks occurred in China, but their consequences have mostly not been reported.

Expected fatality rates associated with hypothetical nuclear accidents are lowest among the relevant energy chains. However, the estimated maximum credible consequences are very large. The associated risk valuation is subject to stakeholder value judgements and has been pursued in multi-criteria decision analysis.

1. INTRODUCTION

1.1 Context of the study

In 1999 Asea Brown Boveri (ABB) in conjunction with the Alliance for Global Sustainability (AGS), formed by the Massachusetts Institute of Technology (MIT, USA), The Swiss Federal Institutes of Technology (Paul Scherrer Institut, Swiss Federal Institute of Technology, Lausanne, Swiss Federal Institute of Technology, Zurich) and by Tokyo University, Japan), launched a research program to study the potential for the development of a more sustainable Chinese electrical power sector [ABB, 1999]. Apart from the above mentioned AGS members a number of Chinese organizations, representing regulators, industry and science, joined this program, either as research partners or as members of the Stakeholders Advisory Group. This includes among others: China Academy of Sciences, Ministry of Science and Technology, State Environmental Protection Administration (SEPA), State Power Corporation, Shandong Electric Group Corporation (SEPCO) and Tsinghua University.

The primary goal of the China Energy Technology Program (CETP) was to develop a global methodology for the assessment of the impact of electric power generation investigating energy technologies and their environmental impacts. In order to complete the study within the defined timeframe, one region - Shandong province - was selected for detailed study. Shandong was chosen in view of its dynamic development, high energy intensity, high electricity demand growth rate, high population density (about 90 million people on an area of 160’000 km^2), independent grid and strong ABB representation in the province. [ABB, 1999; MIT, 1999]. However, the ambition of the research program was that the developed and implemented inter-disciplinary methodology should be sufficiently general to be applicable to other Chinese provinces and other countries.

Within CETP the Paul Scherrer Institut (PSI) has been responsible for Energy-Economy Modeling (EEM), Life Cycle Assessment (LCA), Environmental Impact and External Cost Assessment (EIA), Risk Assessment (RA), and for a major part of Analysis Integration, including Development of CETP Visualization Software. The framework for the CETP analyses has been inspired by the approaches established within PSI’s GaBE Project on “Comprehensive Assessment of Energy Systems”, previously implemented and applied for the Swiss-specific conditions. The present report covers the Risk Assessment Task dealing with the issue of accidents; other above mentioned tasks are addressed in separate reports. Since the results of the accident analysis have implications for the external cost assessment we refer to the corresponding report focused on health and environmental impacts due to air pollution [Hirschberg et al., 2003].

1.2 Objectives and scope

The overall goal of this activity within CETP was to provide a balanced perspective on the severe accident risks specific to China. The assessment addressed fossil energy sources (coal, oil and gas), nuclear power, and on a lower level of detail, hydro power also.

While the focus is on severe accidents, generally regarded controversial in the energy debate, small accidents are also addressed in order to provide a broad perspective on the accident issue. Given that coal is and will remain for a long time the dominant energy carrier in China, the accidents associated with coal were investigated in detail. The analyses were primarily based on historical accident records for fossil energy chains (coal, oil, natural gas and LPG) and to a lesser extent for hydro power. This limitation of the analysis is partially due to lack of significant water resources in Shandong. Furthermore, the availability of the China-specific data on severe hydro accidents showed to be a major difficulty. Nevertheless, as hydro power constitutes a very important electricity supply option for China, it is covered here though the treatment is much less detailed than for coal. As a result, the findings concerning hydro power are less robust in relative terms.

For the nuclear chain the use of a probabilistic approach is mandatory, as the relevant statistical experience to support the evaluation of severe accidents fortunately does not exist. China has an ambitious program for the expansion of nuclear power. There are currently no nuclear plants in Shandong but building them is seriously considered by the local utility.

Coalbed methane and renewables such as biomass, tidal power, wind, solar and geothermal resources contribute only marginally to China’s present energy mix; the issue of severe accidents is less relevant for these energy sources. For this reason they have not been analyzed in this work.

In the present work the analysis of accident risks is not limited to power plants but covers full energy chains, including exploration, extraction, processing, storage, transports and waste management since accidents can occur at any of these stages. The study includes analysis of the specific chains followed by the comparison of severe accident fatality rates associated with each chain.

The present work builds further on the earlier major PSI effort to carry out comparative assessment of severe accidents in the energy sector in industrialized and developing countries [Hirschberg et al., 1998; Hirschberg et al., 2001]. A major limitation in the previous work, which constitutes the most comprehensive comparison of severe accidents associated with energy chains, was the unsatisfactory (highly incomplete) coverage of accidents in the Chinese coal chain. One of the central achievements of the present study is that this topic is now adequately covered. For details concerning the procedures used for the establishment of the severe accident database, analytical treatment, uncertainties and limitations etc., we refer to our earlier study.

Concerning the period of time used for the evaluations of historical severe accidents the present study focused on the period 1969-1999, having in mind that within the reference work on worldwide severe accidents [Hirschberg et al., 1998] the evaluations were carried out for the period 1969-1996. However, in the quantitative analysis for China it was necessary on a case-by-case basis to perform the evaluations for a more limited time period in view of the availability of reliable accident records.

1.3 Severe accident definition

By severe accidents we understand potential or actual accidents that represent a significant risk to people, property and the environment and may lead to large consequences. Of interest are accidents that might occur at fixed installations where hazardous materials are stored and processed or during transportation of such materials by road, rail, pipelines, open sea and inland waterways. Hazards to be considered include fires, explosions, structural collapses and uncontrolled releases of toxic substances outside of the boundaries of hazardous installations.

In the literature several defintitions of the term “severe accident” have been provided. All definitions include various consequence or damage types (fatalities, injured persons, evacuees, homeless or economic loss) and a minimum damage level for each type. The differences between the definitions concern both the set of specific consequence types considered and the damage threshold [Hirschberg et al., 1998].

In PSI’ database ENSAD (Energy-related Severe Accidents Database) seven criteria were used to define a severe accident in the coal, oil, gas, hydro or nuclear chain:

1) At least 5 fatalities or

2) at least 10 injured or

3) at least 200 evacuees or

4) extensive ban on consumption of food or

5) releases of hydrocarbons exceeding 10’000 t[1] or

6) enforced clean-up of land and water over an area of at least 25 km^2 or

7) economic loss of at least 5 million 1996 USD.

Whenever anyone of the above criteria is satisfied then the accident is considered as severe. However, in this report the quantitative analysis of severe accidents primarily refers to the first criterion above, as the information related to the other criteria was in most cases not available.

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

2. INFORMATION SOURCES

2.1 Overview of selected databases and other sources

To establish an as complete as possible statistical basis for the comparative assessment of accident risks associated with coal and other energy chains, a variety of commercial and non-commercial sources were used. Although scope, quality and time periods covered differed among sources, they can be classified into four broad categories.

1) Major commercial and non-commercial databases:

   - ENSAD: Energy-related Severe Accident Database of PSI [Hirschberg et al., 1998]. ENSAD was the primary reference source for reference data valid for OECD countries and non-OECD countries other than China. ENSAD integrates data from a large variety of sources.

   - MHIDAS: Major Hazards Incidence Data Service of the UK Health and Safety Executive (HSE).

   - HSELINE: Library and Information Services of the UK HSE.

   - NIOSHTIC: a bibliographic database published by the US National Institute of Occupational Safety and Health.

   - CISDOC: a product of the International Occupational Health and Safety Centre (CIS) of the International Labour Organisation (ILO).

   - Reuters Business Briefing.

2) Books such as: China Coal Industry Yearbook, China Petroleum Industry Yearbook, A Complete Work of Coal Mine Safety in China, China Occupational Safety and Health Yearbook, Accident Cases of Typical and Major Casualties on Labour Safety and Health at Home and Abroad.

   Journals and periodicals such as: Mining Journal, Coal Age, Coal Outlook, Miners News, World Coal, Lloyd’s Casualty Week, SIGMA.

3) National and international Chinese newspapers in English such as: China Daily (published in Beijing, owned by the Chinese government), Sichuan Daily, South China Morning Post, Beijing Evening News, China News Digest, Free China Journal (newspaper covering China, published twice a week), China Quarterly (covers all aspects of modern China studies), China Focus (monthly newsletter published by Princeton University), New York Times.

4) Various internet sources including: MuziNet (Muzi Lateline News), Inside China Today, China E-News, Xinhua News Service, BBC World Service, ABC News, CNN News or the British Association for Immediate Care (BASICS) among many others.

The databases ENSAD, MHIDAS, HSELINE, NIOSHTIC and CISDOC are presented in detail elsewhere [Hirschberg et al., 1998].

Reuters Business Briefing is a database of over 5000 specialist trade publications, business magazines, market research reports, the world's leading newspapers, and local and global newswires from Reuters and Dow Jones. The content of Reuters Business Briefing is primarily worldwide, focusing on Europe, the Middle East and Asia. The database is available through internet at http://factiva.com/.

The China Coal Industry Yearbook is published by the China Coal Industry Publishing House in Beijing. It contains detailed information on accidents in coal mining especially for the years 1994-1999.

The journals Engineering and Mining Journal, and Coal Age are published monthly by Intertec Publishing. Both journals provide information about world-wide production, cost-effectiveness and safety for mines and mineral processing plants.

Coal Outlook is published weekly by Financial Times Energy and gives coverage of coal markets specifically the USA, prices, contracts, transactions, mergers, acquisitions, transportation, utility deregulation, company profiles, and labor trends.

Miners News is a bi-monthly (6 issues annually) newspaper covering North American Mining Company International activities including hard rock, coal, and aggregates. It provides information particularly on mining, investments, safety and international developments in the mining sector.

World Coal is a technical magazine, covering the global coal industry and providing total industry coverage. It is published monthly and provides business and technical information on important aspects of the international coal industry: from longwall mining, to coal preparation, to transportation.

SIGMA is published approximately eight times a year by Swiss Re company. A survey of the largest catastrophes and damages is provided each year in January.

Lloyd's Casualty Week (LLP, formerly Lloyd's of London Press) is accessible online through internet providing comfortable search engines. The internet address is http://www.llplimited.com.

MuziNet, founded in 1996, is an English-Chinese bilingual portal site on the World Wide Web. MuziNet was created and is maintained by Muzi Company, an internet content provider, with a strong commitment to act as an information gateway between the East and the West. The internet address of the Muzi Company is http://lateline.muzi.net/.

Inside China Today offers a daily stream of news, analysis, commentary and culture information for China. It was created by an internet publishing company "European Internet Network" (EIN) which was launched in 1995. The internet address of Inside China Today is http://www.insidechina.com.

China E-News is a special section of the Advanced International Studies Unit (AISU) web site dedicated to news, research, statistics and links relating to energy efficiency, environment and the economy in China. The internet address is http://www.pnl.gov/china/aboutcen.htm.

Xinhua News Service (http://www.xinhuanet.com/) is the state news agency of the People's Republic of China.

BBC World News (http://news.bbc.co.uk/), ABC News (http://www.abcnews.go.com/) and CNN News (http://www.cnn.com) all offer extensive internet sites.

The British Association for Immediate Care (BASICS) maintains a database that currently contains details of more than 6350 disasters and incidents around the world. The internet address is http://www.basedn.freeserve.co.uk/.

2.2 Completeness of collected data

2.2.1 Coal chain

2.2.1.1 Completeness issues

China is both the largest consumer and largest producer of coal in the world [EIA, 2001]. According to the State Statistical Bureau [SSB, 1999] production increased from 48.7 Mt in 1952 to 1240 Mt in 1998 contributing 72% to China’s total energy production. Despite the outstanding importance of coal, the number of people killed in China's mines every year was until recently considered a mystery [BBC News Online, 2000a]. In the early 1980s, such figures were considered a state secret. In recent years, the government has acknowledged an annual death toll of the order of 10’000 people in coal and other mines. However, western analysts have suggested that the numbers may still be subject to underestimation due to inadequate surveys of industrial conditions nation-wide [OSH, 1997]:

1) Small mines operated privately or by local governments have strongly expanded in the last two decades. Most of these mines lack basic safety equipment; hence many of the deaths occur in small mines [BBC News Online, 2000a].

2) Mine operators and county officials are reluctant to report accidents to avoid reprisals by the government [BBC News Online, 2000a]. They also regularly require that workers before they start work sign contracts saying that they will not ask for more than 2000 to 3000 Yuan in compensation in case of any damage due to an accident [Lee-Young, 1997].

3) The number of miners working underground, hired by owners without employment contracts, is unknown [LLP, 1995].

4) Due to political reasons relevant accident data were not published before 1994.

2.2.1.2 Fatalities in Chinese coal mining and international experience

As already stated, the number of fatalities in Chinese coal mining has been inadequately known in the past. In recent years the situation has improved with the annual publication of the China Coal Industry Yearbook, especially for years after 1993. With regard to the earlier years at least a qualitative perspective can be obtained by comparing with the historical trends in the industrialized countries.

The Mine Safety and Health Administration (MSHA) has collected accidents in all kinds of mines in the USA since 1897. Figure 1 shows the number of fatalities per produced tonne in coal mining in the USA for the time period 1896 – 1998. The data between 1896 and 1909 are not complete because not all states had inspectors. Additionally, some data from the UK are given for comparison.

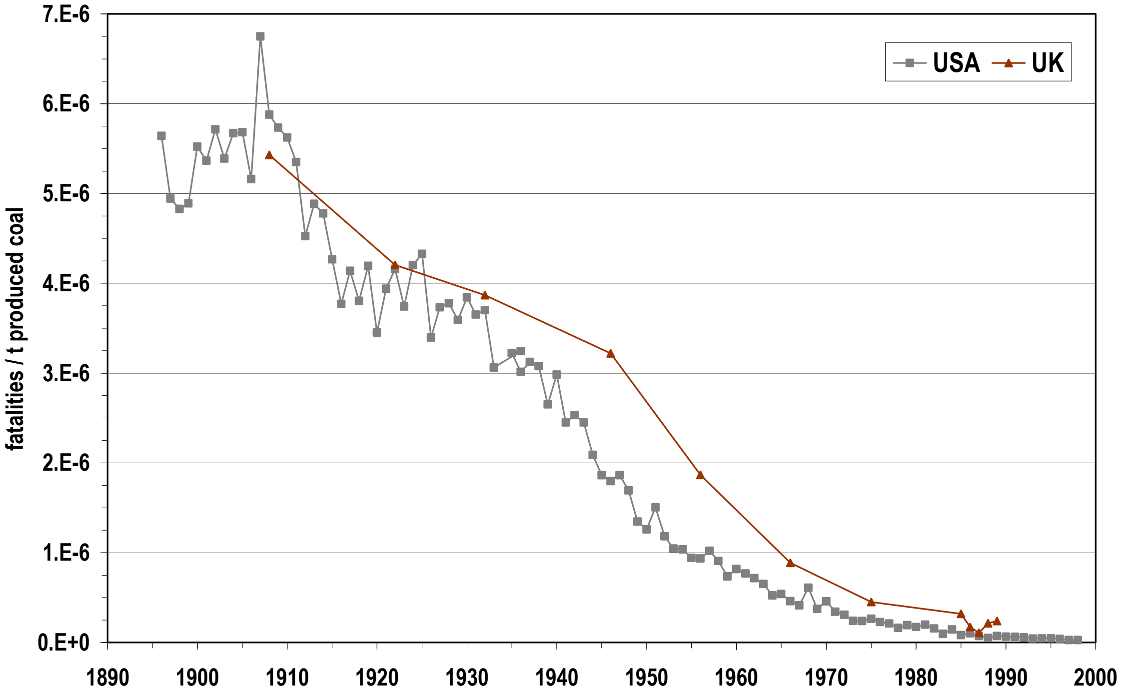


Figure 1: Number of fatalities per produced tonne of coal for 1896-1998 in US coal mining, and for the years 1908, 1922, 1932, 1946, 1956, 1966, 1975, 1985, 1986, 1987, 1988 and 1989 in UK coal mining.

It is clear that in the context of coal mining there is a large gap between the state of technology, education and safety including preventive programs between the USA and China. The US fatality rates from the past can be used as an illustrative reference for China what concerns fatality rates prior to the year 1994, i.e. before reasonably reliable historical data became available. There is a significant element of arbitrariness in this approach, with regard to the suitable reference year to be used. Furthermore, there is a large variation in terms of safety standards between Chinese, sometimes illegal, small mines and large state-owned mines. An official report described the conditions of illegal pits as similar to those in the mines in Britain in the 18th century [BBC News Online, 2000a]. Although state-owned mines have better equipment, there are also cases of chronic bad mine management, outdated equipment and lax safety standards [LLP, 1997]. Using the US fatality rate from 1910, combined with the coal production in China in 1998 we obtain about 6900 fatalities. According to the China Coal Industry Yearbook [CCIY, 1999], there were 6275 fatalities due to accidents in the coal chain in year 1998. This implies that the combined effect of much lower productivity in China (in terms of tonnes per miner and year) and lower safety standards leads to accident fatality rates today in China that are comparable to those typical for the US in the beginning of the last century.

2.2.2 Other energy chains

Similarly to coal, the coverage of severe accidents in the oil chain improved with the publication of the China Petroleum Industry Yearbook. In contrast to coal and oil, no yearbook for the gas industry has been published. Therefore, sources for severe accidents within the natural gas and LPG chains in China rely on those other sources listed in section 2.1.

As for coal, China is rich in coalbed methane (CBM) resources, but CBM development is only in the initial stage. Therefore, no specific data on severe accidents are available at present. In case of severe accidents, the extraction of CBM before coal mining would basically control coal mine gas accidents and improve production safety. The latter is of particular significance in a country where gas accidents happen frequently.

According to various sources, a total of 3241 dams of all sizes and purposes collapsed in China between 1950 and 1990 [Zhang, 1997; Fu, 1998]. Nevertheless, data on failures of large dams related to hydro power generation are hard to obtain and rather incomplete, allowing no detailed analysis of the subject. Information presented in this report is primarily based on official Chinese sources, databases by ICOLD [1995, 1998, 2000] and Vogel [1998], journals such as Water Power & Dam Construction, International Journal on Hydro Power & Dams and Hydro World Review, publications by the World Commission on Dams, Qing et al. [1998], and various internet sources.

No severe accidents occurred in the Chinese nuclear chain.

2.2.3 Severe accident database used for CETP

Available information on severe accidents in various Chinese energy chains is summarized in Table 1. Evaluations and analyses were based exclusively on fatalities because information on other indicators such as injured, evacuees or economic damage were only available to a very limited extent, not allowing a meaningful comparative analysis. Severe accidents in the coal chain are largely underestimated before 1994 due to restrictive reporting. The situation improved a lot with the official release of data and their annual publication in the China Coal Industry Yearbook. Therefore statistics in the CETP-framework are based on the period 1994-1999.

In contrast, the database on severe accidents for oil, natural gas, LPG and especially hydro power is much weaker. As a consequence, Chinese data for these energy chains were pooled with those for non-OECD countries for comparative analyses.

Table 1: Summary of the severe accident database used for CETP. Time periods considered are 1969-1999 for China and 1969-1996 for non-OECD w/o China and OECD.

	China		Non-OECD w/o China		OECD	
Energy chain	**accidents**	**fatalities**	**accidents**	**fatalities**	**accidents**	**fatalities**
Coal Coal CETP (a)	1016 816	17’241 11’321	103	5023	43	1410
Oil	32	613	183	12’737	143	2627
Natural gas	8	201	38	920	45	536
LPG	11	291	27	2308	47	790
Hydro (b)	3	26’028	8	3896	1	14

(a) Coal CETP covers the period 1994-1999, used for statistical evaluations of the Chinese coal chain
(b) Banqiao and Shimantan dam failures in China caused 26’000 fatalities

3. GENERAL INFORMATION AND ISSUES

3.1 China's energy mix

In Figure 2 the production of coal, oil, natural gas, hydro and nuclear power is given for the period 1971-1999. Coal production was about two to four times larger than the sum of the production of oil, gas, hydro, and nuclear. However, coal production is declining since 1997 due to oversupply, whereas the other energy carriers still exhibit an increasing trend.

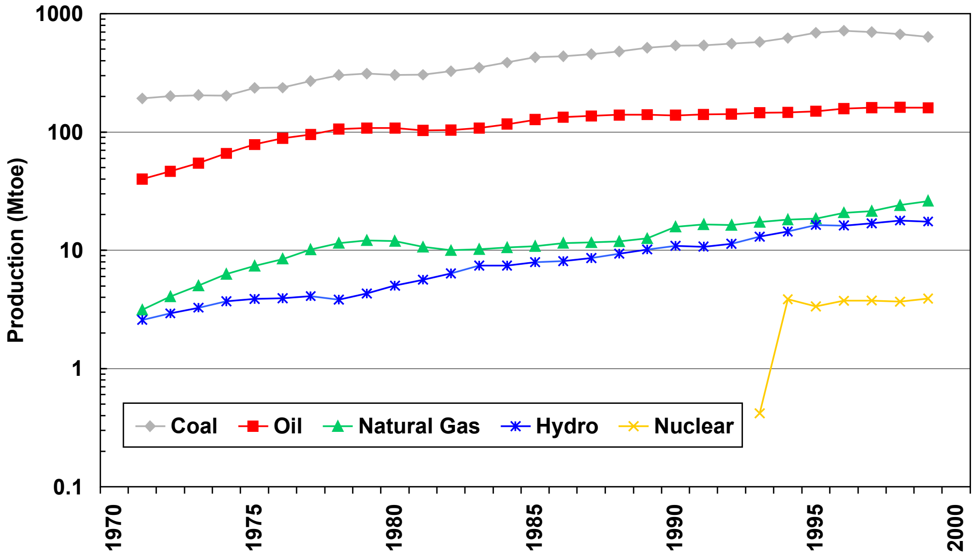


Figure 2: China's energy output mix for the period 1971-1999 [IEA, 2001].

Figure 3 similarly shows the electrical output by energy carriers for the time period 1971-1999. China's electricity is generated overwhelmingly by coal with about 73%. Hydro electricity ranks a distant second with roughly 19%, followed by oil, gas and nuclear power, which together account for the remaining 8%. Although non-hydro renewables have great potential in China, their current contributions are practically negligible.

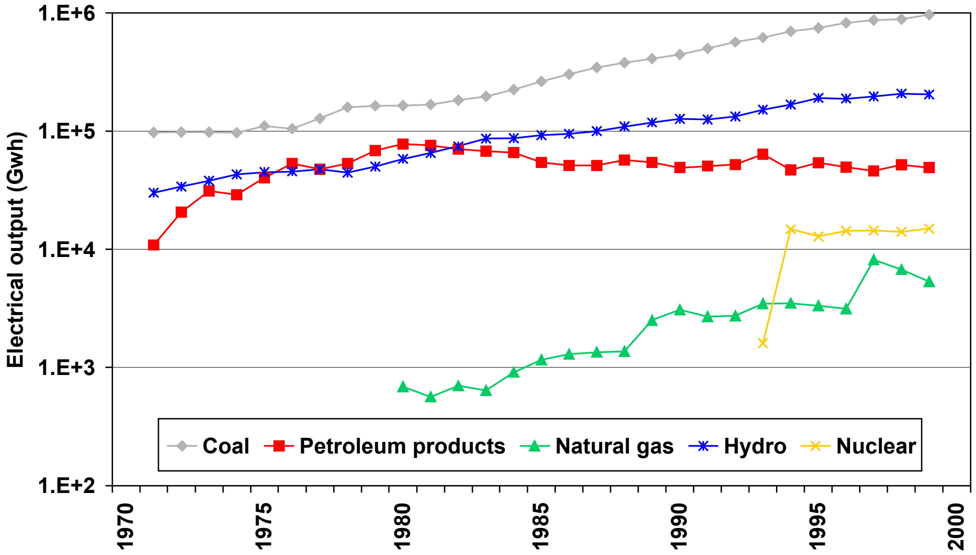


Figure 3: Electrical output by energy carriers in China [IEA, 2001].

3.2 The role of energy in China’s policy for the 21st century

In the 9th Five-Year Plan (1996-2000), the key role of China’s energy sector has been clearly highlighted as being the locomotive for the country’s overall economic growth and modernization [EIA, 1997; Singh, 1999; UNDP, 2000; EIA, 2001]. Coal accounts for about three quarters of China’s primary energy resources and due to abundant reserves it will continue to form the basis for expansion of China’s electric power sector in the foreseeable future [Shaoyi et al., 1996]. However, great efforts are needed to improve the quality of China’s coal exploitation. As a consequence, the Planning Commission’s focus intends to implement numerous improvements rather than forcing further expansion of coal exploration to fulfill the 9th Five-Year Plan:

1) Conversion of coal into a cleaner energy by use of power-generation, coal-power and water mixtures and coal liquefaction.

2) Reduction of inefficiency in the coal industry.

3) Removal of transportation bottlenecks through extension of the country’s railway-system and other transportation infrastructure to regulate the large regional imbalances between supply and demand.

4) Enable state-owned enterprises and local mining operations access to international financing and markets.

5) Encouragement of foreign funds and advanced technologies in China’s coal industry.

6) Construction of pilot plants to convert coal to liquid fuel

4. EVALUATIONS FOR SPECIFIC ENERGY CHAINS

The risks to the public and the environment, associated with various energy systems, arise not only within the power plant stage of energy chains. Investigations of past accidents show that accidents occur at all stages of energy chains. In general, an energy chain may comprise the following stages: exploration, extraction, transport, storage, power and/or heat generation, transmission, local distribution, waste treatment and disposal (for details see Hirschberg et al., 1998). However, one should be aware that not all these stages are applicable to specific energy chains. Table 2 gives an overview of the distinct stages for the coal, oil, gas, nuclear and hydro chains.

Table 2: Stages of different energy chains.

	Coal		**Oil**		**Natural Gas**		**LPG**	**Nuclear**	**Hydro**
Exploration	Exploration		Exploration		Exploration		--	Exploration	
Extraction	Mining and Coal Preparation		Extraction		Extraction and Processing		--	Mining / Milling	
Transport	Transport to Conversion Plant		Transport to Refinery (Long Distance Transport)		Long Distance Transport (pipeline)		--	Transport	
Processing	Conversion Plant		Refinery				• Refinery • Natural gas processing Plant	Upstream Processing [a]	
Transport	Transport		Regional Distribution		Distribution: • Long Dist. • Regional • Local		Distribution : • Long Dist. • Regional • Local	Transport [b]	
Power / Heat Generation	Power Plant	Heating Plant	Power Plant	Heating Plant	Power Plant	Heating Plant	Heating Plant	Power Plant	Power Plant
Transport								Transport to Reprocessing Plant	
Processing								Reprocessing	
Waste Treatment	Waste Treatment							Waste Treatment	
Waste Disposal	Waste Disposal							Waste Disposal	

[a] Includes: Conversion, Enrichment, Fuel Fabrication.
[b] Includes transports between the processing stages mentioned in note a.

4.1 Coal chain

4.1.1 Background

Figure 4 gives an overview of the various coal categories. Generally, coal can be divided into two main classes; hard and low rank coals. Low rank coals, such as lignite and sub-bituminous coals, are typically softer, friable materials with a dull, earthly appearance; they are characterized by high moisture levels and a low carbon content, and hence a low energy content. Higher rank coals are typically harder and stronger and often have a black vitreous luster. Increasing rank is accompanied by a rise in the carbon and energy content and a decrease in the moisture content of the coal.

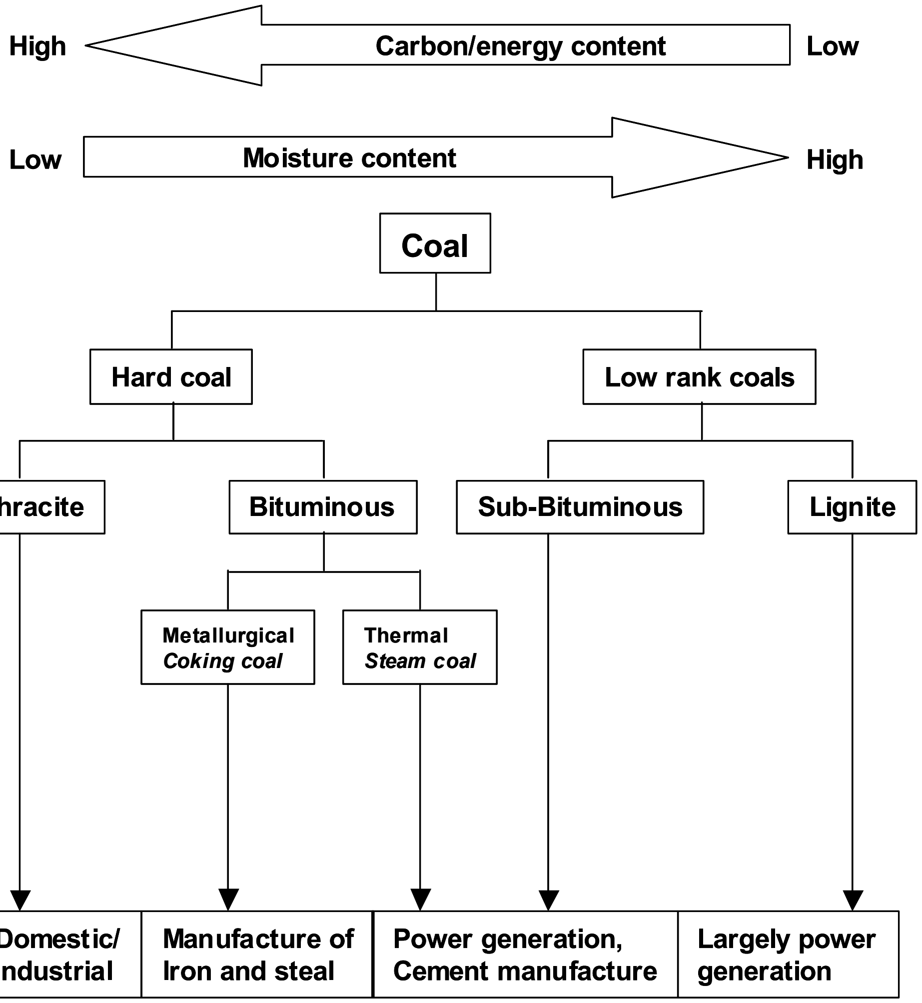


Figure 4: Classification and uses of coal.

4.1.2 China's coal industry

4.1.2.1 Coal characteristics

Table 3 shows the sulfur and ash contents of Chinese coal [Zhu & Zhang, 1995]. Figures 5 and 6 show the mean values and the ranges of the sulfur content and heat value of bituminous including anthracite (BA), sub-bituminous (SB) and lignite (L) coal for the world's most important coal producers [IEA, 1993; 2001], with eastern and western Canada reflecting differences in geological conditions. Sub-bituminous coal data for Germany, Poland and South Africa are lacking because these countries do not produce this type of coal [IEA, 2001]. Figure 5 shows that the average sulfur content values of Chinese bituminous, sub-bituminous and lignite coal are comparable to those of the other countries. However, the range of sub-bituminous coal is relatively large in comparison to the other countries. Figure 6 shows that the heat value of Chinese bituminous coal is comparable to those of the other countries. In contrast, Chinese sub-bituminous coal has the highest mean value and smallest range. However, these values are not fully representative for current Chinese conditions. Therefore, calculations using heat values are in this report based on 20.9 MJ/kg for China in general [Sinton & Fridley, 2000], and 26.01 MJ/kg for Shanxi and 22.3 MJ/kg for Shandong [Fridley et al., 2001].

Table 3: Sulfur and ash contents of Chinese coal.

	Sulfur content				Ash content		
Content [%]	0.5	0.51-1.0	1.01-2.0	>2.0	15	15-35	>35
Percentage in the total reserves	48.6	14.9	15.1	16.4	41.2	55.1	3.

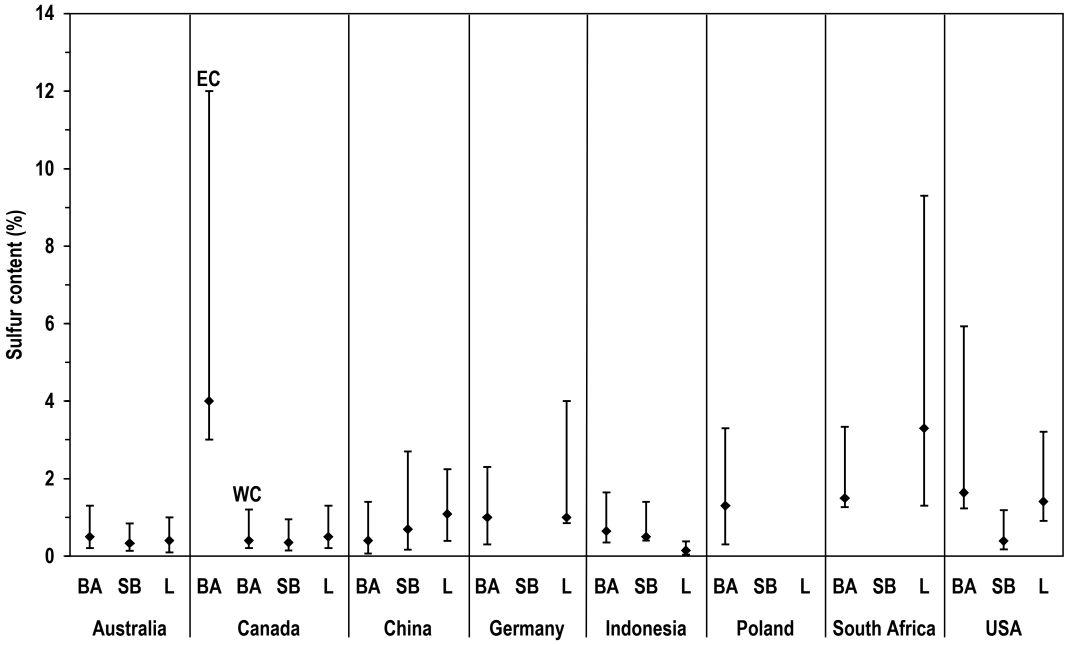


Figure 5: Sulfur content of bituminous including anthracite (BA), sub-bituminous (SB) and lignite (L) coal. WC: Western Canada, EC: Eastern Canada.

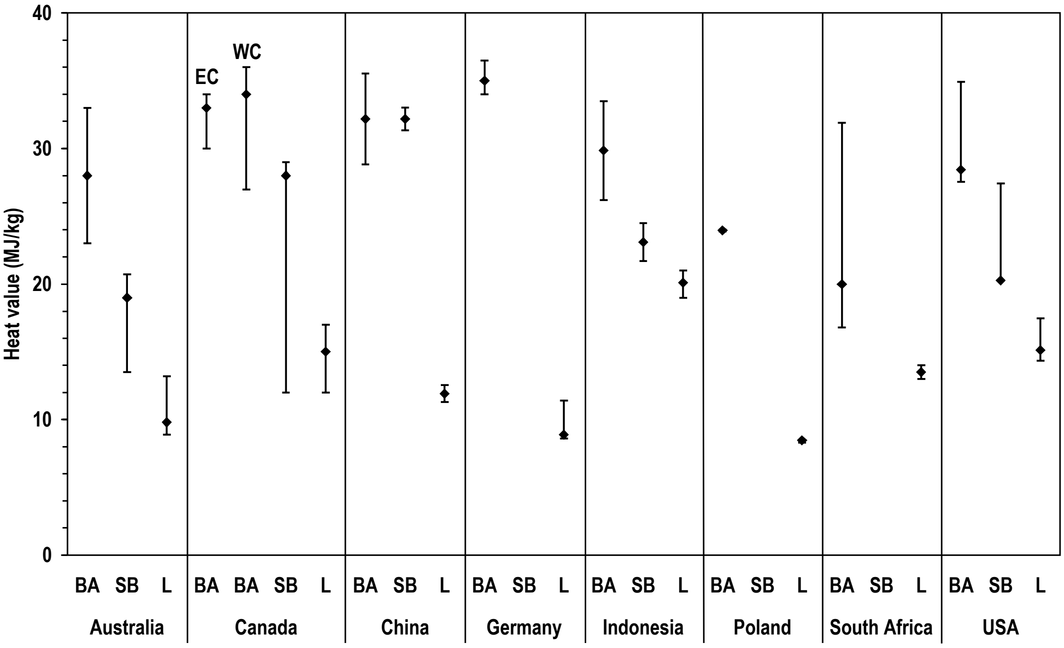


Figure 6: Heat value of bituminous including anthracite (BA), sub-bituminous (SB) and lignite (L) coal. WC: Western Canada, EC: Eastern Canada.

4.1.2.2 Coal supply and demand

China is both the world's largest producer and consumer of coal. Figures 7 and 8 show the world's ten largest coal (brown and hard coal) producers and consumers in 1999, respectively [IEA, 2001]. For comparison the corresponding values for 1990 and 1995 are also given. Chinese hard coal production is somewhat higher than that from the USA (Figure 7). In contrast, China's hard coal consumption is substantially larger than in any other country, amounting to nearly half of the world's consumption (Figure 8).

However, from a peak of nearly 1400 Mt in 1996, China's coal production declined to 1240 Mt in 1998 [SSB, 1999] and even 1044 Mt in 1999 [CCIY, 2000]. For 2000, government planned to limit production to 870 Mt [People's Daily, 2000a]. The goal of this reduction is to resolve the overproduction problem as well as to increase efficiency and competitiveness of large state-owned mines. According to the State Administration of Coal Industry, the number of legal coal production enterprises has been cut down from 300'000 to 80'000 nationwide, with a large number of illegal small coal mines closed down [People's Daily, 2000b].

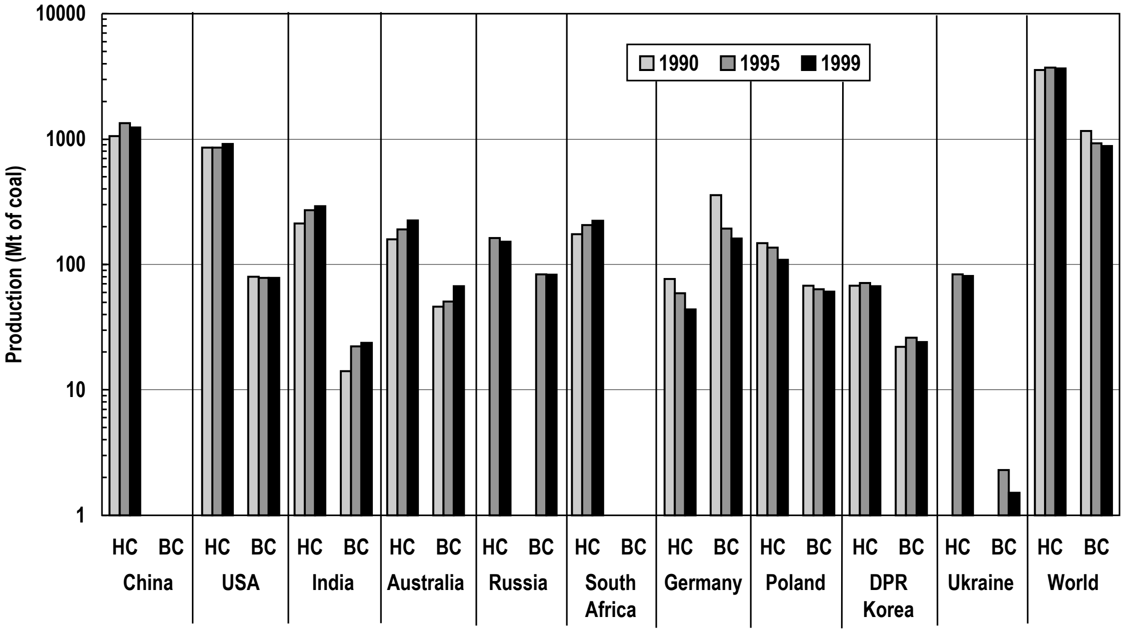


Figure 7: World’s ten largest coal producers of hard (HC) and brown coal (BC) in year 1999. Values for 1990 and 1995 are included for comparison. Data are from IEA [2001].

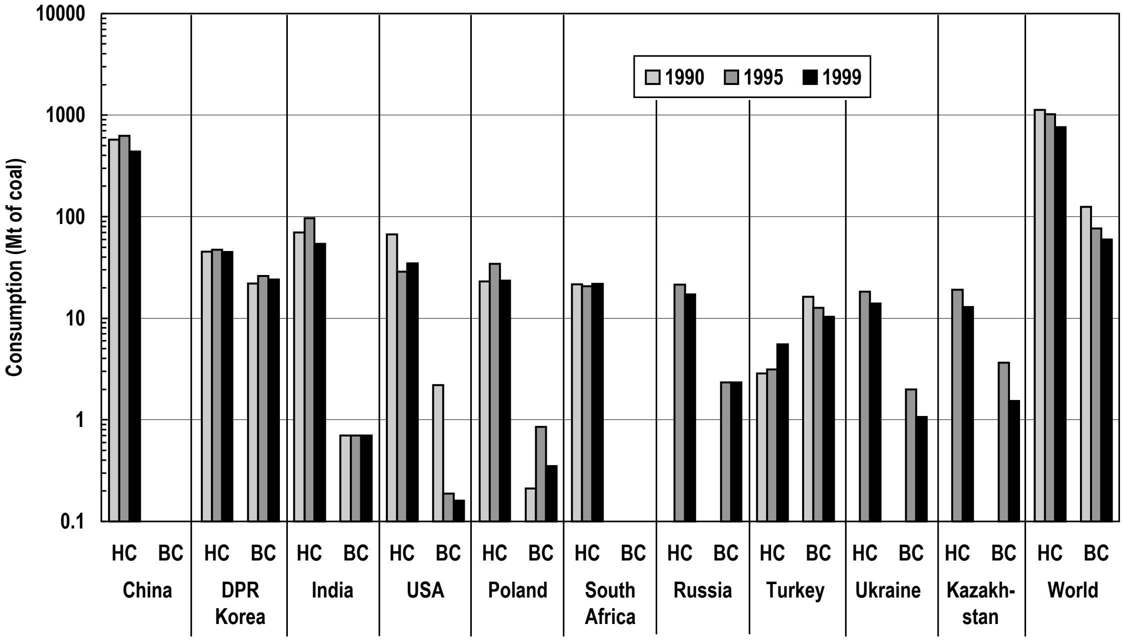


Figure 8: World’s ten largest coal consumers of hard (HC) and brown coal (BC) in year 1999. Values for 1990 and 1995 are included for comparison. Data are from IEA [2001].

Figure 9 shows the ten countries with the world’s largest reserves of coal (hard and brown coal) at the end of 1999. China, with proven reserves of 114’500 Mt, ranks on the third place after the USA and the Russian Federation. The majority of China's coal reserves are located in rather remote areas in the north, i.e., Shanxi and Heilongjiang provinces, and supplies for the south must be railed to the coast and then shipped. Based on reserves/production (R/P) ratios, China’s coal reserves are projected to last for 116 yr, much less than for the Russian Federation (>500 yr), Kazakhstan (455 yr) or Ukraine (423 yr) [BP Amoco, 2001].

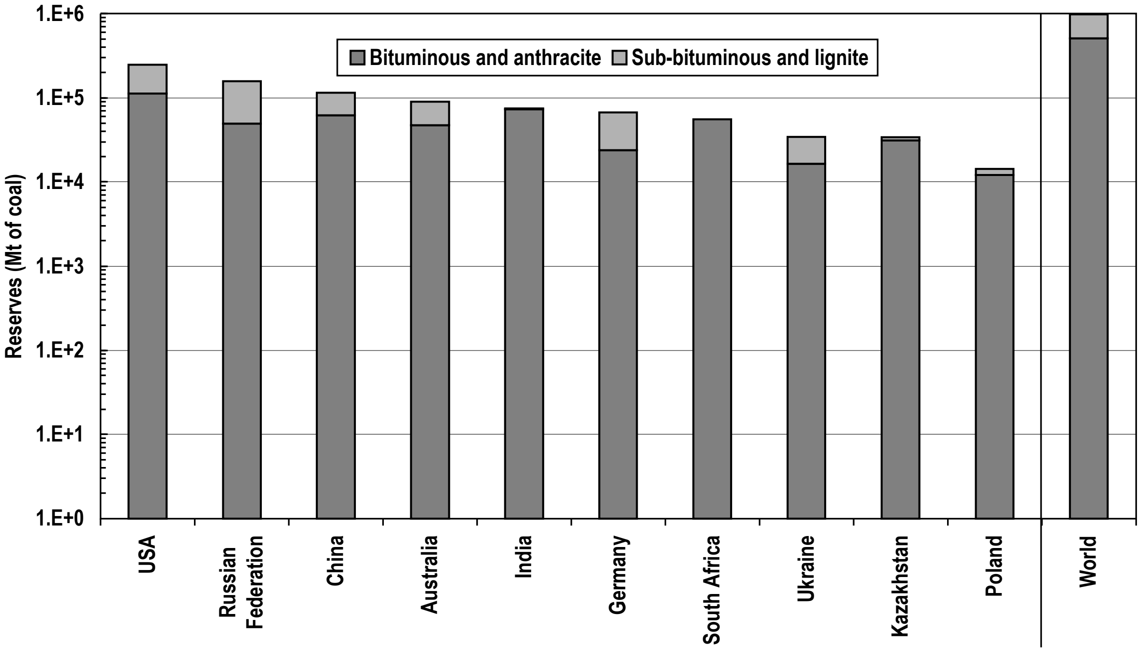


Figure 9: World's ten countries with largest proven coal reserves at the end of 1999 [BP Amoco, 2001].

Coal production by provinces for 1998 and 1999 shows that Shanxi contributes about 25% to total Chinese production whereas most other provinces have shares of less than 5% (Figure 10). Some large provinces in the South-west of China such as Qinghai and Xizang have negligible or no coal production. Considering absolute values, Shanxi, Guizhou, Sichuan and Shaanxi exhibited the highest reductions in production from 1998 to 1999. Generally, coal from northern provinces is of relatively good quality (high heat content and sulfur content below 1%) whereas coal from southern provinces contains more than 25% ash and sulfur content ranges between 2-5% [Stover, 1998]. Finally, large Chinese coal mines with an annual output of 10 Mt or more (based on 1998 values) are listed in Table 4.

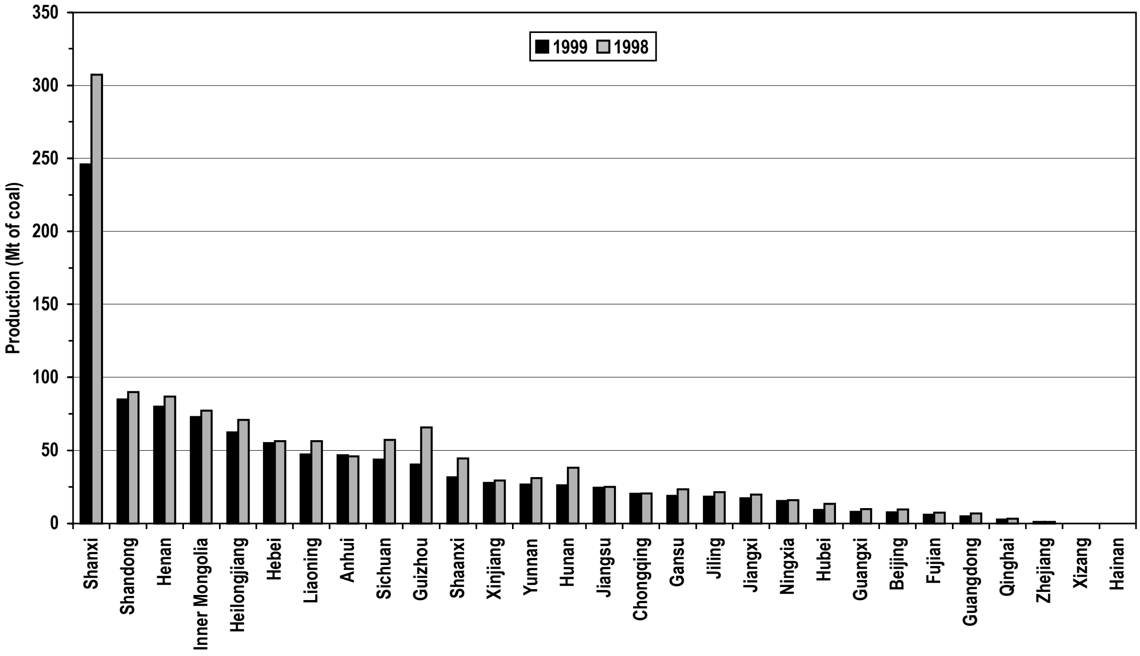


Figure 10: Coal production by provinces for 1998 and 1999 [CCIY, 1999; 2000].

Table 4: Top ten coal mining enterprises that had an annual production greater than 10 Mt in 1998 [Fridley et al., 2001].

Name of mine	Province	Production (Mt)		
		1980	1990	1998
Datong	Shanxi	24.5	29.9	28.7
Yanzhou	Shandong	2.3	9.7	21.8
Kailuan	Hebei	19.3	17.8	18.7
Pingdingshan	Henan	13.7	17.5	18.5
Xishan	Shanxi	9.3	15.2	16.1
Huaibei	Anhui	13.3	14.2	14.9
Tiefa	Liaoning	2.2	8.6	14.2
Huainan	Anhui	9.0	10.1	13.2
Xuzhou	Jiangsu	12.6	13.2	12.8
Hegang	Heilongjiang	12.7	15.7	12.5

China is also a net exporter of coal to neighbouring countries, mainly Japan, North and South Korea but also to Europe. Figure 11 gives the world's ten largest coal exporters with China taking the fifth place. Exports of countries such as Australia, USA, South Africa or Canada are rather constant whereas China and Indonesia show substantial increases. Unfortunately major coal production centres are located considerable distances from major urban areas (i.e., Shanghai, Guangzhou) on the rapidly developing coastline, placing a tremendous burden on the transportation infrastructure. Therefore, China is also forced to import coal to meet its demand in the industrial south.

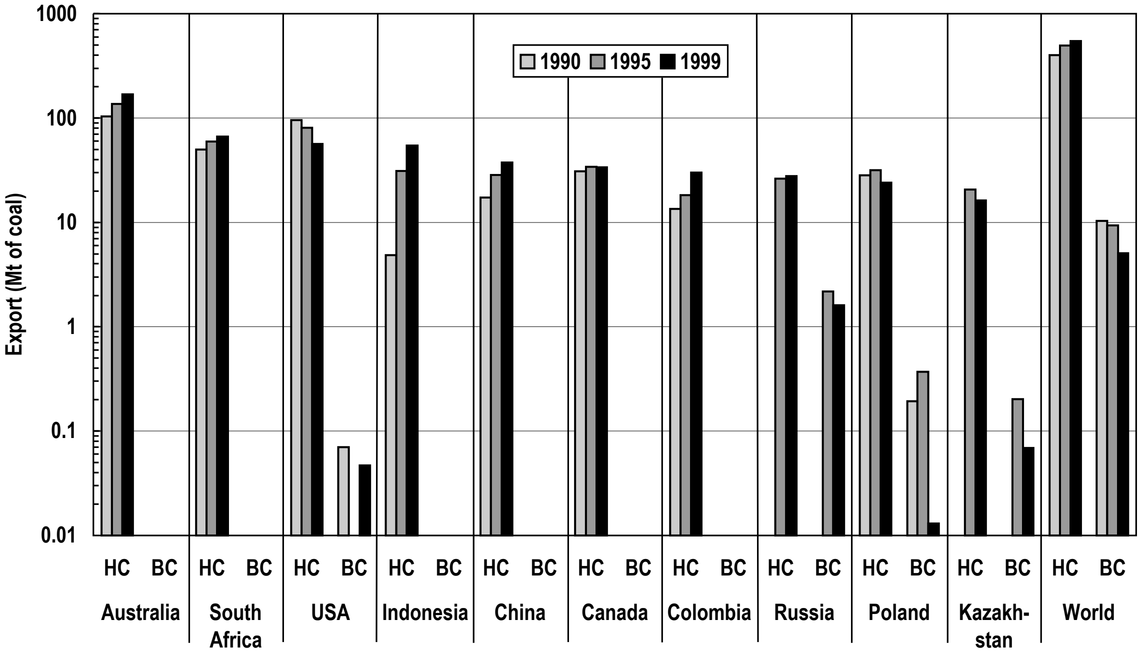


Figure 11: World's ten countries with largest coal exports [IEA, 2001].

China's final consumption of coal by sectors for the years 1990, 1995 and 1999 is summarized in Figure 12. The most coal consuming sectors were the iron, steel, chemical and non-metallic minerals industry as well as the residential sector (households). Whereas the demands in the formerly stated industry sectors are still increasing, consumption in the residential sector is decreasing since 1990.

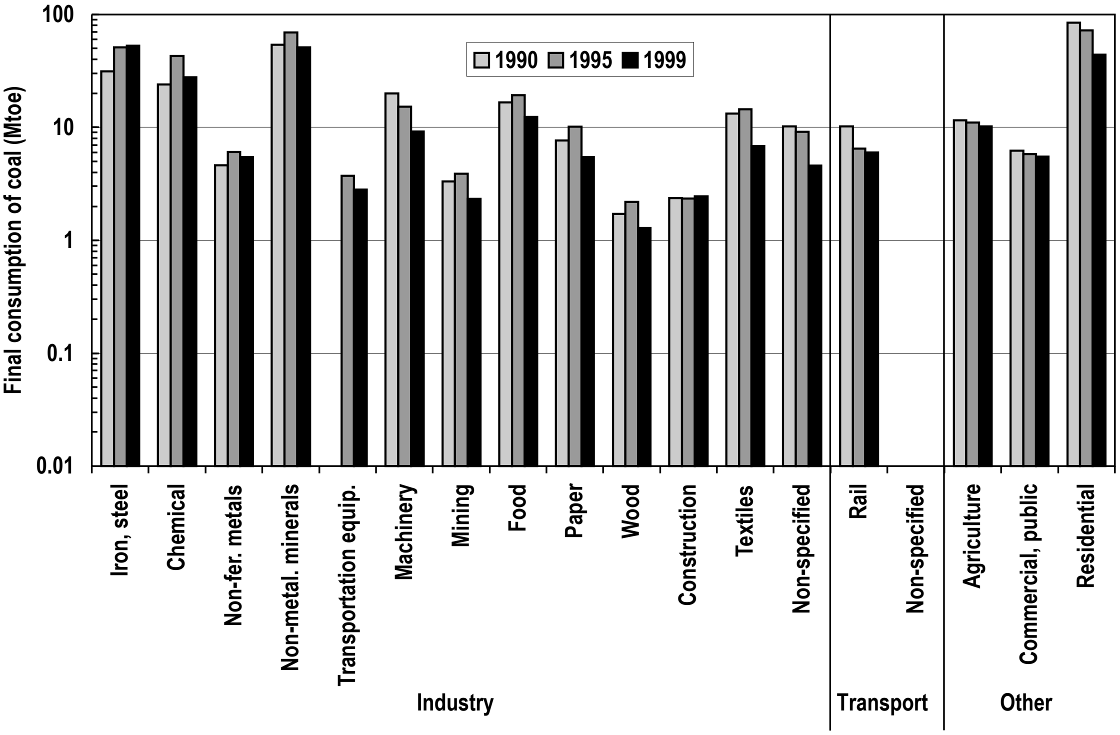


Figure 12: China's final coal consumption by sectors for years 1990, 1995 and 1999 [IEA, 2001].

4.1.2.3 Control, operation and number of employees in Chinese coal mines

Several categories of mines can be distinguished in China's coal industry:

- There are 94 key coal mines or "super pits" that fall under the control of the administration of the State Coal Industry Administration (SCIA), formerly the Ministry of Coal Industry [China Labour Bulletin, 2000]. Generally, they are supplied with advanced technology and equipment.

- An additional 2500 local state-owned mines also are controlled by SCIA or local governments at the provincial, county or prefecture level.

- Local collective/individual owned township and village coal mines are mostly of small size. Although several definitions of small mines exist, they generally have less than 50 workers, an annual production between 15'000-250'000 t, and low levels of mechanization [China Labour Bulletin, 2000]. Cited numbers range from 75'000 [China EE Info, 1998] up to 250'000 [China Labour Bulletin, 2000].

In this report large mine is a large or medium sized mine owned by central or local government; a small mine is a collectively or private owned village or town mine.

In November 1998, Vice Premier Wu Bangguo urged the closing of small coal mines that are operating illegally or represent redundant or inefficient capacity to reduce overall production by about 250 Mt and to help eliminate the production of low quality coal and pollution. According to official sources, about 25’000 small coal mines were shut down by the end of 1999. This corresponds to about half of the official estimate of 51’200 illegal coal mines nationwide [Stover, 1998]. As a result, total production decreased by approximately 200 Mt from 1998 to 1999 [CCIY, 1999; 2000], but it is still over 1000 Mt. However, many of the closed down mines reopen in the absence of constant government supervision because the areas in which they are located are often poor and people are willing to risk their lives for a job [Times of India, 2001a].

Large mines bear the financial burdens of relatively high wages and a large number of retired staff to care for. In contrast, small mines employ cheap migrant work force, lack even basic safety standards and thus have low overhead costs. Closing all small mines would destabilize local economics and create huge unemployment. Small mines in China provide labor for about 3 million people or roughly 75% of all employees in the coal sector (compare Figure 13). Figure 13 also depicts that considering the number of employees the coal industry with a total of about 4 million persons ranks on the second position after the machinery and equipment manufacturing industry. Finally, small mines generate substantial local purchasing power and lead to a demand for locally sourced inputs (food, equipment, tools, housing) when they are available, or encourage their production [China Labour Bulletin, 2000].

Although there is no foreign ownership, at present foreign investment is welcome. Amendments to China’s Mineral Resources Law of 1986 encourage additional foreign investment by providing a comprehensive legal framework for coal exploration and extraction. Currently, China is seeking foreign investment and technology for construction of pilot plants and the development of coalbed methane [WEC, 1998].

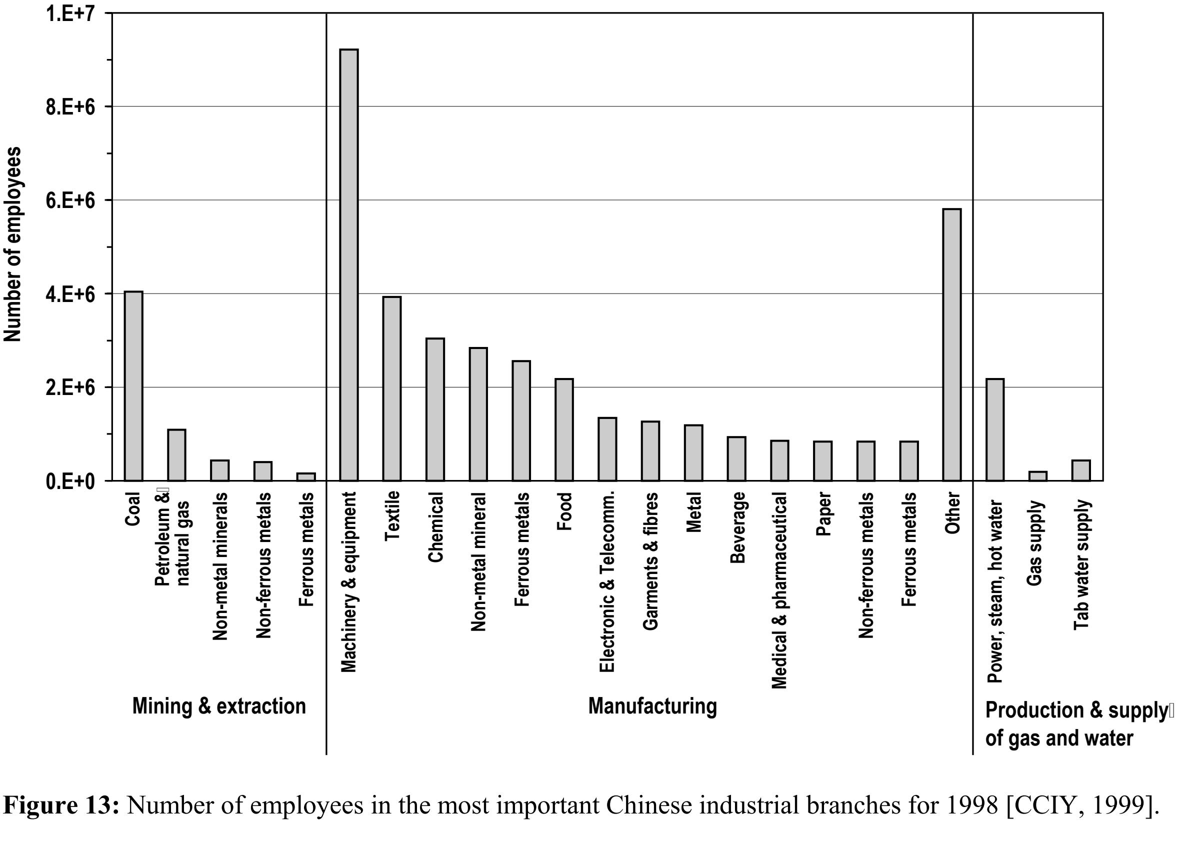


Figure 13: Number of employees in the most important Chinese industrial branches for 1998 [CCIY, 1999].

4.1.2.4 Major problems in coal industry

Large number of coal accidents and lack of funds for supervision

Accidents in Chinese coal mines resulted in 6400 fatalities in 1999 [CCIY, 2000], whereas other independent sources suggest that there might be up to 10’000 fatalities each year as some disasters are locally covered up [e.g., BBC News Online, 1998a; 2000a; Times of India, 2001b]. Furthermore, the government acknowledges that another 10’000 miners die of lung diseases every year in addition to those killed in accidents [BBC Online News, 1998a; 2000a]. The officially acknowledged number of fatalities in China’s coal mines is higher than the total number of people killed annually in mining accidents anywhere else in the world (compare Hirschberg et al., 1998). It also exceeds the average number of people killed by floods in China, which every year sweep across vast swathes of territory populated by millions of people [BBC News Online, 2000a].

In an official report the ministry acknowledged widespread violations of China’s 1992 Mining Safety Law, but said federal authorities were ill-equipped to enforce safety standards. The government has estimated that the industry should have as many as 500’000 safety inspectors, but at present it has only a few thousands experts responsible for inspecting more than 200’000 mines [BBC News Online, 2000a].

Lack of efficiency

Several factors restrict the development of large mines. The overstaffed management, the considerable amount of employees not directly involved in the mining work, and the burden of a large number of retired workers result in high production costs and reduced efficiency, thus decreasing overall competitiveness. Productivity in terms of coal produced per number of employees in China is 12 times lower than in South Africa and 25 times lower than in the USA (Figure 14).

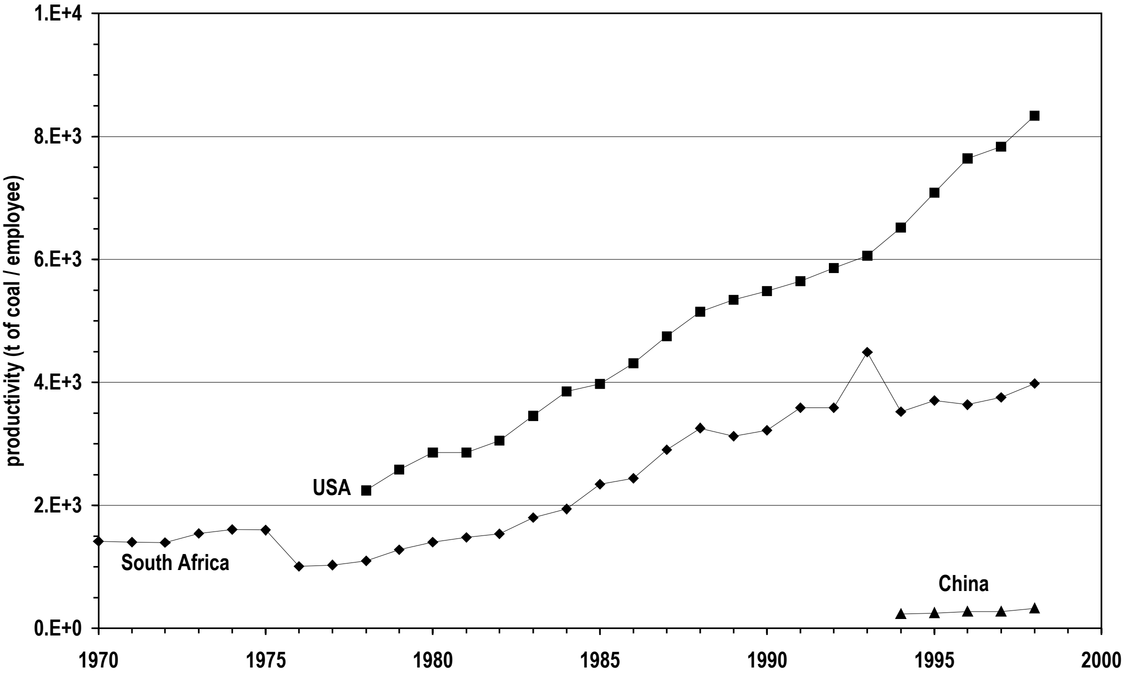


Figure 14: Productivity in coal mining for China, South Africa and USA (IEA, 2001; CCIY, 1997-2000; MSHA, 2002).

Structural problems of Chinese coal industry

Large state-owned mines are under the planning economic structure, whereas small mines utilize a market-based strategy. Therefore, large mines are very much dependent on other industry branches and overall planning and coordination. Transportation costs exert another constraint because most Chinese coal mine sites are situated in the north far away from urban areas whereas the industrialized and urban areas are primarily in the south and eastern provinces. This causes temporary shortages, but also additional expenses for long distance transport. For example, enormous amounts of energy are being wasted due to poor transportation decisions, which are a result of inadequate industry management and communication in the massive state-run coal industry [Stover, 1998]. Furthermore, the present infrastructure is unable to meet future demand and already operates at expensive levels [WEC, 1998]

China's coal industry has had an enormous oversupply problem, starting in the first half of the 90's due to an uncontrolled increase in coal output primarily by small mines [EIA, 2001]. In 1998, production of 1200 Mt of raw coal exceeded the demand by about 200 Mt [Stover, 1998]. Therefore, the government launched a large-scale effort to close down the small mines. More than 30'000 small coal mines have been closed since 1998, and the effort is continuing [EIA, 2001]. As a result of the closures, depressed local coal prices have partially started to recover, and combined with cost-cutting measures, some of the large-scale mines have returned to profitability in 2000 [EIA, 2001]. However, it remains unclear how many of the small mines, which have been closed officially, have re-opened. Overall, China's coal market remains flat with increasing defaults on payments and growing losses of numerous large coal enterprises due to low prices and because industrial customers cannot pay their debts.

4.1.2.5 Hazards of mining

Exploration and extraction stages

Coal mining is a hazardous operation. Records of the UK coal-mining industry show that since 1850 over 100'000 deaths occurred as a direct result of accidents [Clifton, 1992]. The majority of underground fatalities were historically attributable to four types of accidents [Encyclopædia Britannica, 1972]:

- Falls of roof or rock bursts
- Haulage activities (truck, loader, sweeper, conveyor, train forklift)
- Toxic or explosive gas, dust explosions and fires
- Operating or moving machinery

Surface coal mines, such as trip or opencast and auger operations, inherently represent a much lower degree of hazard to workmen than underground mining. Consequently, the death rates of surface mines are much lower.

In room-and-pillar mines deep underground, the extreme weight of the overlying rock can break the pillars down, either gradually or in a violent collapse. If the mine roof or floor consists of softer material such as clay, the massive weight of the overburden can slowly push the pillars into the floor or ceiling, endangering the stability of the mine. When the mine roof and floor consist of particularly hard rock, massive overhead weight can overload the pillars, sometimes causing a spontaneous collapse, or rock burst. Such rock bursts can be on a very large scale and accompanied by air-pressure waves of sufficient violence to disrupt the mine ventilation circuit. Once the mine ventilation fails inflammable and poisonous gases, frequently termed “damps”, cannot be adequately diluted causing serious accidents. However, the relatively small falls of rock, account for most deaths as they occur regularly and constitute a major hazard in many coal fields [Encyclopædia Britannica, 1972].

Since coal and natural gas are formed by similar natural processes, methane (a principal component of natural gas) is often trapped inside coal deposits. Gases trapped in deeper coalbeds are less likely to escape. Consequently, high-grade coals, which are typically buried deeper than low-grade coals, often contain more methane (firedamp) in the pores and fractures of the deposit. As coal miners saw or blast into a coal deposit, these methane pockets can be released, often leading to spontaneous explosions with deadly results [Pomroy & Carigiet, 1995]. Miners apply a technique called methane drainage to reduce dangerous releases of methane. Before mining machinery cuts into the wall face, holes are drilled into the coal and methane is drawn out and piped to the surface [Mitchell, 1990].

Coal miners also risk being exposed to other deadly gases, including carbon monoxide (CO), a poisonous by-product of partially burned coal. Carbon monoxide is deadly in quantities as small as 1%. It is especially prevalent in underground mines after a methane explosion. Other dangerous gases locked inside coal deposits include hydrogen sulfide (H_2S), a poisonous, colorless gas with an odor of rotten eggs, and carbon dioxide (CO_2), a colorless, odorless gas. To prevent injury from inhaling these gases, underground coal mines must be sufficiently ventilated. A good overview on topics ranging from accurate airflow to modern instrumentation is given in Tien [1999]. The total weight of air pumped through the mine often exceeds the total weight of coal removed.

As coal is blasted, shredded and hauled in a mine, large amounts of coal dust are produced. Coal dust is extremely flammable, and if ignited, it can be a more violent explosive than methane [Cybulska, 1981]. Miners can reduce the development of coal dust by injecting pressurized water into coalbeds before the coal is blasted or cut. Other methods to reduce coal dust include washing the dust from mining surfaces with water or covering it with dust from incombustible (non-flammable) rock.

Fire remains one of the most important hazards facing all stages of coal production. Most of the world’s major coal fields have experienced some fire accidents or incidents. Of special interest are seam fires where the coalbed itself is ignited. Fires in coal fields can be triggered by mechanical or instrument failures, human factors [Mitchell, 1990] or external events such as bush fires or lighting strikes. Furthermore, under appropriate conditions the natural oxidation of coal accelerates rapidly, leading to self-heating and spontaneous combustion [Walker, 1999]. Since coalbeds provide an almost inexhaustible fuel source, once a coal seam is ignited, it can be extremely difficult to extinguish. The intense heat generated by burning coal can rupture the overlying rock strata, sometimes causing the roof to collapse. The cost of controlling fires caused by spontaneous combustion can be very high, with incidents occasionally leading to the abandonment of a mine. Uncontrollable fires in some coal deposits have continued burning for years or centuries, posing a danger not only to coal miners but also to local communities. Prominent examples include the Centralia coal fire in Pennsylvania [DeKok, 1986] or the fire in the Baiyanghe coal field (region of Xinjiang) that had spontaneously ignited in 1560 [Muzi Lateline News, 1997].

China has suffered tremendously from earthquake damage throughout history. China has had six massive earthquakes which rank among the top fifteen most destructive quakes in the world (Table 5). Five of these earthquakes caused 100’000 or more fatalities. The quake of 23 January 1556 in Shansi, China, caused 830’000 fatalities. However it seems that seismic damage in underground mines can be far less severe than at the surface. For instance, the Tangshan earthquake of 1976 resulted in approximately 240’000 deaths and was responsible for 164’000 serious injuries and structural damage of immense proportion. The area has eight coal mines, which together form the largest underground coal mining operation in China. Approximately 10’000 miners were working underground at that time of the earthquake. With few exceptions, all survived and returned safely to the surface [Lee, 1989].

A particular risk in China concerns coal mining near reservoirs. Naihua [1995] describes several damages to arch dams caused by underground coal mining.

Table 5: Most destructive earthquakes that occurred worldwide causing 50’000 fatalities or more [USGS National Earthquake Information Center, 2000].

Date	Location	Deaths	Magnitude	Comments
January 23, 1556	**China**, Shansi	830’000	N.A.	N.A.
July 27, 1976	**China**, Tangshan	255'000 (official)	8.0	Estimated death toll as high as 655’000
August 9, 1138	Syria, Aleppo	230’000	N.A.	N.A.
May 22, 1927	**China**, near Xining	200’000	8.3	Large fractures
December 22, 856+	Iran, Damghan	200’000	N.A.	N.A.
December 16, 1920	**China**, Gansu	200’000	8.6	Major fractures, landslides
March 23, 893+	Iran, Ardabil	150’000	N.A.	N.A.
September 1, 1923	Japan, Kwanto	143’000	8.3	Great Tokyo fire.
October 5, 1948	USSR (Turkmenistan, Ashgabat)	110’000	7.3	N.A.
December 28, 1908	Italy, Messina	70’000 to 100’000 (estimated)	7.5	Deaths from earthquake and tsunami.
September, 1290	**China**, Chihli	100’000	N.A.	N.A.
November, 1667	November, 1667	80’000	N.A.	N.A.
November 18, 1727	Iran, Tabriz	77’000	N.A.	N.A.
November 1, 1755	Portugal, Lisbon	70’000	8.7	Great tsunami
December 25, 1932	**China**, Gansu	70’000	7.6	N.A.
May 31, 1970	Peru	66’000	7.8	530’000 USD damage, great rock slide, floods
1268	Asia Minor, Silicia	60’000	N.A.	N.A.
January 11, 1693	Italy, Sicily	60’000	N.A.	N.A.
May 30, 1935	Pakistan, Quetta	30'000 to 60’000	7.5	Quetta almost completely destroyed
February 4, 1783	Italy, Calabria	50’000	N.A.	N.A.
June 20, 1990	Iran	50’000	7.7	Landslides

N.A. = not available; + = prior to 1000 AD.

Transport and processing stage

Accidents in the transport stage within the coal chain are rare in comparison to other energy carriers such as oil, natural gas or LPG, where especially at the transport stage a large number of severe accidents occurred in the past [Hirschberg et al., 1998]. Severe accidents often occur when trains transporting coal collide with other vehicles transporting explosives or flammable substances.

The worst accident at the coal transport stage worldwide in terms of fatalities occurred in 1983 and involved a coal freighter carrying 27'000 t of coal; the freighter capsized and sank in storm-battered seas off the coast of Chincoteague, Virginia, USA, resulting in the death of 33 of the 36 crewmen. Transport of coal in cargos with insufficient ventilation exhibits another risk. Finally, coal dust can be ignited in storage plants with insufficient ventilation.

Accidents in the processing stage rarely result in multiple fatalities. The worst accident in the last twenty years occurred in 1985. An explosion occurred during a test run of a British gas prototype plant to convert coal to natural gas. Large lumps of shrapnel were thrown. The explosion was felt up to 5 miles away.

Heating or power station stage

One of the worst disasters in the heating or power station stage was the smog catastrophe in London in December 1952. On December 4, an anticyclone settled over London. The wind dropped, the air grew damp and a thick fog began to form. The Great London Smog lasted for five days and led to around 4000 deaths. The deaths were attributable to breathing difficulties due to the dramatic increase in air pollution during the period, with levels of sulfur dioxide increasing 7-fold, and levels of smoke increasing 3-fold. The peak in the number of deaths coincided with the peak in both smoke and sulfur dioxide pollution levels [Encyclopedia of the Atmospheric Environment, 2000].

Severe air pollution catastrophes of this type have not occurred in industrial countries since 1966 due to more strict emission and air pollution regulations. However, in developing countries air pollution disasters are still a big problem. For instance, in Tianjin China every winter hundreds of people die from carbon monoxide poisoning from indoor coal-burning heaters due to sharp rises in temperature which bring inside and outside temperatures to similar levels so that air flow is reduced through chimneys [Muzi Lateline News, 1998a].

Severe accidents at the power station stage with large number of fatalities are rare. However the monetary losses can be large [Hirschberg et al, 1998]. An investigation of past fatal and non-fatal accidents around the world showed that risks come from coal dust which could be ignited due to insufficient ventilation in storage vessels at the plant, overpressure in boilers, blocked water inflow to condensers of the power station and tornados.

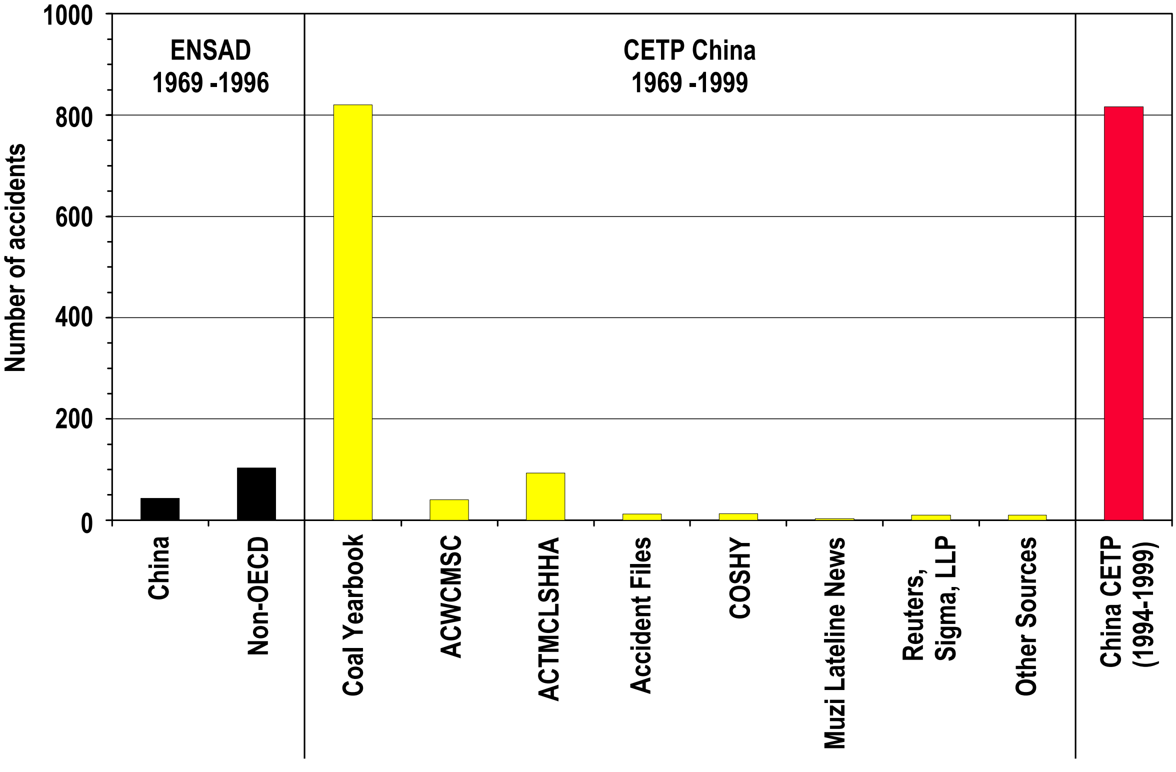
Waste storage and disposal stage

Coal refuse is a waste material generated in the mining and preparation of coal. But very often coal waste is piled into huge slag tips or is used to build tailing dams lacking very often the features of an engineered dam. Parts of these tips can slip down the mountains and destroy villages and miners accommodations or tailing dams can breach causing flood waves downstream the tailing dam.

4.1.3 Severe accidents in China's coal chain

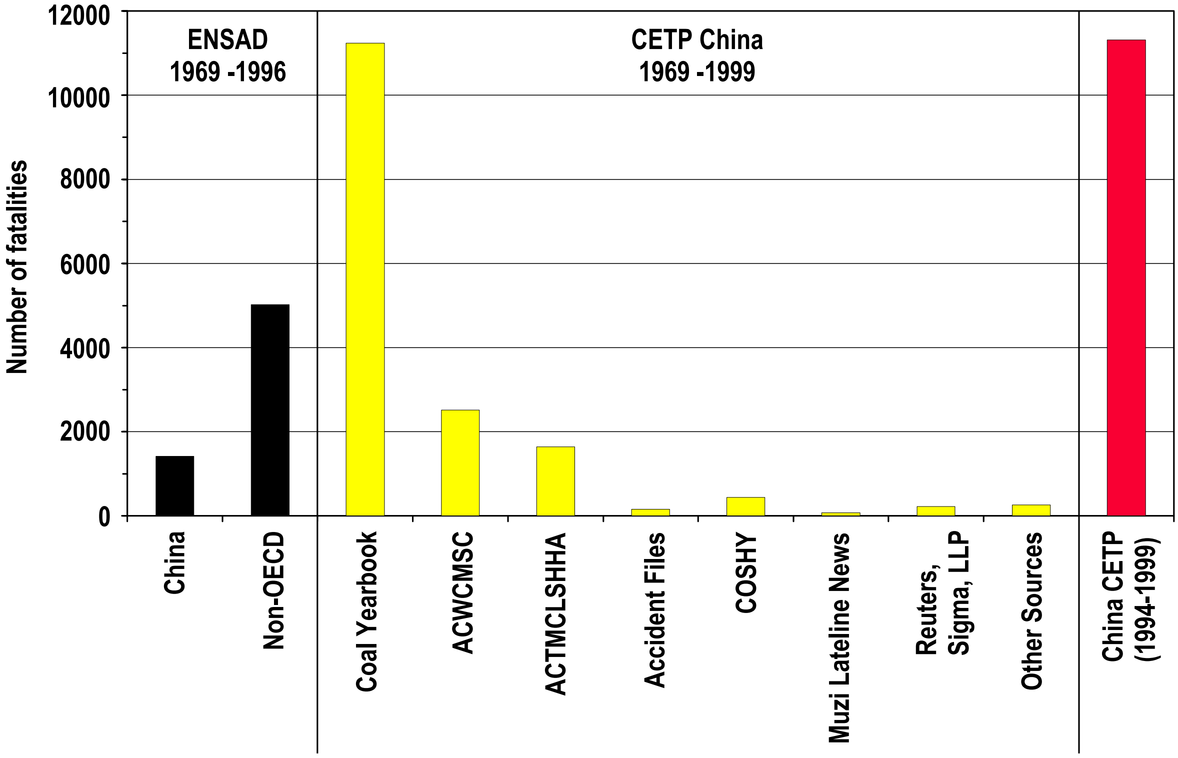
4.1.3.1 Severe accidents by information sources

For the period 1969-1999, a total of 1016 severe accidents with cumulated 17'241 fatalities in the Chinese coal chain were identified from a variety of information sources. Figures 15 and 16 show a comparison of severe accidents and fatalities originally contained in ENSAD, additionally collected for CETP, and those finally used within the CETP framework. Incompleteness of the ENSAD data for China was earlier recognized as a weak point. Both figures clearly demonstrate that ENSAD-data alone strongly underestimate the real situation in China, and that no accurate assessment is possible without data of the China Coal Industry Yearbook. Furthermore, data for China before 1994 were of rather poor quality with regard to completeness and consistency (compare also Figures 17 and 18). This shortcoming has been resolved thanks to the major improvements in documentation since 1994. Annual publication of the China Coal Industry Yearbook enables a complete and comprehensive picture of the number of severe accidents and fatalities. As a consequence, for specific analyses within the CETP framework (e.g., severe vs. smaller accidents, separation of accidents by criteria such as energy chain stages or causes), only data of the period 1994-1999 were considered, representing 816 severe accidents with cumulated 11'321 fatalities (see Appendix A).



ACWCMSC: A Complete Work of Coal Mine Safety in China; **ACTMLSHA**: Accident Cases of Typical and Major Casualties on Labour Safety and Health at Home and Abroad; **COSHY**: China Occupational Safety and Health Yearbook

Figure 15: Number of severe accidents that occurred in the Chinese coal chain according to various sources. Black bars represent severe accidents contained in ENSAD, whereas yellow bars represent those additionally collected from various other sources during CETP. The red bar gives the number of accidents used for statistical evaluations within the CETP framework.



ACWCMSC: A Complete Work of Coal Mine Safety in China; **ACTMLSHA**: Accident Cases of Typical and Major Casualties on Labour Safety and Health at Home and Abroad; **COSHY**: China Occupational Safety and Health Yearbook

Figure 16: Number of severe accident fatalities that occurred in the Chinese coal chain according to various sources. Black bars represent fatalities from severe accidents contained in ENSAD, whereas yellow bars represent those additionally collected from various other sources during CETP. The red bar gives the number fatalities used for statistical evaluations within the CETP framework.

4.1.3.2 Severe accidents by years

Figures 17 and 18 show the number of accidents and fatalities separated by mine type from 1969-1999 that occurred in China's coal chain. Both figures exhibit two distinct peaks for 1995 and 1997 for large and small mines, respectively. The large increase in number of accidents and fatalities after 1993 is most likely due to the improved reporting by the Chinese Ministry of Coal Industry.

The development of small mines took place in two steps. First, small mines started to develop with China's economic structure reform in the 1980s. Second, a much more dramatic increase was due to the government's release of the indicated coal price in the early 1990s. Furthermore, the data support the premise that very poor safety standards in small mines result in a higher accident and fatality rate.

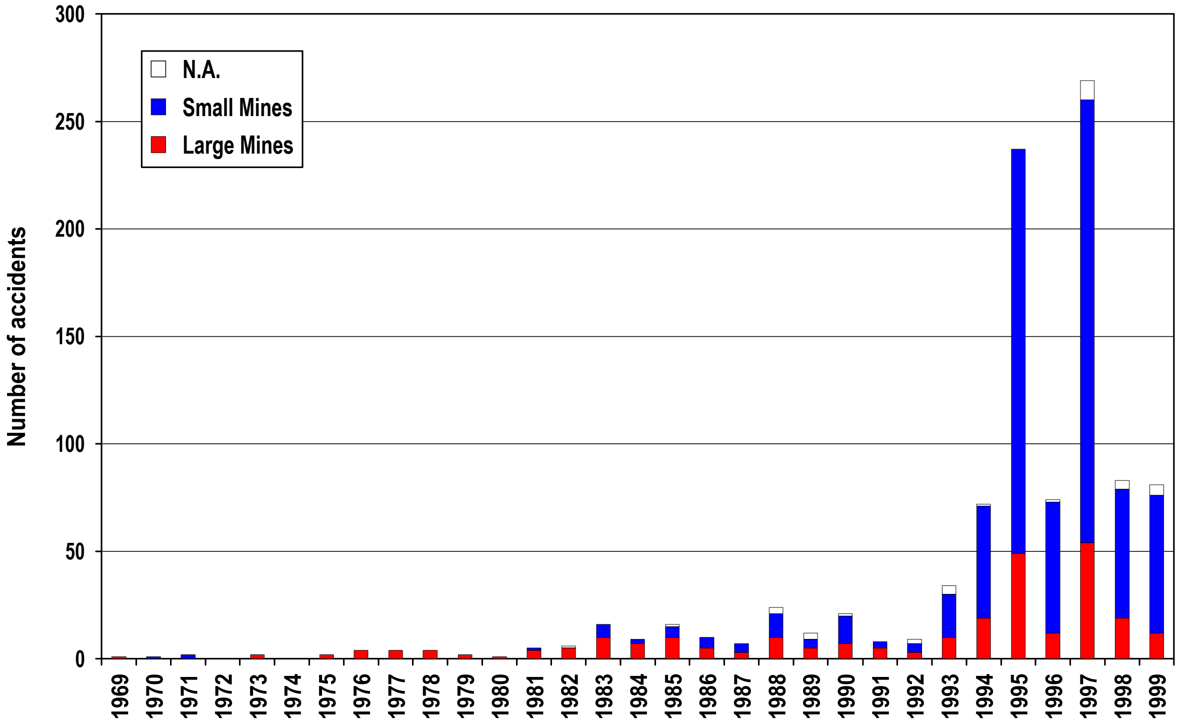


Figure 17: Number of severe accidents in China's coal chain by year and mine type.

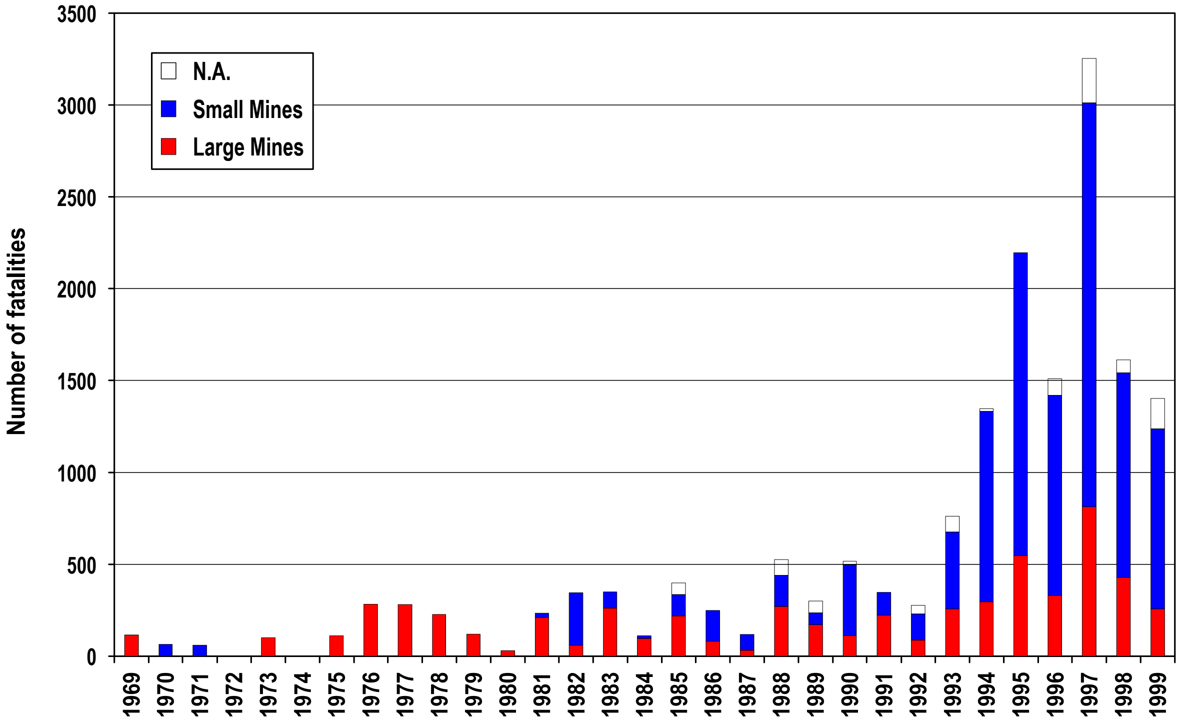


Figure 18: Number of severe accident fatalities in China's coal chain by year and mine type.

4.1.3.3 Severe vs. smaller accidents

On average, accidents in China's coal chain resulted in 6200 fatalities per year for the period 1994-1999, of which severe accidents comprised 30% (Figure 19). Compared to the USA this is a much higher share. Averages per decade for the USA are given in Table 6. Values range from a minimum of 1.8% (1990-1999) to a maximum of 10.6% (1980-1989).

A detailed analysis of smaller accidents was not performed. First, severe accidents are in focus of the present work. Second, severe accidents usually are better documented than accidents with minor consequences thus enabling a higher level of completeness. Third, for smaller accidents only cumulated data were available which does not allow detailed statistical evaluations and comparisons.

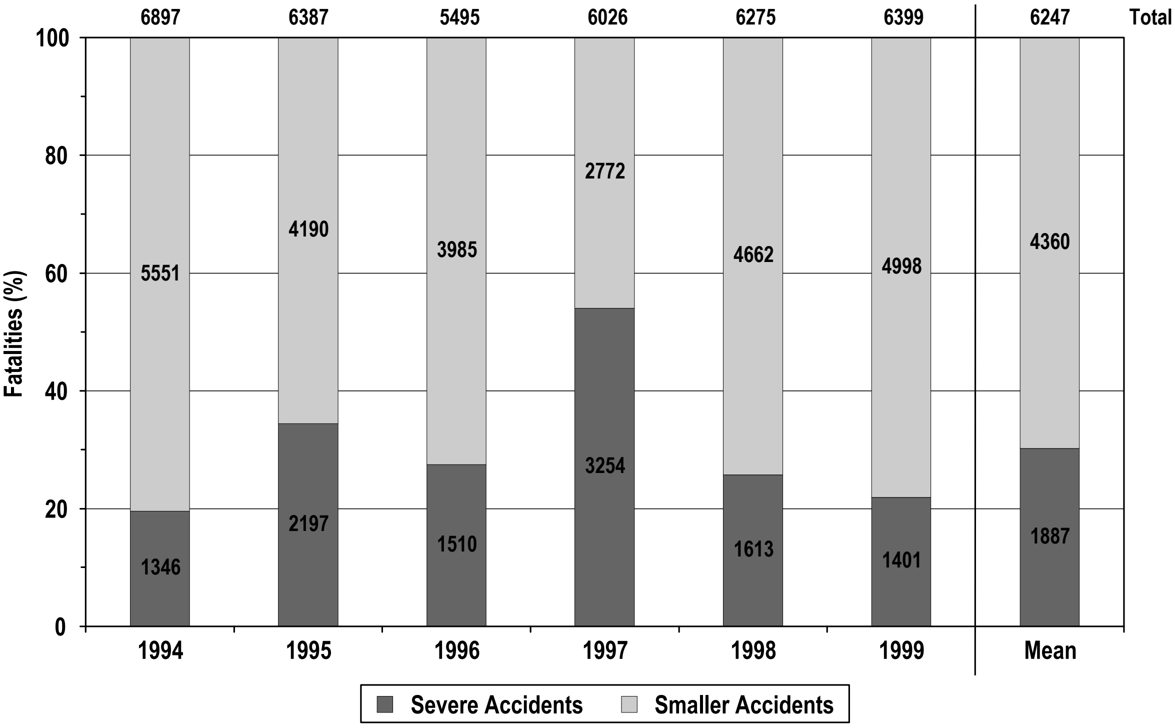


Figure 19: Shares and absolute number of fatalities in severe and smaller accidents that occurred in China's coal chain from 1994 to 1999. The mean value for this period is also given.

Table 6: Share of severe accident fatalities compared to all accidents in the US coal industry for the period 1950-1999.

Time period	Share of fatalities in severe accidents (%)
1950-1959	6.7
1960-1969	5.8
1970-1979	5.9
1980-1989	10.6
1990-1999	1.8

Figures 20 and 21 show the number of fatalities per Mt of produced coal for severe and smaller accidents according to mine type. Overall patterns for severe and smaller accidents were quite similar, although variations were somewhat different. On average, fatality rates for small mines were about five times higher than for large mines. Furthermore, accident fatality rates were about 2.5 times higher for smaller accidents compared to severe accidents.

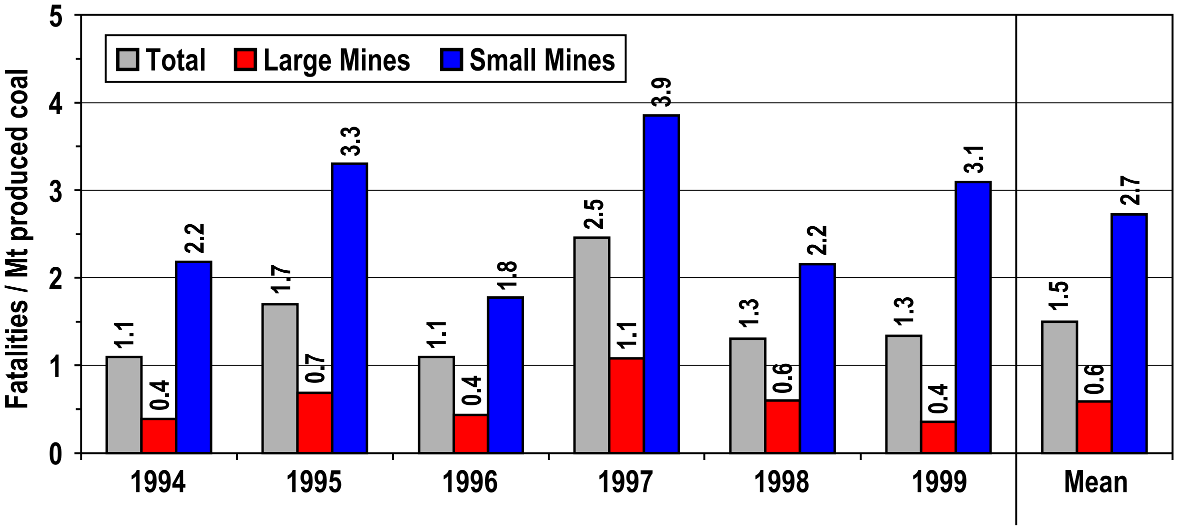


Figure 20: Fatalities per Mt of produced coal in severe accidents according to mine type for the years 1994-1999. The average value for this period is also given.

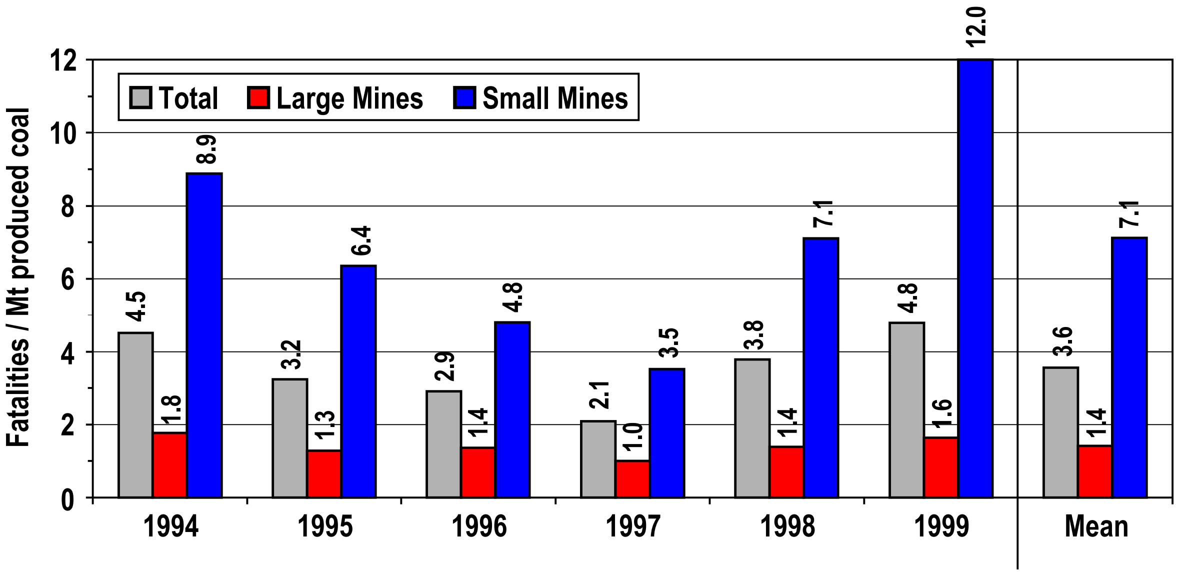


Figure 21: Fatalities per Mt of produced coal in smaller accidents alone according to mine type for the years 1994-1999. The average value for this period is also given.

Finally, fatalities per Mt produced coal in severe and smaller accidents by province were calculated (Figure 22). Values for individual provinces were only available for 1997-1999. Fatality rates were lowest in large mines of provinces such as Shanxi, Shandong, Henan, Inner Mongolia and Heilongjiang that are most important for China's coal production. Correspondingly, provinces with low coal productions (e.g., Zhejiang, Qinghai among others) had distinctly higher fatality rates. Differences in mechanization levels and safety standards may account for this finding, but lack of extensive data allows no validation of this hypothesis.

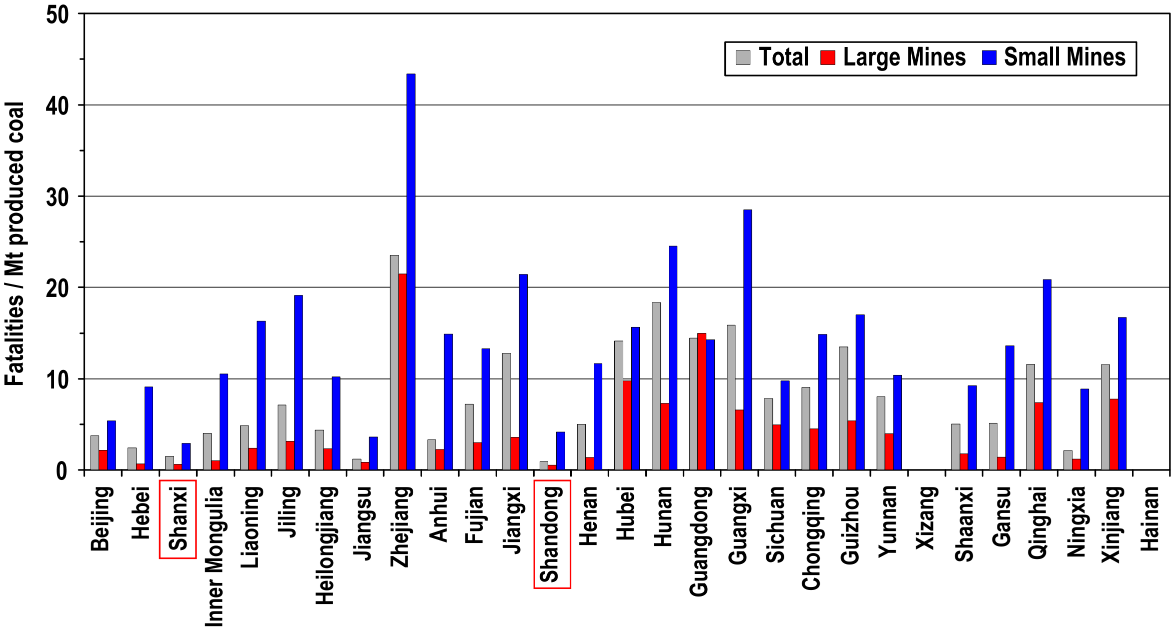


Figure 22: Fatalities per Mt produced coal in severe and smaller accidents according to mine type for individual provinces Values represent means for 1997-1999. Provinces marked by a frame are discussed in detail in Section 4.1.3.6.

4.1.3.4 Breakdown of severe accidents into coal chain stages

Figures 23 and 24 show the number of accidents and fatalities according to the different coal chain stages for the years 1994-1999. The majority of accidents and fatalities occurred in the extraction stage. Exploration ranked second with a substantially lower contribution, whereas the transport stage contributed only marginally. For the period considered, no severe accidents were reported at the power station, heating or waste storage and disposal stages. According to Hirschberg et al. [1998] severe accidents at these stages are rare worldwide. Table 7 lists the most severe accident for each coal chain stage that happened in China between 1969 and 1999.

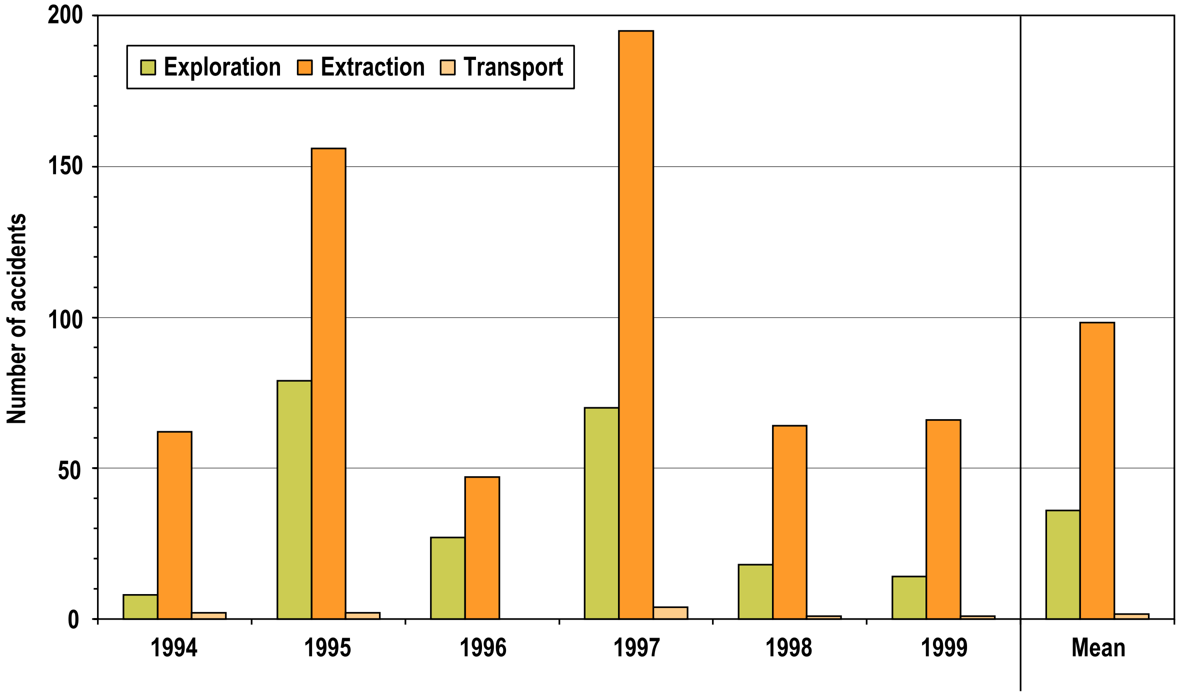


Figure 23: Number of accidents according to coal chain stages for the years 1994-1999. The average value for this period is also given.

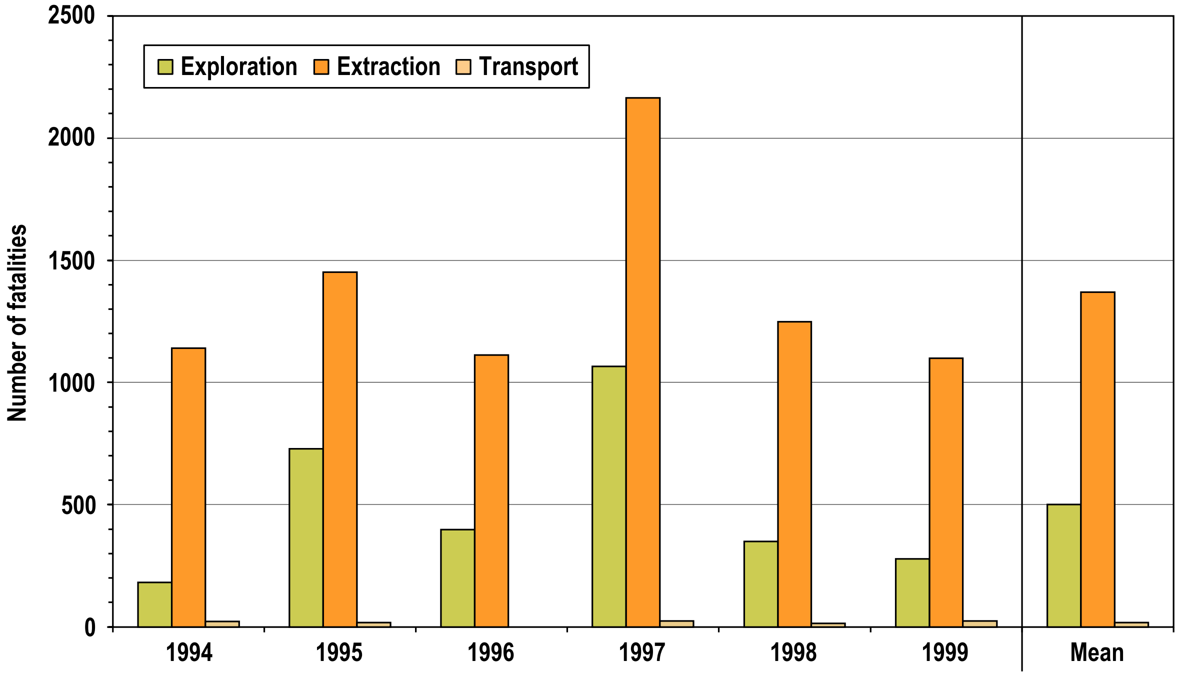


Figure 24: Number of fatalities according to coal chain stages for the years 1994-1999. The average value for this period is also given.

Table 7: The worst severe accidents in each coal chain stage during 1969-1999.

Date	Location	Province	Energy chain stage	Number of Fatalities
21.04.1991	Hongtong	Shanxi	Exploration	148
24.12.1981	Pingdingshan	Henan	Extraction	133
31.10.1989	Bohai Bay		Transport	30
10.03.1993	Beilungang	Zhejiang	Power Gen.	20

At the extraction stage, an accident with 284 fatalities occurred on 01.01.1982, but the location was not specified.

4.1.3.5 General causes of severe accidents

Figures 25 and 26 show the number of accidents and fatalities according to different causes for 1994-1999. Gas accidents dominated with respect to number of accidents (80%) and fatalities (83%), respectively. Water hazard accidents ranked second, followed by roof, fire and transport accidents. Electromechanical, blast and other accidents were negligible. A study conducted in state-owned mines between 1988 and 1993 yielded similar results [Wang & Xu, 1996]. On average, accidents due to gas explosions contributed 66% of all accidents, and the associated fatalities amounted to 77%.

In a second step it would be possible to assign sub-categories (i.e., specific causes) to each general cause. For example, fatalities in a gas accident could be due to gas asphyxiating (poisoning), gas (coal dust) explosion (ignition), or coal (rock) and gas outburst. Considering mine management and safety standards, such investigations may help to improve conditions in specific cases but also with regard to general prevention. Relatively simple measures such as training of workers, adequate supervision, maintenance of equipment and replacement of outdated equipment may have significant effects.

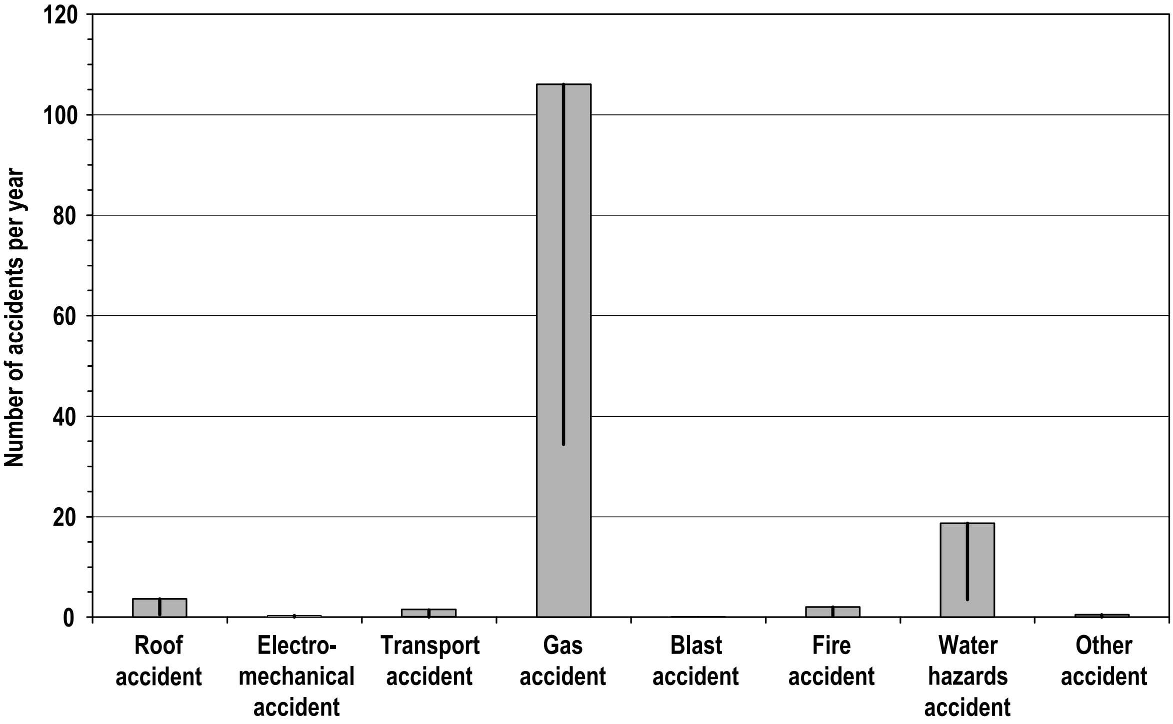


Figure 25: Average number of accidents per year according to different causes for the period 1994-1999. Dark lines within bars represent one standard deviation.

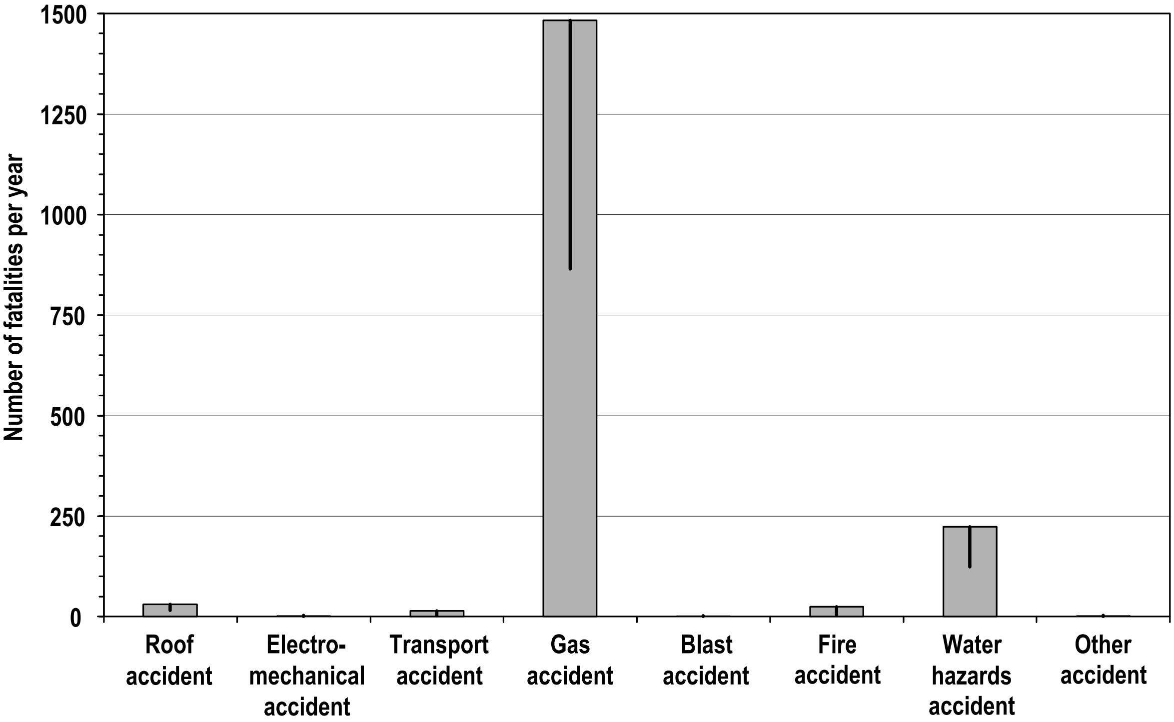


Figure 26: Average number of fatalities according to different causes for the period 1994-1999. Dark lines within bars represent one standard deviation.

4.1.3.6 Shandong vs. Shanxi provinces

Shanxi with 246 Mt and Shandong with 85 Mt in 1999 are the two provinces with the largest contributions to China's overall coal production. Although production in Shanxi is only about 3 times higher than in Shandong, the number of accidents and fatalities were almost 10 times higher in Shanxi in the period 1994-1999 (Figures 27 and 28).

Considering accident causes both provinces followed the general pattern described before, with gas accidents clearly dominating (Figure 29). However, gas accidents contributed about 3.5 times more fatalities per Mt and yr in Shanxi than Shandong. This is most likely attributable to differences in fugitive coalbed methane (CBM) emissions between the two provinces. Coal mines in Shanxi are rich in coalbed methane with 15 to 25 m^3 gas per ton coal extracted, whereas mines in Shandong contain only <1 to 3.6 m^3 gas per ton coal extracted.

China has abundant CBM resources that provide a valuable resource. Additionally, extraction of CBM provides a potentially important safety measure to prevent explosions in coal mines, which could reduce the large number of gas accidents and contribute to lowering the number of accidents and fatalities.

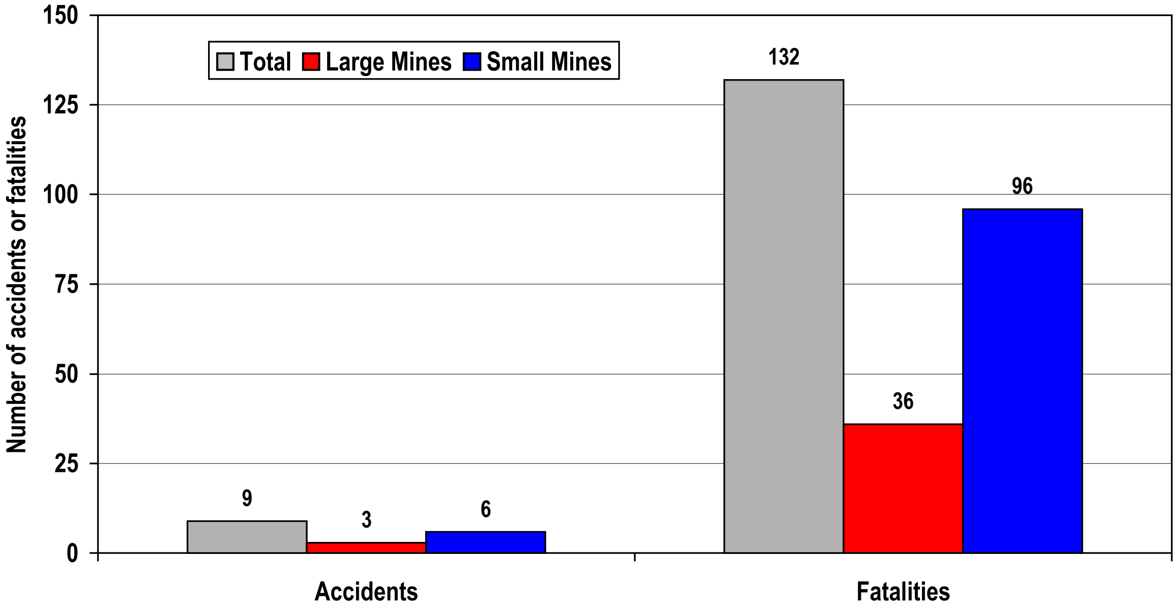


Figure 27: Number of severe accidents and fatalities according to mine type in Shandong province for the period 1994-1999.

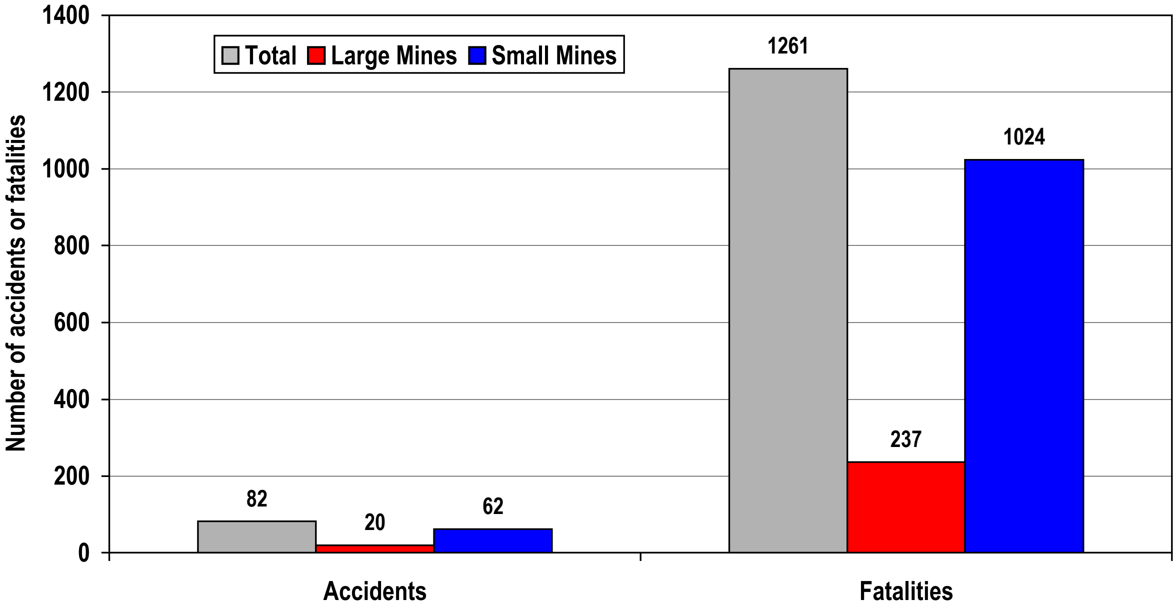


Figure 28: Number of severe accidents and fatalities according to according to mine type in Shanxi province for the period 1994-1999.

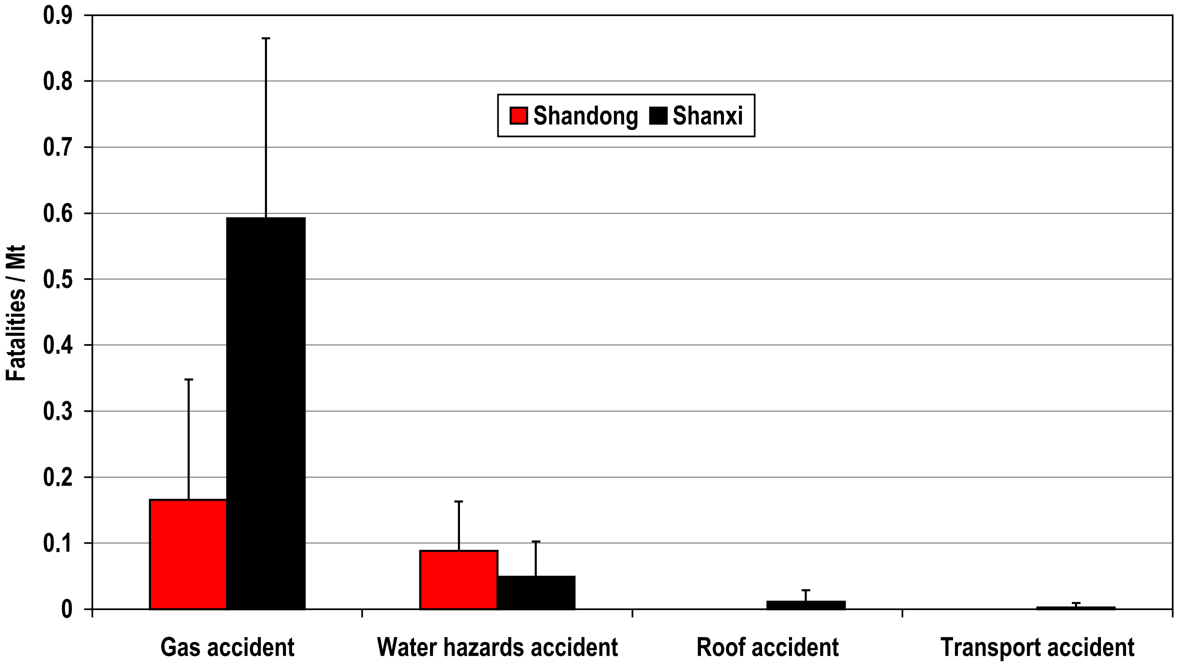


Figure 29: Average severe accident fatality rates per Mt according to different causes for Shandong and Shanxi for the period 1994-1999. Error bars indicate one standard deviation.

4.1.3.7 Comparison of severe accidents in coal mining and other industries

Health hazards need to be considered in virtually every industrial branch, from manufacturing, construction, and large-scale hydroelectric power plants, to oil, gas, and mining exploration. It is estimated that China suffers direct economic losses of several billions of yuans per year because of lost productivity, reduction in product quality, and increased retraining and medical expenses resulting from industrial injuries and illnesses. Toxic work environments are a serious concern. According to the central government, an estimated 33.8 million Chinese people work in factories that produce toxic substances. Exposed workers frequently encounter levels of toxicity that can have adverse human health effects. According to government statistics, in 1995, 18’160 workers died in industrial accidents in China's factories and mines; another 4’879 died from various diseases caused by poisonous fumes and dusts; and 148 perished from acute poisoning. The mining industry accounted for 60% of the work-related fatalities. Furthermore, more than every third severe accident occurred in the coal industry.

4.2 Oil chain

4.2.1 Background

4.2.1.1 General information

Crude oil is defined as a naturally occurring mixture consisting predominantly of hydrocarbons; it exists in liquid phase in natural underground reservoirs and is recoverable as liquid at typical atmospheric conditions of pressure and temperature. Crude oil has a viscosity no greater than 10'000 cP (centipoise) at original reservoir conditions. For the purpose of this survey, crude oil also includes natural gas liquids, namely hydrocarbons that exist in the reservoir as natural gas but which are recovered as liquids in separators, field facilities or gas processing plants. Natural gas liquids include (but are not limited to) ethane, propane, butanes, pentanes, natural gasoline and condensate; they may include small quantities of non-hydrocarbons. Hydrocarbons that exist in the reservoir as natural gas and are recovered in the gaseous phase (including amounts flared or re-injected) are covered in the chapter on natural gas.

4.2.1.2 Risks of different oil chain stages

Exploration and extraction

During exploration and extraction, health impairment is likely to be in the form of mechanical injury as a result of accidents. Workers are exposed to hazardous situations resulting from maintenance activities, equipment failure, oil rig set-up, rig dismantling activities and adverse weather conditions. In addition, high risk may be involved in geographical or seismographic exploration and testing which often require extensive aerial surveys and the use of explosives to determine geological formation profiles. In conjunction with drilling a direct threat to the health and safety of workers may arise from well blowouts, especially in the drilling of deep wells. In addition to direct injury, blowouts also cause direct cutaneous, aerosol, and vapor exposures to crude petroleum with its associated organics, poisonous gases (such as hydrogen sulfide) and drilling mud constituents. The combination of such an event with fire also leads to emissions of carbon monoxide, sulfur and nitrogen oxides, and organic matter [MITRE, 1981].

The worst accident worldwide in the extraction stage happened on the oil rig "Piper Alpha" near the Scottish coast in the North Sea. Explosion and fires on the platform resulted in 167 fatalities and an insured damage of 2913 million USD at 2000 prices [Sigma, 2001]. The worst exploration accident occurred in 1980 when the flotel Alexander Kielland overturned off the coast of Norway [Hirschberg et al., 1998] with the loss of 123 lives.

Long distance transport and regional distribution

The long distance transport and regional distribution stages are two distinct transportation stages, which involve different materials with different properties and potentials for incidents. The first stage involves the transportation of crude oil, whereas the second deals with the transport of refined oil products. Accidents of super-tankers on sea are among the largest incidents, which have affected mankind and the environment. Spillages of pipelines also have the potential to cause huge damage. On the one hand large quantities of oil can be discharged before detection of the leakage, and on the other hand the oil products stemming from the leakage can cause fires and hence result in fatalities [Clifton, 1992; Hirschberg et al., 1998]. According to CONCAWE[2] the causes of spillage by oil pipelines can be assigned to the following categories: third party activities, corrosion, mechanical failure, operation failure and natural hazard. Figure 30 gives the causes for pipeline spillages based on western European cross-country statistics for 1971-1995 [Lyons, 1998]. Despite some fluctuations over the period of observation, all causes except natural hazards decreased between 30-60% resulting in an overall reduction of pipeline spillages by almost 50%. Percent shares of mechanical failures increased by 9% between 1971-1975 and 1991-1995, and causes attributable to involvement of third parties decreased by 10%, whereas the other categories remained constant.

The worst severe accident in the transport to refinery stage occurred in 1987 when the Dona Paz ferry collided with the oil tanker Victor off the Coast of Mindoro (Philippines), causing, based on various sources, between 3000 and 4375 fatalities [Hirschberg et al, 1998; Sigma, 2001]. Considering the regional distribution stage, the collision of a Soviet fuel truck with another vehicle in the 2.7 km long Salang tunnel in the northern part of Afghanistan was the worst accident. Fire and noxious fumes following the explosion lead to the death of 2700 Soviet soldiers and Afghan civilians from burns and asphyxiation [Hirschberg et al., 1998].

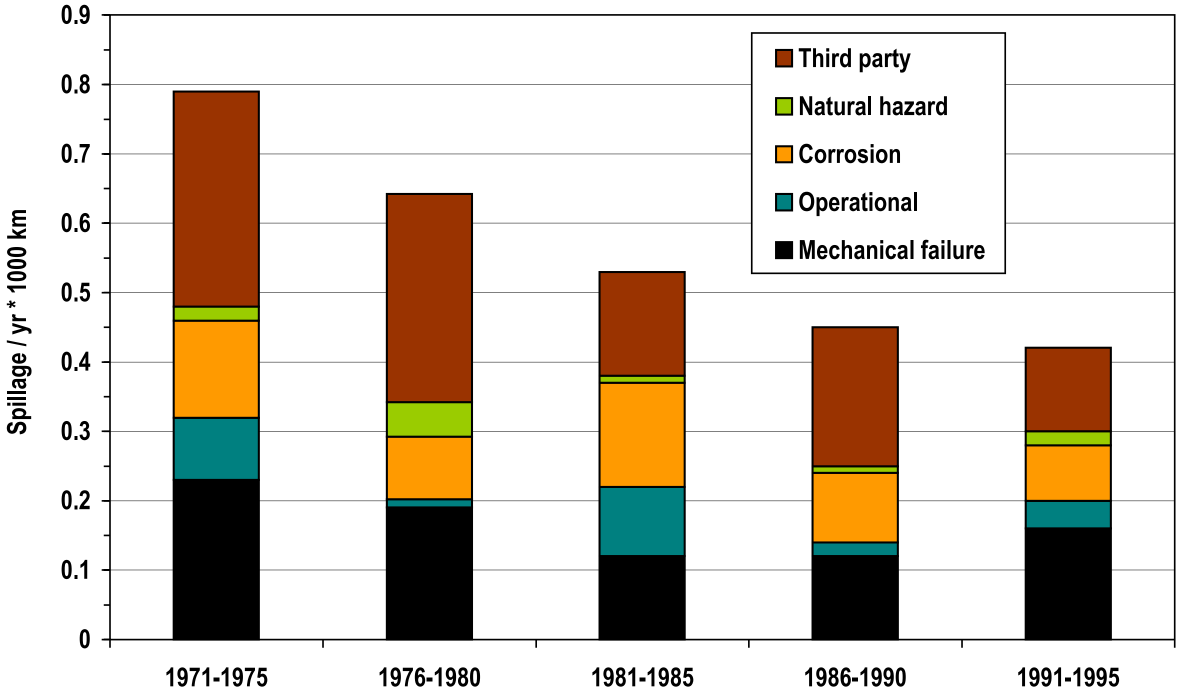


Figure 30: Pipeline spillage frequencies by cause [Lyons, 1998].

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[2] CONCAWE is the organisation for environment, health and safety of the European oil companies.

Refinery, power plant and heating stages

The number of fatalities in accidents at refineries is much lower compared to the previously described stages. The two worst disasters occurred in 1983 in Teleajen (Romania) and 1988 in Shanghai (China) with more than 30 and 25 fatalities, respectively [Hirschberg et al., 1998]. Based on the refinery accidents listed in ENSAD, in most cases an explosion was followed by fire.

At the power plant and heating stages only few accidents are known. For more details compare Hirschberg et al. [1998].

4.2.1.3 Oil spills

Causes of oil spills include carelessness, natural disasters such as earthquakes or weather extremes as well as intentional events (terrorists, war, vandalism and dumping). Every day about 119 billion liters of oil are being transported at sea [Cutter, 2001]. But not all spills come from tankers. Some originate from storage tanks, pipelines, oil wells, tankers and vessels cleaning out tanks.

At the moment oil is spilled into water it tends to float and spread out into a very thin film on the water surface (usually about 0.1 mm thick), and starts immediately to weather and degrade since oil is comprised of hydrocarbons. Weathering is a natural process that breaks down the oil through physical and chemical changes: spreading, evaporation, dispersion, emulsification, biodegradation, dissolution, oxidation, and sedimentation. During the first 24-48 hours after a spill, evaporation is the single most important weathering process. The rate of evaporation depends on the composition of the oil, the surface area of the slick, water temperature, wind speed, the state of the sea and solar radiation. Light components usually evaporate first in a spill. Spills of products such as kerosene and gasoline, which contain lighter components, may evaporate completely within a few hours. It is very rare for oil to sink. Generally, it needs to adhere to heavier particles such as sand, algae or silt to sink. An exception is heavy fuel oils used in electric utility plants. This oil can actually sink in water since it is heavier than water.

It is notable that only few very large spills were responsible for a high percentage of the total oil spilled in accidents in the period 1970-1999 [ITOPF, 2001]. Single large accidents such as the Atlantic Empress, Castillo de Bellver and ABT Summer strongly influence the figures for a particular year. Table 8 lists the top ten tanker oil spills in the period 1970-1999 [ITOPF, 2001; Cutter, 2001]. Interestingly, the largest oil spills did not occur on tankers. The biggest spill ever occurred during the 1991 Persian Gulf War when about 768'000 to 1'230'000 tonnes spilled from oil terminals and tankers off the coast of Kuwait [About Inc., 2001; Cutter, 2001]. The second biggest spill occurred over a ten-month period (June 1979 - February 1980) when about 450'000 tonnes spilled at the Ixtoc I well blowout in the Gulf of Mexico near Ciudad del Carmen, Mexico [Cutter, 2001].

Table 8: Top ten tanker oil spills between 1970-1999 from international oil spill statistics [ITOPF, 2001; Cutter, 2001].

Shipname	Year	Location	Distance from coast (km)	Oil spilled (t)
Atlantic Empress	1979	off Trinidad/Tobago off Barbados	32 450	287’000
ABT Summer	1991	off Angola	1287	260’000
Castillo de Bellver	1983	off Table Bay, South Africa	64	252’000
Amoco Cadiz	1978	off Brittany, France	0.5-1	223’000
Haven	1991	Genoa, Italy	in port	144’000
Odyssey	1988	NE of Saint John's, Newfoundland	1175	132’000
Torrey Canyon	1967	Scilly Isles, UK	N.A.	119’000
Urquiola	1976	La Coruna, Spain	in port	100’000
Hawaiian Patriot	1977	W of Kauai Island, Hawaii	593	95’000
Independenta	1979	Bosphorus strait near Istanbul, Turkey	0.8 (from Hydarpasa port)	95’000

N.A. = not available

The ecological impacts of spilled crude and oil products strongly depend on specific conditions. In general, organisms may be affected directly through physical and toxicological processes or indirectly through impacts on habitat conditions, effects on food chains, alterations in community structure or impacts at specific life cycle stages of individual species. The magnitude of the impact is primarily depending on distance to the coast, weather and current conditions, whereas the amount and type of oil spilled may often be of secondary importance. For example, the Exxon Valdez accident (Prince William Sound, Alaska, USA) in 1989 was relatively small with 37’000 t oil lost, but it occurred close to the coastline and wind current moved the oil slick to the beaches leading to an ecological disaster. Shorelines are especially sensitive areas because they comprise important boundaries between aquatic and terrestrial ecosystems. Independently of the accident size, the involvement of endangered species can also result in more severe ecological consequences. For example in 1998, the collision of two tankers in waters off Guangdong province (China) with 2000 t of spilled oil could have a major impact on the ecology of the whole estuary, which is a rich fishing ground as well as one of the last strongholds of the Chinese white dolphin, listed as an endangered species [BBC News Online, 1998b]. In addition to ecological concerns, shoreline spills can have a strong economic impact on resorts and recreational areas, harbors, commercial fishing grounds, tourist attractions and water supplies for drinking and industry.

The most common techniques used after an oil spill has occurred are containment and recovery using sorbents, dispersants, burning bioremediation and shoreline cleanup. Since cleanup after an oil spill is difficult and does not always fully rehabilitate affected areas and their biota, prevention is most important.

4.2.2 China's oil industry

4.2.2.1 Historical development and current status

The first significant oil discovery was the Lachunmia field in the north-central province of Gansu, which was discovered in 1939. In the 1950's an extensive exploration program was launched to achieve self-sufficiency in oil. This resulted in the discovery of two major field complexes, one in Daqing (1959) in the north-eastern province of Heilongjiang and another one in Shengli (1961) near the Bo Hai gulf. The successful development of the Daqing oil field in the 1960s made China self-sufficient in oil. Crude oil output had increased to 6.48 Mt in 1963 compared to 120'000 t in 1949. Since the 1970s, China has explored and developed the Shengli, Dagang, Liaohe, Jianghan, Huabei, Changqing, Jilin, Zhongyuan, Henan, Jiangsu, and Jidong oil fields. China's oil production has increased steadily since then, reaching about 157 Mt in 1996 [IEA, 2001], but slowed down afterwards as indicated by the production of 162 Mt for 2000 [BP Amoco 2001]. In contrast, offshore oil production showed a strong increase in the 1990s from 1 to 10% of total oil production [Fridley et al., 2001] accounting for up to 80% of China's yearly increase in crude oil production [ViTrade, 2001]. In the beginning of 2000 China has found its largest offshore oil field with estimated reserves of 600 Mt in the Bohai Sea [BBC News Online, 2000b]. The field, called Penglai 19-3, is believed to be China's second largest oil field of any kind, after the Daqing onshore oil field. At present, 20 large and extra-large onshore oil operations, several offshore operations in the Bohai Sea and the east and west of the South China Sea have been established [WEC, 1998; Muzi Lateline News, 2000].

By the end of 1994 18'000 km of oil pipelines were laid through the whole country and formed a network in the Northeast, North and East China. The carrying quantity of oil pipelines directly from oil wells at 1994 was equivalent to two thirds of the total crude oil transported in the whole country. The total length of China's oil and gas pipelines will increase from 20'000 to about 35'000-40'000 km between 2000 and 2020.

Oil production in China has lagged behind consumption since 1993. This continuous rise in demand, particularly for tranport fuel, has lead to an increase in imports of both crude oil and petroleum products. By 1998, China's external dependency for oil had risen to 26% [SSB, 1999]. To reduce reliance on imports, China has started to acquire interests in producing concessions overseas, for example in Sudan, Venezuela, Iraq and Kazakhstan.

Before recent economic reforms in 1998, the China National Petroleum Corporation (CNPC) was responsible for all onshore upstream operations (production and exploration), whereas the China Petrochemical Corporation (SINOPEC) primarily dealt with the downstream refining and distribution sector. As a result of the reorganization two vertically integrated regional entities emerged, with CNPC in the north and west and SINOPEC in the south. However, CNPC still has a disproportionate share of oil production capacity compared to SINOPEC. The reverse holds true for refining capacities. In 1997 a third state oil company, China National Star Petroleum Corporation (NSPC), was created in January 1997 to develop onshore and offshore reserves and to compete with CNPC and SINOPEC. In addition, the National Offshore Oil Corporation (CNOOC), established in 1982, explores China's offshore petroleum resources.

Although these companies are state-owned, they must compete with each other to obtain exploration licenses. Furthermore, they are allowed to enter into joint ventures with foreign oil companies. For example, CNPC has completed several deals in Canada, Kazakhstan, Venezuela and Sudan. The Initial Public Offering in 2000 of Petrochina, a subsidiary of CNPC, with a double listing at the stock markets in New York and China was the first test of overseas investor appetite for Chinese state-owned corporate giants [Alexander's Gas and Oil Connections, 2000a]. Such listings are key to China's plans to overhaul state industry and breed powerful multinationals capable of withstanding the competitive challenge posed by its entry to the World Trade Organisation.

For more detailed information compare Alexander's Gas and Oil Connections [2000a], EIA [1997], Inform Special Report [1998], ViTrade Global Financial Risk Analysis [2001] and WEC [1998].

4.2.2.2 Oil supply and demand

Figure 31 shows the world's ten largest oil producers in 1999 and for comparison the production in 1990 and 1995 [IEA, 2001]. China ranks on the 7th place if the production in 1999 is considered. Production in China increased between 1990 and 1999, although the changes were relatively small compared to other countries such as Saudiarabia or Venezuela.

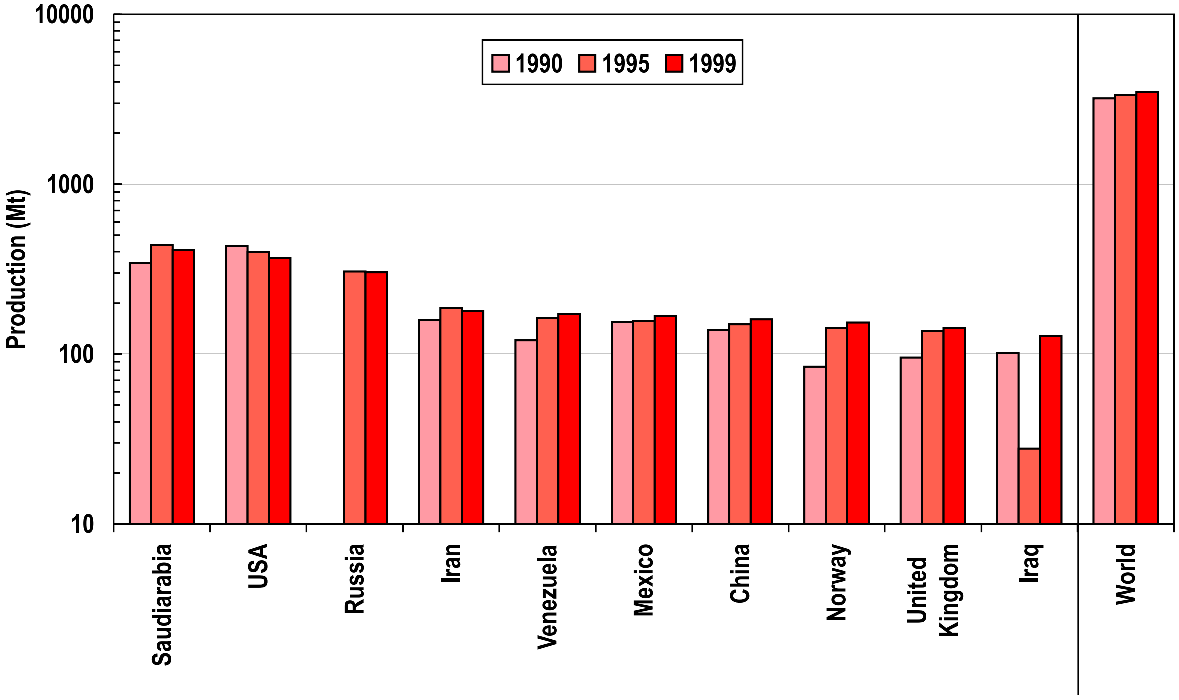

Figure 31: World's ten largest oil producers (based on year 1999). Values for 1990 and 1995 are given for comparison. Data are from IEA [2001].

Figure 32 shows the world's ten largest oil consumers in 1999 and for comparison the respective values for 1990 and 1995. Based on 1999, China ranks on the third position. From 1995 to 1999, Chinese consumption increased by 30%, whereas it was almost constant in the USA and Japan.

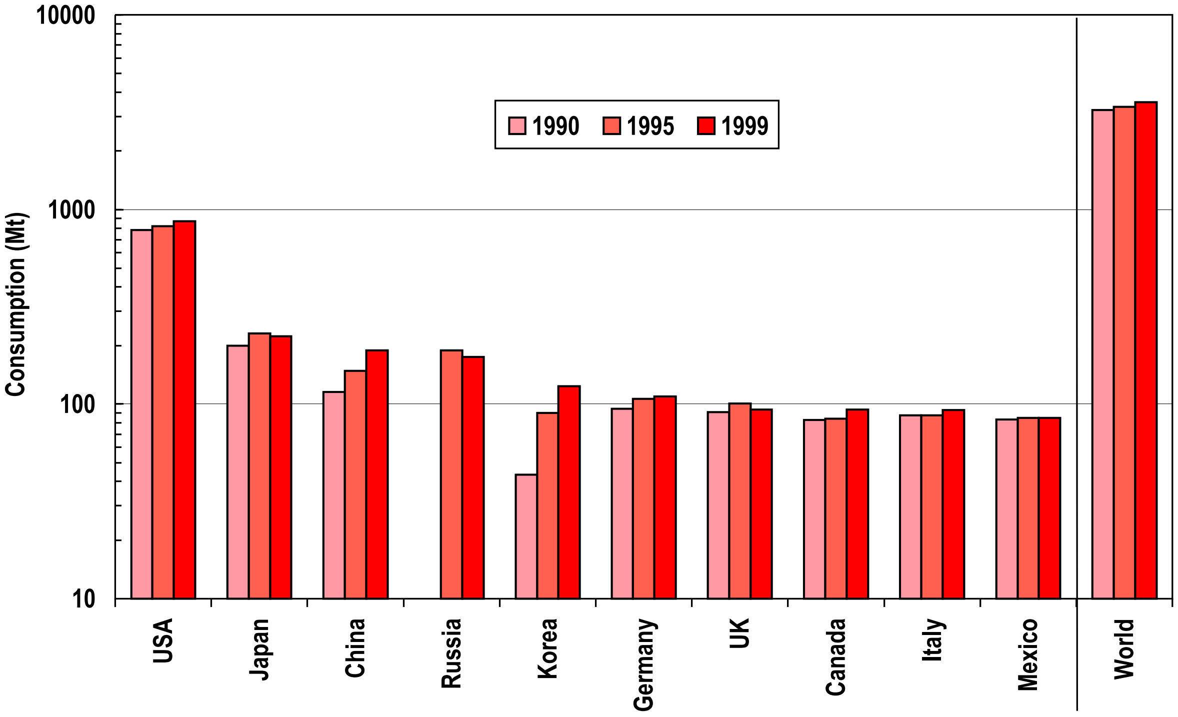

Figure 32: World's ten largest oil consumers (based on year 1999). Values for 1990 and 1995 are included for comparison. Data are from IEA [2001].

Oil reserves can be measured by various benchmarks[3]:

- Proved (recoverable) reserves: those quantities that geological and engineering information indicates can be recovered in the future from known reservoirs under existing economic and operating conditions.

- Reserves/Production(R/P) ratio: this is a measure for the length of time that remaining reserves would last if production were to continue at the same level.

Data presented in Figures 33 to 35 are taken from BP Amoco [2001]. The regional distribution of proved reserves is given in Figure 33. Although China has about 50% of Asia Pacific's oil reserves, they are rather small compared to those located in the Middle East. Similarly, Figure 34 shows individual countries with the largest oil reserves. China takes the 11th position with a quantity more than ten times smaller than that for Saudi Arabia. Finally, Figure 35 depicts R/P ratios for areas covered in Figure 33. Reserves in the Middle East would last for the longest period of time with a R/P of 91 years. China with a value of 20years has a relatively high ratio compared to other areas.

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[3] Definitions according to BP Amoco [2001] and WEC [1998].

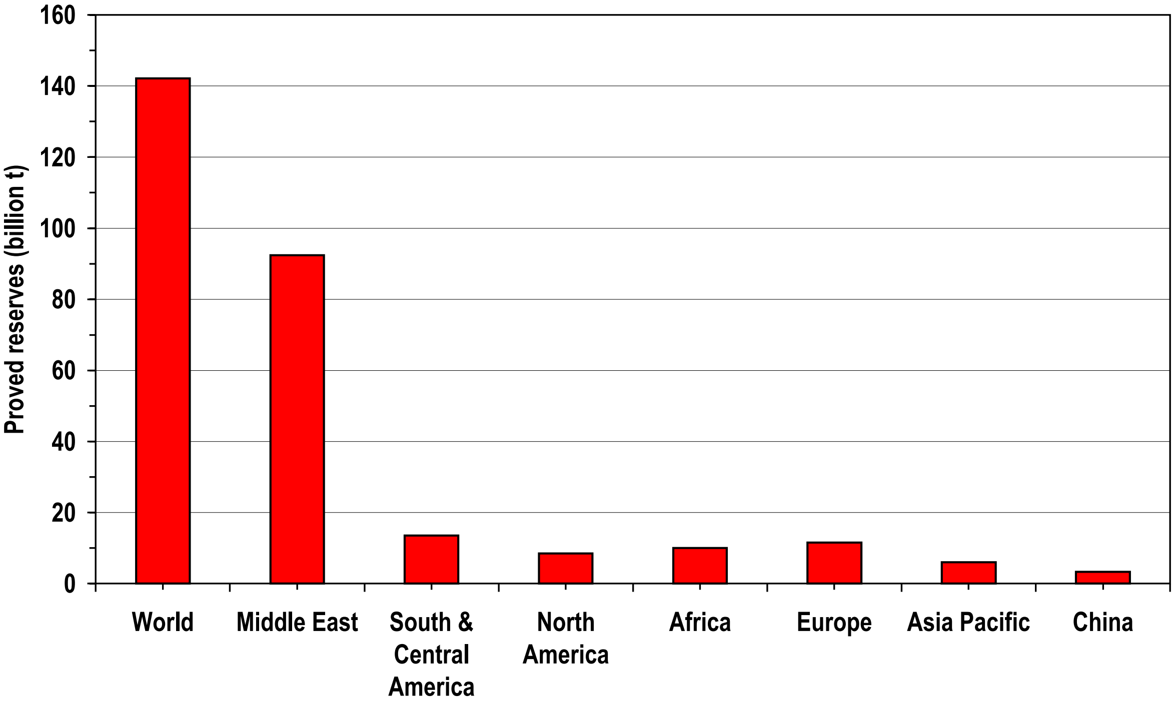

Figure 33: Regional distribution of proved recoverable oil reserves at the end of 2000 [BP Amoco, 2001].

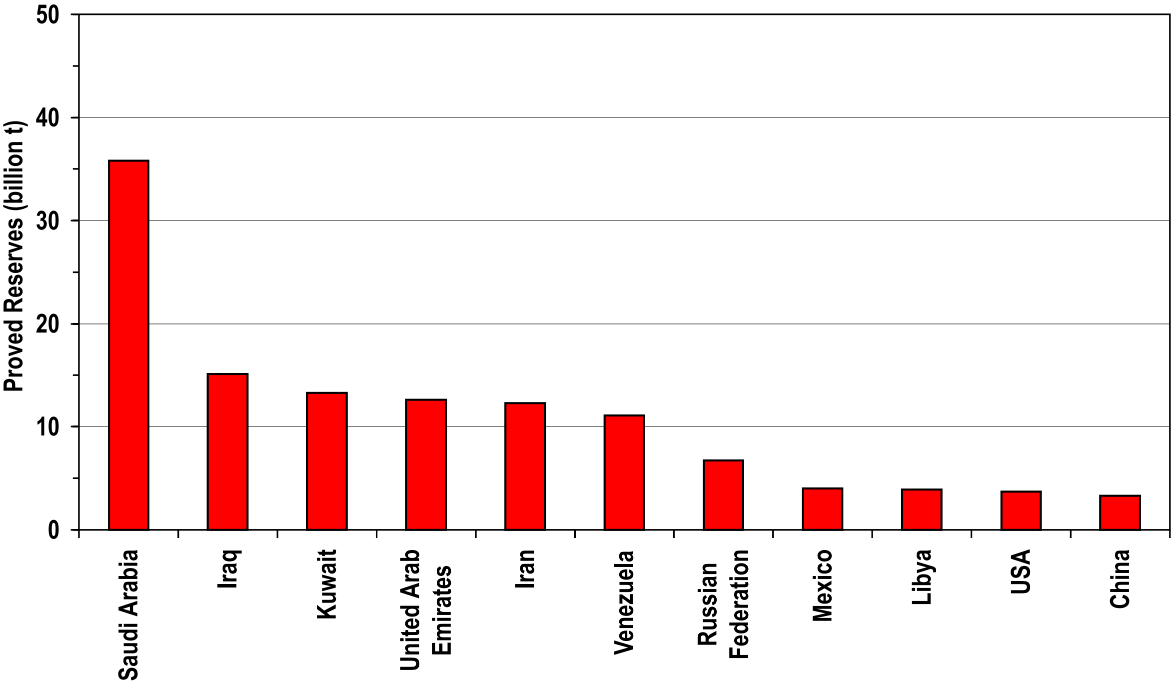

Figure 34: Countries with the largest proved recoverable reserves at the end of 2000 [BP Amoco, 2001].

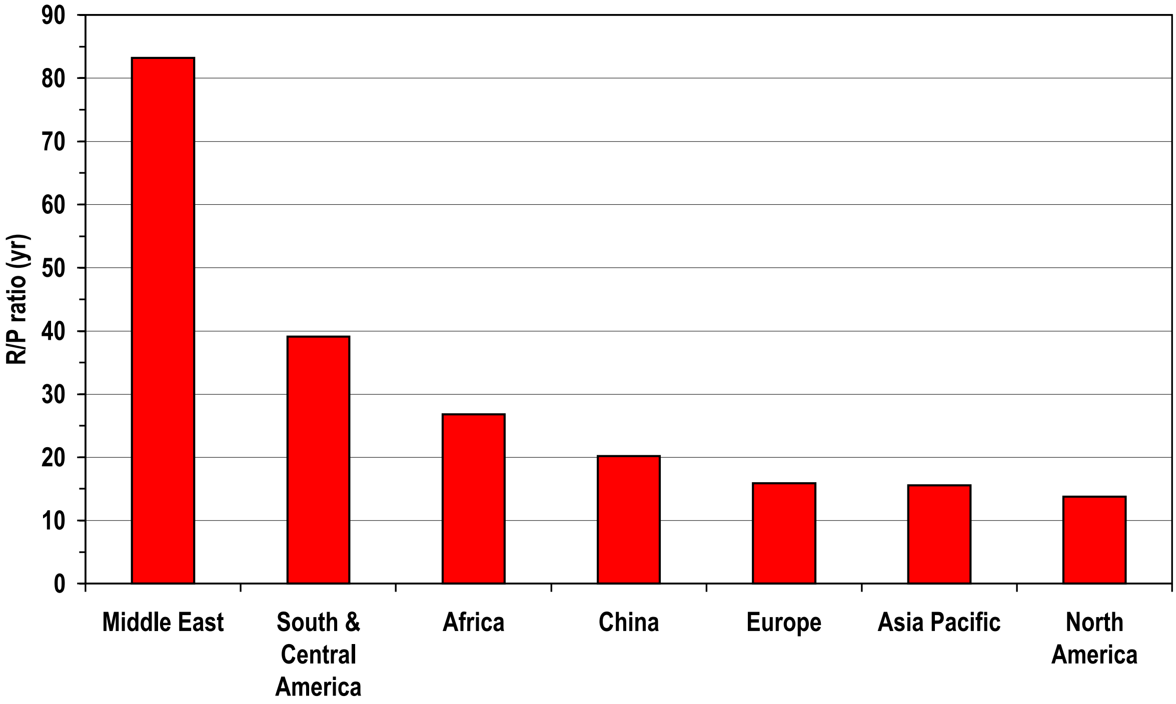

Figure 35: Reserves/Production (R/P) ratio at the end of 2000 for China and other areas [BP Amoco, 2001].

Figure 36 reports the final oil consumption in China by sector for the years 1985, 1990 and 1995 from IEA [1997] because the latest publication [IEA, 2001] provides only very fragmentary information on the sectorial oil consumption in China. The sectors consuming most oil by 1995 were the chemical industry, non-specific transport, agriculture and non-metallic minerals producing industry.

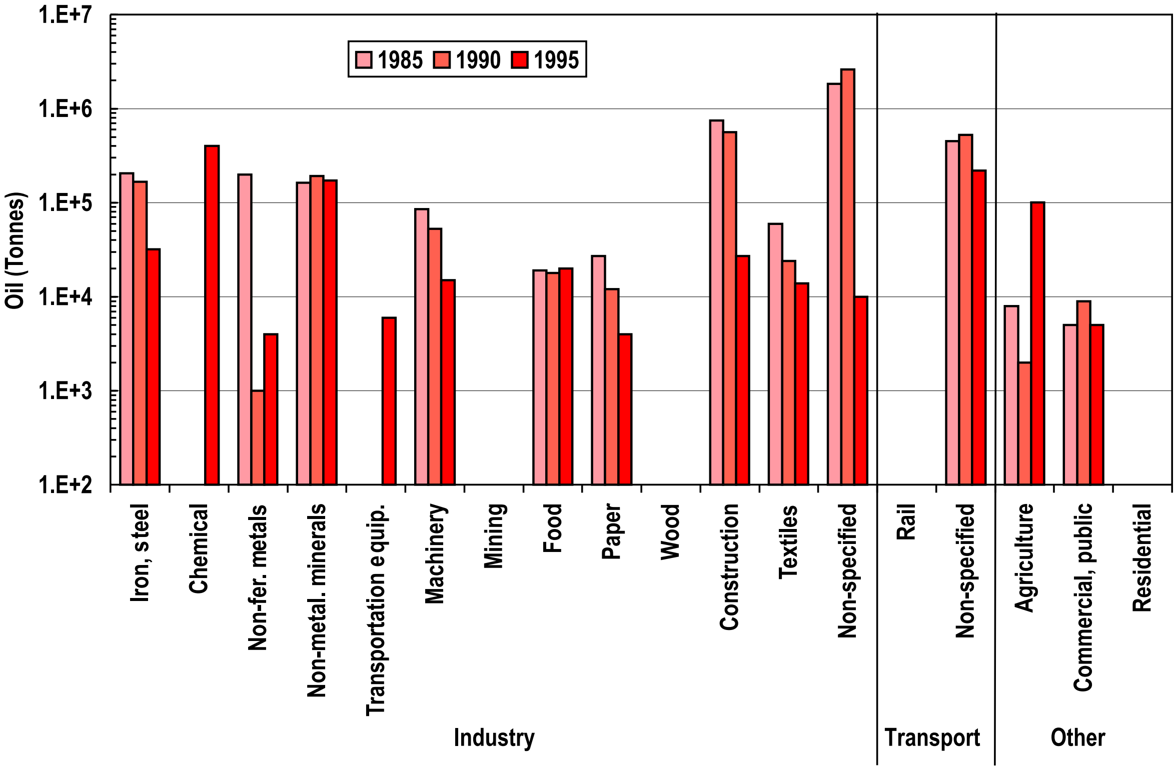

Figure 36: China's final oil consumption by sectors for the years 1985, 1990 and 1995 [IEA, 1997].

4.2.3 Severe accidents in China's oil chain

4.2.3.1 Severe accidents by years

For the period 1969 to 1999, a total of 32 severe accidents with cumulated 613 fatalities in the Chinese oil chain were identified (Appendix B). As for coal, Chinese information sources are of major importance to obtain a complete coverage as the Chinese-specific data in the ENSAD database are likely to be quite incomplete.

Figures 37 and 38 show the number of accidents and fatalities that occurred in China's oil chain in the period 1969-1999. The lack of data from 1969-1976 is most likely due to poor reporting, whereas it is possible that in 1985, 1986 and 1992 no severe accidents occurred. There were typically one or two severe accidents per year (Figure 37). Fatalities peaked in five years, namely 1979, 1980, 1983, 1990 and 1996 (Figure 38). These peaks were attributable to single large accidents and not to any particular accumulation in number of accidents as can be seen from the comparison with Figure 37.

4.2.3.2 Breakdown of severe accidents into oil chain stages

Figures 39 and 40 show the number of accidents and fatalities according to the different oil chain stages for the period 1969-1999. Half of all accidents occurred during transportation (i.e., transport to refinery or regional distribution), followed by exploration and refinery stages (Figure 39). Considering fatalities, exploration ranks first with a share of about 40%, followed by regional distribution and transport to refinery (Figure 40).

4.2.3.3 General causes for severe accidents in the oil chain

Information on general causes of severe accidents was not available. However, it has been reported that safety standards are relatively poor [Reuters, 1991]. It appears that pressure to construct the much-needed offhsore infrastructure resulted in a lax control and application of safety standards. For instance, the captain of the oil barge "McDermott", which was involved in pipe laying operations on the Huizhou 26-1 oilfield, ignored warnings of the impending typhoon Fred, which was predicted several days in advance. Survivors of the accident said that no warnings about the immediate danger were forthcoming until the barge started to capsize and sink. In particular, there was strong criticism about the lack of a special hyperbaric lifeboat for the decompression chamber for the diver activities on the barge [Reuters, 1991].

Fire project is also subject to inadequate safety standards. A circular issued by the Public Security Ministry Fire Department in 1997, stated that fires that spread across the country had caused substantial damages to the petrochemical industry, i.e., refineries, oil tankers etc. because of lack of precautionary measures against fire, lax management and serious disregard of rules and regulations [Reuters, 1997].

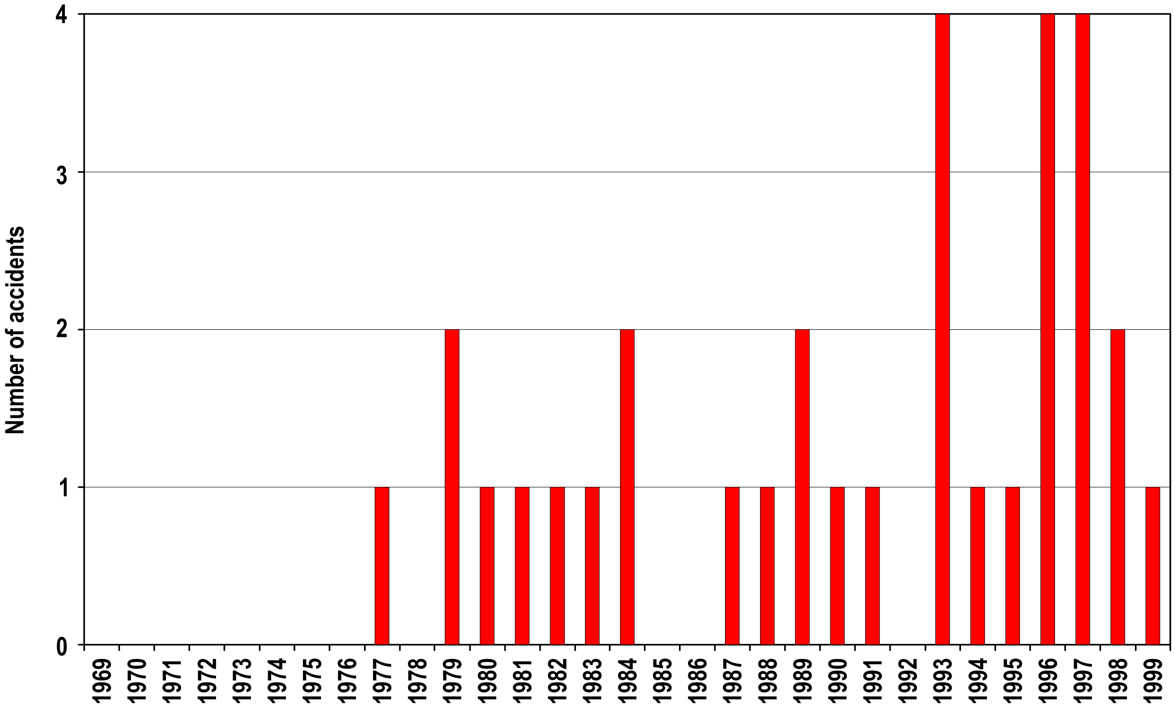

Figure 37: Number of severe accidents in China’s oil chain in the period 1969-1999.

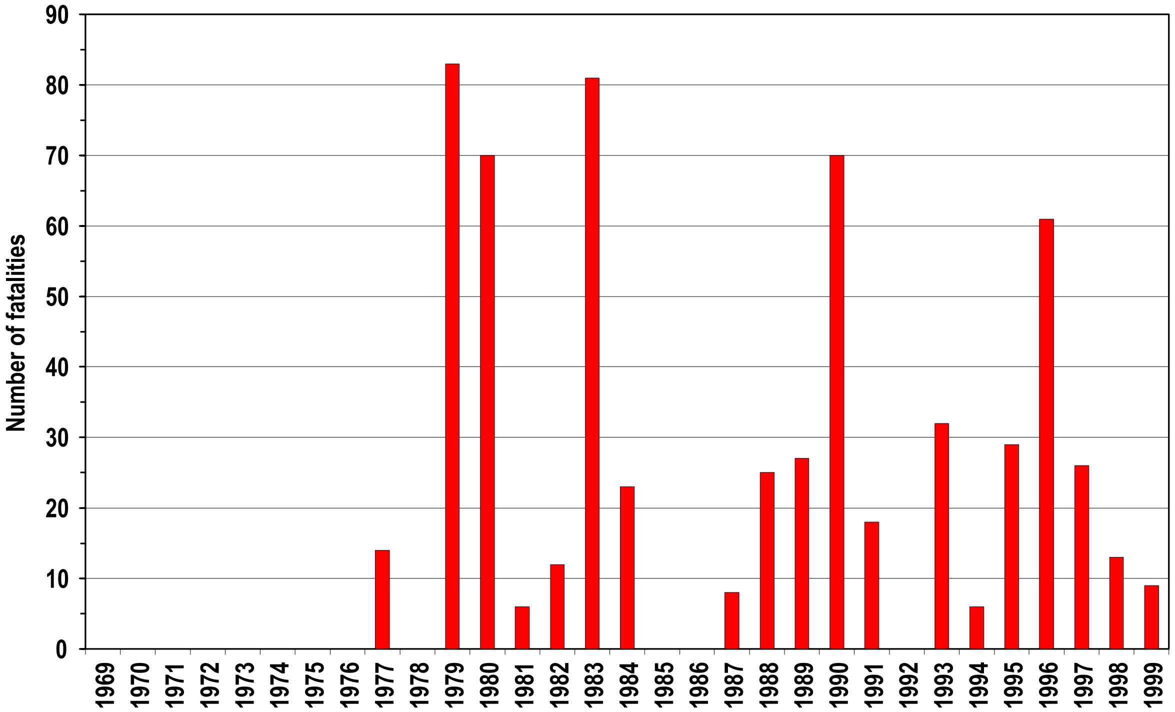

Figure 38: Number of severe accident fatalities in China’s oil chain in the period 1969-1999.

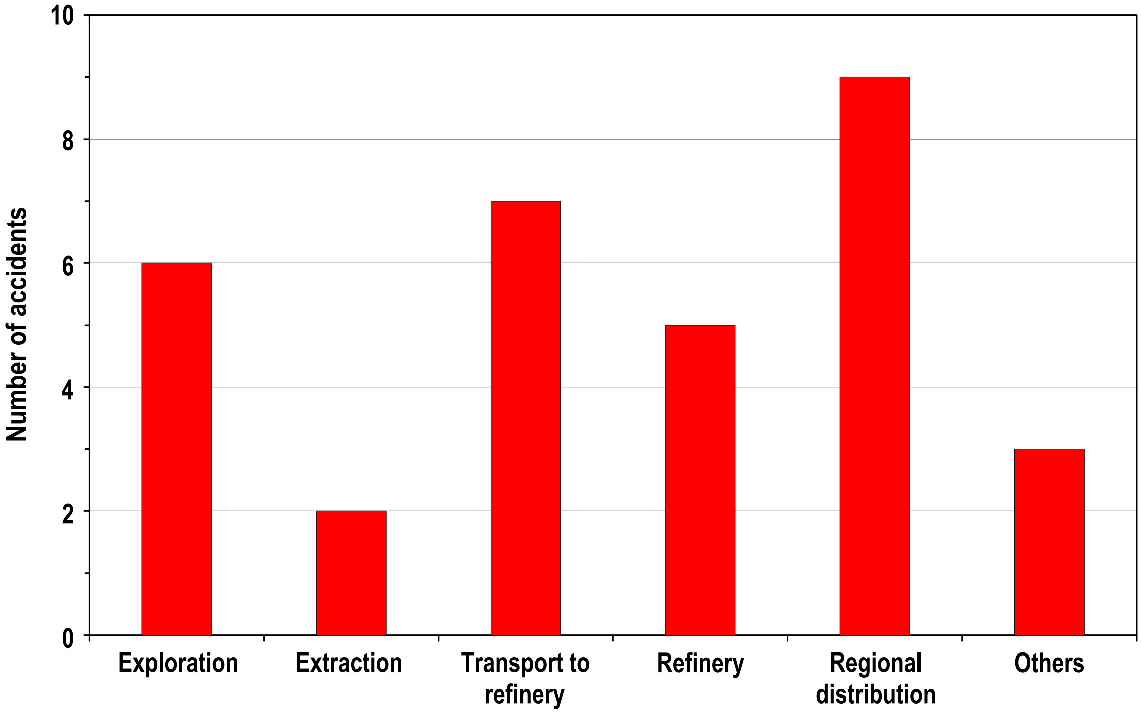

Figure 39: Number of accidents in China according to oil chain stages in the period 1969-1999.

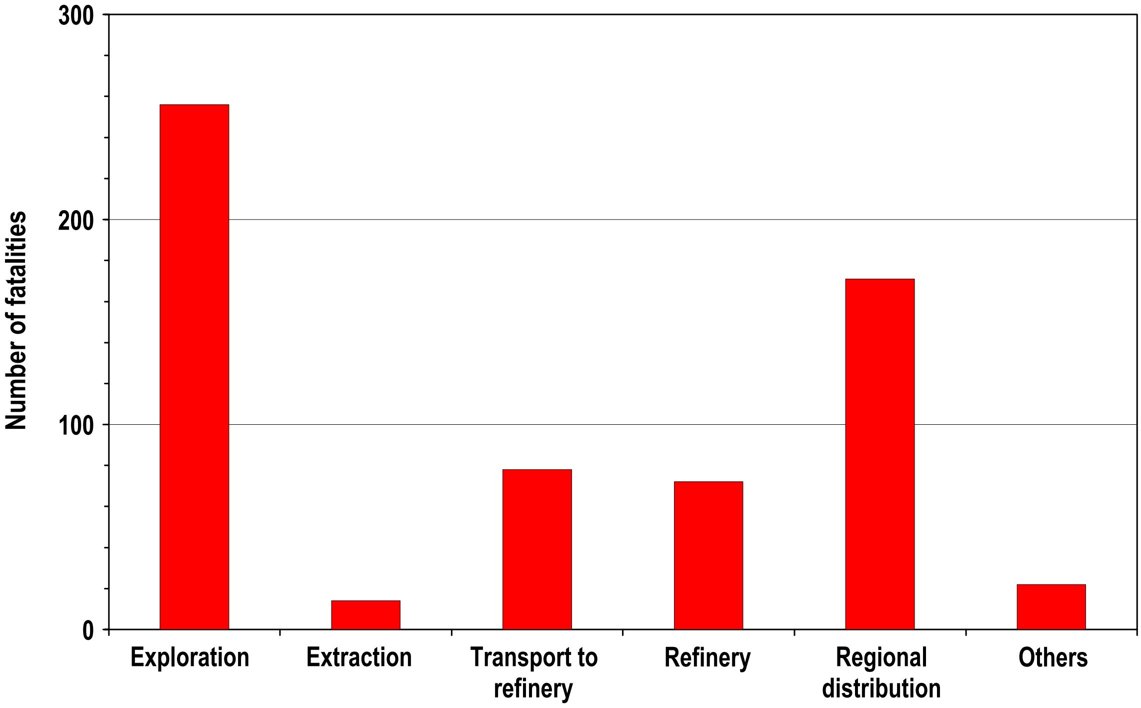

Figure 40: Number of severe accident fatalities in China according to oil chain stages in the period 1969-1999.

4.2.3.4 Oil spills

No major offshore and onshore oil (hydrocarbon) spills exceeding 25’000 t were reported for the period 1969-1999 in China (Table 9). The main reason why no oil spills exceeding 25’000 tons occurred could be that the transported amounts of hydrocarbons by ships, barges, lorries or pipelines were relatively small. Table 9 indicates that most facilities transporting or storing hydrocarbons have capacities lower than 28’000 t. However, oil spills of relatively small quantities could be much more frequent and they can cause severe damages too. In the South China Sea even small spills can have tremendous consequences because people in this densely populated coastal area depend largely on fish and oysters. For example on 24 March 1999, a collision of the tanker Min Rang Gong with the ore carrier Dong Hai caused an oil spill of 150 t resulting in serious pollution and tonnes of dead fish [LLP, 1999].

Table 9: Chinese spills of hydrocarbons that caused major pollution for the period 1969-2000.

Date	Place/ Province	Unit(s)	Hydro-carbon	Cargo (t)	Spilled quantities (t)	Cause	Damages
13.06.1993	Shengli/ Shandong	pipeline	crude oil	N.A.	6000	theft of a key valve in a pipeline	polluted farmland, huge traffic jam
23.10.1993	Nanjing/ Jinling	storage tank	petrol	6000	<1000	human error	2 fatalities
08.01.1994	Yangtze River/ Zheijiang	vessel	oil residue	500	< 500	N.A.	9 million USD
08.05.1994	Long Tau River	vessel	fuel oil	1012	200	collision	considerable pollution
20.08.1995	Guangzhou / Huangpu	tanker	crude oil	28’000	150	N.A.	millions of USD
28.02.1996	Xiaoxi/ Fujian	tanker	crude oil	57’000	N.A.	collision	considerable pollution
01.05.1996	Yantai	tanker	oil	N.A.	N.A.	collision	considerable pollution
14.07.1996	Liuzhou/ Guangxi	2 vessels	diesel	5	5	drastic variation in temperature	monetary damage of vessels: 13’000 USD
17.07.1996	Huxi/ Liuzhou	2 vessels	diesel	30 (each)	< 30	collision	1 fatality, injured persons
11.11.1996	Island of Ketoy	tanker	Fuel	400	< 400	N.A.	irretrievable damage to ecology of Kuril islands
29.12.1996	West of Hong Kong	wooden barge	gasoline	60	60	N.A.	> 9 fatalities
??.??.1997	Zhanjiang, Guangzhou	tanker	crude oil	N.A.	300	valve failure while loading	370’000 USD
07.06.1997	Nanjing/ Jinling	tanker	crude oil	19’700	< 19’700	explosion	9 fatalities
24.09.1998	Jiangyou/ Sichuan	oil tank	crude oil	200	< 200	explosion	loss of at least 20 t of oil
13.11.1998	South China Sea	2 tankers	gasoline	N.A.	2000	collision	ruining fish grounds, 360’000 USD
24.03.1999	off Zhuhai (Guandong) near Hong Kong	tanker	fuel oil	1000	150	collision	serious pollution, tonnes of dead fish, 600 acres of fish farm destroyed, direct losses of 120’000 USD
16.07.1999	Zhanjiang/ Guangdong	tanker	N.A.	N.A.	300	N.A.	N.A.
31.3.2000	Pearl River Delta	tankers	crude oil	N.A.	200	collision	1.2 million USD

N.A. = not available

4.3 Natural gas chain

4.3.1 Background

Natural gas, also known as methane, is a colorless, odorless fuel. It has several advantages over other fossil fuels. Unlike coal or oil, natural gas combustion produces virtually no sulfur dioxide and particulate emissions. In the power sector, a combined-cycle power plant produces less than 40% of the nitrogen oxides and carbon dioxide emitted by a standard coal-burning plant [Logan & Luo, 1999]. Converting coal-burning stoves in residential applications to stoves using natural gas would lower mixtures of particulate, carbon monoxide and toxic emissions that cause damage to human health, and also cut energy consumption due to higher efficiencies.

Chinese reserves of natural gas are estimated at 1.37 trillion m^3 (0.9% of the world's total) by the end of 2000 [BP Amoco, 2001]. Currently natural gas accounts for less than 3% of the nation's primary energy mix [SSB, 1999]. Considering China's domestic reserves and the environmental benefits of using gas, China plans a major expansion of its gas infrastructure [EIA, 2001]. Predictions by the Chinese government assume that gas use will more than triple by 2010 [EIA, 2001]. However, extensive and efficient use of natural gas would require investments in the country's domestic exploration and production capacities as well as infrastructure for import [Sinton & Fridley, 2000]. In addition to natural gas deposits, natural gas produced during oil extraction and gas trapped within seams of coal mines provides another potentially large source for China.

Once the gas is brought to the surface, it is refined to purify it, i.e., remove water, other gases and sand. Long-distance pipelines are then used to bring it to market. While factories and electric power plants acquire gas directly from pipelines, smaller businesses and residential housing buy it from local distribution companies.

4.3.2 China's natural gas industry

4.3.2.1 Natural gas supply and demand

Figure 41 and 42 show the world's largest natural gas producers and consumers, respectively, in 1999 and for comparison in 1990 and 1995 [IEA, 2001]. Russia and USA contribute about 50% to the world's total natural gas production, whereas China ranks only on the 17th position with about 26 Mtoe. Consumption shows a similar picture with USA and Russia also dominating, but China taking again the 17th position. However between 1995 and 1999, increase of consumption in China was substantial (26%), whereas it stabilized in USA and in Russia.

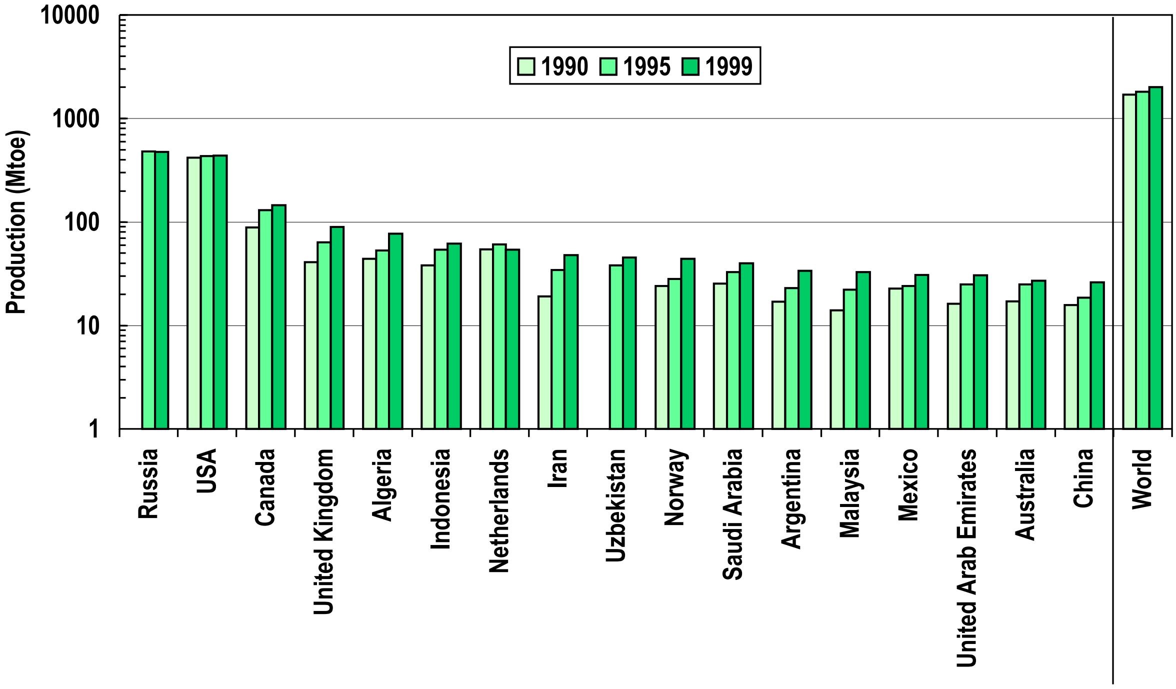

Figure 41: World's largest natural gas producers in 1999. Values for 1990 and 1995 are given for comparison. Data are from IEA [2001].

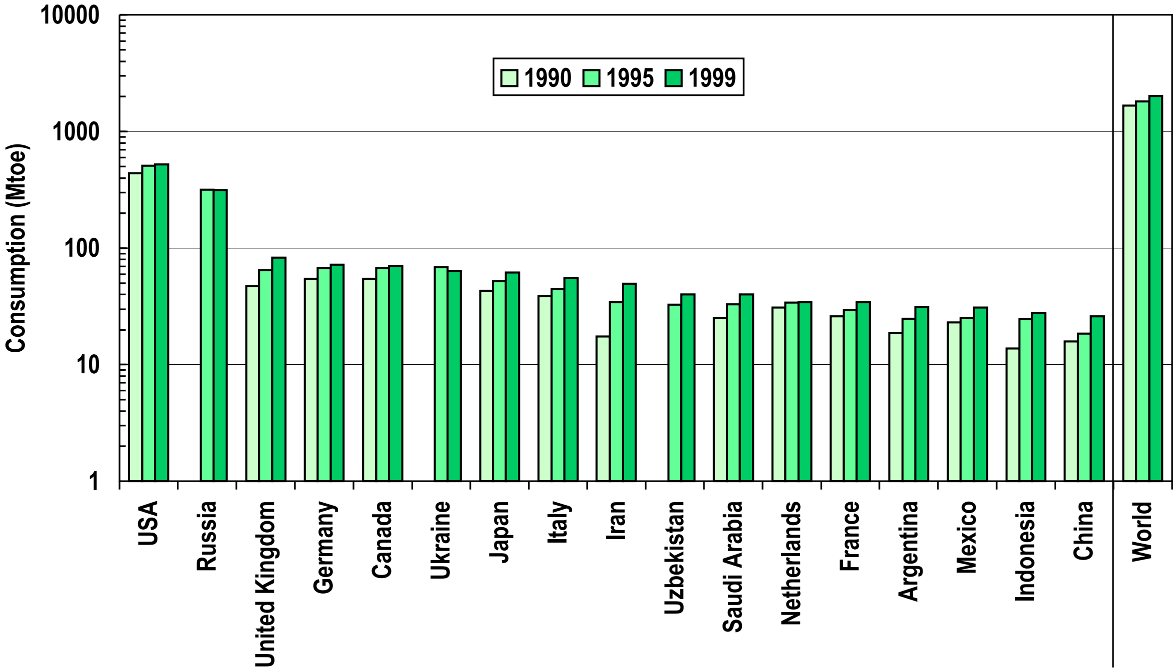

Figure 42: World's largest natural gas consumers in 1999. Values for 1990 and 1995 are given for comparison. Data are from IEA [2001].

The relatively low production and use of natural gas in China compared to the USA and Russia is mostly because the effort devoted to prospecting and developing known reserves has been minimal [Inform Special Report, 1998]. As a result, natural gas production in China accounts for less than 3% of China's energy use, whereas the respective share for USA is higher than 20%. Considering known supplies within Chinese borders or in close reach it appears feasible for natural gas to play a significant role in the future. Based on the Ninth Five-Year Plan and projections of the US Energy Information Administration natural gas production is expected to quadruple in China by 2020, thus increasing its share in the overall energy mix. [EIA, 1997; 2001].

Table 10 gives the distribution of proven reserves at the end of 2000, the share of total and the R/P ratios, i.e., the length of time the remaining reserves would last given current production levels. More than two thirds of the proven reserves are located in the former Soviet Union and the Middle East, whereas China has only 0.9% of the world's total.

Table 10: Natural gas reserves and R/P ratios for countries with the world's largest reserves [BP Amoco, 2001].

	At the end of year 2000		
Country	**Reserves (trillion m^3)**	**Share of total (%)**	**R/P ratio (yr)**
Russia	48.14	32.1	83.7
Iran	23.00	15.3	> 100.0
Qatar	11.15	7.4	> 100.0
Saudi Arabia	6.05	4.0	> 100.0
United Arab Emirates	6.01	4.0	> 100.0
USA	4.74	3.2	8.7
Algeria	4.52	3.0	50.6
Venezuela	4.16	2.8	> 100.0
Nigeria	3.51	2.3	> 100.0
Iraq	3.11	2.1	> 100.0
Turkmenistan	2.86	1.9	61.8
Malaysia	2.31	1.5	52.3
Indonesia	2.05	1.4	32.0
Uzbekistan	1.87	1.3	34.0
Kazakhstan	1.84	1.2	> 100.0
Canada	1.73	1.1	10.3
Netherlands	1.77	1.2	26.9
Kuwait	1.49	1.0	> 100.0
China	1.37	0.9	49.3
World	150.19	100.0	61.0

Figure 43 gives the final consumption of natural gas by sectors in China. In 1999, natural gas was most important in the chemical industry, residential and machinery sector, whereas contributions from other sectors were one to several magnitudes lower. The top three sectors showed a distinct increase since 1990. Most other sectors exhibited a similar trend suggesting use of natural gas is gaining importance.

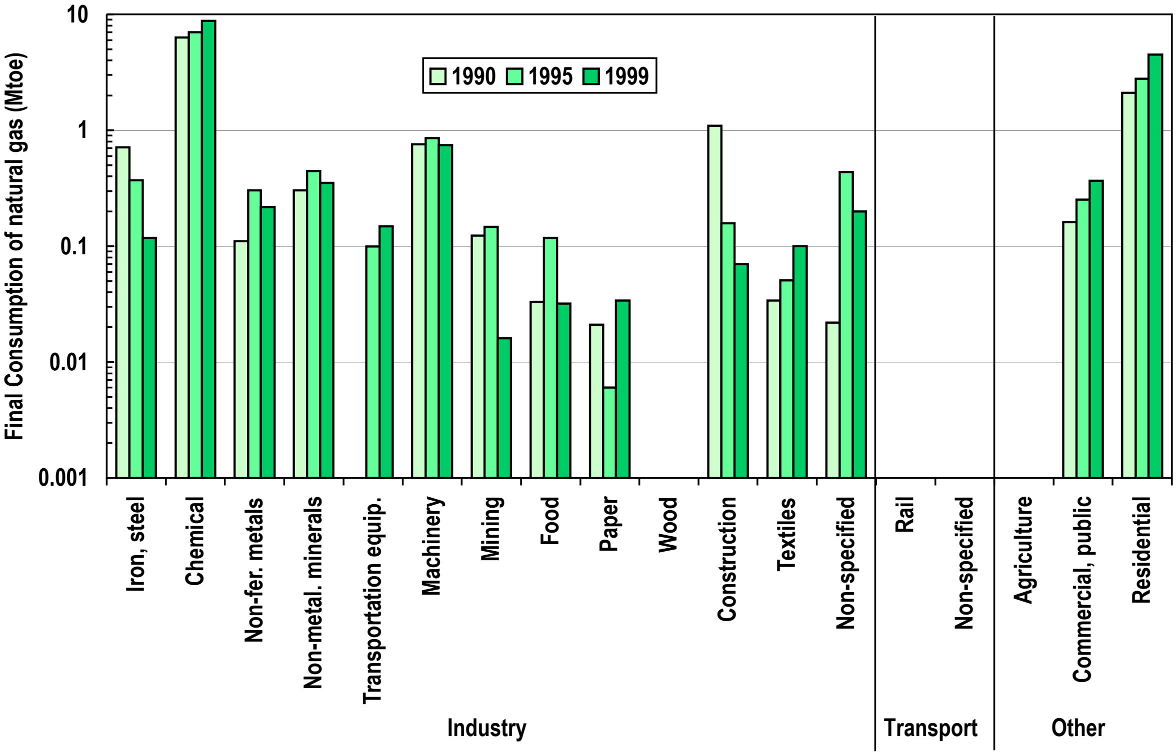

Figure 43: China's final natural gas consumption by sectors for the years 1990, 1995 and 1999 [IEA, 2001].

4.3.2.2 Chinese gas fields

Proven natural gas reserves in China currently amount to about 1.37 trillion m^3 according to BP Amoco [2001]. However, estimates assume that total reserves may be as high as 38 trillion m^3, of which 79% are located onshore and 21% offshore [e.g., Muzi Lateline News, 2001; Xu, 1999]. The largest natural gas fields are located in the areas of Ordos Basin, Tarim and Junggar Basins, Sichuan, Qaidam Basin and offshore (mainly Bohai Bay, the South China Sea and the East China Sea).

– The Ordos Basin sprawls across Shaanxi, Shanxi, and Gansu provinces, and the Ningxia Hui and Inner Mongolia Autonomous Regions, and covers an area of 400'000 km^2. Geologists estimate that the natural gas resources here may total 4 to 10 trillion m^3 [Alexander's Gas and Oil Connections, 2001a; Xu, 1999]. Recently, two massive gas-bearing areas have been discovered in the Inner Mongolia Autonomous Region of the Ordos Basin. Reserves in the Shuligemiao and Sulige area are estimated of about 400 billion m^3 and 220 billion m^3, respectively [Alexander's Gas and Oil Connections, 2001a,b].

– According to the second national oil and gas resource assessment conducted by CNPC, Tarim and Junggar Basin in Xinjiang Uygur Autonomous Region are expected to have 8.4 trillion m^3 of natural gas, one quarter of the country's reserves [Alexander's Gas and Oil Connections, 1998; Xu, 1999].

- Eastern Sichuan Province, with estimated reserves of 7.4 trillion m^3 of natural gas [Xu, 1999], accounts for over 40% of China's natural gas output, most of which has not been a byproduct of refining [Logan & Chandler, 1998].
- The 250'000 km^2 large Qaidam Basin, located in Qinghai Province, is regarded as the treasure basin of the country. Proven gas reserves are 150 billion m^3, making it the fourth largest gasfield in China [Alexander's Gas and Oil Connections, 1999]. Experts believe that Qaidam Basin will be one of China's leading energy reserve basis in the 21st century.

More detailed information about natural gas resources and reserves is available from Fridley et al. [2001]. Today and in the near future, the focus for onshore gas development will be accelerating exploration in the natural gas producing areas mentioned above, and transporting natural gas by pipeline. The project of the Zhongxian-Wuhan gas pipeline is designed to transport the gas from Tarim Basin, Qaidam Basin and Ordos Basin through pipelines to the Yangtze River delta [Alexander's Gas and Oil Connections, 2000b].

Additionally, Liquefied Natural Gas (LNG) imports could become a promising source of natural gas for China. Possible foreign sources include pipeline links to East and West Siberia, the Russian Far East, Turkmenistan and the development of an Asia-Pacific gas network merging existing and proposed gas networks in Indonesia, Malaysia and Thailand with major markets for consumption in China [Xu, 1999].

To maximize the potential of natural gas, massive investments are needed for exploration activities and efficient transportation and distribution structures. Accelerated market reforms by the government accompanied by other key incentives would improve the investment climate and move China's natural gas industry into the 21st century [Logan & Chandler, 1998].

4.3.3 Severe accidents in China's natural gas chain

For the period 1969 to 1999, a total of 8 severe accidents with cumulated 201 fatalities in the Chinese natural gas chain were identified (Appendix C). This roughly corresponds to 17% of all accidents and 18% of all fatalities in severe accidents that occurred in the natural gas chain in non-OECD countries in the period considered.

For comparison with other energy chains, the number of accidents and fatalities per year are shown in Figures 44 and 45. The number of accidents per years ranged between zero and two with no reported accidents before 1989; the corresponding fatalities exhibit no particular trend and just reflect the severity of individual accidents. About 70% of all fatalities are attributable to two accidents in 1993, one in Shenzen (Guandong province) and one in Bahoe (Heilongjiang province), each causing 70 fatalities.

More detailed analyses (e.g., separation by energy chain stages) were not performed because of the small data basis.

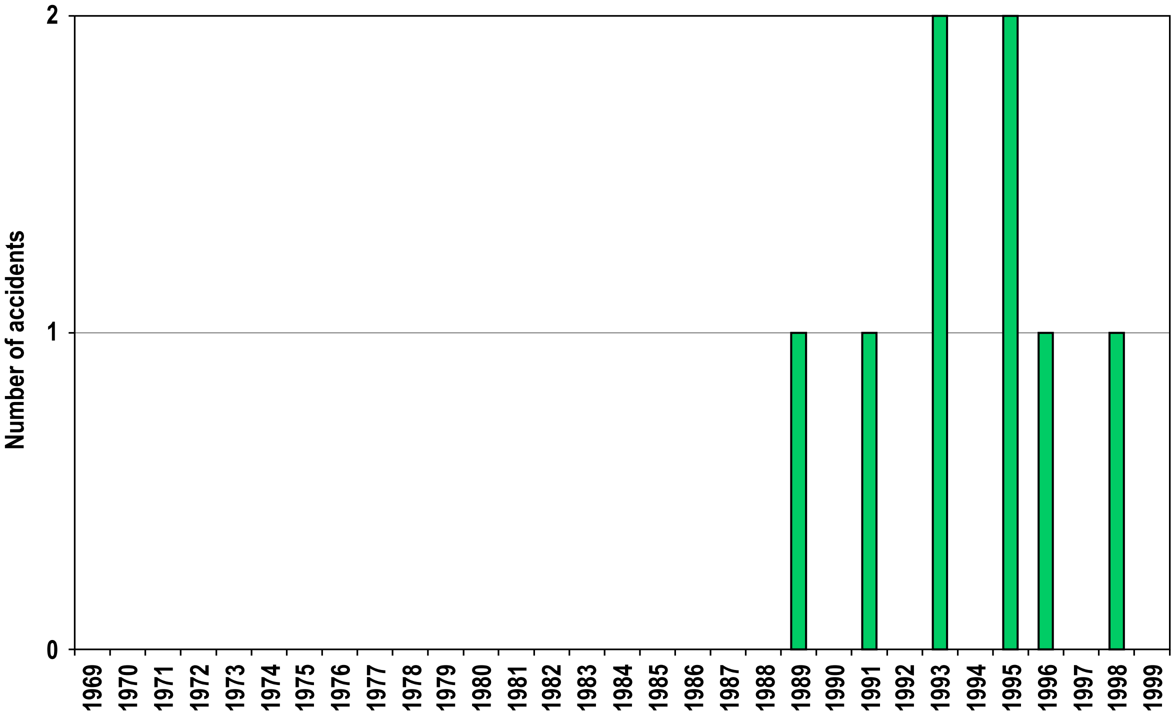

Figure 44: Number of severe accidents in China's natural gas chain in the period 1969-1999.

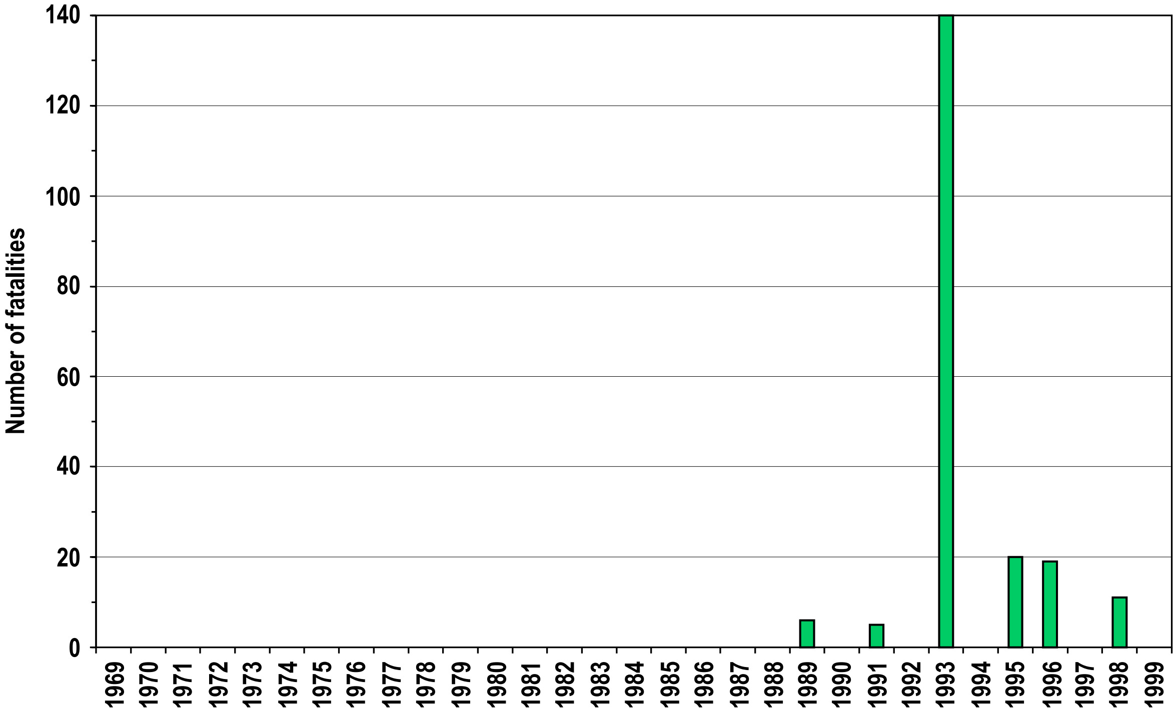

Figure 45: Number of severe accident fatalities in China's natural gas chain in the period 1969-1999.

4.4 Liquefied petroleum gas chain

4.4.1 Background

Liquefied Petroleum Gas (LPG) is colorless, tasteless, non-toxic and odorless, but it is also volatile (expands rapidly), heavier than air and flammable. As the name suggests, it is partly a byproduct in the oil refining process, but also occurs naturally in crude oil and natural gas fields. It is a mixture of light hydrocarbons which are gaseous at normal temperatures and pressures, and which liquefy readily at moderate pressures or reduced temperature. During the production process the gas is compressed into a smaller space, causing it to liquefy and stay in the liquid form until the pressure has been removed. Its main constituents are propane and butane. For safety reasons, a pungent compound, ethyl mercaptan, is added to make any leaks easily detectable.

Even though LPG is one of the newest of the major domestic, commercial and industrial fuels, it has a good acceptance by the public. In contrast to natural gas no LPG is burned in power plants. It is primarily used for heating and cooking, but is also an attractive automobile fuel among many other uses. For example, the extensive list presented on the website of the Liquefied Petroleum Gas Industry (http://www.lpgas.com) demonstrates the versatility of this fuel.

The transport means depend on distance between the LPG production plants and the markets. LPG may be transported by pipeline, sea, road or rail, in pressurized ships as well as trucks and rail cars. Large volumes, particularly within USA, are transported by pipelines. For transportation to the consumers cylinders and bulk vehicles of various sizes are used [Hirschberg et al., 1998].

Finally, LPG has several environmental and economic benefits:

- Clean efficient combustion.
- Among lowest life-cycle greenhouse gas emissions of all commercially available fuels.
- Insignificant levels of sulfur dioxide.
- Extremely low particulates produced during combustion.
- Less damage to soil and water in case of spills, due to rapid evaporation.

However, from the resource point of view LPG can not be fully regarded as an "alternative" fuel because its source is partly petroleum and as a consequence it does less to help relieve the petroleum dependency problem than some other alternative fuels.

4.4.2 China's LPG industry

4.4.2.1 LPG supply and demand

The demand of LPG in China is currently estimated at the level of 13.8 million ton and is expected to reach 29.7 million ton by the year of 2010 [EPC-China, 2001]. Along with the rise of Chinese living standard, the per capita LPG consumption in China will increase substantially. LPG will be used widely for home cooking, as a clean fuel in vehicles and in light industry.

Figures 46 and 47 show the world's ten largest LPG producers and consumers in 1999 and for comparison the situation in 1990 and 1995 [IEA, 2001]. China is the second largest producer of LPG after USA, and the third largest consumer after USA and Japan. Furthermore, the increase in production in China (+312%) is the second highest after Kuwait (+705%), and increase in consumption (+521%) is even the highest worldwide for the period 1990-1999.

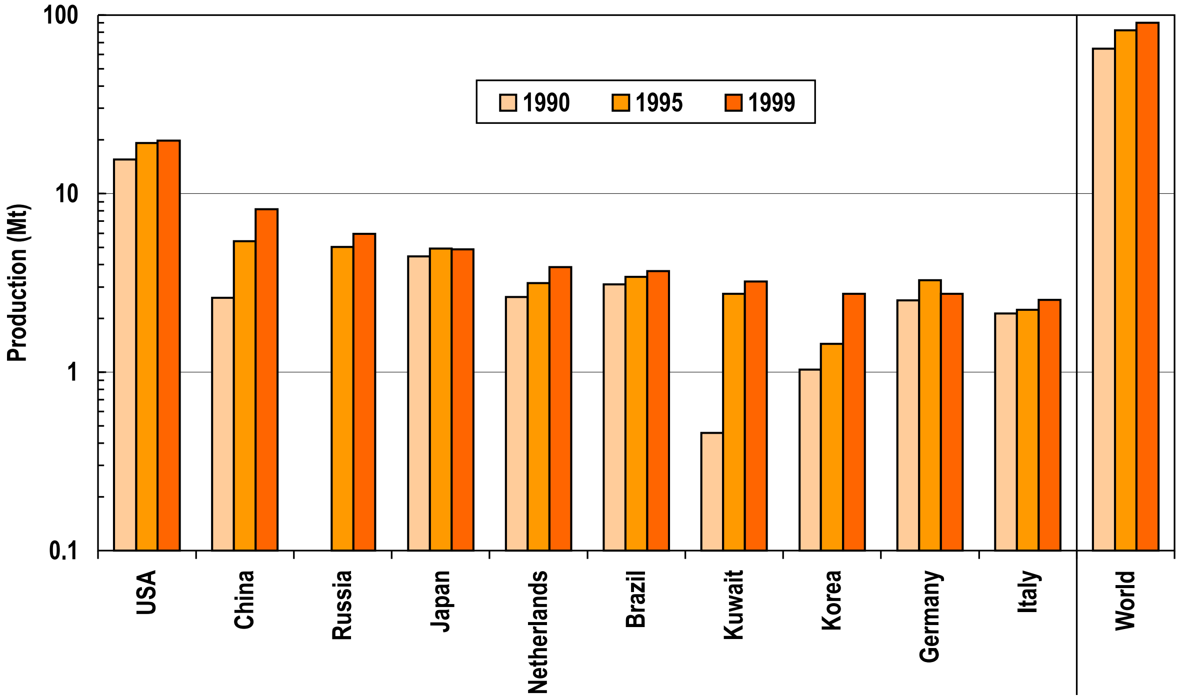

Figure 46: World's largest LPG producers in 1999. Values for 1990 and 1995 are given for comparison. Data are from IEA [2001].

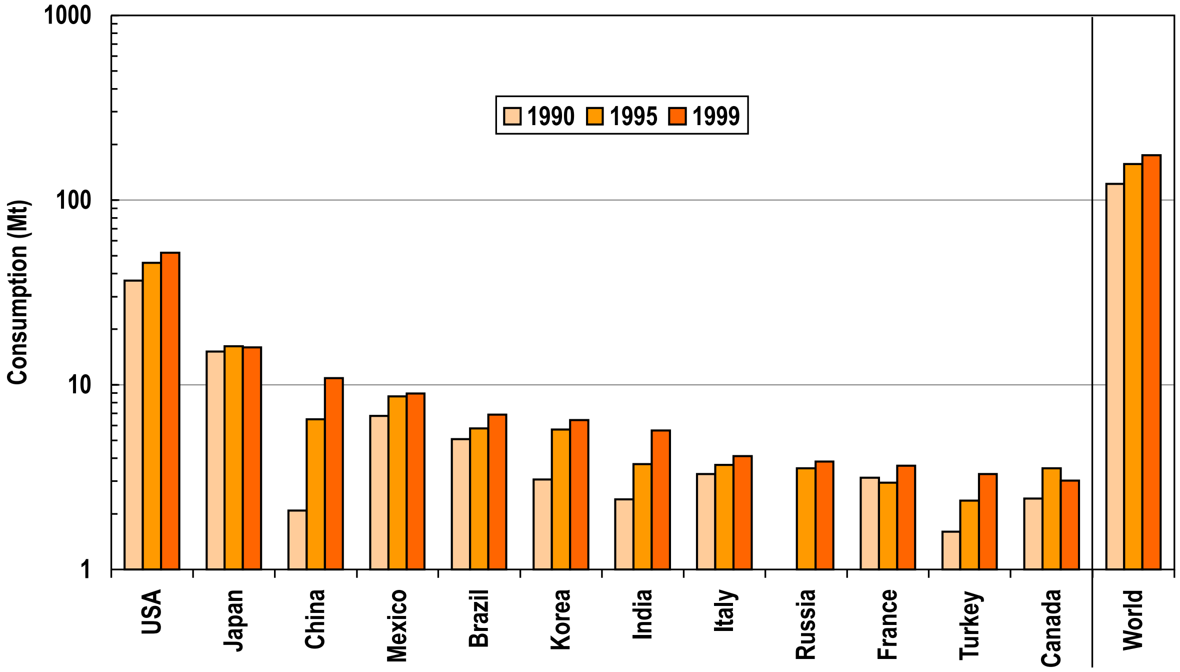

Figure 47: World's largest LPG consumers in 1999. Values for 1990 and 1995 are given for comparison. Data are from IEA [2001].

Figure 48 gives the final consumption of LPG by sectors in China. In 1999, residential use of LPG was strongly dominating with a share of about 81%. Since 1990 the residential sector increased from 1.6 Mt to 8.8 Mt, an increase by almost a factor of six. The chemical, commercial/public, non-metal minerals and machinery sectors also have contributions exceeding 0.1 Mt, whereas all other sectors have smaller shares.

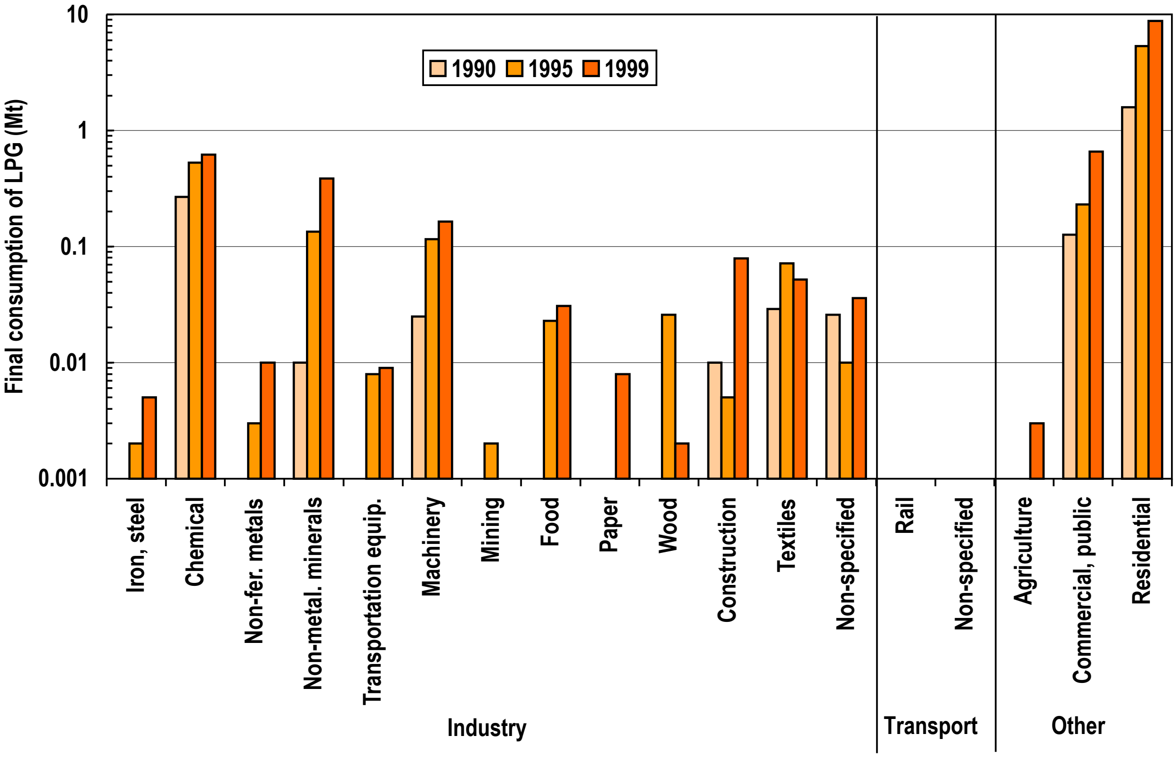

Figure 48: China's final LPG consumption by sectors for the years 1990, 1995 and 1999 [IEA, 2001].

4.4.3 Severe accidents in China's LPG chain

For the period 1969 to 1999, a total of 11 severe accidents with cumulated 291 fatalities in the Chinese natural gas chain were identified (Appendix D). This is about 28% of all accidents and about 11% of all fatalities in severe accidents that occurred in the LPG chain in non-OECD countries in the period considered.

For comparison with other energy chains, the number of accidents and fatalities per year are shown in Figures 49 and 50. The number of accidents per years ranged between zero and two with most accidents having occurred in the nineties. Nevertheless, it would be speculative to conclude that the number of accidents and fatalities are increasing since the late 90's because the data basis is rather small.

As was the case with natural gas, more detailed analyses (e.g., separation by energy chain stage were not performed.

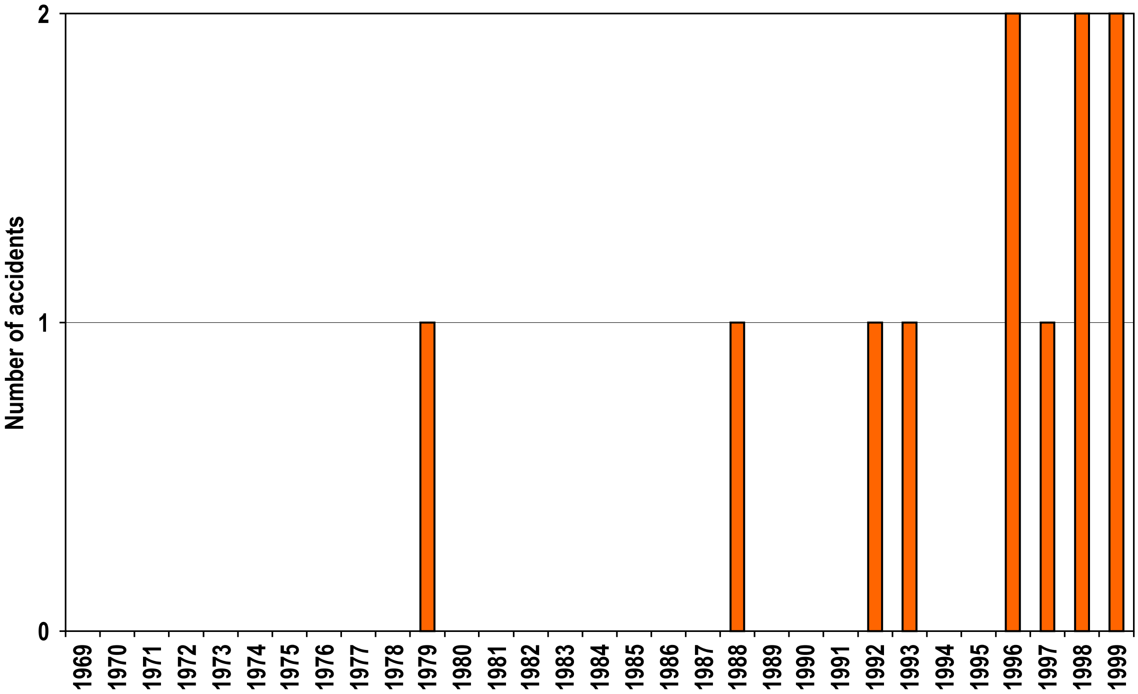

Figure 49: Number of severe accidents in China’s LPG chain in the period 1969-1999.

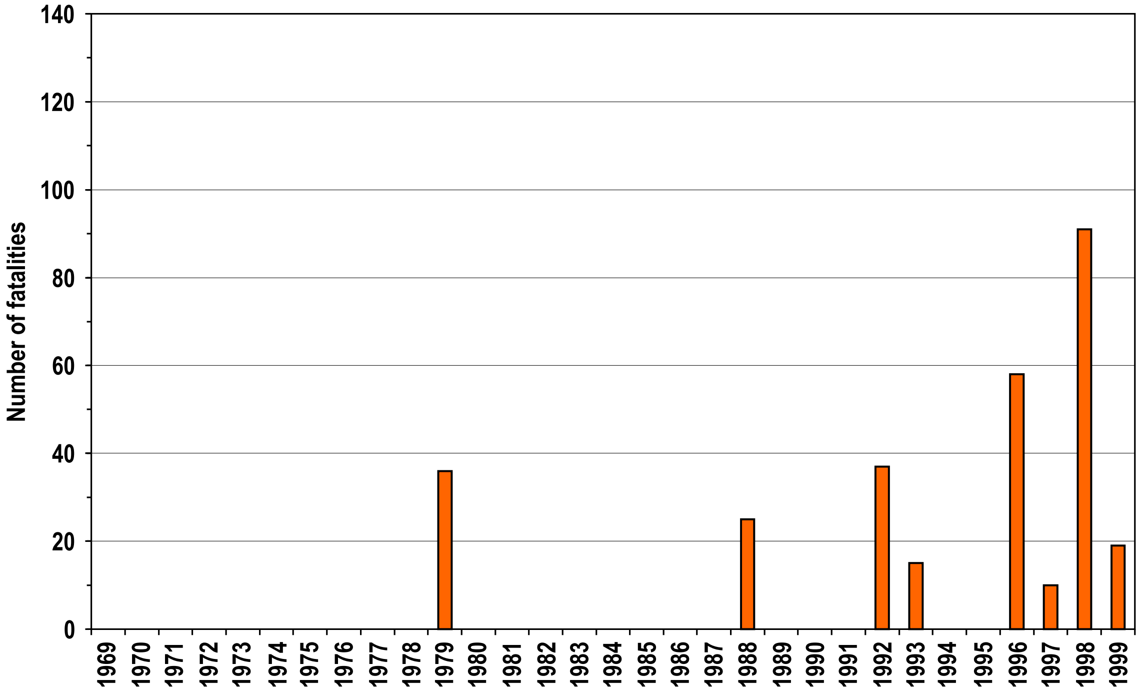

Figure 50: Number of severe accident fatalities in China’s LPG chain in the period 1969-1999.

4.5 Coalbed methane

4.5.1 Background

According to the third national coal resources prediction made by the China General Bureau of Coalfield Geology in 1997, China has total coal resources of 5.57 trillion t to a depth of 2000 m, of which, 18% are proved resources and 82% predicted resources [Ye & Tang, 1998; Wang et al., 2000]. Based on these values, calculations of total coalbed methane (CBM) vary between 14.34 trillion m^3 [Ye & Tang, 1998] and 22.52 trillion m^3 [Wang et al., 2000][4]. One should be aware that results of CBM resource estimations are strongly depending on the criteria applied, i.e., method, used coal resource data, methane content of considered seams and depth limit. Although China has abundant CBM resources, distribution of CBM is very uneven. About 66% of CBM resources are located in North China whereas the rest is distributed over South China, northwest and North-east China.

Presently, CBM development is only at the initial stage in China. For large scale CBM development, a clear exploration strategy is needed as well as improvements in extraction technology because the currently available technology is limited to a depth smaller than 1000 m. China's interest in developing CBM reserves is threefold:

- Efficient use of this abundant energy resource.
- Improvement of productivity and safety of coal mines by reducing the major source of underground gas accidents.
- Lowering greenhouse gas emissions by capturing methane-rich gas before mining or release to the atmosphere.

At the present status of China's CBM industry no sound evaluation of severe accidents is possible.

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[4] Other sources [Li et al., 1998; Logan & Luo, 1999] report even higher numbers of 30-35 trillion m^3.

4.6 Hydro power

4.6.1 Background

4.6.1.1 Water resources

Today, around 3800 km^3 of freshwater is withdrawn annually from the world's lakes, rivers and aquifers [WCD, 2000]. The growing world population and rising levels of economic activities increase demand for water and water-related services. Considering 50 liters per person per day a sufficient amount of water to cover basic human water requirements would mean that over one billion people were below that level in 1990 [Gleick, 1998]. In contrast, the residential use in developed countries is four to fourteen times higher than the reference level of 50 liters per person per day.

The world's water resources stemming from precipitation and other sources of freshwater (rivers, lakes, ground water) are unevenly distributed and not always located where human water demand arises. There is a growing concern that fresh water will be a critical limiting resource for many regions in the near future. About one-third of the world's population lives in countries that are experiencing water stress [Gleick, 1998; Raskin et al., 1995]. In Asia, where water has always been regarded as an abundant resource, per capita availability declined by 40-60% between 1955 and 1990. Projections suggest that most Asian countries will have severe water problems by year 2025. However, not only surface water is under pressure, but the increased extraction of ground water has also resulted in serious depletion of many aquifers. For example, in parts of India, Pakistan and China the water table is sinking at a rate of one to two meters a year [Brown & Halweil, 1998].

4.6.1.2 Dams and development

Around 5500 BC, the Sumerians built the first canals for irrigation of wheat and barley in Mesopotamia (today Iraq and part of Iran) that represent the earliest evidence of river engineering. Ancient dams for water supply, flood control and irrigation are known from Jordan, Egypt, Greece, Yemen or Turkey from 3000-1000 BC [Schnitter, 1994]. Some of these ancient dams are still in operation; e.g., the Kofini dam in Greece (operation period 3300 years), the Bassawak and Tissa dams in Sri Lanka (2300 years) or the Tianping dam in China (2200 years) [Schnitter, 1994].

Use of dams for hydro power generation started at the end of the 19th century. The first hydroelectric power plant was built in 1882 in Appleton (Wisconsin) to provide 12.5 kW to light two paper mills and a home [National Renewable Energy Laboratory, 1998]. In the 20th century a rapid increase in large dam building occurred. By 1949, about 5000 large dams had been constructed worldwide, and by the end of the 20th century there were over 45'000 large dams in over 140 countries [WCD, 2000]. The period of economic growth following World War II lead to a huge rise in the global dam construction rate that lasted into the 1970's and 1980's. However, during the last two decades a decrease in the rate of dam building occurred because most technically attractive sites, especially in North America and Europe, are already developed [WCD, 2000].

4.6.1.3 Definition of large dams

In the literature several definitions of large dams can be found. In this report the definition of a large dam follows the criteria established by the International Commission on Large Dams [ICOLD, 1995]. A large dam is a dam with a height of 15 m or more from the foundation. However, if dams are between 1-15 m high and have a reservoir volume of more than 3 million m^3, they are also classified as large dams.

4.6.1.4 Effects of large dams

Decision-making on water and energy development needs a comprehensive approach integrating economic, environmental and social dimensions of development because there are no simple shortcuts to sustainable development. Besides pertinent legal instruments including such as the Convention on Biological Diversity [CBD, 2000], and Agenda 21 [UNCED, 1992], a variety of international organizations such as the World Bank [World Bank, 1997], the World Business Council on Sustainable Development [e.g., WBSCD, 2001; Stone et al., 1997], the World Conservation Union [McAllister et al., 2000], the World Commission on Dams [WCD, 2000], the International Commission on Large Dams [ICOLD, 1997] or the International Energy Agency [IEA, 2000], have contributed to the development of accepted standards. In the following a number of effects not necessarily related to the main topic of this report, i.e. severe accidents, are elaborated. The reason for devoting some space to these issues here is that most of them have not been treated elsewhere within CETP.

Technical and economic effects

Irrespective of performance against targets, the WCD Knowledge Base confirmed the longevity of large dams with many continuing to generate benefits after 30 to 40 years of operation [WCD 2000]. Some aspects may be ambiguous which may be manifested by both positive and negative impacts (Table 11).

Table 11: Technical and economic effects of large dams.

Positive effects	**Negative effects**
Supply of water for municipal and industrial use	Large initial capital expenses often associated with schedule delays and significant costs overruns
Supply for hydro power generation	Large costs of maintenance; e.g., ensuring safety of dam or prevention of storage losses due to sedimentation
Delivery of irrigation services; i.e., creation of new areas of arable land leading to increased production in agriculture	Waterlogging and salinity affect 20% of irrigated land worldwide; including land irrigated by large dams.
Flood control	Reliability of hydro power generation which often tends to perform close but still below targets
Employment	Flood control benefits can be partly diminished by greater vulnerability to flood hazards due to increased settlement in areas still at risk
Income from tourists and recreation	Costs for residential displacement and building of new cities
Establishment of new cities and communities	Costs of evaporation of reservoirs
Improved navigation of waterways leads to increased trade and commerce	

Ecosystem effects

The awareness about the generic nature of the impacts of large dams on ecosystems, biodiversity and downstream livelihoods is increasing. On balance, the ecosystem impacts are usually more negative than positive, often resulting in significant and irreversible loss of species and ecosystems in the affected area (Table 12). This issue has long been the domain of environmental organizations, but meanwhile such bodies as WCD or ICOLD also pay more attention to environmental performance of large dams, striving towards a more sustainable use of these resources. A major problem in assessing the effects of large dams is that often no reference data are available before the construction, or that only short-term studies are performed, revealing just the most extreme and immediate effects but not considering long-term ecosystem responses.

Concerning ecosystem effects of large dams there is also a growing discussion about "compensatory mechanisms", i.e., offsetting the loss of ecosystems and biodiversity caused by a large dam through investment in conservation and regeneration measures and through protection of other threatened sites of equivalent value.

The issue of greenhouse gas (GHG) emissions of large dams has received attention only recently, and is subject to controversy discussion. Based on studies undertaken on about 30 reservoirs mostly in tropical and boreal latitudes, it can be concluded that GHG are emitted for decades from all dam reservoirs for which measurements have been made [WCD, 2000; WCD Thematic Review, 2000]. This is in contrast to the widespread assumption (e.g., IPCC scenarios) that such emissions are negligible. First estimates indicate that gross emissions from reservoirs may account for about 1% to 28%[5] of the global warming potential of GHG emissions (WCD, 2000). This relatively broad range is largely depending on climate and reservoir depth. GHG emissions from tropical reservoirs are far higher than those from reservoirs in boreal zones, and shallow reservoirs are also likely to have much higher emissions than deep ones [WCD, 2000]. Under such circumstances the gross emissions can be considerable, and in extreme cases even greater than the thermal alternatives.

Social effects

In terms of social effects of large dams, the WCD reported that negative effects were frequently neither adequately assessed nor accounted for [WCD, 2000]. The range of such impacts is substantial, including the lives, livelihoods and health of the affected communities dependent on the riverine environment (Table 13).

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[5] St. Louis et al. (2000) report that globally, these emissions may be equivalent to 7% of the global warming potential of other documented anthropogenic emissions of these gases.

Table 12: Ecosystem effects of large dams.

Positive effects	**Negative effects**
Creation and/or enlargement of riparian zone habitats and wetlands below dam	Destruction of natural habitats; i.e., inundation of large riparian and terrestrial areas causing harms to amphibians and terrestrial species or alteration of aquatic habitats
Change in ecosystem could support a variety of introduced species	Trapping silt in reservoirs deprives downstream deltas and estuaries of materials and nutrients that help make them productive ecosystems
Contribution to the control and prevention of vector causing human and animal diseases (1)	Impacts of changed streamflow and thermal regimes on aquatic, floodplain and coastal ecosystems downstream
Some reservoirs support globally threatened reptiles and others have been declared protected sites of international importance for birds	Filtering out of woody debris which provides habitat and sustains food chains
Fishing and recreational opportunities	Loss of seasonal floods which are maintaining the dynamic balance of the ecosystem
	Accumulation of biotoxic substances in sediments
	Release of PCB's that especially harm top-species in food webs (e.g., otter, eagle)
	Habitat fragmentation and blocking movement of migratory species up and down rivers, leading to decreased gene flow and genetic variation, potential extirpation or extinction, and overall decrease in aquatic biodiversity
	Possibly fostering exotic species; exotic species tend to displace indigenous biodiversity
	GHG emissions of large dams challenge the conventional view that hydro power produces only positive atmospheric effects when compared with power generation sources that burn fossil fuels

(1) The opposite may also happen, i.e., reservoirs providing habitat for such vectors.

Table 13: Social effects of large dams.

Positive effects	**Negative effects**
Provides all social groups with access to electric power	Fatal accidents during the construction process
Supply of water in arid areas	Loss of large areas of agricultural land, forest, grazing land, fishing grounds and other resources from which indigenous communities derived their subsistence
Improvement of nutrition levels due to increased irrigation	Magnitude of displacement and resettlement often not definitively known and in some cases unmanageable
Generating employment; aside from construction jobs, the provision of water and electricity allows the establishment of new productive enterprises	Inadequacies in resettlement and/or rehabilitation policies and serious deficiencies and flaws in implementation
Encourages development	Adverse impacts on weak and disadvantaged groups, tribal communities, women etc
Provides recreation (e.g., water-skiing, sport fishing)	

4.6.1.5 Classification of dams

Dams can either be classified according to type or function (purpose). Six basic dam types can be distinguished. Dams of types earth (Te) or rockfill (Er) are embankment dams whose fill material is earth or rock. A gravity dam (Pg) is constructed of concrete and/or masonry and resists the pressure of impounded water through its own weight. An arch dam (Va) is built of concrete or masonry and resists the pressure of the water by having the form of a single arch often abutted by natural rock formations. Multi-arch dams (Mv) represent a variant of this type. A buttress dam (Cb) consists of a watertight part supported at intervals on the downstream side by a series of buttresses (walls normal to the axis of the dam). For more detailed information see Hirschberg et al. [1998] and references therein.

Additionally, dams can be categorized by their function (purpose). Today, dams are primarily used for irrigation in agricultural production, electricity generation and flood control. To a lesser extent, dams have been built to improve water supply and river transportation or for recreational purposes. Recent data show a trend towards multi-purpose dams.

Furthermore, there is considerable variation in the functions served by large dams and these functions have changed over time [WCD, 2000]. For example, the majority of large dams in Africa and Asia are for irrigation, but there is a growing interest in dams for flood protection and in pumped storage dams for power generation to meet peak demands in Asia.

Concerning severe accidents in the hydro power chain only dams used primarily for hydroelectric power generation are considered. Most hydro power plants are conventional in design, i.e., they use one-way water flow to generate electricity. Run-of-river plants use little, if any stored water, to provide water flow through turbines. This type of plants exhibits significant fluctuations in power output due to seasonal changes in discharge of rivers, whereas storage plants have enough storage capacity to compensate seasonal fluctuations in water flow and provide a constant supply of electricity throughout the year. In contrast to conventional hydro power plants, pumped storage plants reuse water. After water initially produces electricity, it flows from the turbines into a lower reservoir located below the dam. During off-peak hours (periods of low energy demand), some of the water is pumped into an upper reservoir and reused during periods of peak-demand.

4.6.1.6 Risks and failures of large dams

The International Commission on Large Dams [ICOLD, 1995] defines a dam failure as “Collapse or movement of part of a dam or its foundations so that the dam cannot retain the stored water”. This definition does not address partial dam failures. The dam is considered failed when all stored water is released.

Embankment dam failures can be grouped into three general categories, although the various types may often be interrelated in a complex manner. For example, uncontrolled seepage may weaken the soil and lead to a structural failure.

Overtopping failures:

Overtopping failures result from the erosive action of water on the embankment. Erosion is due to uncontrolled flow of water over, around, and adjacent to the dam. Earth embankments are not designed to be overtopped, and therefore are particularly susceptible to erosion. Once erosion has begun during overtopping, it is almost impossible to stop.

Seepage Failures:

All earth dams have seepage resulting from water percolating slowly through the dam and its foundation. Seepage must, however, be controlled in both velocity and quantity. If uncontrolled, it can progressively erode soil from the embankment or its foundation, resulting in rapid failure of the dam.

Structural Failures:

Structural failures can occur in either the embankment or the appurtenances. Structural failure of a spillway, lake drain, or other appurtenance may lead to failure of the embankment.

4.6.2 China's hydro power industry

4.6.2.1 Large dams and reservoirs in China

Dam construction in China has a long history. The most ancient reservoir, Shaopi, was built during Eastern Zhou Dynasty (598-591 BC) in Anhui province. It is a 10 m high earth dam that has been in regular operation up to now [Zhang, 2000]. The well-known Dujiangyan irrigation project, which supplied 800'000 hectares in China, is ca. 2200 years old [WCD, 2000; Zhang, 2000].

Dam construction using modern technology adopted from abroad started in the first half of the 20th century. Before 1949 China had only 22 large dams [Zhang, 2000]. Since 1950 dam construction has developed very fast. At present, an estimated 85'000 dams of all types are in operation in China, excluding small farm-scale irrigation and mini and micro hydro power units [WCD, 2000]. China's actual number of large dams may be around 22'000; accounting for 46% of the world's large dams [WCD, 2000]. However, only 4434 large dams in China are contained in the voluntary World Register of Dams maintained by ICOLD [1998; 2000]. In Figure 51, the number of large dams for the world's top ten countries is given based on both WCD estimates and those contained in ICOLD's database. The figure suggests that ICOLD data for China are highly incomplete considering the huge difference between estimated and registered large dams.

According to Zhang [2000] China had 17'526 large dams with a height of 15-30 m and 4578 dams over 30 m (including 32 higher than 100 m) by the end of 1999. Additional 320 large dams were under construction, of which 23 are higher than 100 m [WCD, 2000].

Regarding dam type, embankment dams comprise the majority [ICOLD, 2000]. The number of concrete dams is gradually growing as dam heights steadily increase, but the new trend is towards the concrete faced rockfill dams and roller-compacted concrete (RCC) dams [Zhang, 2000].

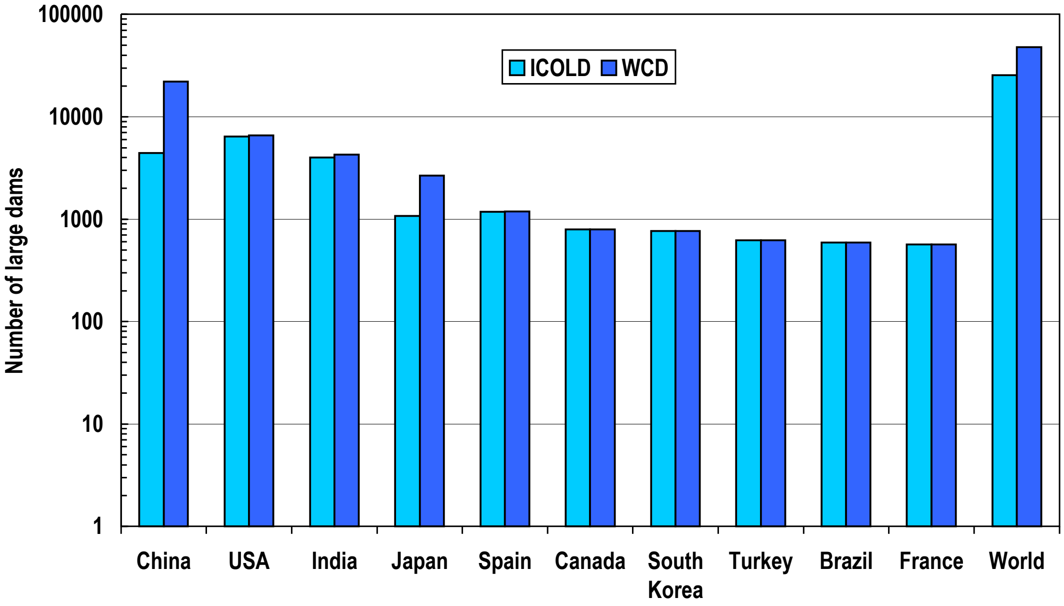

Figure 51: Top ten countries by number of large dams [WCD, 2000; ICOLD, 1998; 2000]. For comparison, estimated numbers of large dams according to WCD and number of dams registered at ICOLD are shown.

Figure 52 shows large dams in China according to purpose, based on ICOLD [2000] data. Irrigation dams (3982) are dominating, followed by hydro power (1758) and flood control (1031) dams. The figure further depicts that most dams serve more than one purpose, except for irrigation dams. Only 260, or 6% of China's large dams, are exclusively used for hydro power generation, whereas 1506, or 34%, are used for at least one other purpose besides hydro power.

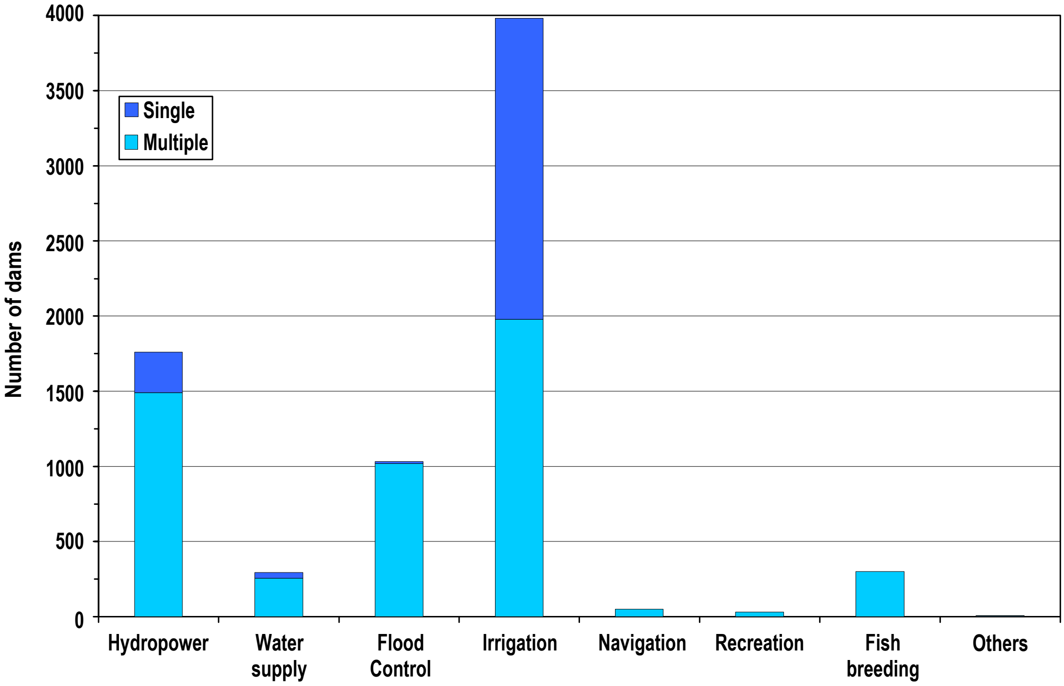

Figure 52: Large dams in China according to purpose, based on database by ICOLD [2000].

Considering sector developments some major topics emerge:

- China is the world leading country by number of large dams used for irrigation, flood control and hydro power [WCD, 2000].
- China's total irrigated area increased from 27 million hectares in 1957 to 51 million hectares today, corresponding to 54% of its cultivated area [WCD, 2000]
- Economic losses from floods were 30 billion USD a year in 1996 and in 1998 [WCD, 2000].
- Increasing demand and overexploitation of groundwater sources causes shortages in water supply in many cities. Shortfalls in those areas can be filled only by diverting water from agriculture, which in turn would imply that losses of irrigation water either must be compensated by switching to rainfed farming, if rainfall is sufficient, or the land has to be abandoned [Brown and Halweil, 1998].
- Although China has the most abundant hydro power resources in the world with an estimated potential of 376 GW, only about 20% or 76.8 GW have been developed by 2000 [ABB, 2001]. Unfortunately, there is great variation in climate and rainfall patterns within China; i.e., most hydro power resources are located in the southwest where approximately one-third of all hydroelectric power was generated in 1997 [Zhou et al., 2000]. Furthermore, suitable rivers are far from centers and carry enormous amounts of silt.

The Chinese government considers the Upper Yangtze and the Upper Mekong (Lancang River) as the most promising sites for hydroelectric developments. Among the sites already developed are Ertan (height 230 m; 2300 MW) in the Upper Yangtze, and Manwan (132 m; 1500 MW) on the Lancang. Apart from the Three Gorges Dam that is currently under construction, China will build two additional multi-billion-dollar reservoirs on the Yangtze River to generate power and trap sediment that would otherwise congest the Three Gorges Dam. The two dams, Xiluodu (height 273 m; 14'400 MW) and Xiangjiaba (161 m; 6000 MW), are located on the Jinsha River, which is on the Yangtze's upper reach in Sichuan and Yunnan provinces [Market Research Center, 2001; Zhang, 2000]. Many other large hydro projects are planned over the next 30 years, including Longtan (216 m; 4200 MW) and Xiaowan (292 m; 4200 MW). For additional information we refer to the studies by the Market Research Centre [2001] and Zhang [2000].

4.6.2.2 The Three Gorges Project

The Three Gorges Project (TGP) is probably the most famous example of the controversy surrounding large dams. In the 75 years since it was first proposed, a large body of literature has emerged detailing the information on TGP. In recent years this amount has been multiplied by a vast number of internet sites. The dam's economic, environmental and social benefits and impacts are still under debate. Unfortunately, in the majority of cases, results are presented in a somewhat biased manner, reflecting agreement or disapproval of the project. To obtain a more concise and balanced picture, this part of the report takes into account facts and arguments coming from both sides. Information sources considered were the Yangtze River Valley Water Resources Protection Bureau [YWRP, 2001], the Environmental Impact Statement for the Yangtze Three Gorges Project [Yintai, 1995], the FIVAS Report on Power Conflicts [FIVAS, 1996], the latest report on China's electric power market by the Market Research Centre [2001], the WCD thematic review on social impacts of large dams in China by Zhang [2000], the WCD country review paper by Fuggle et al. [2000], information provided by the International River Network [IRN, 1985-2001], and Probe International [1995-2001], among many other sources.

The TGP dam – on the main stem of the 6300 km long Yangtze River, the third longest river in the world – will be the world's largest and most expensive hydroelectric power station when completed in 2009 (Table 14). Some key characteristics of the TPG reservoir are summarized in Table 15. Hydro power capacity in China will increase by another 18.2 GW with an average annual output of 84.68 TWh. In addition to power generation, the 175 m high multipurpose dam is intended to control floods and assist river navigation. Finally, the dam will promote fisheries, tourism and recreation activities in the reservoir area. The artificial reservoir lake will have a length of 600-670 km and an average width of 1.1 km, resulting in a total storage volume of 393 x 10^8 m^3. The dam will force relocation of about 1.9 million people, inundation of 19 cities and 326 villages, loss of 2510 km^2 of farmland, and flooding of approximately 8000 cultural sites including the Ghost City Fengdu, the Shibaozhai "Pearl of the Yangtze", and the Leshan Giant Buddha.

The construction timetable can be divided into three parts:

- 1993-1997: Completion of diversion of Yangtze River.
- 1998-2003: Installation of the first batch of generators to produce hydroelectric power, and start of permanent ship lock to open for navigation.
- 2004-2009: Completion of the entire project; all 26 generators will be in operation.

Table 14: World's largest hydroelectric plants (>4000 MW capacity). Source: Information Please [2001].

Name of dam	Location	Rated capacity (MW)		Year of initial operation
		Present	Ultimate	
Three Gorges	China	-	18'200	2009
Itaipu	Brazil/Paraguay	12'600	14'000	1983
Guri	Venezuela	10'000	10'000	1986
Grand Coulee	Washington	6494	6494	1942
Sayano - Shushensk	Russia	6400	6400	1989
Krasnoyarsk	Russia	6000	6000	1968
Churchill Falls	Canada	5428	6528	1971
La Grande 2	Canada	5328	5328	1979
Bratsk	Russia	4500	4500	1961
Moxoto	Brazil	4328	4328	N.A.
Ust-Ilim	Russia	4320	4320	1977
Tucurui	Brazil	4245	8370	1984

N.A. = not available.

Table 15: Major characteristics of TGP dam

Location	Yangtze River, Sandouping near Yichang (Hubei)
Distance to estuary	1800 km
Height	175 m
Expected investment	about 25 billion USD
Installed power generation capacity	18.2 GW
Functions	Power generation, flood control, improved navigation
Reservoir area	1084 km^2
Length of reservoir	600-670 km
Average width of reservoir	1.1 km
Total storage volume	393×10^8 m^3
Regulated volume	165×10^8 m^3
Yearly runoff	451 billion m^3
Storage/runoff ratio	0.087 (seasonal regulation)

The TGP will have many-fold benefits and impacts on the economy, environment and society, with issues involved being complex and interrelated. The following list is far from being complete but it gives a brief overview of the major aspects.

Positive effects

- Politically, the completion of TGP will symbolize China's ambitions to become an industrialized country. In this context, TGP is needed to support economic growth.
- Hydroelectric power does not emit air pollutants. Therefore, the power produced by TGP will contribute to the control of carbon dioxide and sulfur dioxide emitted, and thus benefit the atmospheric environment.
- Supply of water and electric power to those badly needing them.
- Once completed the dam will prevent flooding by stopping floodwaters from reaching the lower areas of the Yangtze, resulting in a significant decrease of the damage caused by floods.
- TGP will strongly contribute to China's development. Construction of the dam provides many jobs, as well as numerous business opportunities such as construction of new cities in order to accommodate people who have been relocated from their original homes and to absorb new enterprises.
- Shipping will become faster, cheaper and safer due to improved navigation capacities, resulting in increased trade and commerce.
- Delivery of irrigation services; i.e., creation of new areas of arable land leading to increased production in agriculture and thus improvement of nutrition levels.
- Income from tourists and recreation opportunities.

Negative effects

Although environmental and social impacts have received most attention there are also some rarely considered economic and engineering impacts.

- The creation of the dam reservoir results in the inundation of large riparian and terrestrial areas altering the structure and function of these ecosystems. Furthermore, changes in discharge patterns, thermal regime and other environmental factors affect downstream aquatic, floodplain and coastal ecosystems and their biota. Besides a general decrease in biodiversity, numerous endangered species are impacted by the project including the Chinese Tiger, Chinese Alligator, Giant Panda, Siberian Crane and Yangtze Dolphin among others.
- Inundation of agricultural land, cities and villages necessitates very extensive resettlement of people, and may also lead to loss of traditions, lifestyles and cultures of the people affected. Additionally, adverse impacts on weak and disadvantaged groups or minorities cannot be fully excluded.
- Increased sediment deposition in the reservoir drastically reduces the downstream deltas and estuaries ability to function in land formation, and downstream fisheries and agriculture will be deprived of much needed nutrients. Farmlands near the estuary are likely to be destroyed as lower than usual river flow during dry seasons exacerbates the salinization. Finally siltation decreases the storage capacity of the reservoir requiring the application of special operation procedures to counter the problem.
- The dam will block the transport of woody debris, which provides important habitat structures, as well as the movement of migratory species causing habitat fragmentation and increased chance of extinction.
- Further concerns include water pollution, accumulation of biotoxic substances in sediments, the increased possibility of an outbreak of water-borne diseases (e.g., malaria and schistosomiasis), and large-scale landslides through increased erosion in the reservoir.
- The bedrock at the TGP site is subject to frequent weak earthquakes. It is believed that tectonic activity could increase due to stress from the weight of the reservoir and the dam. This may weaken the dam, causing damages ranging from minor to disastrous.
- The project engineers face many problems and challenges because the TGP is the largest dam ever built, thus they can only rely on scaling up experience from smaller projects.

4.6.2.3 Hydro power production

Figure 53 shows the world's top ten hydro power producers in 1999 [IEA, 2001] and for comparison the situation in 1990 and 1995. China ranks on the fourth position with a production about 40% lower than that of Canada. Hydro power production in Canada and USA remained at similar levels in the period 1990-1999, whereas it strongly increased in China (+161%) and Brazil (+142%). Currently, hydro power contributes about 6% to China's total primary energy, but it accounts for about 20% of China's electrical generation capacity, or almost all the electricity not generated by coal [SSB, 1999]. By

2009, TGP with its total installed capacity of 18.2 GW is expected to supply about 3% of China's power needs [Zhou et al., 2000].

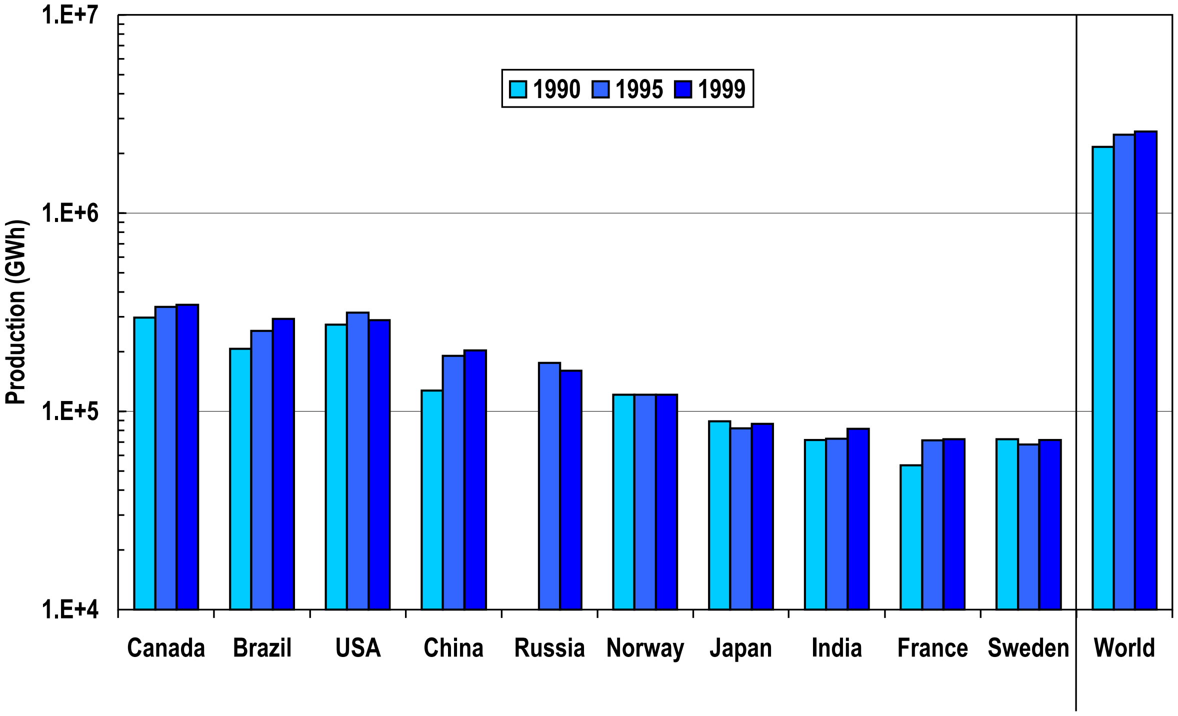

Figure 53: World's largest hydro power producers in 1999. Values for 1990 and 1995 are given for comparison. Data are from IEA [2001].

4.6.3 Severe accidents in China's hydro power chain

According to the Chinese Ministry of Water Resources, more than one third of China's estimated 85'000 dams are defective and must be repaired within the next decade to prevent disaster [BBC News Online, 1999; Muzi Lateline News, 1999]. Costs of government plans to reinforce 33'000 dams by 2010 are estimated to about 33 billion yuan (3.9 billion USD). For example, the Foziling, Meishan and Xianghogdian dams located on the Huaihe River in the western Anhui province are in bad condition after over 40 years of operation [Probe International, 1998]. In 1995, a special inspection team identified some major problems at the Foziling dam, such as enlarged crevices, leaks in several areas, low strength, and dam body displacement, but no repairs have been made since then. Therefore the water has to be kept at low level to reduce the danger of a dam collapse due to a serious flood event. The Meishan and Xianghogdian dams are also in urgent need of repair.

The following summary on failures of dams in China is based on Zhang (1997) and additional information from BBC News Online [1999], ICOLD [1995], Muzi Lateline News [1998b, 1999], Probe International [1998], Fu [1998] and Vogel [1998]. By 1973, 40% or 4501 of the 10'000 Chinese reservoirs with capacities between 10'000 and 1'000'000 m^3 have been built below project specifications and were unable to control floods effectively. In the period 1950-1990, 3241 dams of all purposes had collapsed, of which 123 or 3.8% were large dams and 3118 or 96.2% smaller sized dams. On average, China experienced 81 collapses per year, with the worst year being 1973, when 554 dams collapsed. The official death toll resulting from dam failures came to 9937, not including Banqiao and Shimantan collapses that accounted for 26'000 fatalities alone.

Table 16 shows failed dams of all purposes in China based on data from ICOLD [1995], Vogel [1998], official Chinese sources and the journal “International Water Power & Dam Construction” [1991-1995]. These dam-specific accident data are inconsistent with the overall dam collapse records provided above. Both, the number of specific accidents among all large dams and the number of specific accidents at hydro power dams appear rather low, suggesting this list could be highly incomplete.

- Considering that 40% of Chinese large dams are associated with hydro power purposes, roughly 50 of the 123 recognized collapses of large dams between 1950 and 1990 could be expected to be hydro power accidents. Even when assuming that hydro power dams are safer than other dams, this is in sharp contrast to the officially acknowledged three accidents, thus raising the question of underreporting.
- According to ICOLD data, 0.5% of dams built since 1950 (ex-China) have failed [WCD, 2000], compared to about 4% in China for the same time period [IRN, 1995-1999; Zhang, 1997].

Based on the available data no reasonably reliable evaluation of severe accidents is possible for hydro power, utilizing Chinese-specific data. Therefore, the pooled hydro power experience for non-OECD countries (including China) was used for comparative analyses (see Chapter 5).

Banqiao and Shimantan[6]

The Banqiao and Shimantan, two earthfill dams in the province of Henan, were completed in 1956 and 1952, respectively. In August 1975, a typhoon created a maximum 24-hour rainfall of 1005 mm and a three-day rainfall of 1605 mm in Zhumadian Prefecture of Henan Province, leading to the world’s most catastrophic dam failures. The floods overtopped the Banqiao dam causing its collapse, then the flood wave moved downstream destroying the Shimantan and about 60 smaller dams. More than one million hectares of land, over 100 km of the Beijing-Guangzhou railway line was damaged, countless of villages and small towns were submerged or partially covered, and millions of people lost their homes. Approximately 26’000 people (other sources state up to 85’000 people) were killed by the immediate flood waves from the failed dams, while further 145’000 died of epidemics and famine during the ensuing weeks.

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[6] Sources: DSO [1999], Human Rights Watch Asia [1995], Si [1998], WCD China country review [2000], World Rivers Review [1995]

Table 16: Severe accidents involving dams of all purposes in China.

Dam Name River Province	Dam Type	Purpose	Resevoir Volume (10^6 m³)	Construction year	Year of failure	No of Fatalities
Fushan Huai Shanxi	Earth	Block passage (1)	>10'000	516	516	10'000
Liaohe Huozehe Shanxi	N.A.	Irrigation	N.A.	N.A.	1973	29
Lijiazui N.A. Gansu	N.A.	Irrigation	N.A.	N.A.	1973	580
Banqiao Ru Henan	Earth	**Hydro power**	492	1956	1975	In total: 26'000
Shimantan Hong Henan	Earth	**Hydro power**	94.4	1952	1975	
Jishan &Wenchun Shanxi	N.A.	Irrigation	N.A.	N.A.	1977	30
Zianxinan I	N.A.	N.A.	N.A.	N.A.	1985	N.A.
Zianxinan II	N.A.	N.A.	N.A.	N.A.	1985	N.A.
Anhui	N.A.	N.A.	N.A.	N.A.	1986	N.A.
Wujiangdu Wujiang Guizhou	Gravity Arch	**Hydro power**	N.A.	1985	1989	28
Hongqi (2) Shanghai	Earth	N.A.	N.A.	N.A.	1991	N.A.
Gouhou Qinghai	Earth/ Rockfill	Irrigation	3.3	1988	1993	300
Changping Changpinghe Shanxi	N.A.	Irrigation	N.A.	1982	1997	30

(1) The Fushan dam on the Huai River was used to block passage across the Huai during an attack against the Wei Kingdom in AD 516.

(2) Deliberately breached to discharge water from Taihu lake, which was threatening to flood nearby cities.

4.7 Nuclear chain

4.7.1 *Background*

Figure 54 shows the development of the nuclear electricity production in OECD and non-OECD countries, in the period 1980 to 1999. For comparison, the respective values for China are also reported. After a major expansion phase in the eighties, a phase of stagnation followed in the nineties. This is also corresponding to the decreasing number of nuclear power plants taken into commercial operation after the peak in 1985 with 38 new plants [Hirschberg et al., 1998]. The figure further illustrates China's marginal contribution to total non-OECD nuclear electricity production. This is not surprising since the share of nuclear energy to China's electricity output roughly amounts to 1% in 1999. In contrast, more than 15 countries cover at least 25% of their electricity demand using nuclear based electricity [Hirschberg et al., 1998].

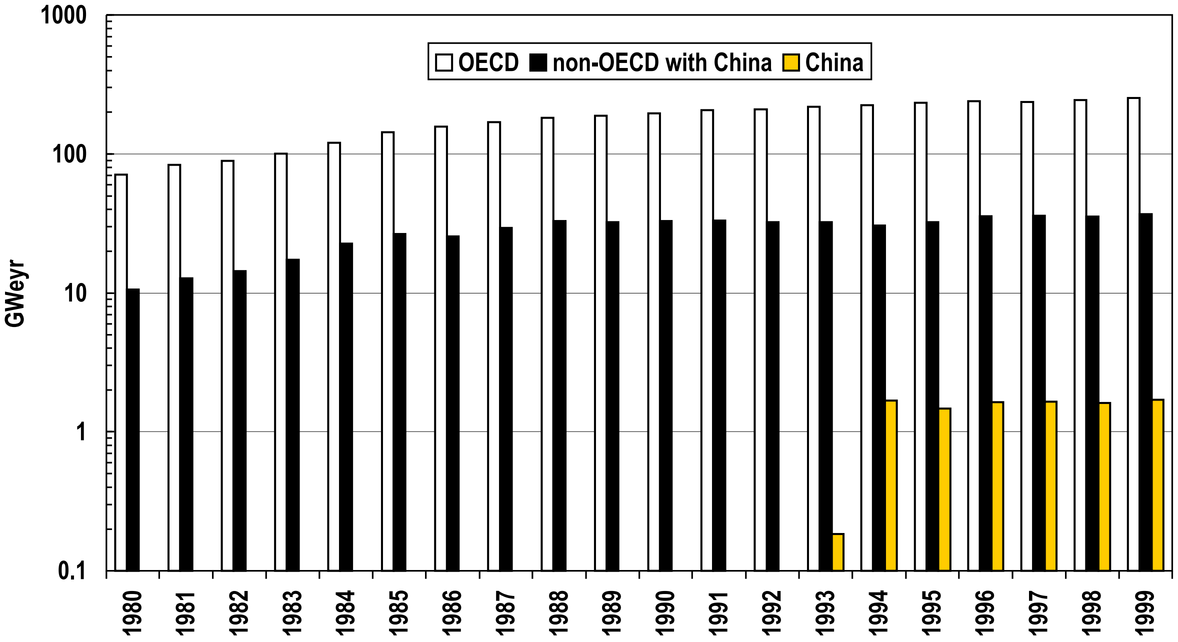

Figure 54: Nuclear electricity production in OECD and non-OECD countries between 1980 and 1999. Respective values for China are also given for comparison. Source: Data are from IEA [2001].

According to IAEA [World Atom Press Release, 2001; PRIS, 2002] China had 3 units in operation by the end of 2000 with a net capacity of 2167 MW_e, whereas another 8 units with 6420 MW_e were under construction. In 2000, nuclear power in China delivered 16 TW_eh to the grid, amounting to 1.2% of the country's total. A more detailed overview of the current status of China's installed and planned nuclear power capacity is given in Table 17. In addition, other sources report projects in Shandong (2 x 1000 MW), Zhejiang (Qinshan Phase IV 2 x 1000 MW and Sanmen 2 x 1000 MW), Fujian (2 x 1000 MW) and Guangdong (Yangjiang 6 x 1000 MW) [Nuclear Europe Worldscan, 2000].

Table 17: Current status of China's installed and planned nuclear power capacity. Op = operational, Uc = under construction, PWR = Pressurized Water Reactor. Source: PRIS, 2002.

Name	Type	Status	Province Location	Capacity (MW_e) Net	Capacity (MW_e) Gross	Date Connected
Guangdong 1	PWR	Op	Guangdong, Daya Bay	944	984	1993
Guangdong 2	PWR	Op	Guangdong, Daya Bay	944	984	1994
Lingao 1	PWR	Uc	Guangdong, Ling Ao	935	985	2002
Lingao 2	PWR	Uc	Guangdong, Ling Ao	935	985	2002
Qinshan 2-1	PWR	Uc	Zhejiang, Qinshan Phase II	610	642	2002
Qinshan 2-2	PWR	Uc	Zhejiang, Qinshan Phase II	610	642	2002
Qinshan 3-1	PWR	Uc	Zhejiang, Qinshan Phase III	665	728	2002
Qinshan 3-2	PWR	Uc	Zhejiang, Qinshan Phase III	665	728	2003
Qinshan 1	PWR	Uc	Zhejiang, Qinshan Phase I	279	300	1991
Tianwan 1	PWR	Uc	Jiangsu, Tianwan (Lianyungang)	1000	1060	2004
Tianwan 2	PWR	Uc	Jiangsu, Tianwan (Lianyungang)	1000	1060	2005

There are currently no nuclear plants in the Shandong province but building them in the near future is seriously considered by the local utility (Shandong Electric Power Corporation; SEPCO). Thus, nuclear energy is strongly represented in a number of scenarios analysed within the CETP.

The analyses of severe accidents, carried out for fossil energy carriers, were primarily based on historical accident records. Particularly in the case of coal, the dominant energy carrier, the statistical basis is very rich. For the nuclear energy there are fortunately no relevant statistical records. There is only one accident in the history of commercial nuclear power (Chernobyl in 1986), with severe consequences in terms of health effects, damages to the environment and economic losses. Since the design characteristics of the Chernobyl plant (reactor type and important safety features) show no parallels with the candidate plants that could be built in the future in the Shandong province, the Chernobyl accident is considered as irrelevant for the purpose of this work. Use of a probabilistic approach for the comparative evaluation of nuclear risks is necessary. For the detailed discussion of the Chernobyl accident and the associated risk comparisons we refer to [Hirschberg et al., 1998].

4.7.2 Analysis scope

The assessment concentrates on nuclear power plants as the issue of severe accident risks is in relative terms most significant for the power generation stage within the nuclear energy chain.

Based on probabilistic considerations, a simplified assessment of accident risks associated with future nuclear plants in the Shandong province, was carried out. Three alternative advanced designs as well as two designs representing currently operating plants were considered in two locations on the opposite sides of the Shandong peninsula. The reference advanced designs are a KWU/EDF Pressurized Water Reactor (PWR) [Eyink, 1997], an

Advanced Boiling Water Reactor, ABWR 1000 [Jo et al., 1991], and a modernized Russian VVER-1000. The considered currently operating plants are a Siemens/KWU PWR, a BWR with MARK-III containment [ERI/HSK, 1996; 1999; HSK/KSA, 1996; 1999; SKI, 1999], and a VVER-1000 of old design [Mladý, 1999)]. The probabilistic data (core damage frequencies, accident sequences, source terms) for the plants of newer generation is not public, however, total core damage frequency and makeup of accident sequences can be extrapolated from the public information for the KWU and ABWR plants, and public information from risk assessments for similar, though less advanced plants, can be used as a surrogate. Note that, very little information is available in the public literature about VVERs of the new design, and little information is also available about VVERs of the older generation. For this reason, only qualitative statements will be made about these types of plants.

For all these cases a simplified evaluation was undertaken, leading to the quantification of the expected risks of hypothetical nuclear accidents. The results are provided in terms of usual risk indicators, specifically, early, late and latent fatalities, land contamination, and maximum credible consequences, and the associated frequency-consequence curves. Formal uncertainty treatment is not feasible within the constraints of the present work, but some indication is provided, based on past evaluations of offsite risks.

The numerical assessment of the accident risks associated with future nuclear plants in Shandong province covers two types of reactors, i.e. BWR and PWR. Each of them was characterized by two Core Damage Frequencies (CDFs) differing by one order of magnitude, corresponding to current and advanced (evolutionary) designs. The plants were located at two sites (Qingdao and Yantai) in the Shandong province with different population density and land fraction relevant for the assessment of consequences of hypothetical accidents. Offsite consequences were assessed on the basis of extrapolation from known results, one from an European site with relatively large population density, and one from a US site, as discussed in the following section and in Appendix E.

4.7.3 Probabilistic methodology

A methodology for a simplified assessment of offsite consequences resulting from a severe accident is briefly described in this section. A simplified model was chosen as it is compatible with publicly available information while using appropriate elements from Probabilistic Safety Assessment (PSA). The full-scope PSA-based assessment of offsite risks for a given plant is a very complex process. For a detailed account of the overall PSA methodology we refer to [USNRC, 1989]. While, the model adopted here can be considered a straightforward development of the methodology used to assess offsite consequences [USNRC, 1989].

A PSA consists of three levels of assessments. The so-called Level 1 deals with plant behavior following a disturbance (accident initiator). Systems behavior and interactions must be modeled, including operator interventions. This part of the study leads to an assessment of Core Damage Frequency (CDF), with associated uncertainties. The number of possible accident sequences can range into billions, but for each sequence the CDF is normally very small, so accident types are grouped by similarity in plant behavior into a finite number of Plant Damage States (PDSs). These are further studied in the Level 2 PSA, which deals with post core damage response by the plant. Level 2 considers severe accident phenomena, and for each PDS, end states of the containment and possible releases of radioactivity to the environment are evaluated. Again, for each PDS depending on complexity of post core damage systems available, up to 100 source terms could result. Therefore, in a typical probabilistic assessment when uncertainties are propagated a very large number of possible source terms are calculated.

These are normally reduced for the Level 3 assessment, which deals with offsite consequences into a manageable number of source terms. The reduction is performed on the basis of simple tools, which in [USNRC, 1989], consisted of a model, named PARTITION, that roughly estimates early and latent fatalities for each source term using the release of activity of Iodine and Cesium alone. This estimate is in part site-specific (i.e., includes a weighting factor for the population which could be affected). All source terms with approximately equal consequences are thus “partitioned” to representative source terms, with a single, average release of all radionuclides, and consequences are then calculated using more detailed probabilistic codes, such as MACCS, and more site-specific uncertainties and characteristics such as weather and population are factored in. Evaluated consequences include immediate health effects, delayed health effects, and possibly economic consequences.

As described, and exemplified in Figure 55, the complete process requires many resources. Just for the preparation of a site-specific input to a consequence code an extensive work volume is required. For this reason, simplified methods are necessary, given time and resource constraints.

An extension of the PARTITION model is used here: offsite risk measures are calculated for the same reactor, with operating power equal to 3600 MWTh, for two hypothetical accidents, one with late containment rupture at relatively high elevation, and one with an early release occurring at much lower elevation. Data for two different sites is used for the dispersion and dose calculations, the first a European continental site with relatively large population density in the vicinity of the plant, and the other a US site with overall relatively low population density. More details are provided in Appendix E. Site-specific calculations for plants located in China were not performed using MACCS, lacking the very detailed population and weather data needed by the code.

The calculations were performed for each of nine radionuclide groups (see section 4.7.4 for the definition and core inventories used), assuming that 100% of the group is released to the environment, without offsite countermeasures, and without cut-offs in effectiveness of doses in inducing cancers. The consequences were correlated then to the released activity, and factors (or effectiveness in causing consequences) were derived for each radionuclide group, i.e, consequences per Bq released. Consequences which were considered are early fatalities (i.e., deaths occurring because either inhalation or immersion in the passing cloud delivers doses larger than what is considered a lethal dose, approximately 3 Gy), delayed cancer deaths due to doses from ingestion and inhalation while the cloud is passing, late cancer deaths due to doses incurred mostly from ingestion of water and foodstuffs, and severely contaminated areas (which may be lost for up to 20 years or longer). Delayed cancer deaths together with late cancer deaths are normally called late fatalities, but due to the different pathways for exposure, they should be accounted for separately.

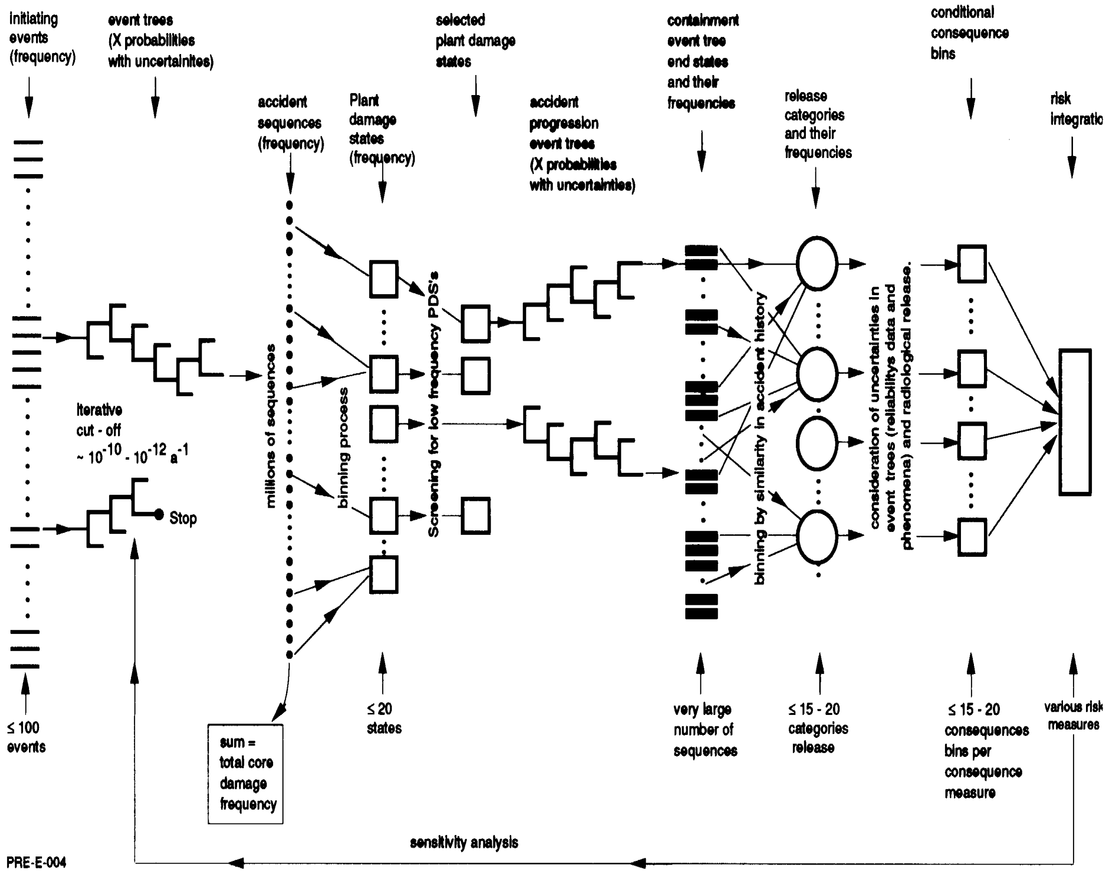

Figure 55: Exemplification of a Probabilistic Safety Assessment [from Cazzoli et al, 1993].

The calculations showed that the Xe group (noble gases) has essentially no influence on offsite consequences, with the exception of a background effect in late cancer fatalities (i.e., only released aerosol shows appreciable consequences). Moreover, the effect of the time of release (from reactor scram, and start of radioactive decay) appears to have little influence on delayed health effects. This is because only long-lived radionuclides are relevant for late health effects. It was found that severe land contamination appears to be only due to the Cs and Sr groups. Early health effects, on the other hand, are dominated by the I and Te groups, which include for the most part relatively short-lived radionuclides.

In addition, the MACCS calculations showed that health effects are strongly correlated to the total population that can be affected, while the variability in weather from site to site appears to play a secondary role. It must be remembered that the full scope consequence code MACCS [Chanin et al., 1993] is a probabilistic tool, and calculations of cloud dispersion in first approximation do not include wind direction. The windrose, or real wind direction, is considered later in the calculations, when probabilities are assigned to possible consequences, according to frequency in wind direction, but since the code uses a Latin Hypercube Sampling (LHS) technique, i.e., with a very limited number of Monte Carlo samples, the probabilities assigned to a given weather and wind direction may be homogenized, and therefore, wind direction plays a small role in the calculations. In fact, while in the input specifications, 16 wind directions, and 8760 hours of weather data are specified, the LHS sampling chooses typically only about 100 hours without specific information on the wind direction for the start of the calculations. It is for this reason that uncertainties in weather variability are not shown in this type of probabilistic results, and only point value estimates for offsite consequences are provided. The only alternative to overcome this point would be to perform deterministic calculations for each of the 8760 hours. From the point of view of a probabilistic study, the results obtained with a code such as MACCS can be considered as representative within factors of two or three. This does not include the uncertainties associated with source terms. The overall uncertainty band for the consequences typically corresponds to a factor of ten.

As shown later, the coefficients derived from the various MACCS calculations (i.e., effects per Bq released) appear to be approximately consistent with the ratio of populations and land fractions, irrespective of weather variability.

In particular, early fatalities can be extrapolated from one site to another from the ratio of population within 8 to 10 km. This is because the radioactive content in a passing cloud is effectively dispersed over a very large volume very quickly (the MACCS code uses a Gaussian plume dispersion model, as recommended by the IAEA), and the MACCS calculations show that acute mortality distance does not exceed 20 km under the worst possible weather conditions (i.e., with very small probability), since beyond this distance doses exceeding 3 Gy, i.e., the immediate mortality limit, are shown not to be delivered under any circumstance.

Delayed cancer deaths are found to be strongly correlated to the total population within 80 to 120 km. The MACCS calculations show that only a very small background of delayed fatalities may occur beyond this distance. This, again, is due to cloud dispersion and dilution of activities, since the dose must be incurred via inhalation or submersion in the passing cloud. Cancer deaths occurring from ingestion (late deaths) are found to be correlated to the total population in the site considered. For both sites, a maximum distance of 800 km was covered, therefore, late deaths are considered proportional to the ratio of populations within 800 km. The calculations for the US site were extended to 1600 km, and the results in this case differ only by fractions of 1% with respect to the results to 800 km.

Finally, land contamination is assumed to be correlated to the ratio of land fractions to 120 km, even though the correlation was found to be weaker than the ones found for health effects. A distance of 120 km is assumed for this type of calculations, because the MACCS results show that the maximum distance where land can be severely contaminated does not exceed 120 km for any of the radionuclide groups.

In conclusion, offsite consequences may be calculated in first approximation using activity of releases, as provided by Level-2 PSAs for the relevant source terms, and the ratios which are discussed above. For the assessment of early fatalities, the ratios for the early release sequence should be used, since they provide more conservative figures (as mentioned, early fatalities are mostly due to short-lived radionuclides).

It must be emphasized that the results, which may be obtained using this simplified methodology, should be viewed as order-of-magnitude results. On the other hand, uncertainties in probabilistic calculations themselves are normally very large.

4.7.4 Assumptions

The main assumptions are related to two different locations in the Shandong province, which were considered as possible sites for new NPPs (see Figure 56), and to the different types of NPPs, as discussed earlier.

4.7.4.1 Sites, population

Two sites are considered for the present calculations (see Fig. 56):

- A site around Yantai with relatively low population density to 20 km (the town counts ca 200’000 citizens)
- A site around Qingdao with high population density (the location chosen would account for ca 2.2 million citizens within 20 km; this figure is called N_Q in the following discussion)

The precise location of the NPPs was assumed at about 10 km from the city limits, and three different areas for consequence calculations around the planned NPPs were considered, according to the probabilistic methodology discussed in section 4.7.3 (see also Figure 56):

a. to 8 km radius

b. to 100 km radius

c. to 800 km radius

The Shandong province had in 1999 a population of 88 million, and an area of about 153’000 km^2 [ABB Corporate Research, 1999].

Considering the average population growth rate for China 1.2% per year according to Harenberg [1995; 2000], an estimate of the population in the entire Shandong Province in 2001 is about 90.973 million, i.e., the average population density in the Shandong province is currently about 595 pers./km^2).

Large cities or urban areas with much higher density of population would misrepresent the average density in the areas considered in the present work, especially at Yantai. For this reason, the population of the largest urban areas in the province (Qingdao, Yantai, Jinan, Jining and Weifang), i.e., about 6.5 million people [Microsoft Encarta, 1999], was subtracted from the total population in the province, and a corrected average population density was calculated (ca. 552 pers./km^2= $\boldsymbol{a}$)

Both the Yantai and Qingdao sites are located near the seashore, so the number of people (in the region to 8 km and 100 km radius area from the sites) was assessed according to the ratio of land and water [Microsoft Encarta, 1999] (Figure 56, Table 18).

Figure 56: Maps with distances. Large and small circles have a radius of 800 km and 100 km, respectively. GIS-Source: ESRI Data & Map CD.

Table 18: Population in Qingdao and Yantai sites.

	100% circle area	**Qingdao**	**Yantai**
to 8 km radius	201.06 km^2	100.53 km^2 (50% of circle)	90.48 km^2 (45% of circle)
to 100km radius	31’415.92 km^2	15'707.96 km^2 (50% of circle)	11’623.89 km^2 (37% of circle)

Yantai

The population density in the Yantai site is expected to be lower than around Qingdao; the population to 8 km and 100 km is based on corrected average density in the whole Shandong province and on the land area in the region.

- Population to 8 km radius: 49’944 (ca **50’000**)
  (45% of circle with radius of 8 km)
- Population to 100 km radius: 6’416’387 (ca **6.4 M**)
  (37% of circle with radius of 100 km)

The population to 800 km radius in 2001 was calculated according to the number of citizens in particular provinces [ABB Corporate Research, 1999] in 1997, South and North Korea [Harenberg, 1995; 2000] in 2000, and considering average growth rates [Harenberg, 1995; 2000] (see Figure 57). The following data was used to 800 km radius:

1997: 100% of Beijing (12.4M), 100% of Tjanjin (9.53M), 100% of Hebei (65.25M), 50 % of Shanxi (15.7M), 100 % of Liaoning (41.38M), 60% of Jilin (15.77M), 100% of Shanghai (14.57M), 100% of Jiangsu (71.48M), 15% of Zhejijang (6.65M), 70% of Anhui (42.89M), 100% of Shandong (87.85M), 40% of Henan (36.97M), 10% of Inner Mongolia (2.33M), **Total 422.77M**

The average growth rate for the listed provinces is 1.2% per year [Harenberg, 1995; 2000]. The whole of South and North Korea are included in the assessment of population, even though a small fraction of North Korea is outside of the 800 km.

2000:	South Korea:	46.8 M, average growth rate 1% [Harenberg, 1995; 2000]
	North Korea:	25.5 M, average growth rate 1.7% [Harenberg, 1995; 2000]
2001:	China:	443.43 M
	South Korea:	47.3 M
	North Korea:	25.9 M
	Total:	516.6 M (ca **517 M**)

Qingdao

Because of expected higher population density, the population for the Qingdao site was calculated as follows:

- Population to 8 km radius: land area (50%) * (**a** + $\mathbf{N_Q}$/50% of area in 100 km radius)
  = 100.53 km^2 *(552 p./km^2 + 2.2 M /15’707.96 km^2) =
  = 69’573 (ca **70’000**)
- Population to 100 km radius: **a** * land area (50%) + $\mathbf{N_Q}$ =
  = 552 p./ km^2 * 15’707.96 km^2 + 2.2 M =
  = 10’872’504 (ca **10.9 M**)

Population to 800 km radius in 2001 was calculated according to number of citizens in particular provinces [ABB Corporate Research, 1999] in 1997, and South and North Korea [Harenberg, 1995; 2000] in 2000 considering average growth rates [Harenberg, 1995; 2000] as follows (see Figure 57):

1997: 100% of Beijing (12.4 M), 100% of Tianjin (9.53 M), 100% of Hebei (65.25 M), 90% of Shanxi (28.27 M), 100% of Liaoning (41.38 M), 2% of Jilin (0.53 M),100% of Shanghaij (14.57 M), 100% of Jiangsu (71.48 M), 60% of Zhejiang (26.61 M), 100% of Anhui (36.76 M), 100% of Fujan (19.69 M), 5% of Jiangxi (2.08 M), 100% of Shandong (87.85 M), 90% of Henan (83.19 M), 10% of Hubei (5.87 M), **Total 505.45 M**

The data shown above consider an average growth rate of 1.2% per year [Harenberg, 1995; 2000].

For the Korean contribution, the assumptions are as follows: 50% of North Korea, 100% of South Korea.

2000: South Korea: 46.8 M, average growth rate 1% [Harenberg, 1995; 2000],
North Korea: 25.5 M, average growth rate 1.7% [Harenberg, 1995; 2000], 50%=12.75 M

In summary:
2001: China: 530.16 M
South Korea: 47.3 M,
North Korea: 12.97 M
Total: 590.4 million people (ca **590 M**)

4.7.4.2 NPP types

Three types of advanced reactors were considered to estimate consequences following hypothetical accidents in the two sites of Shandong Province:

a. KWU/EDF PWR [Eyink, 1997], or EPR

b. European ABWR 1000 [Jo et al., 1991]

c. VVER 1000 [Mladý, 1999]

For western types of reactors two levels for Core Damage Frequencies are used in the present work:

a. One corresponding to that of current NPPs [ERI/HSK, 1996; 1999; HSK/KSA, 1996; 1999; SKI, 1999], ranging from 2E-6/Ryr[7] to 5E-5/Ryr. In fact, results of PSAs for existing Swiss plants are used. The two plants, a BWR with MARK-III containment, and a Siemens/KWU PWR plant, have been assessed to have a total CDF of about 4E-6/Ryr and 2E-6/Ryr, respectively, including some area and external events. It must be noted that neither plant was constructed with specific consideration for severe accident progression.

b. One ten times lower than that for current NPPs (of the order of 1E-7/Ryr to 1E-6/Ryr), to account for advanced features in the designs. The differences due to advanced features will be discussed later, thus justifying this assumption. Briefly, the new designs account for many severe accident progression features, such as less dependence on operator interventions, passive systems, stronger containments, etc.

For VVER-1000 type NPPs, published data [Mladý, 1999] indicates that, even forthe most recently built plants, core damage frequency is of the order of 1E-4/Ryr, i.e., typically one order of magnitude higher than for plants of Western design. Extrapolating from this figure, since for the proposed designs (ABWR and EPR) CDFs are assumed to be one order of magnitude lower than for non-advanced Western reactors, it is plausible to assume that total CDF for advanced VVERs could be of the order of 1E-5/Ryr, i.e., still about two orders of magnitude higher than the CDF used for the EPR design.

Table 19 shows design similarities and differences between the known or assumed features of the advanced designs, and of the plants, which have been used as reference. The combination of improved features as implemented in advanced designs would reduce the expected core damage frequency from internal initiators, especially for the PWR type, which now would implement some passive features. The advanced BWR, as opposed to the currently operating plants, would implement extended containment systems, including a larger containment capacity, thus having only effects on the end states of the containment. The core damage profile is however assumed to be similar. It should be noted that using more modern equipment with a presumable lower failure rate, would possibly much reduce accident initiator frequency and improve systems reliability. Finally, similarity of design would assure that severe accident progression would be similar to what is assessed for the operating plants used for reference, with exceptions that will be discussed later.

Table 20 shows the core inventories used for the present assessment. The inventories are taken from [ERI/HSK, 1996], and are based on ORIGEN calculations for an end-of-cycle core with MOX fuel, for the BWR plant. Inventories for a PWR core are slightly different, especially in the Sr-Ba content, but the difference is within the uncertainties generated by the ORIGEN code itself (about 20 to 30%).

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[7] Ryr = Reactor*year

Table 19: Similarities and differences between basic and advanced types of NPPs.

Feature/NPP type	BWR	ABWR	PWR	EPR	VVER	VVER advanced
Thermal power (MWTh)	3600	3600	3000	3600	3600	3600
Containment venting	yes	yes	yes	no	no	not known
Additional Decay Heat Removal (DHR) systems	yes	yes	yes	yes	no	no
AC/DC hydrogen igniters	yes	yes	no	yes	no	not known
Passive Emergency Core Cooling System (ECCS)	yes	yes	no	yes	yes	not known
Improved Reactor Protection System (RPS) as protection against Anticipated Transient withouth Scram (ATWS) events	no	yes	not relevant	not relevant	not relevant	not relevant
Suppression pool	yes	yes	no	yes	no	not known
Containment capacity	< 5 bar	>> 5 bar	8-10 bar	> 10 bar	5-10 bar	not known
Severe Accident Management (SAM) Measures	BWR Owners Group, to be implemented	As for BWR with MARK-IIIcontainment, but with added cavity flooding	Siemens/ KWU defined, without hydrogen control devices	Siemens/ KWU defined, assuming hydrogen control devices	not known	not known
Core catcher	no	no	no	yes	no	not known

Table 20: Initial Core Inventories, with 3600 MWTh operating power.

Radionuclide group	Initial Activity in Core (x 10^{15} Bq)
Xe	1.6E4
I	3.1E4
Cs	1.1E3
Te	9.0E3
Sr	8.9E3
Ru	1.2E4
La	3.8E4
Ce	9.3E4
Ba	6.6E3
Mo	1.2E4

4.7.4.3 Source terms

As a basis for the calculations of risks and consequences, source terms were taken from officially published references for both BWR and PWR NPP types [ERI/HSK, 1996; 1999; HSK/KSA, 1996; 1999; SKI, 1999]. The source terms are shown in Tables 21 (PWR) and 23 (BWR). Activities of release are presented in Tables 22 (PWR) and 24 (BWR).

For advanced reactors both end states of containment and absolute release fractions are assumed to be the same as for the European plants, mostly due to similarities in Severe Accident Management (SAM) systems, preventive systems and design (especially containment capacity). Due to these similarities, accident progression following a given initiator, i.e., what follows post core damage and containment phenomena, is not expected to be different. However, for the EPR reactor type there are some major differences in the profile of frequency of containment end states because of the core catcher, which may effectively prevent basemat melt-through, and because almost no containment failure due to hydrogen combustion would be expected due to igniters and recombiners. Improved protection against containment isolation failure is also to be expected.

Radionuclides groups used in source terms (Tables 21 and 23) slightly differ from those shown in Table 20. Sr includes also the Ba group, the Mo group is included in the Ru group, and the La group in source terms consists of Ru, Ce and La combined.

Table 21: Source terms for PWR.

Release class	Xe	I	Cs	Te	Sr	La
RC1	9.10E-01	1.80E-01	1.80E-01	1.40E-01	1.70E-02	5.80E-03
RC2	9.60E-01	3.00E-02	3.00E-02	3.50E-02	1.00E-02	1.20E-03
RC3	9.50E-01	6.00E-03	6.00E-03	7.00E-03	2.70E-03	2.40E-04
RC4	1.70E-03	4.20E-06	4.20E-06	6.00E-06	1.60E-06	2.90E-07
RC5	5.00E-04	7.90E-06	7.90E-06	6.00E-06	7.00E-07	5.00E-07
RC6	3.30E-01	1.00E-01	1.00E-01	4.80E-02	1.00E-02	7.40E-03
RC7	3.70E-01	1.60E-01	1.60E-01	1.20E-01	1.00E-02	1.20E-03

Table 22: PWR releases in Bq.

Release class	Xe	I	Cs	Te	Sr	La
RC1	1.46E+19	5.58E+18	1.98E+17	1.26E+18	2.55E+17	9.28E+17
RC2	1.54E+19	9.30E+17	3.30E+16	3.15E+17	1.50E+17	1.92E+17
RC3	1.52E+19	1.86E+17	6.60E+15	6.30E+16	4.05E+16	3.84E+16
RC4	2.72E+16	1.30E+14	4.62E+12	5.40E+13	2.40E+13	4.64E+13
RC5	2.72E+16	2.50E+14	8.69E+12	5.40E+13	1.05E+13	8.00E+13
RC6	5.28E+18	3.10E+18	1.10E+17	4.32E+17	1.50E+17	1.18E+18
RC7	5.92E+18	4.96E+18	1.76E+17	1.08E+18	1.50E+17	1.92E+17

Table 23: Source terms for BWR.

Release class	Xe	I	Cs	Te	Sr	La
RC1	7.20E-01	1.20E-01	1.10E-01	2.80E-02	1.70E-02	2.00E-04
RC2	7.30E-01	7.80E-03	7.60E-03	3.40E-03	2.20E-03	2.10E-05
RC3	7.40E-01	8.80E-02	8.00E-02	3.70E-02	3.70E-02	4.30E-04
RC4	7.40E-01	6.30E-04	2.80E-04	1.00E-04	7.80E-05	6.60E-07
RC5	7.40E-01	5.00E-03	2.90E-03	1.30E-03	1.00E-03	1.10E-05
RC6	7.40E-01	1.50E-03	1.40E-03	9.20E-04	4.80E-04	4.70E-06
RC7	7.80E-01	5.90E-02	5.70E-02	2.90E-02	1.90E-02	2.60E-04
RC8	7.40E-01	8.40E-05	3.80E-05	1.80E-05	1.40E-05	1.20E-07
RC9	7.40E-01	6.60E-03	4.00E-03	1.80E-03	1.40E-03	1.60E-05
RC10	7.40E-01	1.50E-03	1.50E-03	8.60E-04	4.50E-04	4.30E-06
RC11	7.40E-01	2.50E-02	2.60E-02	8.30E-03	4.10E-04	4.80E-06
RC12	7.30E-01	4.10E-05	1.80E-05	7.40E-06	3.50E-06	3.20E-08
RC13	7.40E-01	2.20E-03	1.20E-03	3.40E-04	6.60E-09	2.00E-10
RC14	3.60E-01	5.20E-05	5.30E-05	4.00E-05	4.10E-05	4.10E-07
RC16	3.70E-01	4.00E-06	2.40E-06	1.50E-06	1.70E-06	1.50E-08
RC18	7.80E-01	3.90E-06	4.00E-06	2.60E-06	2.70E-06	2.70E-08
RC21	1.30E-01	1.50E-06	5.40E-07	2.80E-07	2.30E-07	1.80E-09

Table 24: BWR releases in Bq.

Release class	Xe	I	Cs	Te	Sr	La
RC1	1.152E+19	3.72E+18	1.21E+17	2.52E+17	1.462E+18	3.20E+16
RC2	1.168E+19	2.418E+17	8.36E+15	3.06E+16	1.892E+17	3.36E+15
RC3	1.184E+19	2.728E+18	8.8E+16	3.33E+17	3.182E+18	6.88E+16
RC4	1.184E+19	1.953E+16	3.08E+14	9.00E+14	6.708E+15	1.056E+14
RC5	1.184E+19	1.55E+17	3.19E+15	1.17E+16	8.60E+16	1.76E+15
RC6	1.184E+19	4.65E+16	1.54E+15	8.28E+15	4.128E+16	7.52E+14
RC7	1.248E+19	1.829E+18	6.27E+16	2.61E+17	1.634E+18	4.16E+16
RC8	1.184E+19	2.604E+15	4.18E+13	1.62E+14	1.204E+15	1.92E+13
RC9	1.184E+19	2.046E+17	4.40E+15	1.62E+16	1.204E+17	2.56E+15
RC10	1.184E+19	4.65E+16	1.65E+15	7.74E+15	3.87E+16	6.88E+14
RC11	1.184E+19	7.750E+17	2.86E+16	7.47E+16	3.526E+16	7.68E+14
RC12	1.168E+19	1.271E+15	1.98E+13	6.66E+13	3.01E+14	5.12E+12
RC13	1.184E+19	6.82E+16	1.32E+15	3.06E+15	5.676E+11	3.20E+10
RC14	5.76E+18	1.612E+15	5.83E+13	3.60E+14	3.526E+15	6.56E+13
RC16	5.92E+18	1.24E+14	2.64E+12	1.35E+13	1.462E+14	2.40E+12
RC18	1.248E+19	1.209E+14	4.40E+12	2.34E+13	2.322E+14	4.32E+12
RC21	2.08E+18	4.65E+13	5.94E+11	2.52E+12	1.978E+13	2.88E+11

No reliable data on consequences for VVER plants has been published; however, it can be concluded that risks for a VVER design, located in the Shandong peninsula, would be at least one order of magnitude higher than the consequences estimated for the BWR and PR plants, given a higher core damage profile.

4.7.4.4 Offsite consequences

Offsite consequences are calculated for the number of fatalities and area of severely contaminated land. In detail, the following health consequences are considered:

Fatalities

Early fatalities
Early fatalities were considered to occur in a short time period after exposure, and the calculation involves early fatalities in the area up to 8 km of radius from the source of the release.

Late fatalities
Late fatalities were considered to occur due to early exposure in a longer time period. These fatalities are due to the passage of the radioactive cloud, and are mostly due to inhalation and immersion. Population in a radius of 100 km from the plant is used.

Delayed fatalities
Delayed fatalities were considered to occur due to delayed exposure (long term decay) in a long time period in the area up to 800 km of radius from the source of the release.

Latent fatalities
Latent fatalities are the total number of fatalities occurring within 60 years from the accident time period, and this includes the sum of late and delayed fatalities.

Land contamination

Land contamination due to releases after a hypothetical accident was calculated in the area up to 120 km of radius from the source of release, since beyond 120 km the cloud would be so diluted that very high levels of ground activity would not be expected. Heavy land contamination is considered to the extent that the land cannot be decontaminated effectively within several years, as discussed below.

Calculations consider also the ratio of land and water according to the shape of the shore [Microsoft Encarta, 1999].

– Area to 120 km radius:

Total (100% circle area)	Qingdao	Yantai
45’238.924 km^2	22’619.462 km^2 (**50 %**)	16’738.401 km^2 (**37 %**)

For land contamination both interdicted and condemned areas were taken into account. It should be remembered that in the present work interdicted area is land, which can be successfully decontaminated within 20 years and then resettled, and condemned area is land which cannot be decontaminated within 20 years.

Release sequences

Consequences for two specific release sequences were calculated with:

- One starting at two hours from scram, of short duration, and occurring at 100 m (stack elevation).
- A second one starting 20 hours after scram, of relatively long duration, and occurring at 10 m of height (see Appendix E).

One of the main assumptions leading to calculation of hypothetical consequences for Shandong Province was the fact that the ratio of population (**p**) and fatalities (**f**) of two different sites can be considered in first approximation to be the same:

p1/p2 = f1/f2

So, knowing the population and consequences for a reference site and the population for a different site enables to calculate also possible consequences for the other site.

Quotients (**q**) were thus used to calculate the consequences for Qingdao and Yantai sites.

q = p1/p2 = f1/f2 => **f1= q * f2** (see Table 25)

Calculations of consequences for reference sites were made with MACCS code, where two types of reference sites were considered: European with high population density, and US with lower population density.

Weather

The weather was assumed to be uniform (i.e., without a preferred direction) as in the US site. According to the information from [Hirschberg et al., 2003] related to the weather in the region, preferred wind direction for the sites considered in China is South/West, which could result in an added uncertainty of about 25% in the calculations. On the other hand, average precipitation in both reference sites is approximately the same as the average precipitation in the whole Shandong province, which is ca. 75 cm/year. Table 25 summarizes the results of population and land areas calculations, as well the quotients (ratios) used for further consequence calculations.

Table 25: Quotients for consequence calculations.

	European site	US site	Quotient q for US/EU site	Quingdao	Quotient q for Qingdao (*)	Yantai	Quotient q for Yantai (*)
Population to 8 km	24’000	1400	0.06	70’000	2.92	50’000	2.08
Population to 100 km	5E+6	2.2E+6	0.44	1E+7	2.00	6.4E+6	1.28
Population to 800 km	226E+6	90E+6	0.40	590E+6	2.61	517E+6	2.29
Land fraction to 120 km	0.97	0.75	0.77	0.5	0.67	0.37	0.49

(*) For population, the ratio is taken to the European site because of much higher population density (closer to European), while for the land fraction the ratio is taken with respect to the US site, which, as the Shandong peninsula, is situated in the proximity of the ocean.

In Tables 26 to 29 the data obtained for conditional consequences for both the Qingdao and Yantai sites is summarized, using the quotients shown in Table 25, on a radionuclide group basis. Detailed results of the calculations of conditional consequences (named "basic" in the Tables) are shown in Appendix E.

Table 26: Land contamination for Qingdao site with land lost in km^2/Bq.

Radionuclide group	Basic land contamination land lost in km^2/Bq	Qingdao land contamination land lost in km^2/Bq (q=0.67)
Xe	0	0
I	0	0
Cs	6.4 E-15	4.3 E-15
Te	0	0
Sr	2.7 E-15	1.8 E-15
La	0	0

Table 27: Land contamination for Yantai site with land lost in km^2/Bq.

Radionuclide group	Basic land contamination land lost in km^2/Bq	Yantai land contamination land lost in km^2/Bq (q=0.49)
Xe	0	0
I	0	0
Cs	6.4 E-15	3.1 E-15
Te	0	0
Sr	2.7 E-15	1.3 E-15
La	0	0

Table 28: Number of fatalities per Bq for Qingdao site.

Radionuclide group	Basic early fatalities per Bq	Qingdao early fatalities per Bq (q=2.92)	Basic late fatalities (a) per Bq	Qingdao late fatalities (a) per Bq (q=2)	Basic delayed fatalities (b) per Bq	Qingdao delayed fatalities (b) per Bq (q=2.61)
Xe	0	0	5.0 E-18	1.0 E-18	0	0
I	1.4 E-18	4.1 E-18	3.3 E-17	6..6 E-17	2.7 E-17	7.0 E-17
Cs	5.5 E-19	1.6 E-18	1.6 E-15	3.2 E-15	3.3 E-14	8.6 E-14
Te	1.2 E-17	3.5 E-17	3.4 E-16	6.8 E-16	1.3 E-16	3.4 E-16
Sr	5.9 E-19	1.7 E-18	2.4 E-16	4.8 E-16	9.3 E-16	2.4 E-15
La	3.1 E-17	9.0 E-17	1.4 E-15	2.8 E-15	3.6 E-16	9.4 E-16

(a) early exposure; (b) delayed exposure

Table 29: Number of fatalities per Bq for Yantai site.

Radionuclide group	Basic early fatalities per Bq	Yantai early fatalities per Bq (q=2.08)	Basic late fatalities (a) per Bq	Yantai late fatalities (a) per Bq (q=1.28)	Basic delayed fatalities (b) per Bq	Yantai delayed fatalities (b) per Bq (q=2.29)
Xe	0	0	5.0 E-18	6.4 E-19	0	0
I	1.4 E-18	2.9 E-18	3.3 E-17	4.2 E-17	2.7 E-17	6.2 E-17
Cs	5.5 E-19	1.1 E-18	1.6 E-15	2.0 E-15	3.3 E-14	7.6 E-14
Te	1.2 E-17	2.5 E-17	3.4 E-16	4.4 E-16	1.3 E-16	3.0 E-16
Sr	5.9 E-19	1.2 E-18	2.4 E-16	3.1 E-16	9.3 E-16	2.1 E-15
La	3.1 E-17	6.4 E-17	1.4 E-15	1.8 E-15	3.6 E-16	8.2 E-16

(a) early exposure; (b) delayed exposure

Offsite consequences for current reactors

Core damage frequencies from [SKI, 1999] were primarily used to assess risks. Given that safety culture may have a decisive impact on the risk and this aspect has not been addressed for the China-specific conditions, this core damage frequency level is considered for the purpose of the present work as more representative than the results characteristic for the advanced designs. Therefore, the frequencies of postulated accidents outlined here are ten times higher than what is normally assumed for advanced reactors. However, conditional consequences would be the same.

Tables 30 to 34 show estimated conditional consequences (i.e., without accounting for accident frequency) for the worst hypothetical accidents for the Qingdao site. For more detailed information for other release groups, different types of NPPs and other sites see Appendix E. Note that risk in these tables is not considered, just conditional consequences (i.e., consequences given that such accidents would occur).

Table 30: Early fatalities for Qingdao site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	0	0
I	11.2	22.9
Cs	0.14	0.39
Te	11.7	44.1
Sr	5.5	2.5
La	6.3	84.5
TOTAL	35	154

Table 31: Late fatalities (early exposure) for Qingdao site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	11.8	14.56
I	180.0	368.28
Cs	281.6	633.6
Te	226.4	856.8
Sr	1527	701.76
La	192.6	2598.4
TOTAL	2420	5173

Similarly to what was said previously, the La group is a non-negligible contributor to the late fatalities due to early exposure. Again for PWR reactors, the worst consequences seem to be from the release class RC1.

Table 32: Delayed fatalities (delayed exposure) for Qingdao site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	0	0
I	190.96	390.6
Cs	7568	17'028
Te	113.22	428.4
Sr	7636.8	3508.8
La	64.672	872.32
TOTAL	15'574	22'228

Table 33 provides the values for latent fatalities for Qingdao site considering both early and delayed exposure – i.e. summarizes the values from Tables 31 and 32 for late and delayed fatalities.

Table 33: Latent fatalities (early and delayed exposure) for Qingdao site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	11.84	14.56
I	371	758.88
Cs	7849.6	17'661.6
Te	339.66	1285.2
Sr	9164.2	4210.5
La	257.3	3470.72
TOTAL	17'994	27'401

It is evident that the most important contribution to the total latent fatalities is from delayed cancer deaths (i.e., occurring from late exposure).

Table 34: Land contamination – land lost in km^2 for Qingdao site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Land lost in km^2)**	**RC1 / PWR (Land lost in km^2)**
Xe	0	0
I	0	0
Cs	269.61	851.4
Te	0	0
Sr	2941.2	2631.6
La	0	0
TOTAL	3211	3483

Tables 35 to 39 show conditional early, late, latent fatalities as well as land contamination results for the Yantai site, for the same types of reactors, and for the same accidents:

Table 35: Early fatalities for the Yantai site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	0	0
I	7.91	16.182
Cs	0.1	0.22
Te	8.33	31.50
Sr	3.82	1.75
La	4.40	59.39
TOTAL	25	109

Table 36: Late fatalities (early exposure) for the Yantai site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	7.58	9.3
I	114.58	234.4
Cs	176.00	396.0
Te	146.52	554.4
Sr	986.42	453.2
La	123.84	1670.4
TOTAL	1555	3318

Table 37: Delayed fatalities (delayed exposure) for the Yantai site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	0	0
I	169.1	346.0
Cs	6688.0	15’048.0
Te	99.9	378.0
Sr	6682.2	3070.2
La	56.4	761.0
TOTAL	13’696	19’603

Table 38 includes the values for latent fatalities for current reactors for Yantai site considering both early and delayed exposure – i.e. summarizes the values from Tables 36 and 37 for late and delayed fatalities.

Table 38: Latent fatalities (early and delayed exposure) for the Yantai site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Number of fatalities)**	**RC1 / PWR (Number of fatalities)**
Xe	7.58	9.3
I	283.68	580.4
Cs	6864	1’5444
Te	246.42	932.4
Sr	7668.6	3523.4
La	180.24	2431.4
TOTAL	15’251	22’921

Table 39: Land contamination – land lost in km^2 for the Yantai site for the worst conditional consequences.

	Release class / NPP type	
Radionuclide group	**RC3 / BWR (Land lost in km^2)**	**RC1 / PWR (Land lost in km^2)**
Xe	0	0
I	0	0
Cs	272.8	613.8
Te	0	0
Sr	4136.6	1900.6
La	0	0
TOTAL	4409	2514

Offsite consequences for advanced reactors

Given the assumptions on source terms conditional consequences for advanced reactors would be the same as for current design plants, and therefore, the discussions will not be repeated. Needless to say, when risks are considered (i.e., the product of consequences and frequency of accidents), risk will be smaller for plants of newer design.

4.7.5 Main Risk Results

Risks of possible fatalities or land contamination are related to the frequency of core damage states and the conditional probability of containment failure modes (release categories, release bins), given particular plant damage states (accident classes) leading to the release after a hypothetical accident, as discussed briefly in section 4.7.2.

Average risk for particular release categories is understood as the multiplication of frequency of release per year with the absolute conditional consequences related to a given release bin. Total risk is the overall sum of all average risks. Conditional consequences from postulated severe accidents for PWRs and BWRs have been discussed in the previous section.

The comparison of risk results for particular consequences and the particular reactor types and particular sites are summarized in the Tables 40 and 41, and Figures 57 to 64. The results for current designs are shown first; assuming that Core Damage Frequency is ten times higher than for advanced designs, the associated risks (per Ryr) are correspondingly higher, subject to additional differences when the indicators are normalized by GW_eyr (depending on the power level of the various reference designs).

Detailed information related to the calculation of risk, all tables for frequency of releases, consequences and supporting tables are in Appendix F.

Table 40: Risk for Qingdao and Yantai site – current reactors.

	Risk of early fatalities (number/GW$_e$yr)		Risk of latent fatalities (number/GW$_e$yr)		Risk of land contamination (km^2/GW$_e$yr)	
Site / NPP Type	BWR	PWR	BWR	PWR	BWR	PWR
Qingdao	9.8E-6	2.5E-5	4.9E-3	6.1E-3	1.4E-3	6.7E-4
Yantai	7.0E-6	1.7E-5	4.2E-3	5.1E-3	1.1E-3	4.9E-4

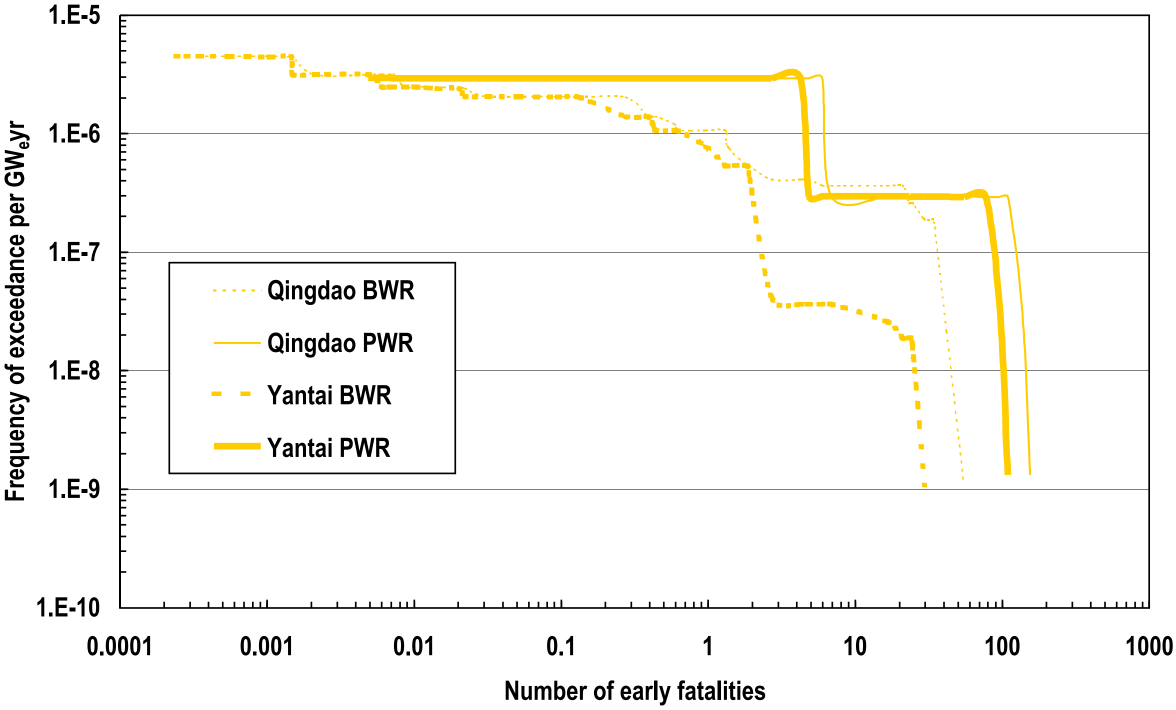

Figure 57: Frequency of exceedance for the number of early fatalities – current reactors.

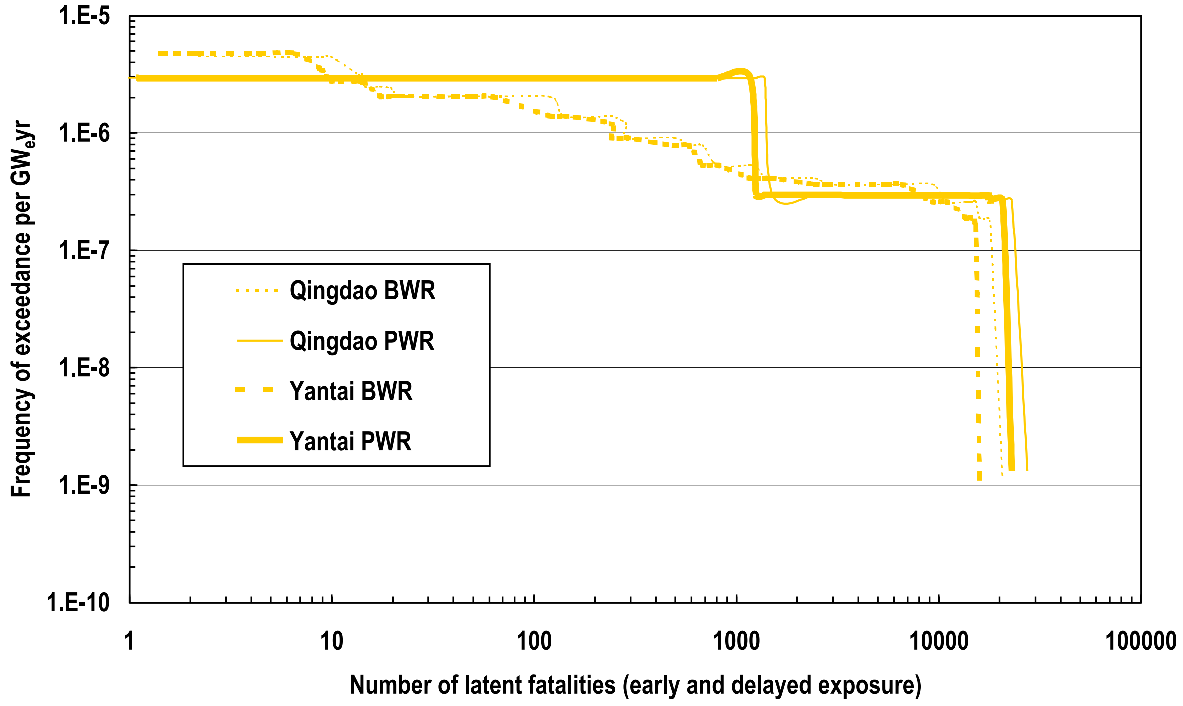

Figure 58: Frequency of exceedance for the number of latent fatalities – current reactors.

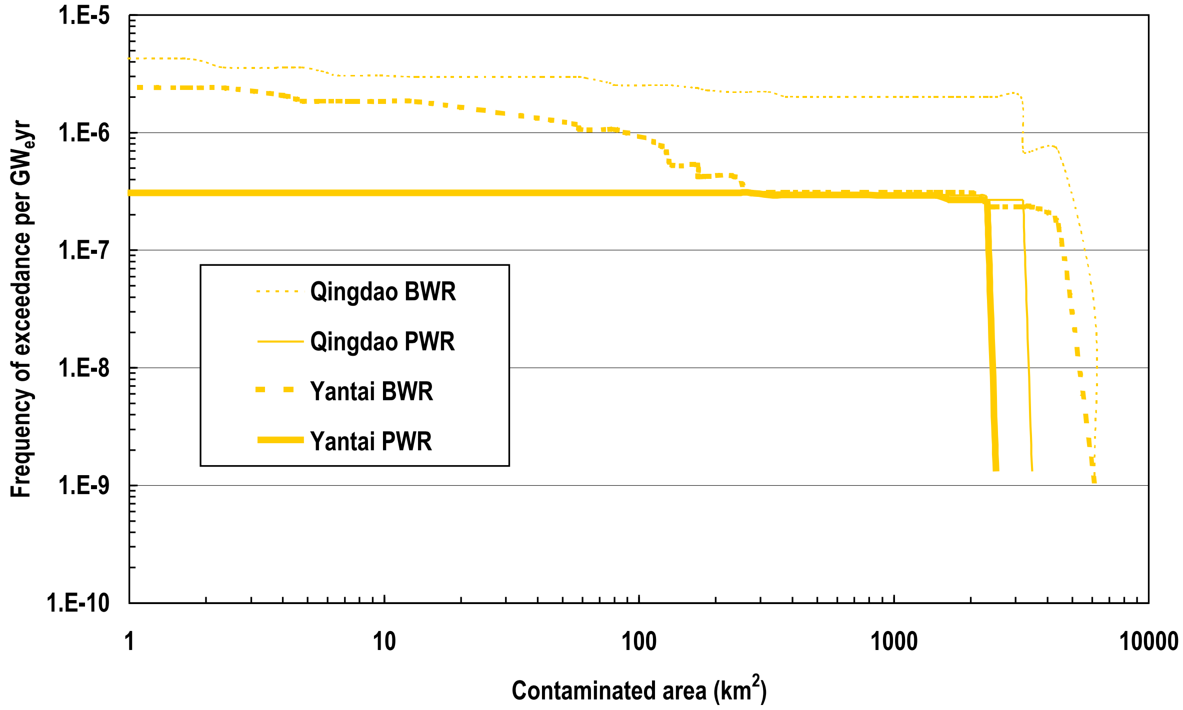

Figure 59: Frequency of exceedance for contaminated area – current reactors.

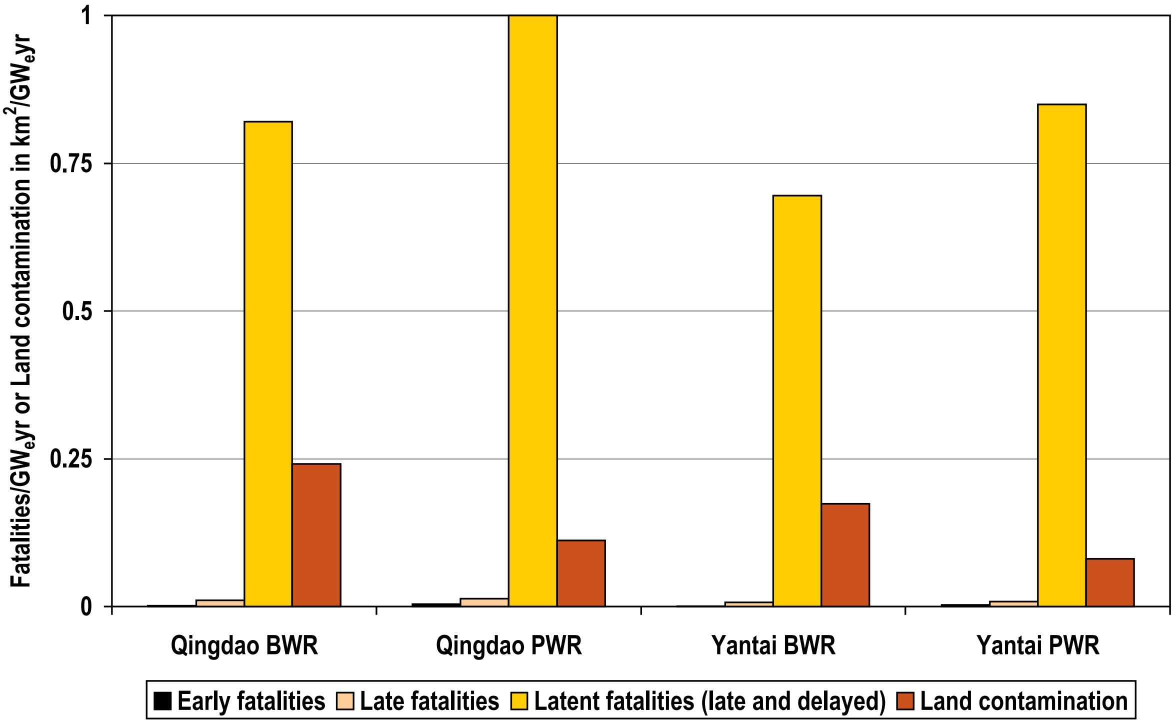

Figure 60: Comparison of risks normalized to the largest risk – current reactors (maximum value – Qingdao PWR, 6.1 E-3 GW$_e$yr).

Table 41: Risk for Qingdao and Yantai site – advanced reactors.

Site / NPP Type	Risk of early fatalities (number/GW$_e$yr)		Risk of latent fatalities (number/GW$_e$yr)		Risk of land contamination (km^2/GW$_e$yr)	
	ABWR	EPR	ABWR	EPR	ABWR	EPR
Qingdao	9.5 E-7	2.0 E-6	4.7 E-4	4.8 E-4	1.4 E-4	5.4 E-5
Yantai	6.7 E-7	1.4 E-6	4.1 E-4	4.1 E-4	1.0 E-4	3.9 E-5

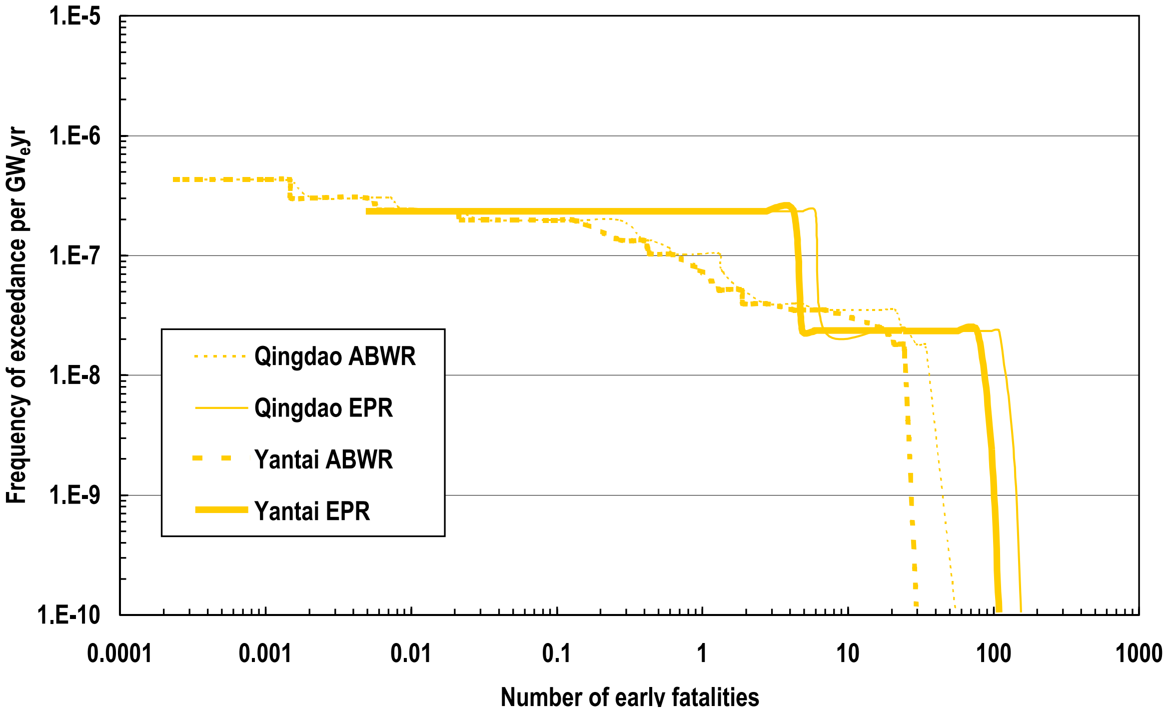

Figure 61: Frequency of exceedance for the number of early fatalities – advanced reactors.

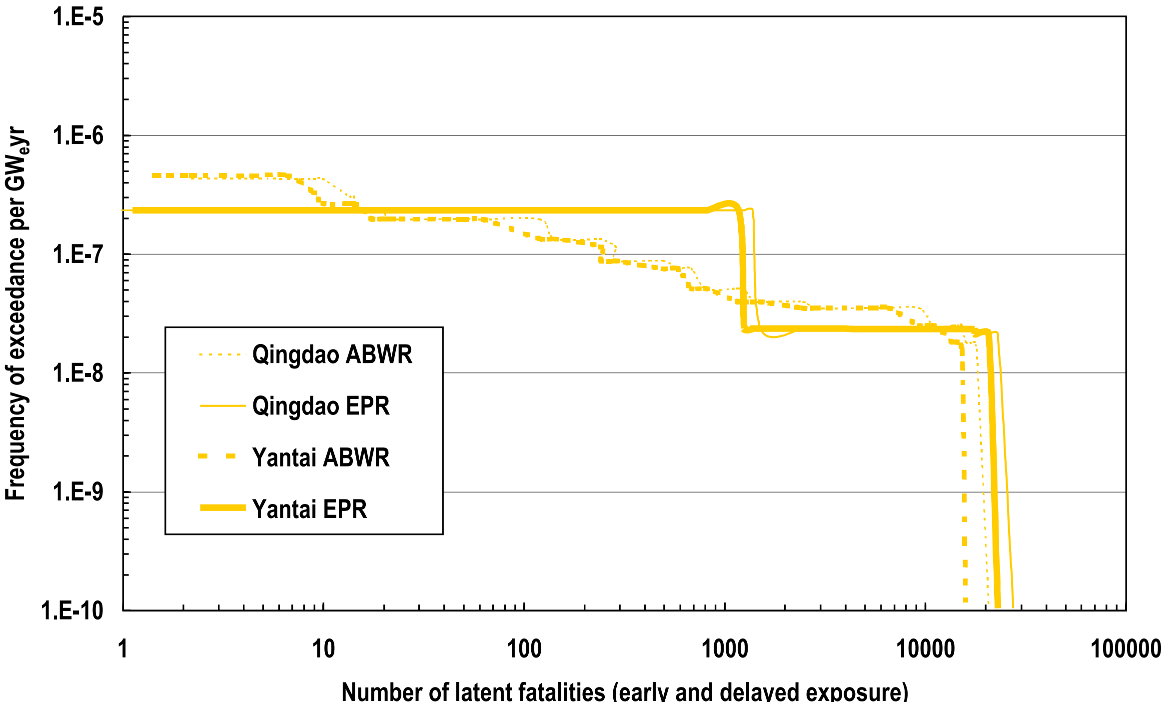

Figure 62: Frequency of exceedance for the number of latent fatalities – advanced reactors.

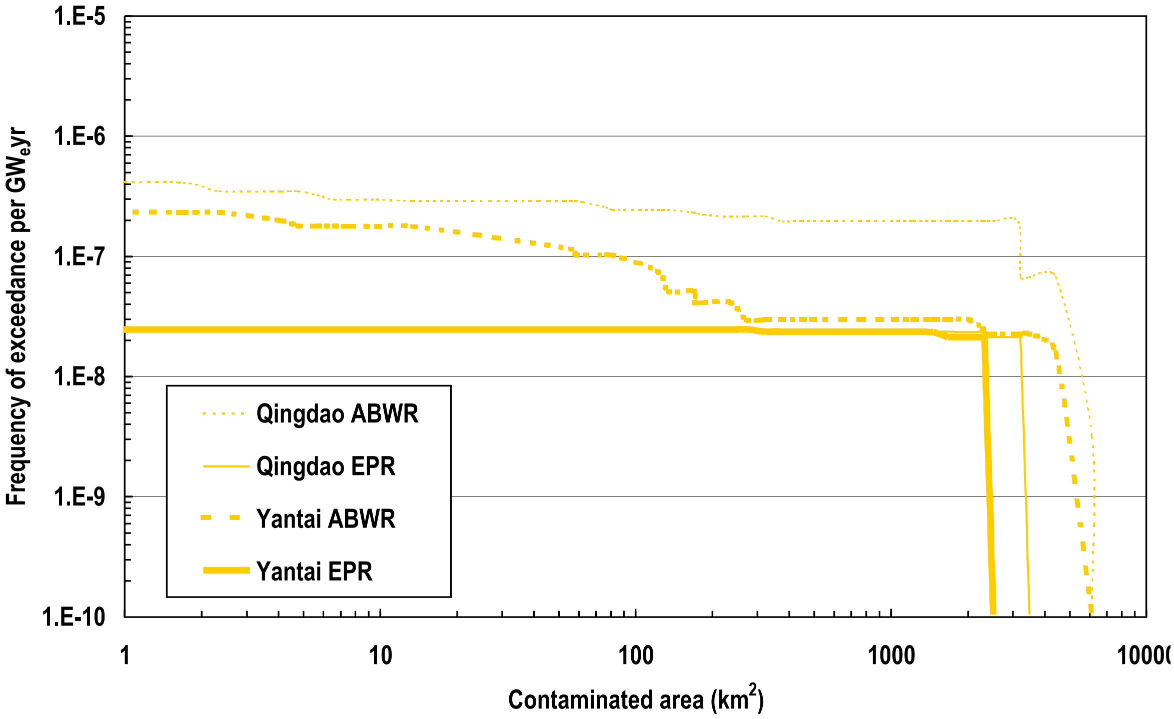

Figure 63: Frequency of exceedance for contaminated area in km^2 – advanced reactors.

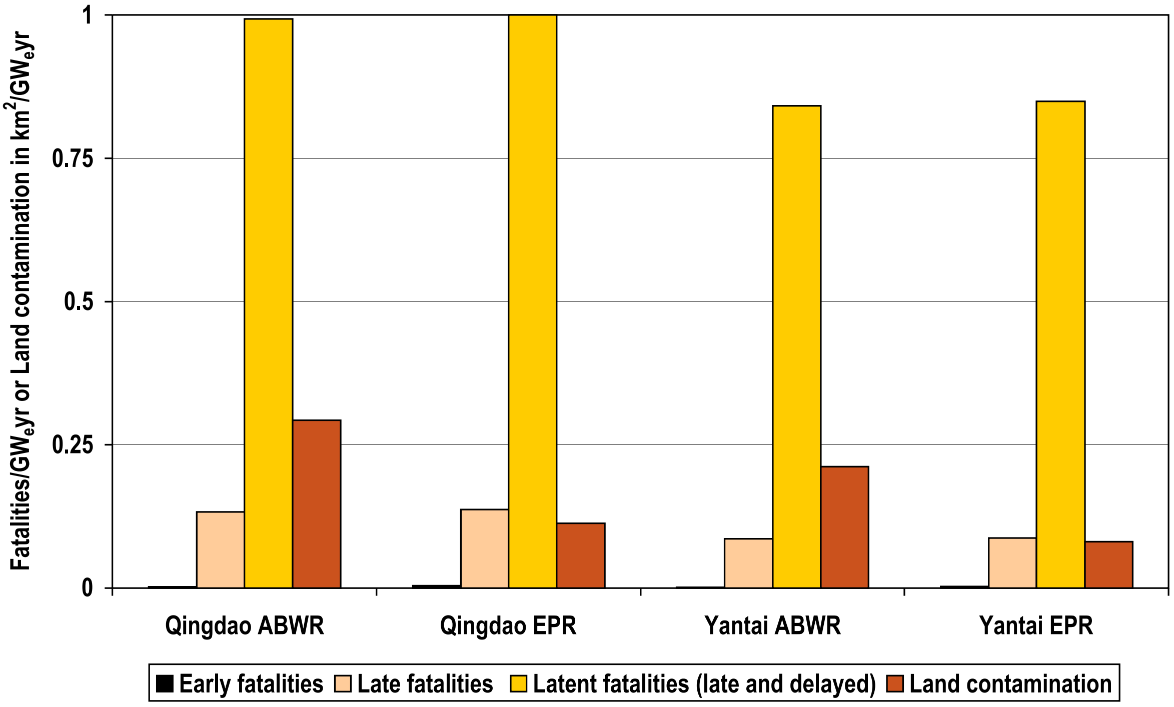

Figure 64: Comparison of risks normalized to the largest risk – advanced reactors (maximum value – Qingdao EPR, 4.8 E-4 GW$_e$yr).

As it is evident from Figures 60 and 64, for both current and advanced reactors, early fatalities are negligible compared to other risks. It should be noted that even early fatalities are overestimated because in the simplified method used to extrapolate the results for fatalities using quotients. In reality the number of fatalities as a function of exposure is strongly exponential, once the 50-th percentile of the Lethal Dose (known as LD-50), which is about 3 Gy, is reached. In the simplified method a linear extrapolation was used, which results in predicting possible fatalities even at low doses. Also, the risk of latent fatalities does not appear significant, given that it is calculated over a 60 years period. In this time, even 100’000 cancer deaths could not be statistically separated from normal cancer deaths (perhaps with the exception of thyroid cancers in the young population). In relative terms, the risk of land contamination is a major concern due to the related social consequences. Moreover, risk is found to be plant- and site-sensitive.

Influence of plant type:

The risk of early fatalities for a BWR type reactor is about 100 smaller than for a PWR. It can be explained by the influence of the BWR pressure suppression pool, which is very effective in suppressing the release of aerosols. The difference in risk between BWR and PWR for latent fatalities is smaller because latent fatalities are caused mostly by long lived radionuclides, and the release of these species appears to be insensitive to plant design. On the other hand, results for land contamination appear more favourable for PWR type reactors. This can be explained as follows: the only contributors to land contamination from the MACCS calculations are the Sr and Cs groups. The Sr-Ba group is mostly released late, ex-vessel, so the pressure suppression pool is less effective. Another reason can be higher containment capacity in a PWR, so the frequency of relatively large and early releases of Sr and Cs for this type of reactor is lower.

In general it can be said, that the differences in risk measures due to plant differences are not decisive, i.e., risk measures for both BWR and PWR are comparable.

Influence of site:

The results are in general favorable for the Yantai site because of smaller population density and smaller land fraction in the area. The difference between risks caused by different siting of the plants is comparable or somewhat smaller than the difference between risks caused by different plants designs, when plants belonging to the same generation are considered. Comparing current and advanced plants the design differences are dominant.

4.7.6 Uncertainties

The results presented in the report were obtained by using simplified methods, which involve uncertainties of different types for two different reactor designs, and considers both currently operating plants and of advanced designs. In this section, some of the leading uncertainties in the assessment of offsite consequences will be discussed and investigated. Detailed information on these sensitivity calculations is included in Appendix G.

Core inventories used in the calculations were assumed to be the same for all types of reactors. Using the assumption, that the uncertainties of the ORIGEN code for core inventories depending on reactor design could be about ±20/30%, the uncertainty resulting from inventories alone can be as high. Calculations were repeated under these assumptions, and results are compared in Tables 42 to 46.

Table 42: Risk for basic inventories (inventories are defined in Table 20).

Risk measure	Qingdao ABWR	Qingdao EPR	Yantai ABWR	Yantai EPR
Early fatalities (number/GW$_e$yr)	9.5E-07	2.0E-06	6.7E-07	1.4E-06
Late fatalities (number/GW$_e$yr)	6.4E-05	6.6E-05	4.1E-05	4.2E-05
Latent fatalities (late+delayed)	4.8E-04	4.8E-04	4.1E-04	4.1E-04
Land contamination (km^2/GW$_e$yr)	1.4E-04	5.4E-05	1.0E-04	3.9E-05

Results for core inventories 30% higher than considered:

Table 43: Risk for core inventories 30% higher than considered for advanced reactors.

Risk measure	Qingdao ABWR	Qingdao EPR	Yantai ABWR	Yantai EPR
Early fatalities (number/GW$_e$yr)	1.3E-06	2.6E-06	8.7E-07	1.8E-06
Late fatalities (number/GW$_e$yr)	8.3E-05	8.5E-05	5.1E-05	5.5E-05
Latent fatalities (late+delayed)	6.2E-04	6.3E-04	5.3E-04	5.4E-04
Land contamination (km^2/GW$_e$yr)	1.8E-04	7.0E-05	1.4E-04	5.1E-05

The calculations of weather influence did not consider the predominant wind direction in the Shandong peninsula. According to Hirschberg et al. [2003], preferred wind direction is from the S/W quadrants towards N/E. This could add a source of uncertainty of 25%, and calculations for the Yantai site could be overestimated by 25%, while for the Qingdao site they could be underestimated by 25%.

Another source of uncertainties can occur from the population data. Even as precise data related to Shandong Province as possible was used [China Statistical Information Center, 2000; ABB Corporate Research, 1999], to estimate the population in the area to 800 km radius, still the uncertainty may be substantial. It is possible that the uncertainty on this estimate may be as high as ±20%. The following tables show the results, when the assumption on higher population data is used.

Table 44: Original table for quotients (compare Table 25).

	European site	US site	Quotient q for US/EU site	Quingdao	Quotient q for Qingdao (*)	Yantai	Quotient q for Yantai (*)
Population to 8 km	24’000	1400	0.06	70’000	2.92	50’000	2.08
Population to 100 km	5E+6	2.2E+6	0.44	1E+7	2.00	6.4E+6	1.28
Population to 800 km	226E+6	90E+6	0.40	590E+6	2.61	517E+6	2.29
Land fraction to 120 km	0.97	0.75	0.77	0.5	0.67	0.37	0.49

(*) For population, the ratio is taken to the European site because of much higher population density (closer to European), while for the land fraction the ratio is taken with respect to the US site, which, as the Shandong peninsula, is situated in the proximity of the ocean.

Table 45: Population to 800 km 20% higher.

	European site	US site	Quotient q for US/EU site	Quingdao	Quotient q for Qingdao (*)	Yantai	Quotient q for Yantai (*)
Population to 8 km	24'000	1400	0.06	70'000	2.92	50'000	2.08
Population to 100 km	5E+6	2.2 E+6	0.44	1E+7	2.00	6.4 E+6	1.28
Population to 800 km	226E+6	90E+6	0.40	708E+6	3.13	620E+6	2.74
Land fraction to 120 km	0.97	0.75	0.77	0.5	0.67	0.37	0.49

(*) For population, the ratio is taken to the European site because of much higher population density (closer to European), while for the land fraction the ratio is taken with respect to the US site, which, as the Shandong peninsula, is situated in the proximity of the ocean.

Table 46: Risk for population in 800 km higher by about 20%.

Risk measure	Qingdao ABWR	Qingdao EPR	Yantai ABWR	Yantai EPR
Early fatalities (number/GW$_e$yr)	9.5E-07	2.0E-06	6.7E-07	1.4E-06
Late fatalities (number/GW$_e$yr)	6.4E-05	6.6E-05	4.1E-05	4.2E-05
Latent fatalities (late+delayed)	5.6E-04	5.6E-04	5.3E-04	5.3E-04
Land contamination (km^2/GW$_e$yr)	1.4E-04	5.4E-05	1.0E-04	3.9E-05

Table 47 (in absolute terms) and Figure 65 (in relative terms) show the combined effect of increasing population data and core inventories. Results for the "dominant" risk measure (i.e., latent fatalities) are approximately proportional to the assumptions of increases in both sets of data.

Table 47: Risk for increased core inventories (30%) and population to 800 km (20%).

Risk measure	Qingdao ABWR	Qingdao EPR	Yantai ABWR	Yantai EPR
Early fatalities (number/GW$_e$yr)	1.3E-06	2.5E-06	8.7E-07	1.8E-06
Late fatalities (number/GW$_e$yr)	8.3E-05	8.5E-05	5.1E-05	5.5E-05
Latent fatalities (late+delayed)	7.2E-04	7.3E-04	6.8E-04	6.8E-04
Land contamination (km^2/GW$_e$yr)	1.8E-04	7.0E-05	1.4E-04	5.1E-05

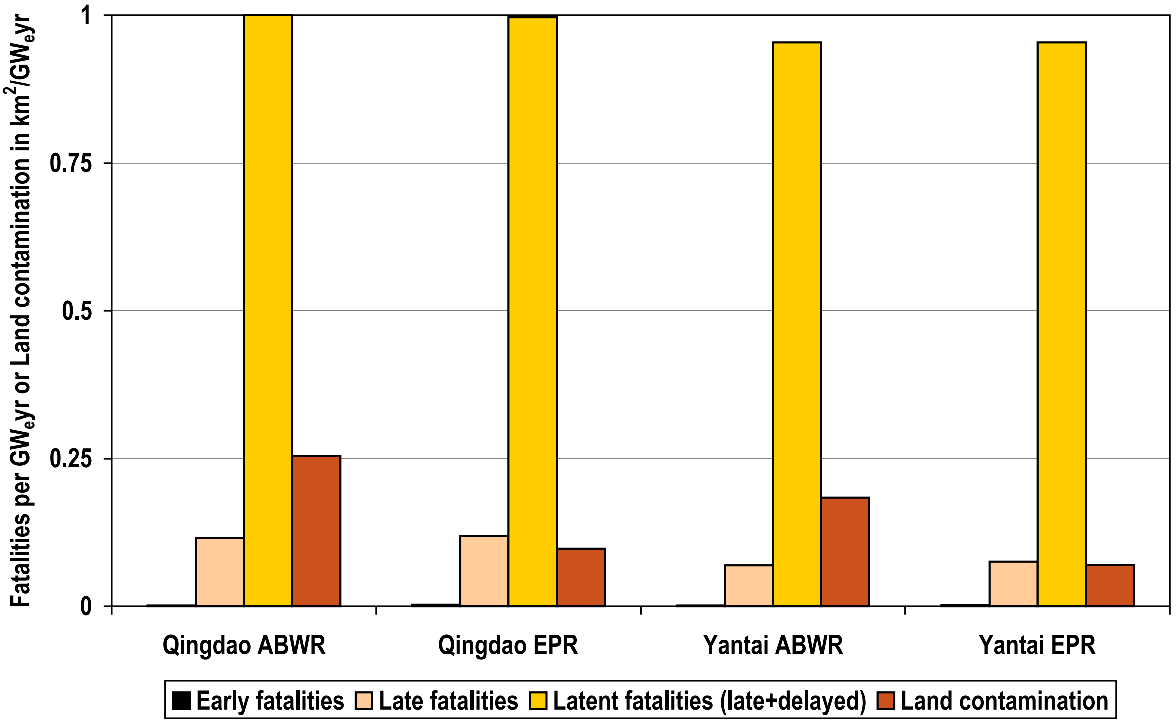

Figure 65: Comparison of risk measures for increasing core inventories about 30% and increasing population to 800 km by about 20% (maximum value – Qingdao ABWR latent fatalities, 7.2 E-4).

Table 48 shows the percentual increase of risks due to the same assumptions. Figures 66 to 68 are illustrative of the effect of different assumptions.

Table 48: Increase of risk based on increased core inventories and population.

Risk measure	Qingdao ABWR	Qingdao EPR	Yantai ABWR	Yantai EPR
Early fatalities (number/GW$_e$yr)	33.0%	30.5%	29.7%	30.8%
Late fatalities (number/GW$_e$yr)	29.5%	28.6%	23.0%	30.0%
Latent fatalities (late+delayed)	53.3%	47.8%	67.0%	66.7%
Land contamination (km^2/GW$_e$yr)	30.8%	31.4%	34.0%	29.7%

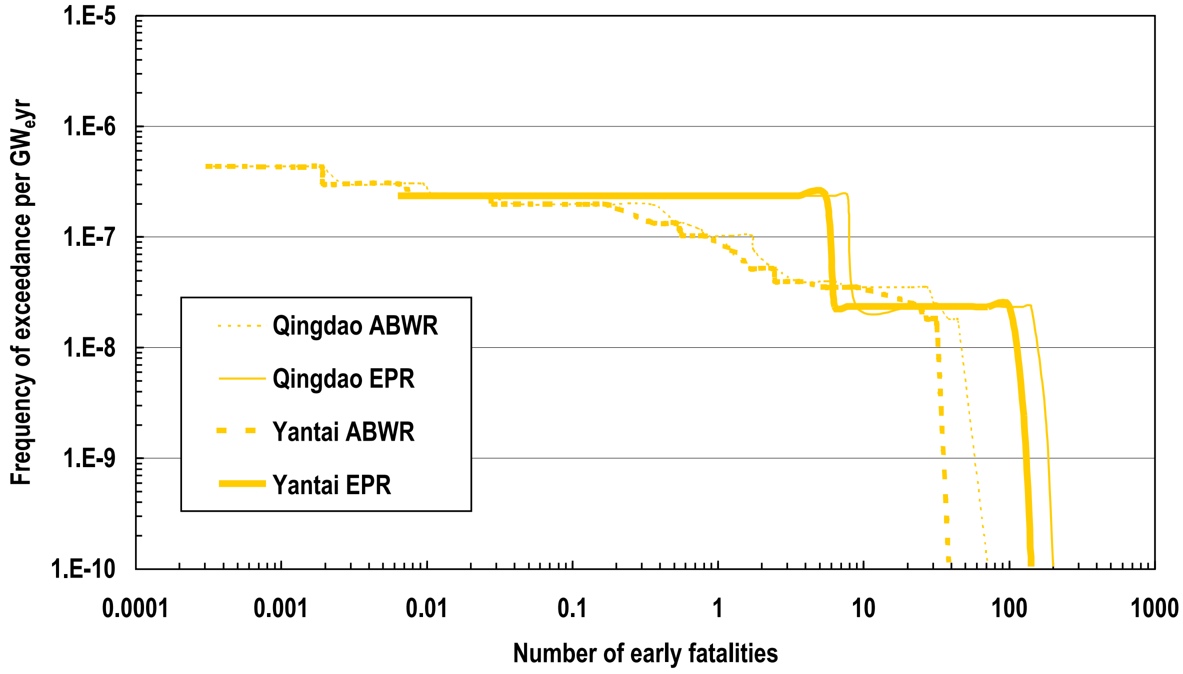

Figure 66: Frequency of exceedance for number of early fatalities (30% higher inventories, 20% higher population in 800 km area).

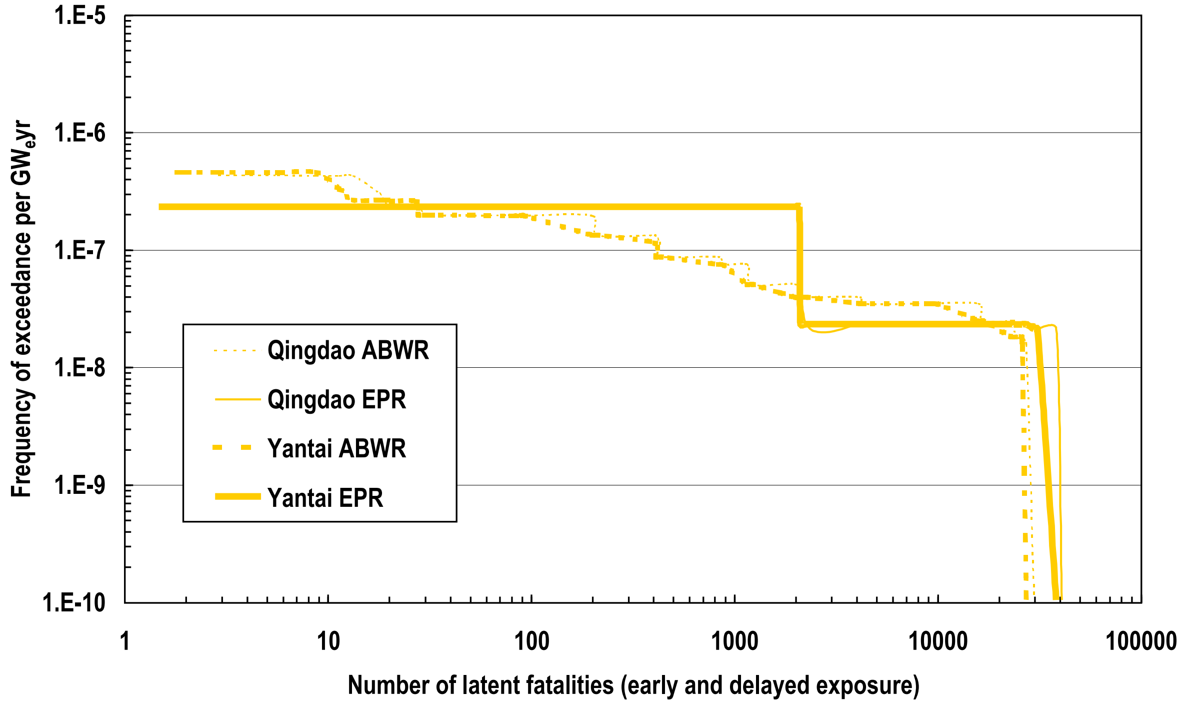

Figure 67: Frequency of exceedance for the number of latent fatalities (30% higher inventories, 20% higher population in 800 km area).

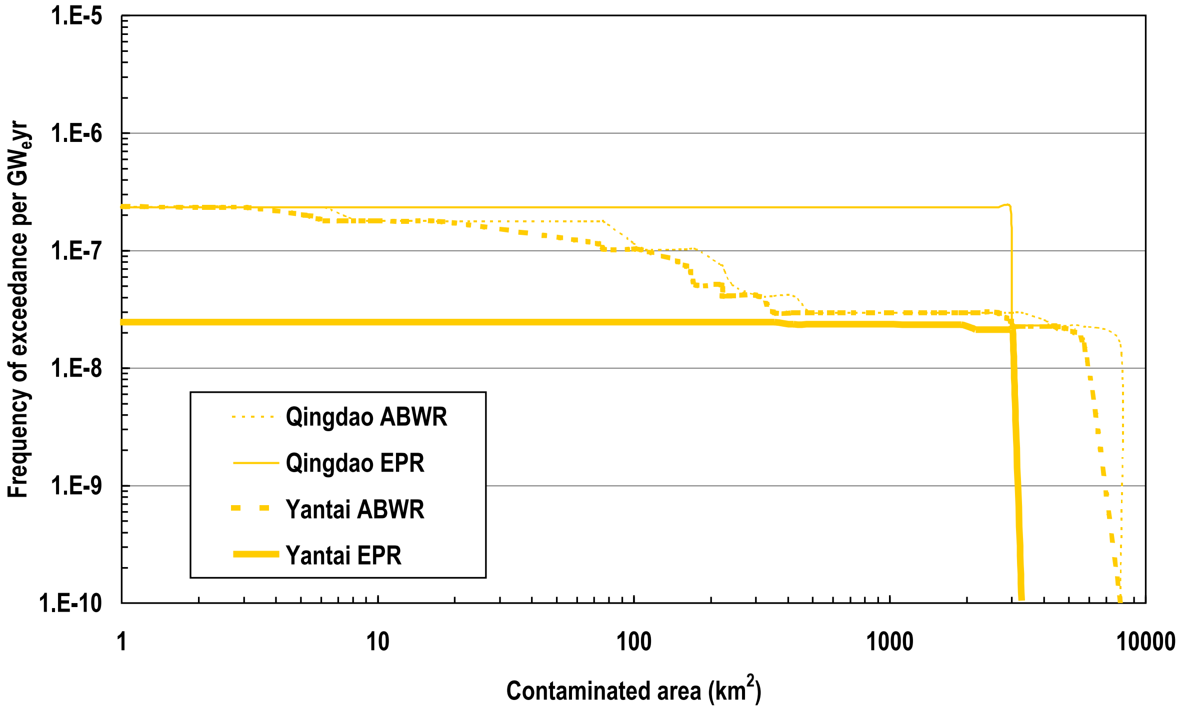

Figure 68: Frequency of exceedance for contaminated area (30% higher inventories, 20% higher population in 800 km area).

Comparing the results related to basic calculations shown in Figures 58 to 60 (basic calculations for advanced reactors) with the results from the Figures 66 to 68 (increased values), it can be concluded, that increasing inventories by 30% and the population to 800 km from the NPP by 20% does influence the risk substantially in a relative sense but the overall risks remain small from the absolute point of view.

Source terms have large uncertainties in general, e.g. factors ±10-20 for small releases (i.e., for release fractions of iodine smaller than 1%), factors of ±2-3 for large releases (i.e., for release fractions of iodine larger than 10%). In the present sensitivity study, releases larger by a factor of 2 are used for large releases, and factors of 10 for small releases. Releases of noble gases have not been changed, but this has very little influence on risk. To demonstrate the influence of the source terms uncertainties on the final risk, results are provided for Qingdao site, both for the advanced BWR and PWR designs (Tables 49 to 52)

Table 49: Original source terms for Qingdao ABWR (compare Table 23).

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.72	1.20E-01	1.10E-01	2.80E-02	1.70E-02	2.00E-04
RC2	0.73	7.80E-03	7.60E-03	3.40E-03	2.20E-03	2.10E-05
RC3	0.74	8.80E-02	8.00E-02	3.70E-02	3.70E-02	4.30E-04
RC4	0.74	6.30E-04	2.80E-04	1.00E-04	7.80E-05	6.60E-07
RC5	0.74	5.00E-03	2.90E-03	1.30E-03	1.00E-03	1.10E-05
RC6	0.74	1.50E-03	1.40E-03	9.20E-04	4.80E-04	4.70E-06
RC7	0.78	5.90E-02	5.70E-02	2.90E-02	1.90E-02	2.60E-04
RC8	0.74	8.40E-05	3.80E-05	1.80E-05	1.40E-05	1.20E-07
RC9	0.74	6.60E-03	4.00E-03	1.80E-03	1.40E-03	1.60E-05
RC10	0.74	1.50E-03	1.50E-03	8.60E-04	4.50E-04	4.30E-06
RC11	0.74	2.50E-02	2.60E-02	8.30E-03	4.10E-04	4.80E-06
RC12	0.73	4.10E-05	1.80E-05	7.40E-06	3.50E-06	3.20E-08
RC13	0.74	2.20E-03	1.20E-03	3.40E-04	6.60E-09	2.00E-10
RC14	0.36	5.20E-05	5.30E-05	4.00E-05	4.10E-05	4.10E-07
RC16	0.37	4.00E-06	2.40E-06	1.50E-06	1.70E-06	1.50E-08
RC18	0.78	3.90E-06	4.00E-06	2.60E-06	2.70E-06	2.70E-08
RC21	0.13	1.50E-06	5.40E-07	2.80E-07	2.30E-07	1.80E-09

Table 50: Increased source terms for Qingdao ABWR.

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.72	2.40E-01	2.20E-01	5.60E-02	3.40E-02	2.00E-03
RC2	0.73	7.80E-02	7.60E-02	3.40E-02	2.20E-02	2.10E-04
RC3	0.74	1.76E-01	1.60E-01	7.40E-02	7.40E-02	4.30E-03
RC4	0.74	6.30E-03	2.80E-03	1.00E-03	7.80E-04	6.60E-06
RC5	0.74	5.00E-02	2.90E-02	1.30E-02	1.00E-02	1.10E-04
RC6	0.74	1.50E-02	1.40E-02	9.20E-03	4.80E-03	4.70E-05
RC7	0.78	1.18E-01	1.14E-01	5.80E-02	3.80E-02	2.60E-03
RC8	0.74	8.40E-04	3.80E-04	1.80E-04	1.40E-04	1.20E-06
RC9	0.74	6.60E-02	4.00E-02	1.80E-02	1.40E-02	1.60E-04
RC10	0.74	1.50E-02	1.50E-02	8.60E-03	4.50E-03	4.30E-05
RC11	0.74	5.00E-02	5.20E-02	8.30E-02	4.10E-03	4.80E-05
RC12	0.73	4.10E-04	1.80E-04	7.40E-05	3.50E-05	3.20E-07
RC13	0.74	2.20E-02	1.20E-02	3.40E-03	6.60E-08	2.00E-09
RC14	0.36	5.20E-04	5.30E-04	4.00E-04	4.10E-04	4.10E-06
RC16	0.37	4.00E-05	2.40E-05	1.50E-05	1.70E-05	1.50E-07
RC18	0.78	3.90E-05	4.00E-05	2.60E-05	2.70E-05	2.70E-07
RC21	0.13	1.50E-05	5.40E-06	2.80E-06	2.30E-06	1.80E-08

Table 51: Original source terms for Qingdao EPR (compare Table 21).

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.91	1.80E-01	1.80E-01	1.40E-01	1.70E-02	5.80E-03
RC2	0.96	3.00E-02	3.00E-02	3.50E-02	1.00E-02	1.20E-03
RC3	0.95	6.00E-03	6.00E-03	7.00E-03	2.70E-03	2.40E-04
RC4	1.70E-03	4.20E-06	4.20E-06	6.00E-06	1.60E-06	2.90E-07
RC5	5.00E-04	7.90E-06	7.90E-06	6.00E-06	7.00E-07	5.00E-07
RC6	0.33	1.00E-01	1.00E-01	4.80E-02	1.00E-02	7.40E-03
RC7	0.37	1.60E-01	1.60E-01	1.20E-01	1.00E-02	1.20E-03

Table 52: Increased source terms for Qingdao EPR.

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.91	3.60E-01	3.60E-01	2.80E-01	3.40E-02	5.80E-02
RC2	0.96	6.00E-02	6.00E-02	7.00E-02	2.00E-02	1.20E-02
RC3	0.95	6.00E-02	6.00E-02	7.00E-02	2.70E-02	2.40E-03
RC4	1.70E-03	4.20E-05	4.20E-05	6.00E-05	1.60E-05	2.90E-06
RC5	5.00E-04	7.90E-05	7.90E-05	6.00E-05	7.00E-06	5.00E-06
RC6	0.33	2.00E-01	2.00E-01	9.60E-02	2.00E-02	7.40E-02
RC7	0.37	3.20E-01	3.20E-01	2.40E-01	2.00E-02	1.20E-02

Table 53 and Figures 69 to 72 show the estimated risk when uncertainties in source terms are accounted for.

Table 53: Risk for increased source terms for Qingdao ABWR, EPR.

Risk measure	Qingdao ABWR	Qingdao EPR
Early fatalities (number/GW_eyr)	4.0E-06	9.0E-06
Latent fatalities (late+delayed)	1.4E-03	1.2E-03
Land contamination (km^2/GW_eyr)	3.9E-04	5.4E-05

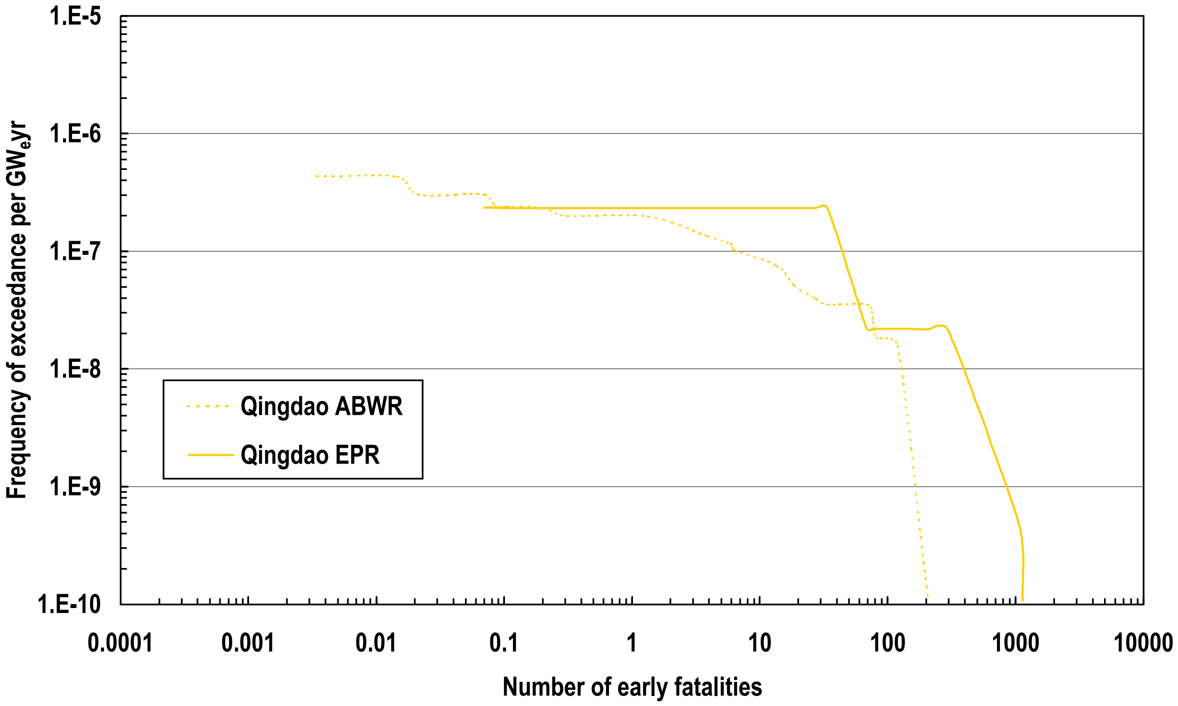

Figure 69: Frequency of exceedance for early fatalities for increased source terms – advanced reactors.

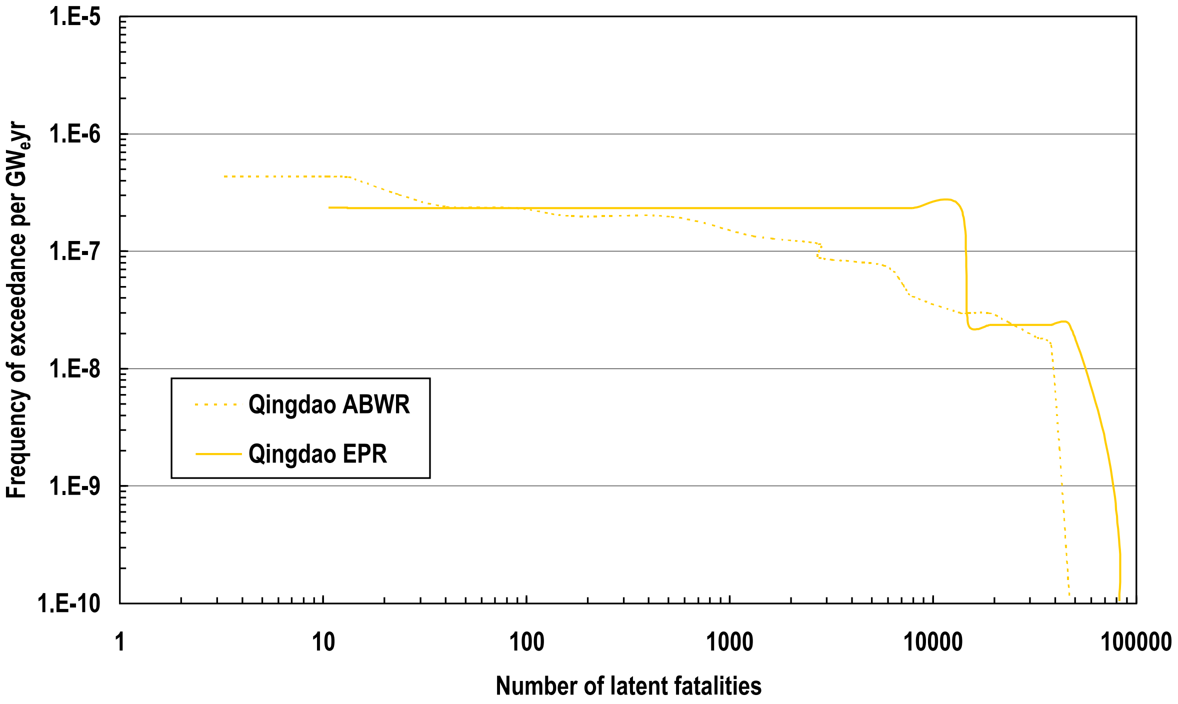

Figure 70: Frequency of exceedance for latent fatalities for increased source terms – advanced reactors.

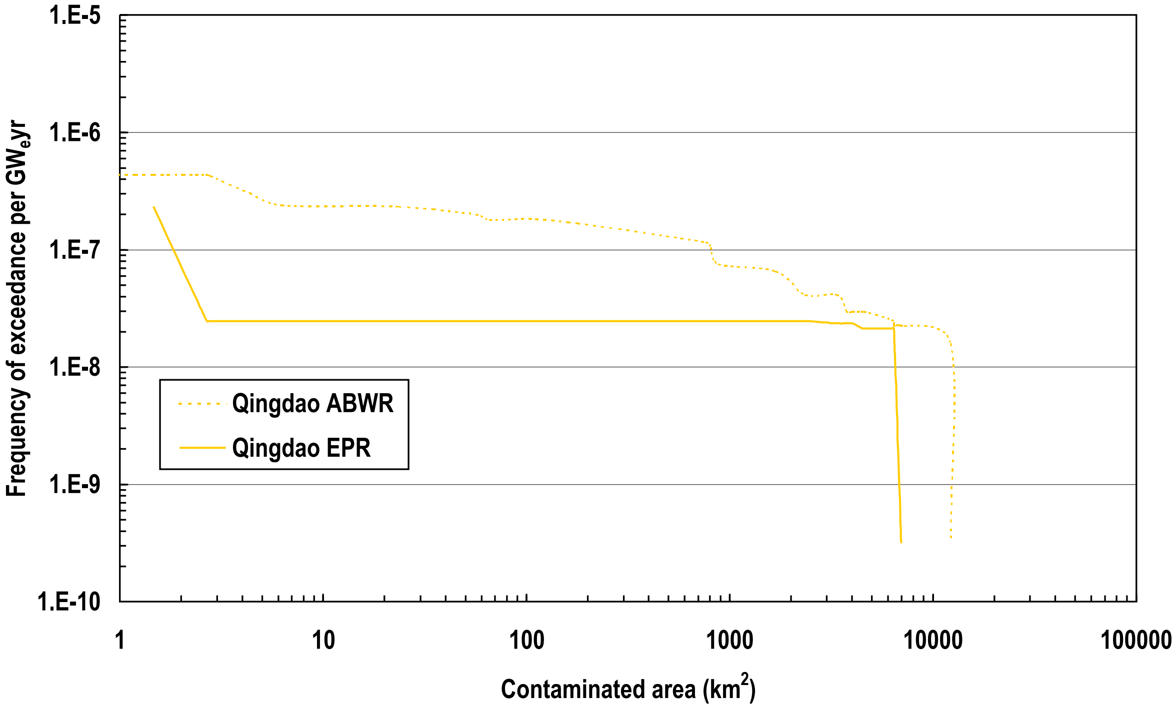

Figure 71: Frequency of exceedance of land contamination for increased source terms – advanced reactors.

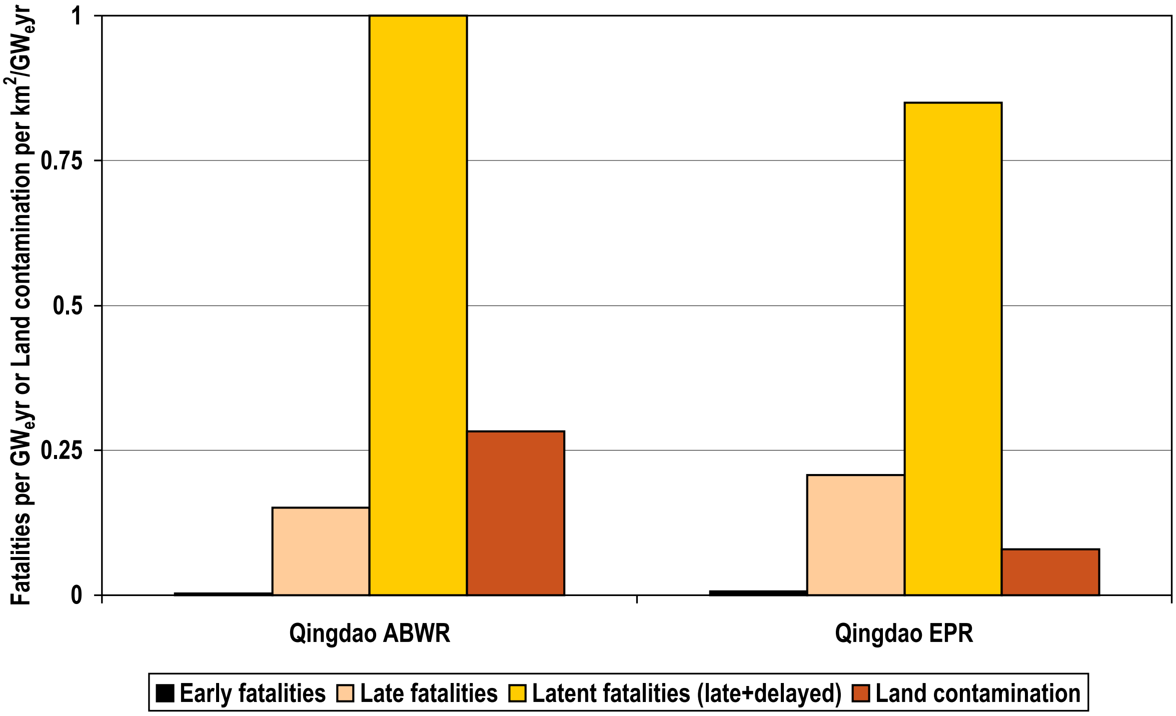

Figure 72: Normalized risk measures for increased source terms – advanced reactors (maximum value – Qingdao ABWR latent fatalities, 1.4 E-3).

Figure 73 shows a comparison of the risk measures for the sensitivity studies, which have been considered. As it is evident, the increase of the source terms has the most significant influence on the average risk. It is important to remember that early fatalities are driven by release of I, Te and La; latent fatalities essentially by Cs only; and, land contamination by Cs and Sr. Thus, in the context of land contamination the higher sensitivity for ABWR can be explained by the much increased release of Sr inventory due to loss of effectiveness of the pressure suppression pool late during an accident.

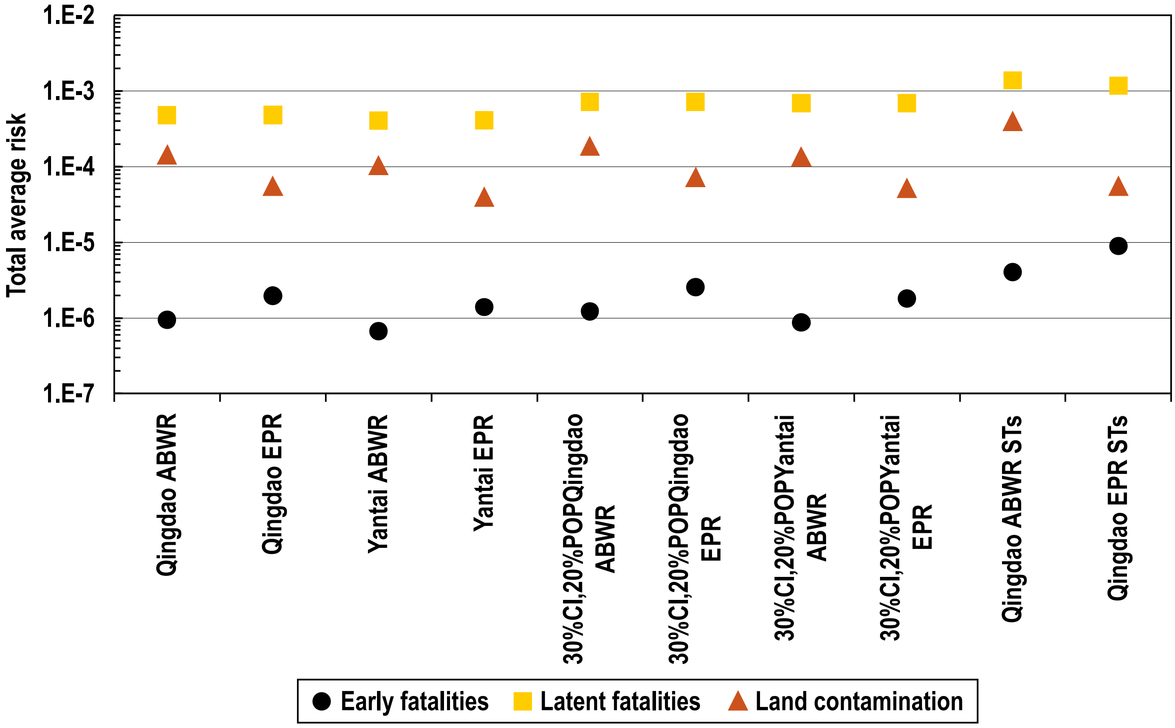

Figure 73: Comparison of risks for different sites and different plants and uncertainty results.

4.7.7 Conclusions

In general it can be said, that the sensitivity cases investigated were shown to be not of significant importance in relation to risk measures, with exception to uncertainties in core damage frequency, and source terms. Risk measures presented in the report are small, even lower than some US estimates – e.g. [Park et al., 1991]. The main reason for these results is that the NUREG-1150 analyses mostly relied on core damage frequencies, which were estimated according to technology which was available in the early ‘80s, while the present results are based on studies performed with a much larger reliability data base and experience gained from earlier PSA studies. For instance, it may be remembered that estimated risks were reduced already by a factor of about 10 between the WASH-1400 and the NUREG-1150 studies.

Differences in risk between the designs of particular types of reactors only reflect known features, which are, for instance less severe accident mitigative defenses in BWRs, but more preventive defenses, less capacity of containment of BWRs in comparison with PWRs, and the impact of pressure suppression pools in BWRs.

Differences in risk due to site characteristics are mostly due to different population density patterns at the considered sites but they still are approximately of the same order of magnitude, and therefore the results can be considered not highly sensitive to assumptions on the population density in the Chinese sites.

The risk measures for all considered cases, including the sensitivity analyses, are small. Weather effects would only add about 25% of risk to the estimated measures. Finally, even if total CDF were 100 times higher than assumed, risk measures would be still relatively small. However, it should be kept in mind that safety culture may have a decisive impact on the risk and this aspect has not been addressed for the China-specific conditions.

5. ENERGY CHAIN COMPARISONS

5.1 Aggregated indicators and frequency consequence curves

Based primarily on the historical evidence, comparisons among the different energy chains were carried out. They are focused on the experience in China, complemented by the records from non-OECD countries. For reference also some evaluations for OECD countries are provided.

In view of the availability of the extensive Chinese-specific statistical material for coal accidents in the period 1994-1999, and considerable differences between Chinese coal energy chain accident rates compared to other countries, within the CETP-framework the Chinese data are considered as the only relevant representation of the risks associated with coal mine in China. In contrast, the China-specific database on severe accidents for oil, natural gas, LPG and especially hydro power is much less extensive. Also, with the possible exception of hydro power, there are no strong indications that the Chinese situation would be much different from the average in non-OECD countries. As a consequence, Chinese data for these energy chains were pooled with those for non-OECD countries for the purpose of comparative analysis.

The comparison covers aggregated indicators (i.e., fatality rates per GW_eyr) and frequency-consequence curves. It addresses exclusively fatality rates since no consistent data could be found for other accident indicators for all energy chains. Furthermore, some of the consequences are associated with only one energy carrier (e.g. oil spills) or are most pronounced for a specific chain (e.g. long-term land contamination). We refer to the appropriate sections of the preceding chapter for a detailed account of such issues.

Figure 74 shows severe accident fatality rates for immediate fatalities in major energy chains for China, non-OECD countries without China, non-OECD countries with China, and OECD countries. Results for coal in China clearly demonstrate that the risk performance of small mines is much worse compared to large mines as reflected by an almost five times higher accident fatality rate. The Chinese severe accident fatality rate for the coal chain is about 6.5 per GWeyr, about ten times higher than in non-OECD countries, and about 50 times higher than in OECD countries. The Chinese fatality rate for the oil chain is about 40% lower compared to non-OECD countries. This difference is primarily attributable to two very large accidents with 2700 (Afghanistan) and 3000 (Philippines) fatalities. If these two accidents were excluded, the non-OECD fatality rate would decrease to 0.47 per GWeyr, similar to that of China. As observed for coal, the OECD fatality rate for oil is lowest. The natural gas, LPG and hydro chains all exhibit distinctly lower fatality rates for OECD countries, compared to non-OECD countries (including China). The non-OECD fatality rate for the hydro chain is strongly dependent on if the world’s worst accident that occurred at Banqiao and Shimantan dams in 1975 in China is included or not in the evaluation.

Only immediate fatalities are covered here. Thus, latent fatalities, of particular relevance for the Chernobyl accident, are not shown in the figure. The associated estimates and an extensive discussion of the related issues are provided in [Hirschberg et al., 1998]. We also refer to the results obtained for the types of nuclear power plants of more direct interest to China, generated using Probabilistic Safety Assessment (PSA) approach and discussed in detail in chapter 4.7 of the present report. These results show that risk of early fatalities associated with hypothetical accidents at current type or advanced nuclear power plants at selected sites in Shandong is extremely low; risk of latent fatalities is higher but remains to be 3-4 orders of magnitude lower than the experience-based severe accident results for coal in China and hydro in non-OECD countries with China, and 2-3 and 1-2 orders of magnitude lower than oil respectively gas severe accident fatality rates in non-OECD countries with China. The predictive estimates for latent nuclear fatalities are of the same order as the experience-based results for hydro power in OECD countries.

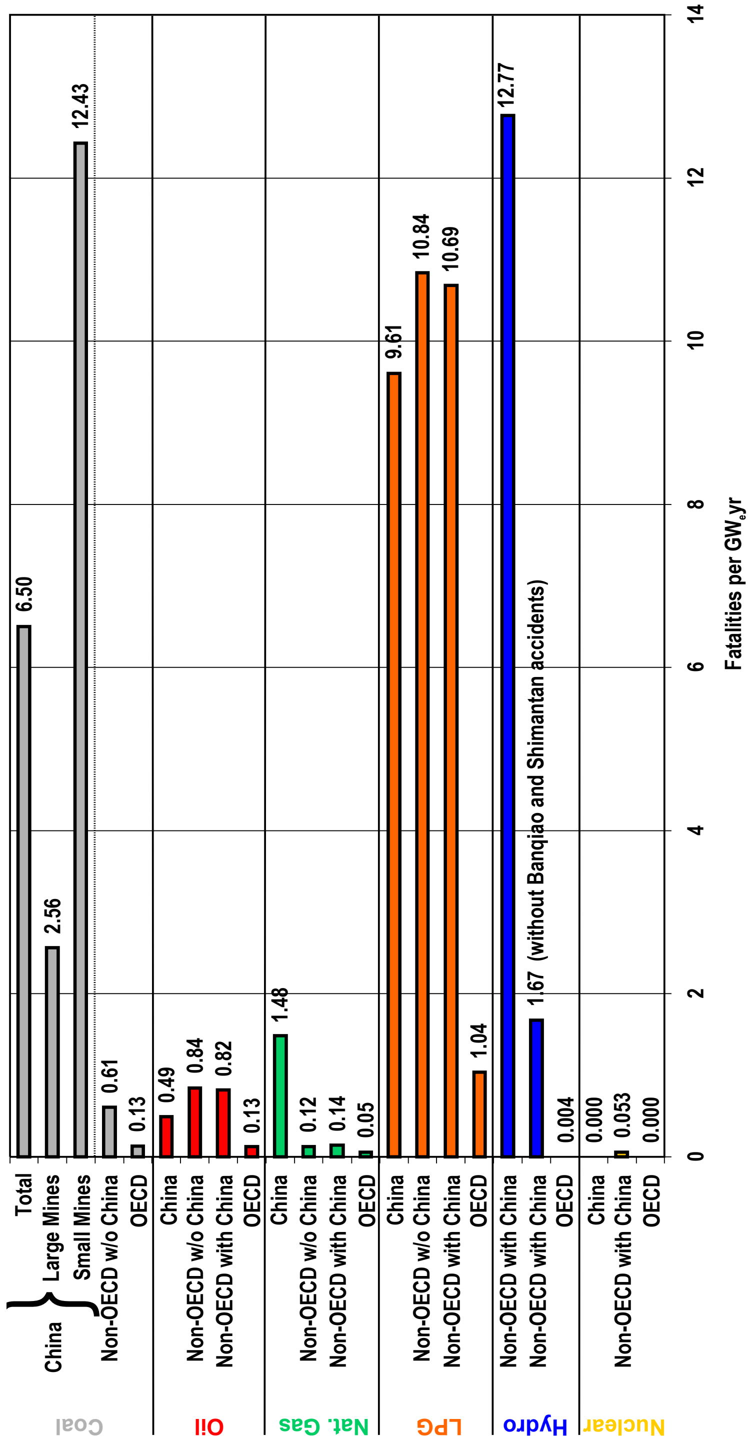

Figure 74: Severe accident fatality rates for <u>immediate</u> fatalities in major energy chains for China (1994-1999), non-OECD countries without China (1969-1996), non-OECD countries with China (1969-1999), and OECD countries alone (1969-1996). All results are based on historical experience; <u>latent</u> fatalities, of particular relevance for the nuclear chain, are commented in the text.

Figure 75 gives the frequency-consequence curves for coal in China, non-OECD countries without China and OECD countries. Differences among curves are very distinct with the Chinese curve ranking last with regard to risk performance. Among Chinese mines there is a large difference between the performance of large mines and small mines; the latter have shocking accident records. On the positive side, the maximum number of fatalities in any single accident was lower for China (114) than for other non-OECD (434) or OECD countries (272) for the periods considered. Nevertheless, accidents with more fatalities also occurred in the Chinese coal chain before and after the period 1994-1999. For example, an accident in 1982 caused 284 fatalities (exact location unknown), and one in 2000 resulted in 159 fatalities (Muchonggou mine, Guizhou).

Frequency-consequence curves for oil are shown for China, non-OECD countries with and without China and OECD countries (Figure 76). Although the data basis on severe accidents in the Chinese oil chain is rather small compared to non-OECD countries, deviations are much smaller than found for coal. Therefore, the non-OECD experience is here considered to be also representative for China. In non-OECD countries, six accidents with more than 200 fatalities occurred, whereas in China the worst accident in 1983 in the South China Sea claimed 81 fatalities.

Figures 77 and 78 show frequency-consequence curves for the natural gas and LPG chains. The risk performance of China’s natural gas chain appears to be worse compared to other non-OECD countries, but it is likely that this result is caused by very limited statistical experience. Therefore, it seems more appropriate to use non-OECD experience as representative also for China. Non-OECD experience is also considered to be representative for China’s LPG chain.

Frequency-consequence curves for hydro power are given in Figure 79. Due to the generally small available database Chinese hydro power experience is not shown separately. The most severe dam accident that occurred in the period examined was the failure at Banqiao and Shimantan dams in China resulting in 26’000 fatalities.

Frequency-consequence curves for the nuclear chain were based on Probabilistic Safety Assessment (PSA) and presented for the two sites Qingdao and Yantai (Figure 80).

Figure 81 shows the final selection of frequency-consequence curves for comparison of the different Chinese energy chains. Among Chinese energy chains, coal exhibits the highest accident frequencies. However, the vast majority of severe coal accidents in China results in less than 100 fatalities. The natural gas chain shows a favorable performance with regard to accident frequencies and maximum fatalities, but natural gas is currently of relatively minor importance for China's energy mix. Accident frequencies of the oil and hydro chains are also much lower than for the coal chain. However, maximum numbers of fatalities within the oil and hydro chains are one respectively two orders of magnitude higher than for coal and natural gas chains. Finally, expectation values for severe accident fatality rates associated with hypothetical nuclear accidents are lowest among the relevant energy chains. The maximum credible consequences may be very large, i.e. comparable to the Banqiao and Shimantan dam accident that occurred in China in 1975.

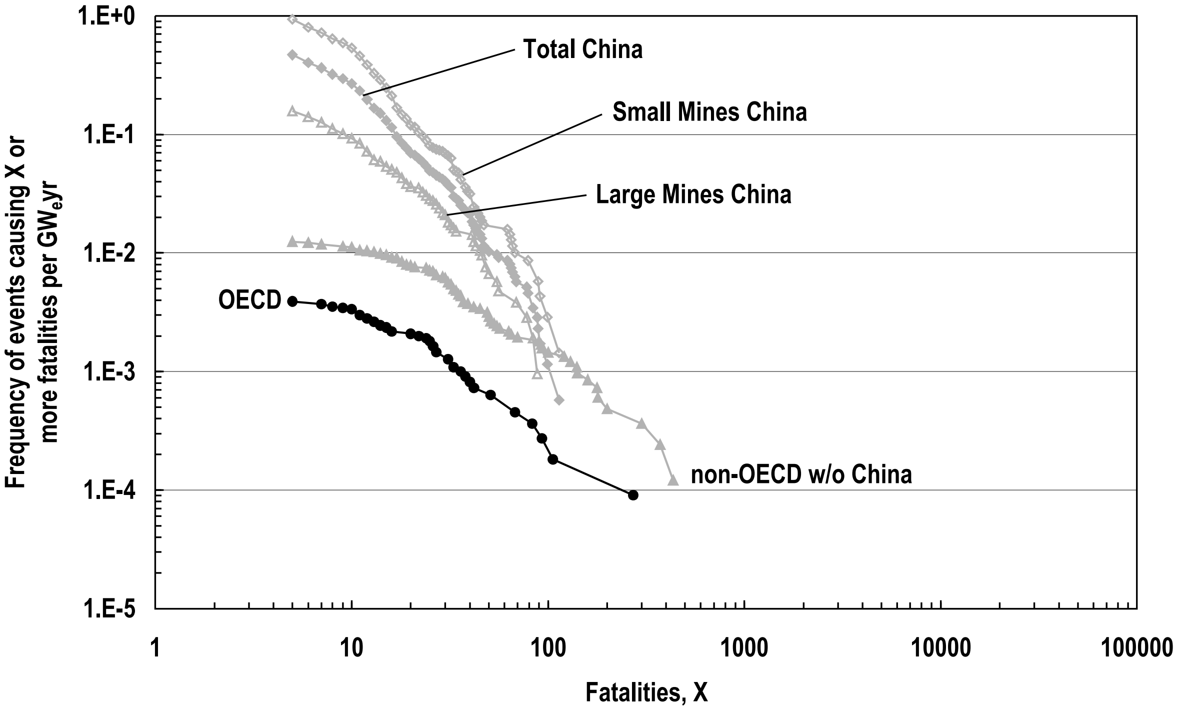

Figure 75: Frequency-consequence curves for the coal chain for China (1994-1999), non-OECD countries without China (1969-1996) and OECD countries alone (1969-1996).

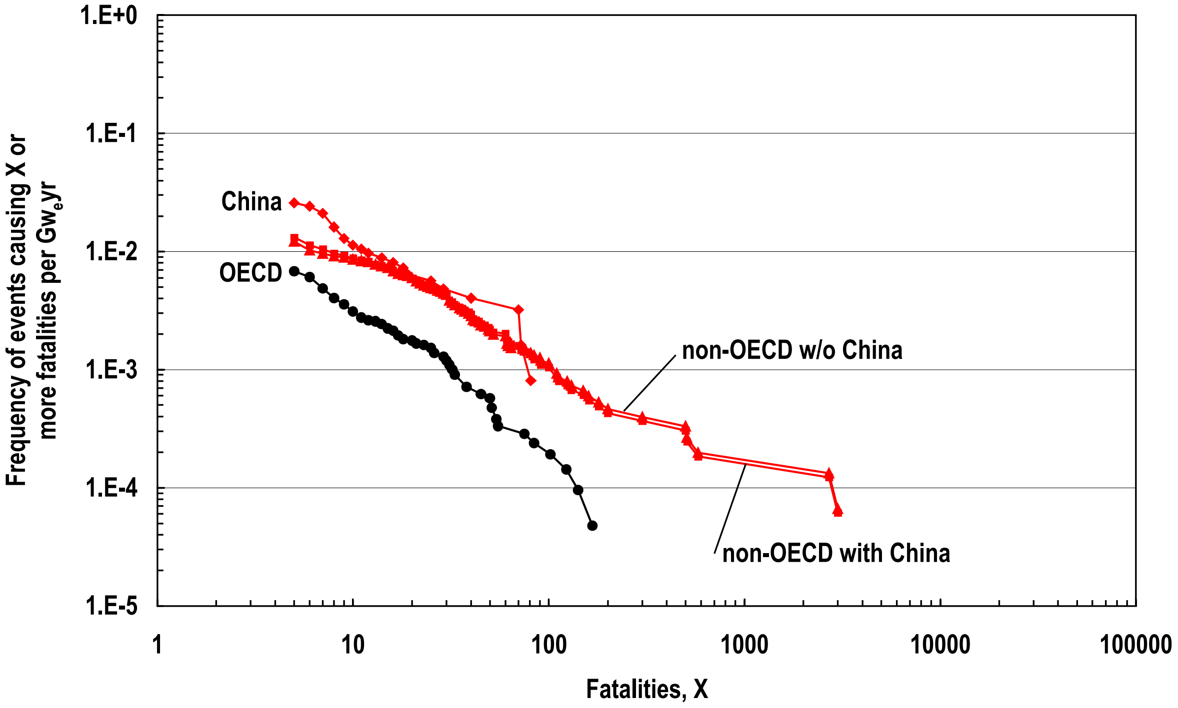

Figure 76: Frequency-consequence curves for the oil chain for China (CETP, 1969-1999), non-OECD countries without China (1969-1996), non-OECD countries with China (1969-1999), and OECD countries alone (1969-1996).

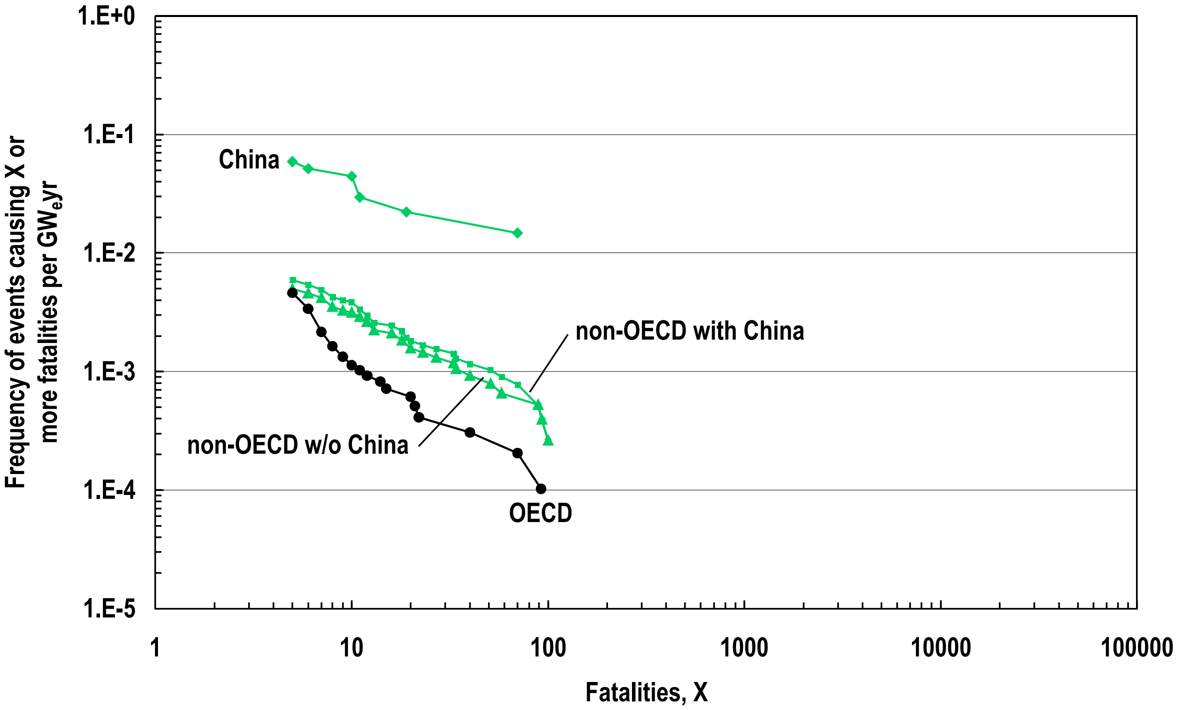

Figure 77: Frequency-consequence curves for the natural gas chain for China (CETP, 1969-1999), non-OECD countries without China (1969-1996), non-OECD countries with China (1969-1999), and OECD countries alone (1969-1996).

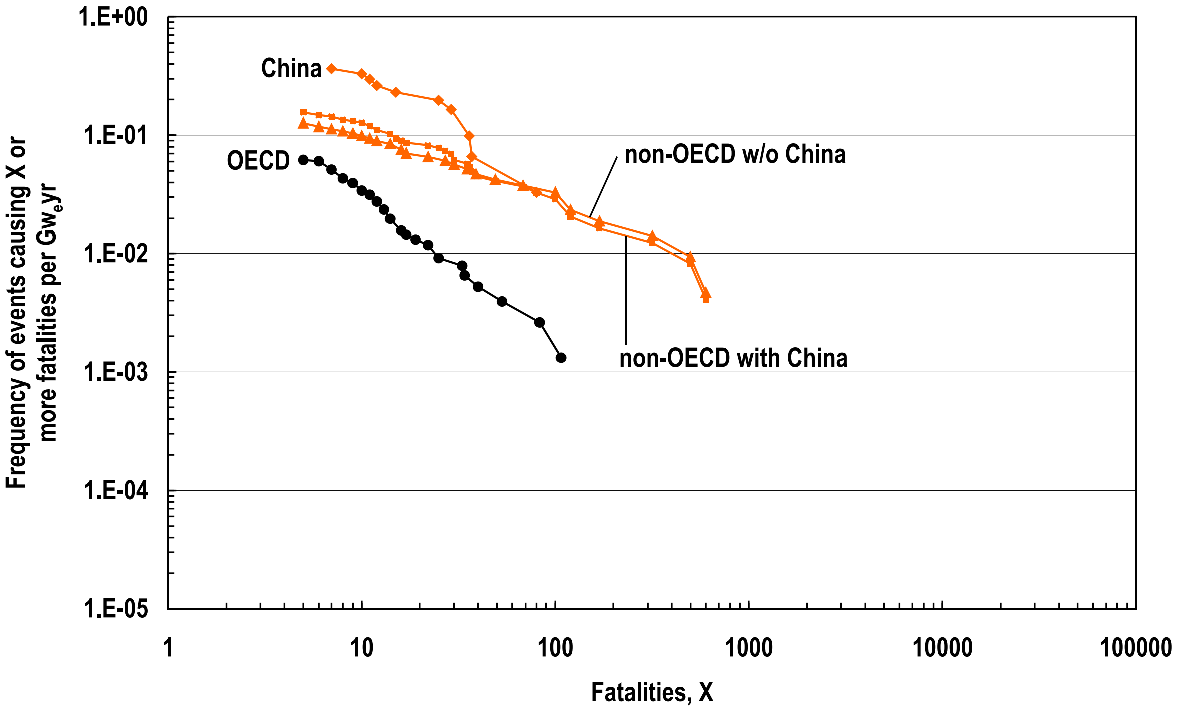

Figure 78: Frequency-consequence curves for the LPG chain for China (CETP, 1969-1999), non-OECD countries without China (1969-1996), non-OECD countries with China (1969-1999), and OECD countries alone (1969-1996).

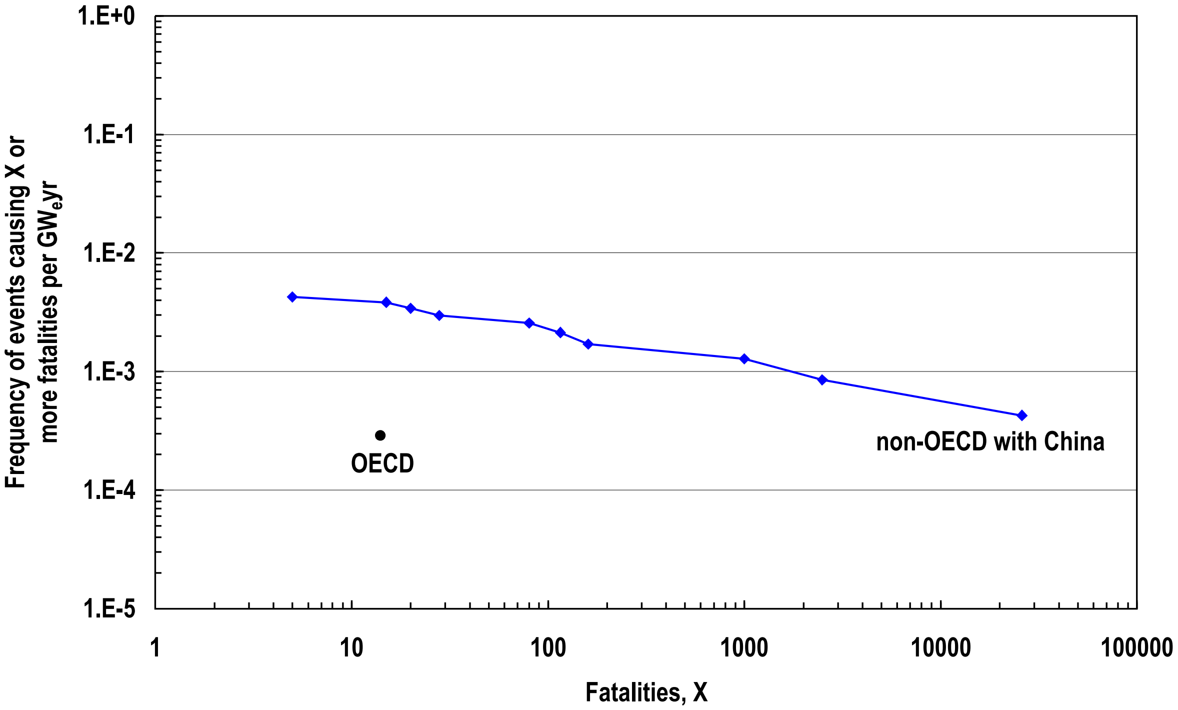

Figure 79: Frequency-consequence curves for the hydro power chain for non-OECD countries with China (1969-1999), and OECD countries alone (1969-1996).

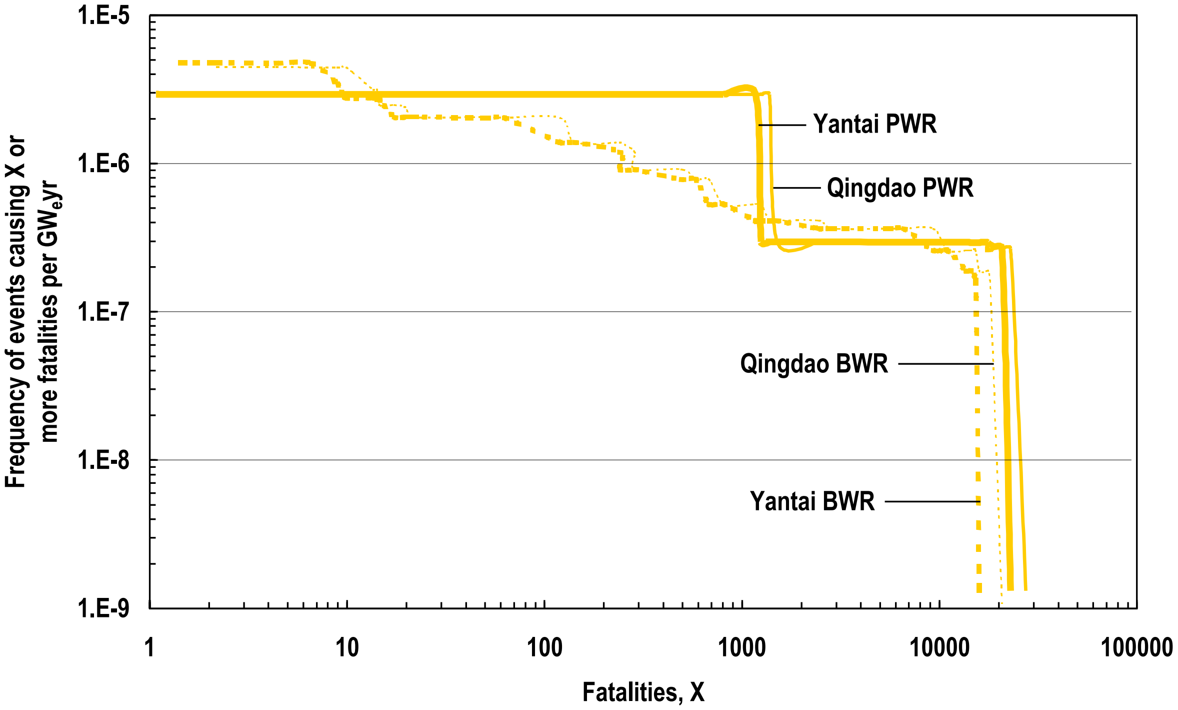

Figure 80: Frequency-consequence curves for the nuclear chain based on Probabilistic Safety Assessment for the 2 sites Qingdao and Yantai in Shandong province.

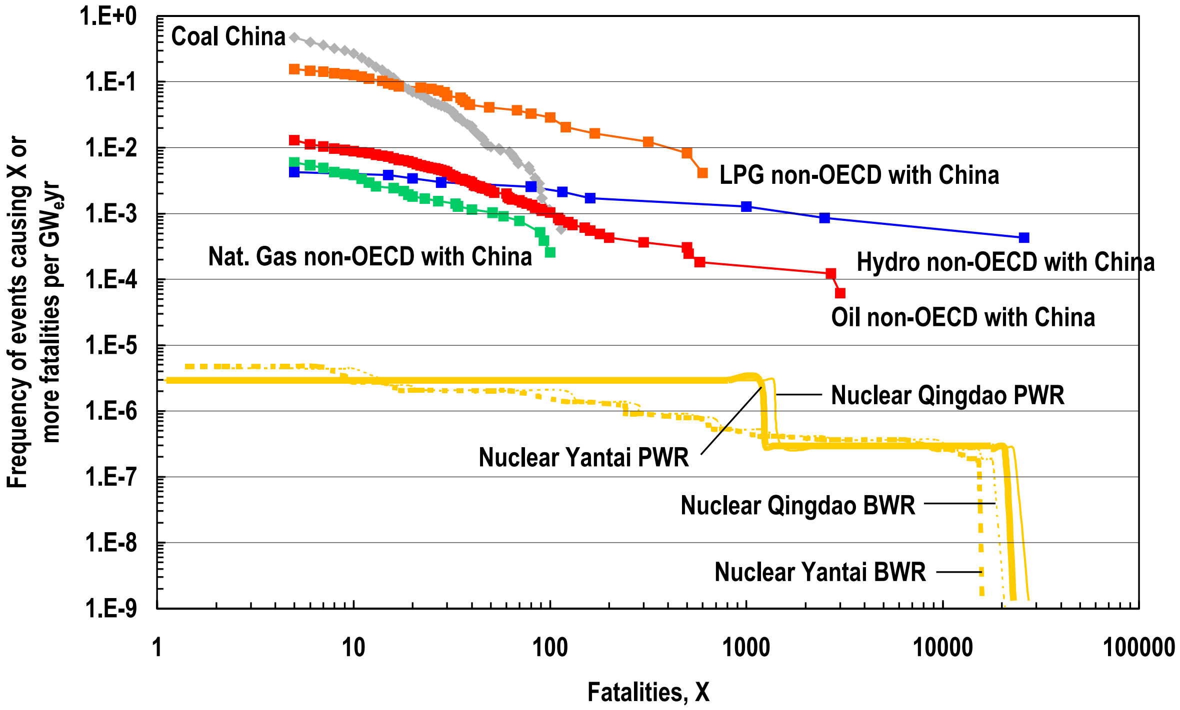

Figure 81: Comparison of severe accident records based on frequency-consequence curves for different energy chains in the period 1969-1999, except for Coal (1994-1999). The results for the nuclear chain are based on Probabilistic Safety Assessment and represent latent fatalities, whereas the other chains are based on historical accidents and represent immediate fatalities.

5.2 Indicators for the future

Results of risk assessment were also used as part of the input for an overall multi-criteria decision analysis (MCDA) of selected Shandong electricity supply scenarios based originating from Electric Sector Simulation (ESS). A modified set of indicators was chosen to meet the criteria definitions used in MCDA. Potential health impacts due to severe accidents were addressed using two sub-criteria. Expected risks under current conditions and for 2020 were evaluated by means of aggregated indicators (Fatalities per GW_eyr). Additionally, Maximum credible consequences were defined as the accident with the largest number of fatalities that ever occurred worldwide for a specific energy chain; for the nuclear case the Shandong-specific PSA-based results were used. Table 54 explains on which assumptions the aggregated indicators for the various energy chains were based. Hydro power is not included since its potential in the Shandong province is insignificant.

Table 54: Assumptions for selection of aggregated indicators for MCDA input.

	Current	**2020**
Coal	Weighted average based on coal output in Shandong and Shanxi corrected for contributions from large and small mines.	Performance of the Chinese coal chain is expected to become similar to non-OECD w/o China (1969-1996) experience. It is assumed that phasing out small, inefficient mines, characterized by very poor safety standards, will continue.
Oil	Non-OECD with China (1969-1999) experience is considered representative for China as the statistical basis in terms of China-specific records is relatively small.	The level corresponding to the current China-specific experience (1969-1999) appears as a meaningful reference for the future, particularly given the fact that the rate for non-OECD countries is driven by two very large and thus untypical accidents (Philippines, 1987 and Afghanistan, 1982).
Natural gas	Non-OECD with China (1969-1999).	Non-OECD w/o China (1969-1996).
Nuclear	There are currently no nuclear power plants in Shandong.	Current reactors (Qingdao site); no substantial change.

Aggregated indicators for current conditions and 2020 are shown in Figure 82. Although the coal chain is predicted to improve by about 45%, it will still rank on the last position what concerns the expectation values. Expected fatality rate for the oil chain is in the same range as for coal, whereas no major changes in the natural gas chain are expected. For the nuclear chain current reactors are assumed as the reference technology for China, having in mind that the estimates generated in the present work reflect the design features of the plants analyzed as well as the physical conditions (primarily population density) around the selected reference site but may not represent possible negative impacts of the different safety culture.

Figure 83 indicates the maximum credible consequences for each energy chain. Here the picture is somewhat reversed. Nuclear that has the lowest expected fatality rates, exhibits the potentially largest maximum credible consequences among the various energy chains. In contrast, accidents in the coal chain are more frequent but the number of maximum credible fatalities is much smaller. It should be noted that the basis for generation of indicators for the maximum credible consequences is not as balanced as desirable due to lack of PSA studies for fossil energy chains. Such studies would probably generate higher values than those based on the historical experience though at a lower frequency level.

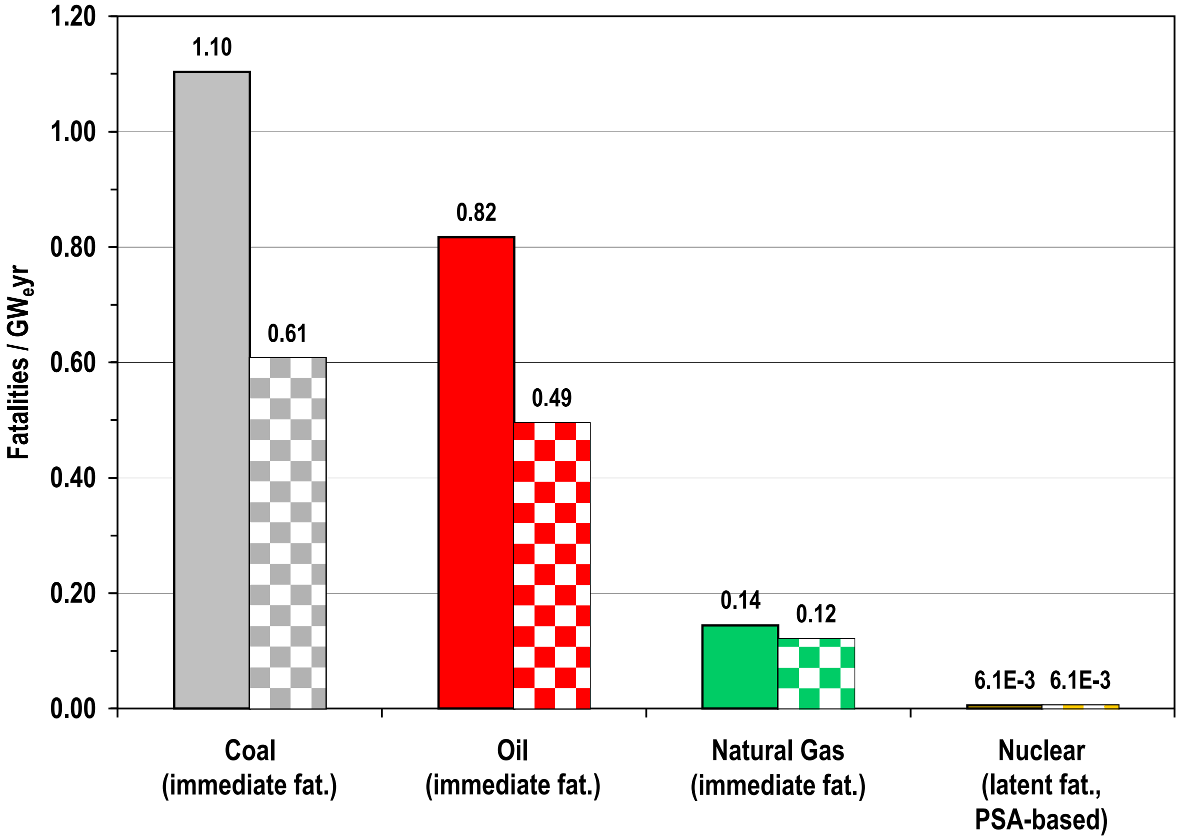

Figure 82: Expected severe accident fatality rates for current conditions (solid bars) and in 2020 (checkered bars) for various energy chains.

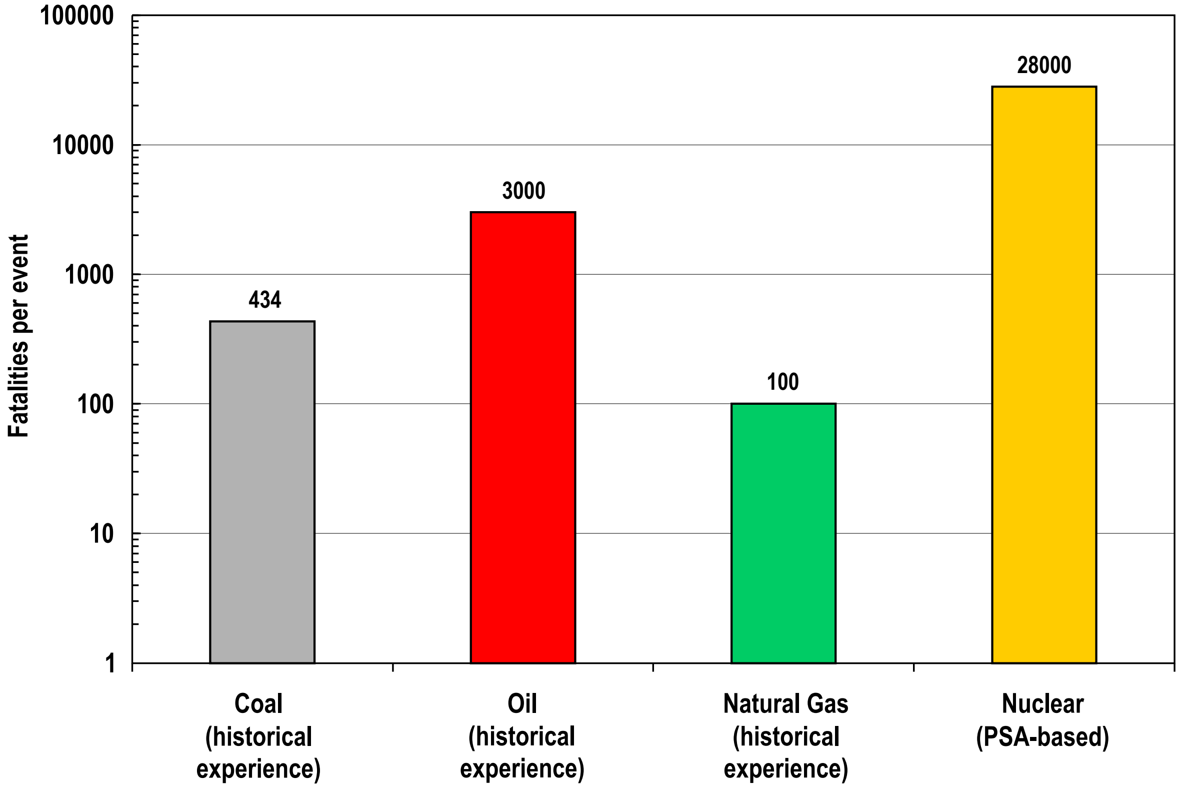

Figure 83: Maximum credible consequences for various energy chains.

6. CONCLUSIONS

Conclusions are provided here for the major energy chains individually and what regards comparisons between the chains. To the extent possible risks associated with full energy chains were considered unless it was clear that major risks are concentrated to one specific stage in the chain.

6.1 Specific chains

Coal chain

- The experience-based evaluation focused particularly on coal as the dominant energy chain in China. During the period 1994-1999 a total of 816 severe coal accidents occurred in China, with the total number of 11’321 fatalities.
- Every year about 6000 fatalities occur in Chinese mines due to small and severe accidents. Though severe accidents receive more attention than the small ones about 2/3 of the fatalities is due to small accidents.
- More than every third industrial severe accident in China occurs in the coal industry.
- The Chinese severe accident fatality rate for the coal chain is about 6.5 per GW_eyr. On average, this is about ten times higher than in non-OECD countries and about fifty times higher than in OECD countries.
- Coal production in Shanxi province is not more than about three times higher than in Shandong but the number of accidents and fatalities was in the period 1994-1999 almost ten times higher in Shanxi.
- Small mines in China exhibit on average five times higher severe accident fatality rates compared to large mines. Closing small mines with unacceptably low safety standards would significantly reduce accident risks. The current developments in the Chinese mining industry go in this direction and should continue.
- Additonally, extraction of coalbed methane (CBM) would provide an important safety measure to reduce the large number of gas accidents occurring in Chinese coal mines and thus potentially contribute to a reduction in numbers of accidents and fatalities.
- The accident reports for the coal chain clearly show that the majority of severe accidents were due to bad mine management, lax safety standards by the mine owners, poor training and lack of appropriate supervision by officials.

Oil chain

- During the period 1969-1999 a total of 32 severe oil chain accidents occurred in China, with the total number of 613 fatalities.

- Due to the limited Chinese-specific experience the generic non-OECD experience is considered to be representative also for China.

- Half of the accidents occurred during transportation (i.e. transport to refinery or regional distribution), followed by exploration and refinery stages. Considering fatalities, exploration ranks first with a share of about 40%, followed by regional distribution and transport to refinery.

- No major offshore or onshore oil spills exceeding 25’000 t were reported in China. However, many smaller oil spills that caused major environmental problems were identified. In the South China Sea even small spills can have serious social consequences due to the high dependence of the population on fish.

Natural gas chain

- During the period 1969-1999 a total of 8 severe accidents with cumulated 201 fatalities occurred in the Chinese natural gas chain. The use of natural gas in China though currently increasing has been historically on a low level.

- Similar to oil the generic non-OECD experience is considered representative for China for the purpose of the present work.

Hydro power

- Hydro power accident risks were not studied in detail. Hydro is of high importance for China but hydro resources in the Shandong province are low.

- Between 1950 and 1990 3241 dam failures occurred in China, of which 123 or 3.8% were at large dams and 3118 or 96.2% at smaller dams. The consequences of these collapses have mostly not been reported.

- The official death toll resulting from dam failures is 9937, not including the failure of Banqiao and Shimantan dams in 1975, which caused about 26’000 fatalities [Fu, 1998].

- Due to the clear indication of underreporting of dam accidents a reliable estimate of the Chinese-specific fatality rates due to severe hydro power accidents is not feasible. Therefore, the pooled non-OECD with China hydro power experience is used for comparative analyses in the present work. Progress towards more reliable Chinese-specific estimates is totally dependent on the access to the relevant historical records. For the current major projects, such as Three Gorges, carrying out a dam-specific Probabilistic Safety Assessment (PSA) would be advisable.

Nuclear power

- Given the total lack of relevant historical accidents, PSA methodology utilizing a simplified approach to the assessment of consequences was employed to provide estimates of the risks associated with hypothetical nuclear accidents at two selected sites in Shandong. Typical current designs with good safety standards and advanced (evolutionary) designs were considered as reference plants.

- The estimated risks were found to be plant- and site-sensitive. The orders of magnitude for specific risk measures are, however, the same for almost all cross-comparisons. The only exception is the comparison of current and advanced designs, with the latter being one order of magnitude better from the risk point of view.

- Generally, early fatality risks are negligible in comparison with latent fatality rates. Latent fatality rates are significantly higher but remain in absolute terms on a low level. In relative terms, the risk of land contamination, though also low, is a major concern due to the related social consequences.

- A number of sensitivity cases showed that the estimated risk measures are relatively insensitive to moderate variations of a number of crucial parameters. However, all results are subject to uncertainties associated with core damage frequency and source terms. When contemplating the results it should be kept in mind that they primarily reflect the good safety standard of the selected reference designs. Safety culture may have a decisive impact on the risk once the plants are operated; this aspect has not been addressed here for the China-specific conditions.

6.2 Comparative aspects

- The comparison covers aggregated indicators (i.e., fatality rates per GW_eyr) and frequency-consequence curves. It addresses exclusively fatality rates since no consistent data could be found for other accident indicators for all energy chains. Furthermore, some of the consequences are associated with only one energy carrier (e.g. oil spills) or are most pronounced for a specific chain (e.g. long-term land contamination).

- Among the major energy chains relevant for electricity generation the coal chain exhibits the highest fatality rates when the aggregated indicators considered as most representative for the Chinese conditions are compared. The corresponding indicators for the oil chain are one order of magnitude lower and between one to two orders of magnitude lower for natural gas. Depending on the choice of reference and subject to the above mentioned reservations regarding the underreporting of Chinese accidents, the severe accident fatality rate for hydro power in China is of the same order of magnitude as that for the coal chain. Probabilistic analysis indicate that risk of early fatalities associated with hypothetical accidents at current type or advanced nuclear power plants at selected sites in Shandong is negligible compared with the severe accident immediate fatality rates for the other energy chains. Risk of latent fatalities is higher but remains to be 3-4 orders of magnitude lower than the experience-based severe accident results for coal in China and hydro in non-OECD countries with China, and 2-3 and 1-2 orders of magnitude lower than oil respectively gas severe accident fatality rates in non-OECD countries with China. The predictive estimates for latent nuclear fatalities are of the same order or lower than the experience-based results for hydro power in OECD countries. The results for nuclear are only valid under the assumptions that the nuclear power plants will be operated under stringent licensing requirements and in an environment characterized by safety culture comparable to what is typical for OECD countries. Verifying the realism of this assumption is beyond the scope of the present work.

- A somewhat different perspective is gained through the examination of frequency-consequence curves. Among Chinese energy chains, coal exhibits the highest accident frequencies. However, the vast majority of coal accidents in China results in less than 100 fatalities. The natural gas chain shows a favorable performance with regard to the accident frequencies and maximum fatalities, but natural gas is currently of relatively minor importance for China's energy mix. Accident frequencies of the oil and hydro chains are also much lower than for the coal chain. However, maximum number of fatalities within the oil and hydro chains are one respectively two orders of magnitude higher than for coal and natural gas chains. Finally, the nuclear curves are at a very low frequency level, orders of magnitude below those for other chains. The maximum credible consequences due to hypothetical nuclear accidents may be very large, i.e. comparable to the Banqiao and Shimantan dam accident that occurred in China in 1975. The associated risk valuation is subject to stakeholder value judgments and has been pursued along with other economic, environmental and social criteria in multi-criteria decision analysis carried out by the CETP.

- Damage costs associated with severe accidents were not explicitly estimated within this project. The results expressed in terms of risk measures indicate that compared to OECD these damage costs are bound to be very high for the coal chain and probably also for hydro power. For the Chinese conditions, however, they are of low significance when compared to the damage costs associated with air pollution.

- Diversification of the energy mix, improvements in energy efficiency, energy conservation and safety promoting measures, are key aspects for a sustainable development of the energy sector, with significant gains in terms of reducing the number of severe accidents among other positive effects.

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GLOSSARY

ABWR
Advanced Boiling Water Reactor

ACTMCLSHHA
Accident Cases of Typical and Major Casualties on Labour Safety and Health at Home and Abroad

ACWCMSC
A Complete Work of Coal Mine Safety in China

AFSTC
Accident Files: Selected Typical Cases

AGS
The Alliance for Global Sustainability was created in 1994 as a new strategic approach to global issues of sustainability. The founding partners are three of the world's leading research universities, namely the Massachusetts Institute of Technology, MIT, USA, the Federal Institute of Technology, ETH, Switzerland and the University of Tokyo, Japan. In March 2001, Chalmers University of Technology in Gothenburg, Sweden has been specially invited to join the group.

Anticyclone
An anticyclone is a region of high atmospheric pressure; anticyclones are commonly referred to as "highs".

AISU
Advanced International Studies Unit

ATWS
Anticipated Transient withouth Scram

BASICS
British Association for Immediate Care

BMT
Basemat Melt-Through

BWR
Boiling Water Reactor

CBD
Convention on Biological Diversity

CBM
CoalbedCoalbed Methane

CCDF
Complementary Cumulative Distribution Function

CCIY
China Coal Industry Yearbook

CDF
Core Damage Frequency

Centipose
Dynamic viscosity ("absolute viscosity") is the tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid. In SI units the theoretical unit is the Poise (grams / centimetre second). As these units are large, it is more usual to divide them by 100, to give a smaller unit called the centipose (cP).

CETP
China Energy Technology Program

CISDOC
International Occupational Health and Safety Centre Bibliographic Database

CNOOC
China National Offshore Oil Corporation

CNPC
China National Petroleum Corporation

CONCAWE
European organisation for environment, health and safety of the oil companies

COSHY
China Occupational Safety and Health Yearbook

CPIY
China Petroleum Industry Yearbook

COY
China Ocean Yearbook.

DHR
Decay Heat Removal

DOE
US Department of Energy

DSO
Dam Safety Office, Bureau of Reclamation, US Department of Interior

ECCS
Emergency Core Cooling System

EEM
Energy Economy Modeling

EIA
Energy Information Administration; official energy statistics from the U.S. government

EIN
European Internet Network

ENSAD
Energy-related Severe Accidents Database; this comprehensive database on severe accidents with emphasis on those associated with the energy sector has been established by the Paul Scherrer Institute, Switzerland.

EPR
European Pressurized Water Reactor

ESS
Electric Sector Simulation

Final consumption
The term final consumption implies that energy used by the energy producing industries and for transformation is excluded

HSE
Health and Safety Executive (UK).

HSELINE
Library and Information Services of HSE

IAEA
Interanational Atomic Energy Agency

ICOLD
International Commission on Large Dams

IEA
International Energy Agency

ILO
International Labour Organisation

ITOPF
International Tanker Owners Pollution Federation Ltd.

KWU/EDF
Kraftwerkunion/Electricité de France

LCA
Life Cycle Assessment

LLP
Lloyd’s Casualty Week; formerly Lloyd’s of London Press

LNG
Liquefied Natural Gas

LPG
Liquefied Petroleum Gas

MACCS
Accident Consequence Code System

MCDA
Multi-criteria decision analysis

MHIDAS
Major Hazards Incidence Data Service

MOX
Mixed Oxide

MSHA
Mine Safety and Health Administration (USA)

NIOSHTIC
National Institute of Occupational Safety and Health (USA)

NLG
Natural Liquefied Gas

NPP
Nuclear Power Plant

NSPC
National Star Petroleum Corporation

OECD
Organisation for economic cooperation and development

OSH
Occupational Health and Safety

PDS
Plant Damage State

PRIS
IAEA’s Power Reactor Information System

PSA
Probabilistic Safety Assessment

PWR
Pressurized Water Reactor

RA
Risk Assessment

Reserves/Production (R/P) ratio
If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that level.

RPS
Reactor Protection System

SA
Severe Accident

SAM
Severe Accident Management

SCIA
State Coal Industry Administration

SEPA
State Environmental Protection Administration

SEPCO
Shandong Electric Power Corporation

SIGMA
Sigma is published approximately eight times a year by Swiss Re’s Economic Research & Consulting Team based in Zurich, New York and Hong Kong

SINOPEC
China Petrochemical Corporation

SSB
State Statistical Bureau of China

TGP
Three Gorges Project

UNCED
United Nations Conference on Environment and Development

UNDP
United Nations Development Programme

USGS
United States Geological Survey

VVER
The VVER is the Russian version of the Pressurized Water Reactor

WBSCD
World Business Council on Sustainable Development

WCD
World Commission on Dams

WEC
World Energy Council

UNITS

t	tonne, metric ton (1 t = 1000 kg)
Mt	one million tonnes or one megatonne (1 Mt = 10^6 t)
toe	tonnes of oil equivalent
tce	tonnes of coal equivalent
W	watt (1 W = 1 J/sec)
kW	kilowatt (1 kW = 10^3 W)
MW	megawatt (1 MW = 10^6 W)
GW	gigawatt (1 GW = 10^9 W)
kWh	kilowatt hour (1 kWh = 3.6 MJ
GW_eyr	gigawatt-year (1 GW_eyr = 8.76 x 10^9 kWh)
J	joule (1 J = 1 Nm^{-1} = 1 $kgm^{-1}s^{-2}$)
MJ	megajoule (1 MJ = 10^6 J)
Bq	1 Becquerel = amount of material which will produce 1 nuclear decay per second. The Bequerel is the more recent SI unit for radioactive source activity. The curie (Ci) is the old standard unit for measuring the activity of a given radioactive sample. It is equivalent to the activity of 1 gram of radium. 1 curie = 3.7 x 1010 Becquerels.
Gy	Gray; SI unit of absorbed radiation dose in terms of the energy actually deposited in the tissue. The Gray is defined as 1 joule of deposited energy per kilogram of tissue. The old SI unit is the rad. 1 Gy = 1 J/kg = 100 rad.
Ryr	Reactor*year

APPENDIX A:
LIST OF SEVERE ACCIDENTS WITHIN THE CHINESE COAL CHAIN IN THE PERIOD 1994-1999

Table A.1: Severe accidents with at least five fatalities. Injured persons and economic damages were not included because this information was only available for few accidents. S = small mine, L = large (or medium) mine. Accident causes: RA = roof accident, EMA = electro-mechanical accident, TA = transport accident, GA = gas accident, BA = blast accident, FA = fire accident, WHA = water hazards accident, OA = other accident, NA = not available. CCIY = China Coal Industry Yearkbook.

Date	Place	Province	Type of Mine	Energy chain stage	Cause	Max. No. Fatalities	Source
02.01.1994	Panxian	Guizhou	S	Extraction	GA	14	CCIY, 1997.
23.01.1994	Xinglong	Hebei	L	Extraction	GA	12	CCIY, 1997.
24.01.1994	Jixi	Heilongjiang	S	Exploration	GA	99	CCIY, 1997.
27.01.1994	Chenxi	Hunan	S	Extraction	GA	36	CCIY, 1997.
29.01.1994	Liuzhi	Guizhou	L	Exploration	GA	16	CCIY, 1997.
12.02.1994	Xuzhou	Jiangsu	L	Exploration	FA	14	CCIY, 1997.
06.03.1994	Liaoyuan	Jilin	L	Extraction	GA	14	CCIY, 1997.
11.03.1994	Miquan	Xinjiang	S	Transport	FA	10	CCIY, 1997.
12.03.1994	Xiyang	Shanxi	S	Extraction	GA	12	CCIY, 1997.
18.03.1994	Qingyuan	Shanxi	L	Extraction	GA	11	CCIY, 1997.
21.03.1994	Baotou	Inner Mongolia	L	Extraction	GA	10	CCIY, 1997.
21.03.1994	Hegang	Heilongjiang	S	Extraction	GA	14	CCIY, 1997.
25.03.1994	Panxian	Guizhou	S	Extraction	GA	10	CCIY, 1997.
30.03.1994	Honggu	Gansu	S	Extraction	GA	12	CCIY, 1997.
01.04.1994	Hejing	Shanxi	S	Exploration	GA	10	CCIY, 1997.
02.04.1994	Huaiying	Jiangsu	L	Extraction	GA	10	CCIY, 1997.
03.04.1994	Xishan	Shanxi	S	Extraction	GA	14	CCIY, 1997.
03.04.1994	Xin'an	Henan	S	Extraction	GA	14	CCIY, 1997.
03.04.1994	Zibo	Shandong	S	Extraction	WHA	16	CCIY, 1997.
04.04.1994	Pingdingshan	Henan	S	Extraction	FA	14	CCIY, 1997.
18.04.1994	Panxian	Guizhou	S	Extraction	GA	12	CCIY, 1997.
20.04.1994	Qitaihe	Heilongjiang	S	Extraction	GA	35	CCIY, 1997.
23.04.1994	Shuangyang	Jiling	L	Exploration	GA	12	CCIY, 1997.
29.04.1994	Puding	Guizhou	S	Extraction	GA	16	CCIY, 1997.
01.05.1994	Fengcheng	Jiangxi	L	Extraction	GA	41	CCIY, 1997.
02.05.1994	Fencheng	Jiangxi	S	Extraction	GA	19	CCIY, 1997.

05.05.1994	Xishui	Guizhou	S	Extraction	GA	14	CCIY, 1997.
13.05.1994	Dafang	Guizhou	S	Extraction	GA	16	CCIY, 1997.
14.05.1994	Leibin	Guangxi	S	Extraction	WHA	13	CCIY, 1997.
15.05.1994		Jiangxi		Extraction	N.A	38	ENSAD
17.05.1994	Linwu	Hunan	S	Extraction	GA	11	CCIY, 1997.
21.05.1994	Gaoxian	Sichuan	S	Extraction	GA	36	CCIY, 1997.
28.05.1994	Wuxiang	Shanxi	S	Extraction	GA	24	CCIY, 1997.
29.05.1994	Liupanshui	Guizhou	S	Extraction	GA	12	CCIY, 1997.
07.06.1994	Agan	Guansu	S	Extraction	GA	11	CCIY, 1997.
12.06.1994		Xinjiang	L	Exploration	WHA	10	CCIY, 1997.
18.06.1994	Xinfeng	Jiangxi	S	Extraction	RA	11	CCIY, 1997.
24.06.1994	Baofeng	Henan	S	Extraction	WHA	24	CCIY, 1997.
22.07.1994	Denfeng	Henan	S	Extraction	GA	13	CCIY, 1997.
27.07.1994	Yuzhou	Henan	S	Extraction	WHA	19	CCIY, 1997.
27.07.1994	Zhangjiakou	Hebei	S	Extraction	GA	10	CCIY, 1997.
30.07.1994	Weining	Guizhou	S	Extraction	GA	32	CCIY, 1997.
30.07.1994	Yangcheng	Shanxi	L	Extraction	GA	11	CCIY, 1997.
01.08.1994	Hebi	Henan	S	Extraction	GA	11	CCIY, 1997.
03.08.1994	Pingdingshan	Henan	L	Extraction	FA	17	CCIY, 1997.
04.08.1994	Qingxu	Shanxi	S	Extraction	GA	10	CCIY, 1997.
09.08.1994	Lianyuan	Hunan	S	Extraction	WHA	25	CCIY, 1997.
26.08.1994	Panxian	Guizhou	S	Extraction	WHA	34	CCIY, 1997.
27.08.1994	Tongling	Anhui	L	Exploration	RA	10	CCIY, 1997.
29.08.1994	Baiyin	Gansu	S	Extraction	GA	10	CCIY, 1997.
29.08.1994	Wuhai	Inner Mongolia	S	Extraction	WHA	24	CCIY, 1997.
30.08.1994	Changguang	Zhejiang	L	Exploration	GA	12	CCIY, 1997.
31.08.1994	Suicheng	Guizhou	S	Extraction	GA	16	CCIY, 1997.
01.09.1994	Xingbing	Liaoning	L	Extraction	GA	12	CCIY, 1997.
01.09.1994	Panxian	Guizhou	S	Extraction	GA	11	CCIY, 1997.
02.09.1994	Leping	Jiangxi	S	Extraction	GA	19	CCIY, 1997.
05.09.1994	Pingdingshan	Henan	S	Extraction	GA	10	CCIY, 1997.
17.09.1994	Hegang	Heilongjiang	L	Extraction	GA	56	CCIY, 1997.
19.9.1994	Hechuan	Guanxi	S	Extraction	WHA	16	CCIY, 1997.
19.09.1994	Leping	Jiangxi	S	Extraction	GA	12	CCIY, 1997.
27.09.1994	Fuxin	Liaoning	S	Extraction	GA	10	CCIY, 1997.
24.10.1994	Hegang	Heilongjiang	L	Transport	EMA	12	CCIY, 1997.

28.10.1994	Wanshen	Chongqing	S	Extraction	GA	17	CCIY, 1997.
06.11.1994	Linfen	Shanxi	S	Extraction	GA	18	CCIY, 1997.
12.11.1994	Luxi	Yunnan	S	Extraction	GA	17	CCIY, 1997.
13.11.1994	Liaoyuan	Jiling	S	Extraction	GA	79	CCIY, 1997.
17.11.1994	Fengcheng	Jiangxi	S	Extraction	GA	14	CCIY, 1997.
17.11.1994	Shuanrao	Jiangxi	S	Extraction	GA	16	CCIY, 1997.
19.11.1994	Leping	Jiangxi	S	Extraction	GA	12	CCIY, 1997.
24.11.1994	Nantong	Jiangsu	L	Extraction	OA	10	CCIY, 1997.
26.11.1994	Urumqi	Xinjang	L	Extraction	WHA	17	CCIY, 1997.
06.12.1994	Qiannan	Guizhou	S	Extraction	GA	17	CCIY, 1997.
01.01.1995	Tongchuan	Shaanxi	L	Extraction	RA	16	CCIY, 1996.
01.01.1995	Wudang	Guizhou	S	Extraction	GA	5	CCIY, 1996.
03.01.1995	Luzhou	Sichuan	L	Extraction	GA	5	CCIY, 1996.
03.01.1995	Qurenju	Guangdong	S	Extraction	GA	6	CCIY, 1996.
03.01.1995	Xinyu	Jiangshu	S	Extraction	GA	7	CCIY, 1996.
04.01.1995	Urumqi	Xingjiang	S	Extraction	GA	7	CCIY, 1996.
06.01.1995	Tonghua	Jiling	S	Extraction	GA	6	CCIY, 1996.
07.01.1995	Zhibo	Shandong	L	Exploration	GA	9	CCIY, 1996.
09.01.1995	Yongxing	Hunan	S	Exploration	WHA	5	CCIY, 1996.
10.01.1995	Ningxiang	Hunan	S	Extraction	GA	7	CCIY, 1996.
10.01.1995	Xingfeng	Jiangxi	S	Exploration	GA	11	CCIY, 1996.
10.01.1995	Yangchun	Guangdong	S	Extraction	GA	6	CCIY, 1996.
11.01.1995	Zhongyang	Shanxi	S	Extraction	GA	9	CCIY, 1996.
12.01.1995	Qitaihe	Heilongjiang	S	Exploration	WHA	10	CCIY, 1996.
17.01.1995	Xincheng	Guangxi	S	Extraction	GA	23	CCIY, 1996.
17.01.1995	Qujing	Yunnan	S	Extraction	GA	6	CCIY, 1996.
19.01.1995	Hebi	Hunan	L	Exploration	WHA	6	CCIY, 1996.
19.01.1995	Nanpiao	Liaoning	L	Transport	TA	11	CCIY, 1996.
21.01.1995	Datong	Shanxi	L	Extraction	GA	6	CCIY, 1996.
22.01.1995	Zhangchun	Hebei	L	Extraction	RA	5	CCIY, 1996.
27.01.1995	Huaihua	Hunan	L	Extraction	GA	7	CCIY, 1996.
06.02.1995	105 Tuan	Xinjiang	L	Extraction	GA	5	CCIY, 1996.
06.02.1995	Mudanjiang	Heilongliang	S	Exploration	GA	7	CCIY, 1996.
14.02.1995	Chengde	Hebei	L	Extraction	GA	9	CCIY, 1996.
15.02.1995	Changning	Hunan	S	Extraction	GA	5	CCIY, 1996.
15.02.1995	Kailuan	Hebei	L	Extraction	WHA	12	CCIY, 1996.

16.02.1995	Datong	Shanxi	S	Exploration	GA	5	CCIY, 1996.
17.02.1995	Liuzhi	Guizhou	S	Extraction	GA	9	CCIY, 1996.
19.02.1995	Heshan	Guangxi	S	Extraction	GA	9	CCIY, 1996.
21.02.1995	Xishui	Guizhou	S	Extraction	GA	5	CCIY, 1996.
25.02.1995	Changning	Hunan	S	Extraction	GA	5	CCIY, 1996.
25.02.1995	Jixi	Heilongjiang	S	Extraction	GA	5	CCIY, 1996.
26.02.1995	Lingwu	Hunan	S	Extraction	GA	7	CCIY, 1996.
26.02.1995	Jiale	Hunan	S	Extraction	GA	8	CCIY, 1996.
26.02.1995	Tongshan	Jiangshu	S	Extraction	GA	5	CCIY, 1996.
27.02.1995	Yongxing	Hunan	S	Exploration	GA	15	CCIY, 1996.
28.02.1995	Fengcheng	Jiangxi	S	Exploration	GA	8	CCIY, 1996.
01.03.1995	Jingxian	Shanxi	S	Extraction	GA	16	CCIY, 1996.
02.03.1995	Gaoping	Shanxi	L	Exploration	WHA	7	CCIY, 1996.
09.03.1995	Xiahuayuan	Hebei	S	Extraction	WHA	8	CCIY, 1996.
10.03.1995	Baiying	Ganshu	L	Extraction	OA	6	CCIY, 1996.
10.03.1995	Lankong	Ganshu	S	Exploration	WHA	6	CCIY, 1996.
11.03.1995	Benxi	Liaoning	S	Extraction	GA	6	CCIY, 1996.
13.03.1995	Baotou	Inner Mongolia	S	Extraction	GA	9	CCIY, 1996.
13.03.1995	Fuyuan	Yunnan	S	Extraction	GA	32	CCIY, 1996.
14.03.1995	Baoding	Hebei	S	Extraction	GA	7	CCIY, 1996.
14.03.1995	Qujing	Yunnan	S	Exploration	WHA	9	CCIY, 1996.
14.03.1995	Xinfeng	Jiangxi	S	Extraction	GA	8	CCIY, 1996.
15.03.1995	Zhunyi	Guizhou	S	Exploration	WHA	8	CCIY, 1996.
16.03.1995	Huainan	Anhui	L	Exploration	GA	6	CCIY, 1996.
16.03.1995	Guangde	Anhui	L	Exploration	GA	15	CCIY, 1996.
17.03.1995	Yizhang	Hunan	S	Extraction	GA	6	CCIY, 1996.
19.03.1995	Heshan	Guangxi	S	Transport	TA	7	CCIY, 1996.
19.03.1995	Xunyi	Shaanxi	S	Extraction	GA	15	CCIY, 1996.
20.03.1995	Lengshui	Hunan	S	Extraction	GA	8	CCIY, 1996.
21.03.1995	Handan	Hebei	S	Exploration	WHA	16	CCIY, 1996.
21.03.1995	Liaoyuan	Jiling	S	Extraction	RA	8	CCIY, 1996.
23.03.1995	Nayong	Guizhou	S	Extraction	GA	5	CCIY, 1996.
24.03.1995	Qiyang	Hunan	S	Exploration	WHA	6	CCIY, 1996.
25.03.1995	Panxian	Guizhou	S	Extraction	GA	6	CCIY, 1996.
26.03.1995	Pingdingshan	Henan	S	Exploration	GA	40	CCIY, 1996.
30.03.1995	Baodou	Inner Mongolia	S	Extraction	GA	6	CCIY, 1996.

31.03.1995	Chenxian	Hunan	S	Extraction	GA	6	CCIY, 1996.
01.04.1995	Luxi	Yunnan	S	Exploration	GA	5	CCIY, 1996.
06.04.1995	Jiaozuo	Henan	S	Exploration	WHA	8	CCIY, 1996.
07.04.1995	Datong	Shanxi	L	Exploration	WHA	7	CCIY, 1996.
09.04.1995	Hebi	Henan	S	Extraction	GA	6	CCIY, 1996.
09.04.1995	Xinyu	Jiangxi	S	Extraction	WHA	6	CCIY, 1996.
09.04.1995	Weixian	Shaanxi	S	Exploration	GA	13	CCIY, 1996.
10.04.1995	Fengcheng	Jiangxi	S	Exploration	WHA	6	CCIY, 1996.
14.04.1995	Qujiang	Guangdong	L	Exploration	WHA	6	CCIY, 1996.
15.04.1995	Baiying	Ganshu	S	Extraction	GA	5	CCIY, 1996.
16.04.1995	Shangrau	Jiangxi	S	Extraction	GA	9	CCIY, 1996.
17.04.1995	Tangshan	Hebei	L	Extraction	GA	7	CCIY, 1996.
18.04.1995	Fushun	Liaoning	L	Exploration	GA	26	CCIY, 1996.
18.04.1995	Lingwu	Hunan	S	Extraction	GA	5	CCIY, 1996.
21.04.1995	Bijie	Guizhou	S	Exploration	GA	11	CCIY, 1996.
25.04.1995	Puding	Guizhou	S	Extraction	GA	10	CCIY, 1996.
29.04.1995	Aksu	Xinjiang	L	Exploration	GA	22	CCIY, 1996.
29.04.1995	Lingfeng	Shanxi	S	Extraction	GA	5	CCIY, 1996.
30.04.1995	Jingzhong	Shanxi	L	Extraction	GA	5	CCIY, 1996.
30.04.1995	Qitaihe	Heilongjiang	S	Extraction	GA	5	CCIY, 1996.
30.04.1995	Shauyang	Hunan	S	Exploration	GA	5	CCIY, 1996.
01.05.1995	Pingyuan	Guangdong	S	Exploration	GA	5	CCIY, 1996.
06.05.1995	Shangrau	Jiangxi	S	Extraction	GA	5	CCIY, 1996.
06.05.1995	Shuiyang	Guizhou	S	Extraction	GA	6	CCIY, 1996.
06.05.1995	Xiangfen	Shanxi	S	Extraction	GA	35	CCIY, 1996.
07.05.1995	Tianzhu	Gansu	S	Extraction	GA	9	CCIY, 1996.
07.05.1995	Yangxin	Hubei	S	Extraction	GA	7	CCIY, 1996.
07.05.1995	Zunyi	Guizhou	S	Exploration	WHA	15	CCIY, 1996.
08.05.1995	Baishan	Jiling	L	Exploration	GA	8	CCIY, 1996.
09.05.1995	Lianshao	Hunan	L	Extraction	GA	8	CCIY, 1996.
09.05.1995	Quren	Guangdong	S	Exploration	WHA	8	CCIY, 1996.
09.05.1995	Shuangfeng	Hunan	S	Extraction	GA	5	CCIY, 1996.
10.05.1995	Tacheng	Xinjiang	S	Extraction	GA	5	CCIY, 1996.
13.05.1995	Renhua	Guangdong	S	Extraction	GA	7	CCIY, 1996.
14.05.1995	Lingkou	Heilongjiang	S	Extraction	GA	10	CCIY, 1996.
15.05.1995	Shuiyang	Guizhou	S	Extraction	GA	6	CCIY, 1996.

16.05.1995	Chaohu	Anhui	S	Exploration	GA	7	CCIY, 1996.
19.05.1995	Shuangfeng	Hunan	S	Exploration	GA	7	CCIY, 1996.
22.05.1995	Qiyang	Hunan	S	Extraction	GA	12	CCIY, 1996.
22.05.1995	Shuoxian	Shanxi	S	Extraction	GA	8	CCIY, 1996.
23.05.1995	Zhuoyun	Shanxi	S	Extraction	GA	22	CCIY, 1996.
25.05.1995	Lingwu	Hunan	S	Extraction	GA	9	CCIY, 1996.
26.05.1995	Taiyuan	Shanxi	S	Exploration	WHA	7	CCIY, 1996.
26.05.1995	Yubei	Chongqing	S	Extraction	GA	7	CCIY, 1996.
27.05.1995	Qinshui	Shanxi	S	Extraction	GA	13	CCIY, 1996.
28.05.1995	Changzhi	Shanxi	S	Extraction	TA	5	CCIY, 1996.
31.05.1995	Shangjing	Fujian	S	Extraction	WHA	5	CCIY, 1996.
03.06.1995	Anyang	Henan	S	Extraction	GA	14	CCIY, 1996.
06.06.1995	Linwu	Hunan	S	Extraction	GA	7	CCIY, 1996.
06.06.1995	Zhuoquan	Shanxi	S	Extraction	GA	6	CCIY, 1996.
07.06.1995	Huaibei	Anhui	L	Exploration	GA	7	CCIY, 1996.
09.06.1995	Ningxiang	Hunan	S	Exploration	GA	6	CCIY, 1996.
10.06.1995	Fuxin	Liaoning	S	Exploration	GA	9	CCIY, 1996.
12.06.1995	Liaoyuan	Jiling	S	Extraction	GA	5	CCIY, 1996.
14.06.1995	Changji	Xingjiang	S	Exploration	GA	6	CCIY, 1996.
16.06.1995	Baiyin	Gansu	S	Extraction	GA	5	CCIY, 1996.
16.06.1995	Yaojie	Ganshu	S	Extraction	RA	5	CCIY, 1996.
17.06.1995	Pingdingshan	Henan	S	Extraction	GA	5	CCIY, 1996.
17.06.1995	Shangrao	Jiangxi	S	Extraction	GA	7	CCIY, 1996.
17.06.1995	Suixi	Anhui	S	Extraction	EMA	7	CCIY, 1996.
19.06.1995	Hengyang	Hunan	L	Extraction	GA	7	CCIY, 1996.
22.06.1995	Guiyang	Guizhou	S	Extraction	GA	21	CCIY, 1996.
23.06.1995	Fengcheng	Jiangxi	S	Extraction	GA	5	CCIY, 1996.
23.06.1995	Huainan	Anhui	L	Extraction	GA	46	CCIY, 1996.
23.06.1995	Lianshao	Hunan	L	Exploration	GA	19	CCIY, 1997.
23.06.1995	Shaotong	Yunnan	S	Extraction	GA	9	CCIY, 1996.
24.06.1995	Huainan	Anhui	L	Extraction	GA	30	CCIY, 1996.
24.06.1995	Mashan	Guanxi	S	Exploration	WHA	13	CCIY, 1996.
26.06.1995	Chenzhou	Hunan	L	Extraction	GA	7	CCIY, 1996.
26.06.1995	Laibin	Guangxi	S	Extraction	GA	16	CCIY, 1996.
27.06.1995	Hongshan	Hunan	S	Extraction	GA	16	CCIY, 1996.
28.06.1995	Libo	Guizhou	S	Extraction	GA	6	CCIY, 1996.

03.07.1995	Anyang	Henan	S	Exploration	GA	10	CCIY, 1996.
04.07.1995	Qiyang	Hunan	S	Extraction	GA	8	CCIY, 1996.
04.07.1995	Tuyouqi	Inner Mongolia	S	Exploration	GA	5	CCIY, 1996.
05.07.1995	Hegang	Heilongliang	L	Exploration	GA	7	CCIY, 1996.
08.07.1995	Quyang	Hebei	S	Extraction	GA	9	CCIY, 1996.
09.07.1995	Qitaihe	Heilongjiang	L	Extraction	GA	6	CCIY, 1996.
11.07.1995	Xinmi	Henan	S	Extraction	GA	16	CCIY, 1996.
14.07.1995	Anyang	Henan	L	Extraction	GA	5	CCIY, 1996.
17.07.1995	Nongsishi	Xinjiang	L	Extraction	GA	6	CCIY, 1996.
17.07.1995	Pingba	Guizhou	S	Extraction	GA	5	CCIY, 1996.
17.07.1995	Qinyuan	Shanxi	S	Extraction	GA	8	CCIY, 1996.
19.07.1995	Gongyi	Henan	L	Extraction	WHA	5	CCIY, 1996.
19.07.1995	Pingxiang	Jiangxi	S	Exploration	RA	9	CCIY, 1996.
20.07.1995	Xiangfan	Hubei	S	Extraction	GA	5	CCIY, 1996.
23.07.1995	Qitaihe	Heilongjiang	S	Extraction	GA	7	CCIY, 1996.
24.07.1995	Shuangqiao	Chongqing	S	Extraction	GA	5	CCIY, 1996.
25.07.1995	Fengcheng	Jiangxi	L	Extraction	WHA	14	CCIY, 1996.
27.07.1995	Pingdingshan	Henan	S	Extraction	FA	9	CCIY, 1996.
01.08.1995	Pingdingshan	Henan	L	Extraction	WHA	5	CCIY, 1996.
06.08.1995	Qujing	Yunnan	S	Extraction	GA	7	CCIY, 1996.
07.08.1995	Qitaihe	Heilongjiang	S	Exploration	GA	7	CCIY, 1996.
08.08.1995	Yan'an	Shaanxi	S	Extraction	GA	12	CCIY, 1996.
10.08.1995	Tanmu	Hunan	S	Extraction	GA	5	CCIY, 1996.
11.08.1995	Laibing	Guangxi	S	Extraction	GA	9	CCIY, 1996.
11.08.1995	Xinhua	Hunan	S	Extraction	GA	5	CCIY, 1996.
12.08.1995	Xingnaing	Guangdong	S	Exploration	WHA	16	CCIY, 1996.
15.08.1995	Xishan	Shanxi	L	Exploration	GA	7	CCIY, 1996.
16.08.1995	Heshan	Guangxi	S	Exploration	WHA	5	CCIY, 1996.
16.08.1995	Jingyuan	Ganshu	L	Exploration	WHA	8	CCIY, 1996.
17.08.1995	Mentougou	Beijing	S	Exploration	WHA	5	CCIY, 1996.
18.08.1995	Laibing	Guangxi	S	Exploration	WHA	5	CCIY, 1996.
19.08.1995	Fusui	Guangxi	S	Exploration	GA	5	CCIY, 1996.
20.08.1995	Laibing	Guangxi	S	Extraction	GA	5	CCIY, 1996.
25.08.1995	Hegang	Heilongjiang	S	Extraction	GA	5	CCIY, 1996.
03.09.1995	Dengfeng	Henan	S	Extraction	GA	10	CCIY, 1996.
05.09.1995	Pingxiang	Jiangxi	S	Extraction	WHA	7	CCIY, 1996.

08.09.1995	Xianyang	Shaanxi	L	Extraction	GA	15	CCIY, 1996.
08.09.1995	Zhaohe	Hunan	S	Extraction	GA	6	CCIY, 1996.
09.09.1995	Panxian	Guizhou	S	Extraction	WHA	5	CCIY, 1996.
14.09.1995	Neijiang	Sichuan	L	Exploration	WHA	6	CCIY, 1996.
16.09.1995	Panjiang	Guizou	L	Extraction	GA	9	CCIY, 1996.
16.09.1995	Xinning	Hunan	S	Extraction	GA	5	CCIY, 1996.
16.09.1995	Zuanjiang	Chongqing	S	Exploration	GA	5	CCIY, 1996.
18.09.1995	Shaodong	Hunan	S	Exploration	GA	7	CCIY, 1996.
19.09.1995	Yiliang	Yunnan	S	Exploration	GA	6	CCIY, 1996.
25.09.1995	Shizhuishan	Ningxia	L	Extraction	GA	8	CCIY, 1996.
26.09.1995	Lengshuijiang	Hunan	S	Extraction	GA	7	CCIY, 1996.
28.09.1995	Boli	Heilongjiang	S	Extraction	GA	6	CCIY, 1996.
30.09.1995	Qujiang	Guangdong	S	Extraction	GA	7	CCIY, 1996.
02.10.1995	Shenyang	Liaoning	L	Exploration	GA	14	CCIY, 1996.
03.10.1995	Baisha	Hunan	S	Extraction	GA	12	CCIY, 1996.
05.10.1995	Lianzhou	Guangzhou	S	Extraction	GA	13	CCIY, 1996.
08.10.1995	Yizhang	Hunan	S	Extraction	WHA	12	CCIY, 1996.
09.10.1995	Jingcheng	Shanxi	S	Extraction	GA	6	CCIY, 1996.
10.10.1995	Yubei	Chongqing	S	Extraction	GA	8	CCIY, 1996.
11.10.1995	Qujiang	Guangdong	S	Exploration	GA	5	CCIY, 1996.
11.10.1995	Zhenxiong	Yunnan	S	Extraction	GA	16	CCIY, 1996.
12.10.1995	Jingcheng	Shanxi	S	Extraction	GA	9	CCIY, 1996.
12.10.1995	Lioupanshui	Guzhou	S	Exploration	WHA	9	CCIY, 1996.
19.10.1995	Leiyang	Hunan	S	Extraction	GA	7	CCIY, 1996.
20.10.1995	Hezhang	Guizhou	S	Extraction	GA	12	CCIY, 1996.
21.10.1995	Beijiang	Guangdong	S	Extraction	GA	5	CCIY, 1996.
23.10.1995	Harbing	Heilongjiang	L	Extraction	WHA	41	CCIY, 1996.
24.10.1995	Loufan	Shanxi	S	Extraction	GA	5	CCIY, 1996.
24.10.1995	Fenyang	Shanxi	S	Exploration	WHA	5	CCIY, 1996.
26.10.1995	Lianyuan	Hunan	S	Extraction	GA	5	CCIY, 1996.
26.10.1995	Yizhang	Hunan	S	Extraction	GA	11	CCIY, 1996.
27.10.1995	Qunli	Hunan	S	Exploration	GA	10	CCIY,1997.
30.10.1995	Turpan	Xinjiang	L	Exploration	WHA	6	CCIY, 1996.
31.10.1995	Jingmen	Hubei	S	Exploration	WHA	6	CCIY, 1996.
01.11.1995	Chuijiagou	Shaanxi	S	Extraction	GA	15	CCIY, 1997.
03.11.1995	Chifeng	Inner Mongolia	S	Extraction	GA	6	CCIY, 1996.

04.11.1995	Jingcheng	Shanxi	S	Extraction	WHA	7	CCIY, 1996.
04.11.1995	Xingan	Inner Mongolia	S	Extraction	RA	5	CCIY, 1996.
09.11.1995	Zhuoquan	Shanxi	S	Exploration	GA	12	CCIY, 1996.
10.11.1995	Yongxing	Hunan	S	Extraction	GA	6	CCIY, 1996.
12.11.1995	Loudi	Hunan	L	Exploration	WHA	5	CCIY, 1996.
12.11.1995	Shaodong	Hunan	S	Extraction	WHA	8	CCIY, 1996.
14.11.1995	Chixian	Hebei	S	Extraction	GA	14	CCIY, 1996.
14.11.1995	Zhaozhuang	Shandong	S	Exploration	WHA	11	CCIY, 1996.
15.11.1995	Lianyan	Hunan	S	Extraction	GA	5	CCIY, 1996.
19.11.1995	Hancheng	Shaanxi	S	Exploration	GA	9	CCIY, 1996.
19.11.1995	Qitaihe	Heilongjiang	S	Extraction	GA	12	CCIY, 1996.
20.11.1995	Xuzhou	Jiangsu	S	Exploration	GA	10	CCIY, 1996.
22.11.1995	Xinmi	Henan	L	Exploration	GA	6	CCIY, 1996.
22.11.1995	Tonghua	Jiling	S	Extraction	GA	6	CCIY, 1996.
24.11.1995	Ameng	Inner Mongolia	S	Extraction	GA	6	CCIY, 1996.
03.12.1995	Fengfeng	Hebei	L	Exploration	WHA	17	CCIY, 1996.
04.12.1995	Shaodong	Hunan	S	Exploration	WHA	8	CCIY, 1996.
05.12.1995	Datun	Jiangshu	L	Extraction	FA	27	CCIY, 1996.
05.12.1995	Guangde	Anhui	S	Exploration	GA	7	CCIY, 1996.
07.12.1995	Jixi	Heilongjiang	S	Exploration	GA	7	CCIY, 1996.
10.12.1995	Mentougou	Beijing	S	Extraction	GA	8	CCIY, 1996.
11.12.1995	Chifeng	Inner Mongolia	S	Exploration	GA	7	CCIY, 1996.
14.12.1995	Laiwu	Shandong	S	Exploration	GA	18	CCIY, 1996.
19.12.1995	Baotou	Inner Mongolia	S	Extraction	GA	5	CCIY, 1996.
23.12.1995	Fuyuan	Yunnan	S	Exploration	GA	15	CCIY, 1996.
26.12.1995	Jixi	Heilongjiang	S	Extraction	GA	6	CCIY, 1996.
27.12.1995	Zhengzhou	Henan	S	Exploration	WHA	6	CCIY, 1996.
28.12.1995	Hebi	Henan	S	Extraction	GA	9	CCIY, 1996.
29.12.1995	Xiangfan	Hubei	S	Exploration	WHA	7	CCIY, 1996.
30.12.1995	Guangde	Anhui	S	Extraction	GA	5	CCIY, 1996.
31.12.1995	Panjiang	Guizhou	S	Extraction	GA	65	CCIY, 1996.
01.01.1996	Leping	Jiangxi	S	Extraction	GA	16	CCIY, 1997.
07.01.1996	Fengcheng	Jiangxi	S	Extraction	GA	16	CCIY, 1997.
08.01.1996	Xiangtan	Hunan	S	Extraction	GA	15	CCIY, 1997.
12.01.1996	Wudang	Guizhou	S	Extraction	GA	15	CCIY, 1997.
24.01.1996	Loyang	Henan	S	Exploration	WHA	11	CCIY, 1997.

13.02.1996	Datong	Shanxi	S	Extraction	GA	19	CCIY, 1997.
08.03.1996	Panxian	Guizhou	S	Exploration	GA	11	CCIY, 1997.
08.03.1996	Dazu	Chongqing	S	Extraction	GA	13	CCIY, 1997.
19.03.1996	Jiahe	Hunan	S	Extraction	GA	23	CCIY, 1997.
20.03.1996	Lioupanshui	Guizhou	S	Extraction	GA	12	CCIY, 1997.
03.04.1996	Weinan	Shaanxi	S	Extraction	GA	10	CCIY, 1997.
06.04.1996	Xingtai	Hebei	S	Exploration	WHA	14	CCIY, 1997.
11.04.1996	Xingyu	Jiangxi	S	Extraction	GA	15	CCIY, 1997.
16.04.1996	Nanchuan	Sichuan	S	Extraction	GA	15	CCIY, 1997.
19.04.1996	Xingmi	Henan	S	Extraction	GA	11	CCIY, 1997.
23.04.1996	Jiaocheng	Shanxi	L	Extraction	GA	20	CCIY, 1997.
25.04.1996	Dengfeng	Henan	S	Extraction	GA	12	CCIY, 1997.
02.05.1996	Jinzhong	Shanxi	L	Extraction	GA	15	CCIY, 1997.
14.05.1996	Xishan	Shanxi	S	Exploration	GA	18	CCIY, 1997.
21.05.1996	Fengfeng	Hebei	S	Extraction	GA	18	CCIY, 1997.
21.05.1996	Loudi	Hunan	S	Exploration	GA	10	CCIY, 1997.
21.05.1996	Pingdingshan	Henan	L	Extraction	GA	84	CCIY, 1997.
26.05.1996	Lianyuan	Hunan	S	Exploration	GA	15	CCIY, 1997.
31.05.1996	Fengcheng	Jiangxi	S	Extraction	RA	14	CCIY, 1997.
20.06.1996	Shenyang	Liaoling	L	Exploration	GA	14	CCIY, 1997.
25.06.1996	Heshan	Guangxi	S	Exploration	WHA	14	CCIY, 1997.
25.06.1996	Xiangtan	Hunan	S	Extraction	WHA	15	CCIY, 1997.
26.06.1996	Fengfeng	Hebei	S	Extraction	GA	35	CCIY, 1997.
27.06.1996	Fengfeng	Hebei	S	Extraction	GA	17	CCIY, 1997.
28.06.1996	Qinzhen	Guizhou	S	Extraction	GA	11	CCIY, 1997.
30.06.1996	Panxian	Guizhou	S	Extraction	GA	19	CCIY, 1997.
02.07.1996	Fengcheng	Jiangxi	S	Exploration	WHA	22	CCIY, 1997.
11.07.1996	Wongan	Guizhou	S	Exploration	GA	12	CCIY, 1997.
15.07.1996	Liaoyuan	Jiling	S	Extraction	GA	20	CCIY, 1997.
16.07.1996	Hadagang	Heilongjiang	L	Exploration	GA	12	CCIY, 1997.
21.07.1996	Loudi	Hunan	S	Extraction	GA	11	CCIY, 1997.
24.07.1996	Panjiang	Guizhou	S	Exploration	GA	21	CCIY, 1997.
30.07.1996	Xishui	Guizhou	S	Exploration	GA	14	CCIY, 1997.
31.07.1996	Shuicheng	Guizhou	S	Exploration	GA	12	CCIY, 1997.
04.08.1996	Xishan	Shanxi	S	Extraction	WHA	33	CCIY, 1997.
08.08.1996	Jincheng	Shanxi	S	Extraction	GA	12	CCIY, 1997.

15.08.1996	Fengfeng	Hebei	S	Exploration	WHA	11	CCIY, 1997.
15.08.1996	Lianyuan	Hunan	S	Exploration	GA	12	CCIY, 1997.
29.08.1996	Fuxin	Liaoning	S	Exploration	GA	13	CCIY, 1997.
29.08.1996	Xinan	Henan	S	Exploration	WHA	11	CCIY, 1997.
05.09.1996	Jiaozhuo	Henan	S	Exploration	WHA	10	CCIY, 1997.
06.09.1996	Leshan	Sichuan	L	Extraction	GA	11	CCIY, 1997.
08.09.1996	Zichuan	Shandong	S	Exploration	WHA	10	CCIY, 1997.
11.09.1996	Heshan	Guangxi	S	Exploration	WHA	38	CCIY, 1997.
12.09.1996	Pingxiang	Jiangxi	S	Exploration	WHA	10	CCIY, 1997.
16.09.1996	Hegang	Heilongjiang	S	Extraction	GA	15	CCIY, 1997.
16.09.1996	Qinshui	Shanxi	S	Extraction	GA	16	CCIY, 1997.
17.09.1996	Qinshui	Shanxi	S	Extraction	GA	16	CCIY, 1997.
03.10.1996	Fangshan	Beijing	S	Extraction	GA	10	CCIY, 1997.
07.10.1996	Jingxi	Guizhou	L	Extraction	GA	28	CCIY, 1997.
07.10.1996	Mengxian	Shanxi	S	Exploration	GA	11	CCIY, 1997.
15.10.1996	Gujiao	Shanxi	L	Extraction	GA	13	CCIY, 1997.
19.10.1996	Chuijagou	Shaanxi	L	Extraction	GA	50	CCIY, 1997.
19.10.1996	Hegang	Heilongjiang	L	Exploration	GA	34	CCIY, 1997.
01.11.1996	Jiahe	Hunan	L	Extraction	GA	18	CCIY, 1997.
14.11.1996	Lianyuan	Hunan	S	Extraction	GA	22	CCIY, 1997.
17.11.1996	Jixi	Heilongjiang	L	Extraction	GA	30	CCIY, 1997.
25.11.1996	Chengdu	Sichuan	S	Extraction	GA	20	CCIY, 1997.
25.11.1996	Xiuwu	Henan	S	Exploration	WHA	15	CCIY, 1997.
27.11.1996	Datong	Shanxi	S	Extraction	GA	114	CCIY, 1997.
29.11.1996	Xinmi	Henan	S	Extraction	GA	18	CCIY, 1997.
29.11.1996	Xuanwei	Yunnan	S	Extraction	GA	21	CCIY, 1997.
30.11.1996	Luxi	Yunan	S	Exploration	WHA	12	CCIY, 1997.
02.12.1996	Liuling	Shanxi	S	Extraction	GA	44	CCIY, 1997.
02.12.1996	Pingdingshan	Henan	S	Extraction	GA	32	CCIY, 1997.
3.12.1996	Gujiavao			Extraction	NA	91	ENSAD
08.12.1996	Datong	Shanxi	S	Exploration	GA	11	CCIY, 1997.
12.12.1996	Zhongshan	Guizhou	S	Extraction	GA	17	CCIY, 1997.
24.12.1996	Changchun	Jiling	S	Extraction	GA	10	CCIY, 1997.
06.01.1997	Xiangyun	Yunnan	S	Exploration	GA	5	CCIY, 1998.
09.01.1997	Panxian	Guizhou	S	Extraction	GA	7	CCIY, 1998.
10.01.1997	Longhui	Hunan	S	Extraction	GA	6	CCIY, 1998.

14.01.1997	Xiahuayuan	Hebei	S	Exploration	GA	11	CCIY, 1998.
14.01.1997	Xishui	Guizhou	S	Extraction	GA	12	CCIY, 1998.
18.01.1997	Tongchuan	Shaanxi	S	Extraction	GA	9	CCIY, 1998.
18.01.1997	Yichuan	Henan	S	Extraction	GA	12	CCIY, 1998.
25.01.1997	Yima	Henan	L	Extraction	GA	31	CCIY, 1998.
28.01.1997	Liuzhi	Guizhou	S	Exploration	GA	10	CCIY, 1998.
28.01.1997	Menyuan	Qinghai	S	Extraction	GA	7	CCIY, 1998.
30.01.1997	Zhijin	Guizhou	S	Extraction	GA	13	CCIY, 1998.
09.02.1997	Datong	Shanxi	L	Extraction	GA	9	CCIY, 1998.
10.02.1997	Huaibei	Anhui	L	Exploration	GA	8	CCIY, 1998.
10.02.1997		Henan		Exploration	NA	31	CNS
14.02.1997	Shuangyashan	Heilongjiang	L	Transport	TA	7	CCIY, 1998.
16.02.1997	A'rashanzuoqi	Inner Mongolia	S	Extraction	GA	6	CCIY, 1998.
17.02.1997	Qijiang	Chongqing	S	Extraction	GA	5	CCIY, 1998.
19.02.1997	Hancheng	Shaanxi	S	Extraction	GA	5	CCIY, 1998.
19.02.1997	Qingxu	Shanxi	L	Extraction	GA	27	CCIY, 1998.
22.02.1997	Qilian	Qinghai	L	Exploration	WHA	5	CCIY, 1998.
22.02.1997	Mashan	Guangxi	S	Exploration	WHA	5	CCIY, 1998.
24.02.1997	Turfan	Xinjian	L	Exploration	GA	22	CCIY, 1998.
25.02.1997	Lengshuitan	Hunan	S	Extraction	GA	11	CCIY, 1998.
26.02.1997	Baishanshi	Jilin	L	Exploration	GA	18	CCIY, 1998.
26.02.1997	Xinhua	Hunan	S	Extraction	GA	5	CCIY, 1998.
01.03.1997	Hegang	Heilongjiang	L	Extraction	RA	7	CCIY, 1998.
04.03.1997	Lushan	Henan	S	Exploration	GA	89	CCIY, 1998.
06.03.1997	Panxian	Guizhou	S	Extraction	GA	5	CCIY, 1998.
09.03.1997	Baiying	Gansu	S	Exploration	FA	5	CCIY, 1998.
09.03.1997	Lianyuan	Hunan	S	Exploration	GA	7	CCIY, 1998.
10.03.1997	Panxian	Guizhou	S	Extraction	GA	6	CCIY, 1998.
12.3.1997	Pingdingshan	Henan		Exploration	NA	12	Reuters
13.03.1997	Lengshuijian	Hunan	S	Exploration	GA	5	CCIY, 1998.
17.03.1997	Gongyi	Henan	S	Extraction	GA	8	CCIY, 1998.
17.03.1997	Xishui	Guizhou	S	Extraction	GA	13	CCIY, 1998.
18.03.1997	Peiling	Chongqing	L	Exploration	GA	5	CCIY, 1998.
20.03.1997	Pingdingshan	Henan	S	Extraction	GA	21	CCIY, 1998.
22.03.1997	Chengde	Hebei	L	Extraction	WHA	9	CCIY, 1998.
23.03.1997	Pingxiang	Jiangxi	S	Extraction	GA	6	CCIY, 1998.

23.03.1997	Pingxiang	Jiangxi	S	Exploration	GA	11	CCIY, 1998.
26.03.1997	Hegang	Heilongjiang	L	Extraction	GA	6	CCIY, 1998.
27.03.1997	Huludao	Liaoning	S	Extraction	GA	9	CCIY, 1998.
27.03.1997	Yongrong	Chongqing	S	Extraction	GA	15	CCIY, 1998.
28.03.1997	Yongxing	Hunan	S	Exploration	WHA	15	CCIY, 1998.
29.03.1997	Lindong	Guizhou	L	Extraction	GA	18	CCIY, 1998.
01.04.1997	Guxian	Shanxi	S	Extraction	GA	8	CCIY, 1998.
01.04.1997	Libo	Guizhou	S	Extraction	GA	5	CCIY, 1998.
01.04.1997	Zhongshan	Guizhou	S	Extraction	GA	5	CCIY, 1998.
04.04.1997	Fuquan	Guizhou	S	Extraction	GA	6	CCIY, 1998.
04.04.1997		Henan		Extraction	NA	21	Muzi Lateline News
06.04.1997	Jiahe	Hunan	L	Extraction	GA	7	CCIY, 1998.
06.04.1997	Linsheng	Liaoning	L	Extraction	GA	11	CCIY, 1998.
07.04.1997	Tongzhi	Guizhou	S	Extraction	GA	5	CCIY, 1998.
08.04.1997	Jianshi	Hubei	S	Extraction	GA	5	CCIY, 1998.
09.04.1997	Xiangning	Shanxi	S	Extraction	GA	26	CCIY, 1998.
10.04.1997	Benxi	Liaoning	S	Extraction	WHA	10	CCIY, 1998.
11.04.1997	Ximing	Shanxi	S	Extraction	GA	45	CCIY, 1998.
13.04.1997	Liuzhi	Guizhou	S	Extraction	GA	12	CCIY, 1998.
13.04.1997	Xinmi	Shanxi	S	Extraction	GA	6	CCIY, 1998.
14.04.1997	Leping	Jiangxi	S	Extraction	GA	10	CCIY, 1998.
16.04.1997	Wansheng	Chongqing	S	Exploration	GA	7	CCIY, 1998.
17.04.1997	Chifeng	Inner Mongolia	S	Exploration	FA	9	CCIY, 1998.
17.04.1997	Jiaxian	Henan	S	Extraction	GA	7	CCIY, 1998.
21.04.1997	Yunshan	Heilongjiang	S	Extraction	GA	6	CCIY, 1998.
24.04.1997	Panxian	Guizhou	S	Extraction	GA	5	CCIY, 1998.
24.04.1997	Puqi	Hubei	S	Exploration	GA	7	CCIY, 1998.
24.04.1997	Zichang	Shaanxi	L	Extraction	GA	17	CCIY, 1998.
27.04.1997	Heshun	Shanxi	S	Extraction	GA	11	CCIY, 1998.
28.04.1997	Quyang	Hebei	S	Extraction	GA	11	CCIY, 1998.
29.04.1997	Linwu	Hunan	S	Extraction	GA	6	CCIY, 1998.
29.04.1997	Jingjing	Hebei	L	Extraction	OA	6	CCIY, 1998.
30.04.1997	Chengde	Hebei	S	Extraction	GA	6	CCIY, 1998.
02.05.1997	Guiyang	Guizhou	S	Extraction	GA	13	CCIY, 1998.
02.05.1997	Laiwu	Shandong	S	Extraction	GA	31	CCIY, 1998.

04.05.1997	Fengcheng	Jiangxi	S	Exploration	GA	9	CCIY, 1998.
06.05.1997	Hebi	Henan	S	Extraction	GA	5	CCIY, 1998.
06.05.1997	Xinmi	Henan	S	Extraction	WHA	5	CCIY, 1998.
07.05.1997	Jinsha	Guizhou	S	Extraction	GA	13	CCIY, 1998.
07.05.1997	Zhongxian	Chongqing	L	Extraction	GA	5	CCIY, 1998.
08.05.1997	Aksu	Xinjiang	S	Extraction	GA	6	CCIY, 1998.
08.05.1997	Fuyuan	Yunnan	S	Extraction	GA	12	CCIY, 1998.
09.05.1997	Xinmi	Henan	S	Extraction	FA	12	CCIY, 1998.
11.05.1997	Mendougou	Beijing	S	Extraction	GA	9	CCIY, 1998.
11.05.1997	Puqi	Hubei	S	Extraction	GA	9	CCIY, 1998.
12.05.1997	Jixi	Heilongjiang	S	Extraction	GA	12	CCIY, 1998.
13.05.1997	Fenxi	Shanxi	S	Extraction	GA	11	CCIY, 1998.
13.05.1997	Xiangtan	Hunan	S	Exploration	GA	9	CCIY, 1998.
16.05.1997	Panxian	Guizhou	S	Extraction	GA	8	CCIY, 1998.
17.05.1997	Nayong	Guizhou	S	Extraction	GA	7	CCIY, 1998.
19.05.1997	Heshan	Guangxi	S	Exploration	WHA	11	CCIY, 1998.
19.05.1997	Wuhai	Inner Mongolia	S	Extraction	GA	30	CCIY, 1998.
20.05.1997	Qiujin	Yunnan	S	Extraction	GA	10	CCIY, 1998.
20.05.1997	Tianzhu	Gansu	S	Extraction	GA	11	CCIY, 1998.
21.05.1997	Wugang	Hunan	S	Extraction	GA	5	CCIY, 1998.
22.05.1997	Yangxing	Hubei	S	Exploration	WHA	8	CCIY, 1998.
22.05.1997	Yingyang	Henan	S	Extraction	GA	8	CCIY, 1998.
24.05.1997	Yichuan	Henan	S	Exploration	GA	11	CCIY, 1998.
25.05.1997	Huludao	Liaoning	S	Extraction	GA	8	CCIY, 1998.
28.05.1997	Bingxian	Shaanxi	S	Extraction	GA	23	CCIY, 1998.
28.05.1997	Fushun	Liaoning	L	Exploration	GA	69	CCIY, 1998.
28.05.1997	Liupanshui	Guizhou	S	Extraction	GA	19	CCIY, 1998.
28.05.1997	Pingwang	Shanxi	S	Extraction	GA	23	CCIY, 1998.
29.05.1997	Pingxiang	Jianxi	S	Extraction	GA	11	CCIY, 1998.
29.05.1997	Tianfu	Chongqing	L	Exploration	GA	9	CCIY, 1998.
30.05.1997	Lingwu	Hunan	S	Extraction	GA	7	CCIY, 1998.
02.06.1997	Meixian	Guangdong	S	Extraction	WHA	6	CCIY, 1998.
03.06.1997	Baiyin	Gansu	S	Extraction	GA	5	CCIY, 1998.
03.06.1997	Tongchuan	Shaanxi	S	Extraction	GA	5	CCIY, 1998.
03.06.1997	Yichun	Jiangxi	S	Extraction	GA	7	CCIY, 1998.
04.06.1997	Nayuong	Guizhou	S	Extraction	GA	13	CCIY, 1998.

06.06.1997	Hezhang	Guizhou	S	Extraction	GA	16	CCIY, 1998.
10.06.1997	Laifeng	Hubei	S	Extraction	GA	9	CCIY, 1998.
11.06.1997	Hechi	Guangxi	S	Extraction	GA	9	CCIY, 1998.
17.06.1997	Chizhou	Anhui	L	Exploration	WHA	6	CCIY, 1998.
17.06.1997	Leping	Jiangxi	S	Extraction	GA	9	CCIY, 1998.
18.06.1997	Leiyang	Hunan	S	Extraction	GA	6	CCIY, 1998.
18.06.1997	Yangquan	Shanxi	S	Extraction	GA	5	CCIY, 1998.
23.06.1997	Xinmi	Henan	S	Extraction	GA	16	CCIY, 1998.
24.06.1997	Tongchuan	Shaanxi	S	Extraction	GA	6	CCIY, 1998.
25.06.1997	Sunan	Gansu	S	Transport	TA	8	CCIY, 1998.
25.06.1997	Wansheng	Chongqing	S	Extraction	GA	5	CCIY, 1998.
27.06.1997	Linwu	Hunan	S	Extraction	GA	5	CCIY, 1998.
28.6.1997	Fushun	Liaoning		Extraction	NA	68	Sigma
28.06.1997	Leping	Jiangxi	S	Exploration	GA	7	CCIY, 1998.
30.06.1997	Leiyang	Hunan	S	Extraction	GA	11	CCIY, 1998.
30.06.1997	Zunyi	Guizhou	S	Extraction	GA	5	CCIY, 1998.
01.07.1997	Hechi	Guangxi		Extraction	NA	9	Reuters
02.07.1997	Lianyuan	Hunan	S	Extraction	GA	7	CCIY, 1998.
03.07.1997	Tongzi	Guizhou	S	Extraction	GA	7	CCIY, 1998.
04.07.1997	Tongzi	Guizhou	S	Extraction	GA	5	CCIY, 1998.
04.07.1997	Yongshan	Jiangxi	S	Extraction	GA	5	CCIY, 1998.
05.07.1997	Dongzhi	Anhui	S	Exploration	GA	8	CCIY, 1998.
05.07.1997	Huangling	Shaanxi	S	Extraction	GA	32	CCIY, 1998.
06.07.1997	Baicheng	Xinjiang	L	Extraction	RA	5	CCIY, 1998.
07.07.1997	Panxian	Guizhou	S	Extraction	GA	8	CCIY, 1998.
07.07.1997	Qingfenghu	Guizhou	S	Exploration	GA	13	CCIY, 1998.
08.07.1997	Anxi	Gansu	S	Extraction	GA	5	CCIY, 1998.
08.07.1997	Jingyuan	Gansu	L	Exploration	GA	8	CCIY, 1998.
09.07.1997	Fuquan	Guizhou	S	Extraction	GA	6	CCIY, 1998.
10.07.1997	Dengfeng	Henan	L	Exploration	WHA	29	CCIY, 1998.
11.07.1997	Longyan	Fujian	S	Extraction	GA	5	CCIY, 1998.
11.07.1997	Wong'an	Guizhou	S	Extraction	WHA	7	CCIY, 1998.
12.07.1997	Leping	Jianxi	S	Extraction	GA	40	CCIY, 1998.
14.07.1997	Baofeng	Henan	S	Extraction	RA	7	CCIY, 1998.
14.07.1997	Jiyuan	Henan	S	Exploration	GA	8	CCIY, 1998.
14.07.1997	Xishui	Guizhou	S	Extraction	GA	5	CCIY, 1998.

16.07.1997	Jiaozhishan	Guizhou	L	Exploration	GA	22	CCIY, 1998.
16.07.1997	Lengshuijiang	Hunan	S	Extraction	GA	9	CCIY, 1998.
20.07.1997	Panzhihua	Sichuan	L	Extraction	RA	5	CCIY, 1998.
20.07.1997	Yuzhou	Henan	S	Extraction	GA	9	CCIY, 1998.
22.07.1997	Sangzhi	Hunan	S	Exploration	RA	6	CCIY, 1998.
24.07.1997	Guiyang	Guizhou	S	Exploration	GA	16	CCIY, 1998.
24.07.1997	Yiyang	Henan	S	Extraction	GA	7	CCIY, 1998.
26.07.1997	Lindong	Guizhou	L	Exploration	GA	8	CCIY, 1998.
28.07.1997	Shuangyashan	Helongjiang	L	Exploration	GA	9	CCIY, 1998.
28.07.1997	Xinglong	Hebei	L	Exploration	RA	5	CCIY, 1998.
30.07.1997	Shuangyashan	Heilongjiang	S	Extraction	FA	7	CCIY, 1998.
31.07.1997	Xiangyuan	Henan	S	Extraction	GA	5	CCIY, 1998.
01.08.1997	Huaibei	Anhui	L	Exploration	WHA	5	CCIY, 1998.
01.08.1997	Zhaozhang	Shandong	S	Exploration	WHA	10	CCIY, 1998.
02.08.1997	Heshan	Guangxi	S	Extraction	GA	7	CCIY, 1998.
03.08.1997	Lu'nan	Yunnan	S	Extraction	GA	5	CCIY, 1998.
03.08.1997	Urumchi	Xinjiang	S	Extraction	GA	6	CCIY, 1998.
04.08.1997	Panxian	Guizhou	S	Extraction	GA	5	CCIY, 1998.
05.08.1997	Benxi	Liaoning	S	Extraction	GA	5	CCIY, 1998.
06.08.1997	Fuxin	Liaoning	S	Transport	TA	5	CCIY, 1998.
06.08.1997	Guanling	Guizhou	S	Extraction	GA	5	CCIY, 1998.
07.08.1997	Beipiao	Liaoning	L	Extraction	RA	7	CCIY, 1998.
07.08.1997	Qingyuan	Shanxi	S	Exploration	GA	5	CCIY, 1998.
07.08.1997	Xishui	Guizhou	S	Extraction	GA	6	CCIY, 1998.
08.08.1997	Mianchi	Henan	S	Extraction	GA	8	CCIY, 1998.
08.08.1997	Pingxiang	Jianxi	S	Extraction	WHA	11	CCIY, 1998.
09.08.1997	Jingyuan	Gansu	S	Extraction	GA	6	CCIY, 1998.
11.08.1997	Shangrao	Jiangxi	S	Extraction	GA	7	CCIY, 1998.
12.08.1997	Leiyang	Hunan	S	Extraction	GA	7	CCIY, 1998.
12.08.1997	Shouyang	Shanxi	L	Exploration	GA	13	CCIY, 1998.
18.08.1997	Hegang	Helongjiang	L	Extraction	GA	9	CCIY, 1998.
19.08.1997	Baiyin	Gansu	S	Extraction	GA	5	CCIY, 1998.
21.08.1997	Fuquan	Guizhou	S	Extraction	GA	14	CCIY, 1998.
21.08.1997	Lianyuan	Hunan	S	Extraction	GA	10	CCIY, 1998.
21.08.1997	Shuicheng	Guizhou	S	Exploration	GA	9	CCIY, 1998.
21.08.1997	Yaoxian	Shaanxi	S	Extraction	GA	5	CCIY, 1998.

22.08.1997	Luntai	Xinjiang	S	Extraction	GA	6	CCIY, 1998.
22.08.1997	Wufeng	Hubei	S	Exploration	GA	7	CCIY, 1998.
23.08.1997	Lengshuijiang	Hunan	S	Exploration	GA	5	CCIY, 1998.
23.08.1997	Panxian	Guizhou	S	Exploration	GA	8	CCIY, 1998.
24.08.1997	Wuhai	Inner Mongolia	S	Extraction	WHA	7	CCIY, 1998.
27.08.1997	Alashanzuoqi	Inner Mongolia	S	Extraction	GA	7	CCIY, 1998.
01.09.1997	Fuyuan	Yunnan	S	Extraction	GA	10	CCIY, 1998.
01.09.1997	Leping	Jianxi	S	Exploration	GA	11	CCIY, 1998.
01.09.1997	Miquan	Xinjiang	L	Extraction	GA	7	CCIY, 1998.
02.09.1997	Fukang	Xinjiang	S	Extraction	GA	5	CCIY, 1998.
03.09.1997	Jixi	Heilongjiang	S	Extraction	GA	6	CCIY, 1998.
04.09.1997	Huairen	Shanxi	L	Extraction	GA	12	CCIY, 1998.
06.09.1997	Renhuai	Guizhou	S	Extraction	GA	16	CCIY, 1998.
07.09.1997	Shaodong	Hunan	S	Exploration	WHA	6	CCIY, 1998.
09.09.1997	Lianyuan	Hunan	S	Extraction	GA	7	CCIY, 1998.
15.09.1997	Changning	Hunan	S	Extraction	GA	9	CCIY, 1998.
17.09.1997	Weiyuan	Sichuan	S	Extraction	GA	16	CCIY, 1998.
18.09.1997	Tonghua	Jilin	L	Exploration	GA	16	CCIY, 1998.
18.09.1997	Wuxiang	Shanxi	L	Extraction	GA	19	CCIY, 1998.
19.09.1997	Liuzhi	Guizhou	S	Extraction	GA	10	CCIY, 1998.
20.09.1997	Fengcheng	Jiangxi	S	Transport	TA	5	CCIY, 1998.
21.09.1997	Huludao	Liaoning	S	Extraction	GA	8	CCIY, 1998.
21.09.1997	Jixi	Heilongjiang	S	Extraction	GA	17	CCIY, 1998.
22.09.1997	Luxi	Yunnan	S	Extraction	GA	8	CCIY, 1998.
24.09.1997	Leping	Jiangxi	S	Extraction	GA	8	CCIY, 1998.
24.09.1997	Pu'an	Guizhou	S	Extraction	WHA	6	CCIY, 1998.
25.09.1997	Jixi	Heilongjiang	L	Exploration	GA	8	CCIY, 1998.
26.09.1997	Mengxian	Shanxi	S	Extraction	GA	9	CCIY, 1998.
26.09.1997	Xiaoyi	Shanxi	S	Exploration	WHA	14	CCIY, 1998.
27.09.1997	Pingxiang	Jiangxi	S	Extraction	GA	12	CCIY, 1998.
27.09.1997	Qujing	Yunan	S	Extraction	GA	9	CCIY, 1998.
30.09.1997	Fencheng	Jianxi	L	Exploration	GA	9	CCIY, 1998.
30.09.1997	Heshan	Guangxi	S	Exploration	WHA	14	CCIY, 1998.
01.10.1997	Xincheng	Guangxi	S	Extraction	GA	12	CCIY, 1998.
03.10.1997	Fushun	Liaoning	L	Exploration	GA	7	CCIY, 1998.
04.10.1997	Tongchuan	Shaanxi	S	Extraction	GA	7	CCIY, 1998.

08.10.1997	Yongxing	Hunan	S	Extraction	GA	8	CCIY, 1998.
09.10.1997	Pingdingshan	Henan	S	Exploration	GA	5	CCIY, 1998.
11.10.1997	Baicheng	Xinjiang	L	Extraction	RA	5	CCIY, 1998.
13.10.1997	Donglo	Guangxi	L	Extraction	WHA	18	CCIY, 1998.
13.10.1997	Handan	Hebei	L	Exploration	GA	33	CCIY, 1998.
13.10.1997	Luxi	Yunnan	S	Exploration	GA	8	CCIY, 1998.
15.10.1997	Baiyin	Guansu	S	Extraction	GA	7	CCIY, 1998.
20.10.1997	Urumqi	Xinjiang	S	Extraction	GA	5	CCIY, 1998.
25.10.1997	Pingdingshan	Henan	S	Extraction	GA	32	CCIY, 1998.
25.10.1997	Tonghua	Jiling	S	Extraction	GA	5	CCIY, 1998.
27.10.1997	Changchun	Jiling	S	Extraction	GA	5	CCIY, 1998.
27.10.1997	Yongding	Fujian	S	Extraction	GA	6	CCIY, 1998.
29.10.1997	Cixian	Hebei	S	Exploration	WHA	14	CCIY, 1998.
03.11.1997	Haibewan	Inner Mongolia	L	Extraction	GA	8	CCIY, 1998.
03.11.1997	Hejing	Shanxi	L	Extraction	GA	8	CCIY, 1998.
03.11.1997	Liuzhi	Guizhou	S	Exploration	GA	5	CCIY, 1998.
03.11.1997	Shaoyang	Hunan	S	Extraction	GA	5	CCIY, 1998.
03.11.1997	Xingfeng	Jiangxi	S	Extraction	GA	7	CCIY, 1998.
04.11.1997	Panjiang	Guizhou	L	Extraction	GA	43	CCIY, 1998.
08.11.1997	Nanchuan	Chongqing	S	Extraction	GA	40	CCIY, 1998.
09.11.1997	Laibing	Guangxi	S	Extraction	WHA	6	CCIY, 1998.
12.11.1997	Jidong	Heilongjiang	S	Extraction	GA	14	CCIY, 1998.
13.11.1997	Chongquing	Sichuan		Exploration	NA	39	Xinhua
13.11.1997	Huainan	Anhui	L	Exploration	GA	88	CCIY, 1998.
13.11.1997	Huangling	Shaanxi	S	Extraction	GA	13	CCIY, 1998.
20.11.1997	Ningguo	Anhui	L	Extraction	GA	6	CCIY, 1998.
21.11.1997	Xiangning	Shanxi	S	Extraction	GA	26	CCIY, 1998.
23.11.1997	Huairen	Shanxi	S	Extraction	GA	10	CCIY, 1998.
25.11.1997	Huangjinsha	Guizhou	S	Extraction	GA	17	CCIY, 1998.
25.11.1997	Lianshao	Hunan	S	Extraction	GA	15	CCIY, 1998.
27.11.1997	Huainan	Anhui	L	Extraction	GA	45	CCIY, 1998.
27.11.1997	Pu'an	Guizhou	S	Extraction	GA	10	CCIY, 1998.
27.11.1997	Qingxu	Shanxi	S	Extraction	GA	11	CCIY, 1998.
27.11.1997	Tongchuan	Shaanxi	S	Exploration	GA	29	CCIY, 1998.
01.12.1997	Turfan	Xinjiang	L	Extraction	GA	8	CCIY, 1998.
02.12.1997	Huainan	Anhui		Extraction	NA	42	Reuters

02.12.1997	Fuxin	Liaoning	S	Exploration	GA	9	CCIY, 1998.
04.12.1997	Lincheng	Hebei	S	Extraction	GA	36	CCIY, 1998.
04.12.1997	Zuoyun	Shanxi	S	Exploration	WHA	9	CCIY, 1998.
05.12.1997	Huaibei	Anhui	L	Extraction	GA	6	CCIY, 1998.
06.12.1997	Suicheng	Guizhou	L	Extraction	RA	5	CCIY, 1998.
09.12.1997	Shuangfeng District	Hunan		Extraction	NA	12	Reuters
10.12.1997	Pingdingshan	Henan	S	Exploration	GA	79	CCIY, 1998.
16.12.1997	Heshan	Guangxi	L	Exploration	WHA	5	CCIY, 1998.
18.12.1997	Lianzhou	Guangdong	S	Extraction	GA	5	CCIY, 1998.
22.12.1997	Changzhi	Shanxi	S	Extraction	GA	19	CCIY, 1998.
22.12.1997	Yangquan	Shanxi	S	Exploration	WHA	7	CCIY, 1998.
28.12.1997	Qingning	Guangdong		Extraction	NA	9	Reuters
28.12.1997	Junlian	Sichuan	S	Extraction	GA	11	CCIY, 1998.
29.12.1997	Leibing	Guangxi	S	Extraction	GA	16	CCIY, 1998.
31.12.1997	Zhongshan	Guizhou	L	Exploration	GA	30	CCIY, 1998.
02.01.1998	Jixi	Heilongjiang	S	Extraction	GA	27	CCIY, 1999.
10.01.1998	Huaxi	Guizhou	S	Extraction	GA	11	CCIY, 1999.
18.01.1998	Pingdingshan	Henan	L	Extraction	RA	11	CCIY, 1999.
24.01.1998	Fuxin	Liaoning	L	Extraction	GA	78	CCIY, 1999.
06.02.1998	Kaiyang	Guizhou	S	Extraction	GA	12	CCIY, 1999.
14.02.1998	Tongchuan	Shaanxi	S	Exploration	GA	10	CCIY, 1999.
08.03.1998	Lishicheng	Shanxi	S	Extraction	GA	17	CCIY, 1999.
18.03.1998	Tonghua	Jiling	S	Extraction	GA	22	CCIY, 1999.
19.03.1998	Zhenfeng	Guizhou	S	Extraction	GA	11	CCIY, 1999.
29.3.1998	Kaijiang county	Sichuan		Extraction	NA	11	LLP 312/1; BASICS, Reuters
25.03.1998	Chengxi	Hunan	S	Extraction	GA	14	CCIY, 1999.
02.04.1998	Hebi	Henan	S	Exploration	GA	22	CCIY, 1999.
03.04.1998	Ruzhou	Henan	S	Exploration	FA	14	CCIY, 1999.
03.04.1998		Tianjin		Extraction	NA	16	Muzi News
06.04.1998	Pingdingshan	Henan	S	Extraction	GA	62	CCIY, 1999.
09.04.1998	Lvliang	Shanxi	S	Extraction	GA	15	CCIY, 1999.
14.04.1998	Jincheng	Shanxi	L	Extraction	GA	14	CCIY, 1999.
22.04.1998	Nayong	Guizhou	S	Extraction	GA	11	CCIY, 1999.
24.04.1998	Loudi	Hunan	S	Extraction	GA	18	CCIY, 1999.

01.05.1998	Dengfeng	Henan	S	Exploration	WHA	15	CCIY, 1999.
01.05.1998	Jixi	Heilongjiang	S	Extraction	GA	10	CCIY, 1999.
12.05.1998	Zhunyi	Guizhou	L	Extraction	GA	10	CCIY, 1999.
12.05.1998	Hezhang	Guizhou	S	Extraction	GA	12	CCIY, 1999.
13.05.1998	Chengdu	Sichuan	L	Extraction	GA	24	CCIY, 1999.
15.05.1998	Chifeng	Inner Mongolia	S	Exploration	WHA	17	CCIY, 1999.
20.05.1998	Wuhai	Inner Mongolia	S	Extraction	WHA	13	CCIY, 1999.
24.05.1998	Leping	Jiangxi	S	Extraction	GA	16	CCIY, 1999.
25.05.1998	Dazu	Sichuan	L	Extraction	GA	26	CCIY, 1999.
25.05.1998	Beihuashan	Jiangxi	S	Exploration	WHA	15	CCIY, 1999.
25.05.1998	Luoyang	Henan	S	Extraction	GA	17	CCIY, 1999.
26.05.1998	Xinlong	Hebei	S	Extraction	WHA	10	CCIY, 1999.
27.05.1998	Xiyu	Shanxi	L	Extraction	GA	10	CCIY, 1999.
04.06.1998	Datong	Shanxi	L	Exploration	GA	11	CCIY, 1999.
06.06.1998	Leping	Jiangxi	S	Extraction	GA	15	CCIY, 1999.
17.06.1998	Qingxu	Shanxi	S	Extraction	GA	17	CCIY, 1999.
19.06.1998	Xiaoshan	Sichuan	S	Exploration	GA	10	CCIY, 1999.
30.06.1998	Zhoushan	Guizhou	S	Extraction	GA	19	CCIY, 1999.
02.07.1998	Qujing	Yunnan	S	Extraction	GA	12	CCIY, 1999.
14.07.1998	Luxi	Yunnan	S	Extraction	GA	15	CCIY, 1999.
23.07.1998	Huaxi	Guizhou	S	Extraction	GA	24	CCIY, 1999.
26.07.1998	Hongtong	Shanxi	S	Exploration	GA	18	CCIY, 1999.
27.07.1998	Lichuan	Hubei	S	Extraction	GA	16	CCIY, 1999.
30.07.1998	Zhenzhou	Henan	S	Exploration	WHA	20	CCIY, 1999.
05.08.1998	Zhenzhou	Henan	S	Extraction	GA	19	CCIY, 1999.
06.08.1998	Wanshen	Chongqing	S	Extraction	WHA	11	CCIY, 1999.
08.08.1998	Linshui	Sichuan	S	Extraction	GA	11	CCIY, 1999.
10.08.1998	Jincheng	Shanxi	S	Extraction	GA	25	CCIY, 1999.
13.08.1998	Jingsha	Guizhou	S	Extraction	GA	18	CCIY, 1999.
19.08.1998	Heshan	Guangxi	L	Extraction	GA	12	CCIY, 1999.
21.08.1998	Kaiyang	Guizhou	S	Exploration	GA	23	CCIY, 1999.
24.08.1998	Qingyuan	Shanxi	L	Extraction	RA	12	CCIY, 1999.
31.08.1998	Shaodong	Hunan	S	Exploration	WHA	10	CCIY, 1999.
09.09.1998	Liupanshui	Guizhou	S	Extraction	GA	14	CCIY, 1999.
18.09.1998	Baofeng	Henan	S	Extraction	GA	29	CCIY, 1999.
20.09.1998	Lianyuan	Hunan	S	Extraction	GA	15	CCIY, 1999.

27.09.1998	Changning	Hunan	S	Extraction	GA	12	CCIY, 1999.
06.10.1998	Chenzhou	Hunan	S	Exploration	WHA	12	CCIY, 1999.
15.10.1998	Hegang	Heilongjiang	S	Exploration	GA	46	CCIY, 1999.
16.10.1998	Pingdingshan	Henan	S	Transport	TA	14	CCIY, 1999.
18.10.1998	Jingsha	Guizhou	S	Extraction	GA	40	CCIY, 1999.
25.10.1998	Heshan	Guangxi	S	Exploration	WHA	36	CCIY, 1999.
27.10.1998	Hegang	Heilongjiang	S	Exploration	GA	11	CCIY, 1999.
28.10.1998	Shangrao	Jiangxi	L	Extraction	GA	11	CCIY, 1999.
29.10.1998	Lanzhou	Gansu	S	Extraction	GA	10	CCIY, 1999.
17.11.1998	Liuzhi	Guizhou	L	Extraction	GA	18	CCIY, 1999.
17.11.1998	Dongliang	Liaoning	S	Extraction	GA	11	CCIY, 1999.
20.11.1998	Yuan'an	Hubei	S	Extraction	GA	12	CCIY, 1999.
21.11.1998	Linfen	Shanxi	S	Extraction	GA	47	CCIY, 1999.
22.11.1998	Yijinholuo	Inner Mongolia	S	Extraction	BA	16	CCIY, 1999.
23.11.1998	Xunyi	Shaanxi	L	Extraction	GA	46	CCIY, 1999.
28.11.1998	Qitaihe	Heilongjiang	S	Extraction	GA	14	CCIY, 1999.
29.11.1998	Laibin	Yunnan	L	Extraction	GA	42	CCIY, 1999.
02.12.1998	Leiyang	Hunan	S	Extraction	GA	10	CCIY, 1999.
11.12.1998	Xiaoping	Hubei		Extraction	NA	12	Reuters
12.12.1998	Changguan	Zhejian	L	Extraction	GA	32	CCIY, 1999.
12.12.1998	Pingdingshan	Henan	S	Extraction	GA	66	CCIY, 1999.
14.12.1998	Changguang	Zheijiang		Exploration	NA	32	Muzi Daily News
15.12.1998	Hegang	Heilongjiang	L	Extraction	GA	12	CCIY, 1999.
19.12.1998	Hegang	Heilongjiang	L	Extraction	GA	23	CCIY, 1999.
21.12.1998	Turpan	Xinjian	L	Extraction	GA	10	CCIY, 1999.
24.12.1998	Shenyang	Liaoning	L	Exploration	GA	28	CCIY, 1999.
26.12.1998	Yiyang	Henan	S	Extraction	GA	12	CCIY, 1999.
27.12.1998	Lianyuan	Hunan	S	Extraction	GA	11	CCIY, 1999.
03.01.1999	Tiefa	Liaoning	S	Transport	TA	24	CCIY, 2000.
05.01.1999	Pingba	Guizhou	S	Extraction	GA	13	CCIY, 2000.
07.01.1999	Subei	Gansu	S	Extraction	GA	11	CCIY, 2000.
16.01.1999	Hezhang	Guizhou	S	Extraction	GA	35	CCIY, 2000.
18.01.1999	Shenyang	Liaoning	L	Extraction	GA	11	CCIY, 2000.
25.01.1999	Qitaihe	Heilongjiang	S	Exploration	GA	11	CCIY, 2000.
28.01.1999	Ganluo	Sichuan	S	Extraction	GA	14	CCIY, 2000.

02.02.1999	Zhangshu	Jiangxi	S	Extraction	GA	16	CCIY, 2000.
04.02.1999	Mengying	Shandong	L	Extraction	GA	10	CCIY, 2000.
11.02.1999	Kaiping	Hebei	S	Extraction	FA	11	CCIY, 2000.
14.02.1999	Qitaihe	Heilongjiang	L	Extraction	GA	48	CCIY, 2000.
20.02.1999	Datong	Shanxi	S	Extraction	GA	17	CCIY, 2000.
07.03.1999	Cixian	Hebei	S	Extraction	WHA	32	CCIY, 2000.
08.03.1999	Gulin	Sichuan	S	Exploration	GA	14	CCIY, 2000.
12.03.1999	Qitaihe	Heilongjiang	S	Extraction	GA	21	CCIY, 2000.
13.03.1999	Yongchuan	Hunan	L	Exploration	WHA	11	CCIY, 2000.
19.03.1999	Lanzhou	Gansu	S	Extraction	GA	17	CCIY, 2000.
20.03.1999	Xingwen	Sichuan	S	Extraction	GA	10	CCIY, 2000.
21.03.1999	Anyuan	Jiangxi	S	Extraction	GA	10	CCIY, 2000.
27.03.1999	Zaozuang	Shandong	L	Extraction	GA	17	CCIY, 2000.
28.03.1999	Laibin	Guangxi	S	Extraction	WHA	12	CCIY, 2000.
30.03.1999	Lengshuijiang	Hunan	S	Extraction	GA	10	CCIY, 2000.
30.03.1999	Panxian	Guizhou	S	Extraction	GA	14	CCIY, 2000.
30.3.1999		Hebei		Extraction	NA	40	China Coal Daily
31.03.1999	Wongan	Guizhou	S	Extraction	GA	10	CCIY, 2000.
02.04.1999	Pingdingshan	Henan	S	Exploration	GA	30	CCIY, 2000.
06.04.1999	Dayangshu	Inner Mongolia	S	Extraction	GA	11	CCIY, 2000.
11.04.1999	A'zhuoqi	Inner Mongolia	S	Extraction	GA	11	CCIY, 2000.
16.04.1999	Leping	Jiangxi	L	Extraction	GA	11	CCIY, 2000.
19.4.1999	Ci county near Handan city	Hebei		Extraction	NA	32	Reuters
20.04.1999	Qianxi	Guizhou	S	Extraction	GA	10	CCIY, 2000.
21.04.1999	Shuicheng	Guizhou	S	Extraction	GA	13	CCIY, 2000.
21.04.1999	Yanggeleng	Inner Mongolia	S	Extraction	GA	10	CCIY, 2000.
24.04.1999	Yaojie	Gansu	S	Exploration	GA	21	CCIY, 2000.
25.04.1999	Jiangyuan	Jiling	S	Extraction	GA	12	CCIY, 2000.
28.04.1999	Subei	Gansu	S	Extraction	GA	11	CCIY, 2000.
03.05.1999	Lanzhou	Gansu		Extraction	NA	19	Lanzhou Chenbao News
10.05.1999	Tongchuan	Shaanxi	S	Exploration	GA	43	CCIY, 2000.
12.05.1999	Yuzhou	Henan	S	Extraction	GA	16	CCIY, 2000.
16.05.1999	Wudang	Guizhou	S	Extraction	GA	14	CCIY, 2000.
17.05.1999	Libo	Guizhou	L	Extraction	GA	11	CCIY, 2000.

20.05.1999	Puding	Guizhou	S	Extraction	GA	12	CCIY, 2000.
27.05.1999	Lingwu	Hunan	S	Extraction	GA	15	CCIY, 2000.
11.06.1999	Hancheng	Shaanxi	S	Extraction	GA	13	CCIY, 2000.
18.06.1999	Jingniu town	Heilongjiang	S	Extraction	GA	16	CCIY, 2000.
21.06.1999	Zhongshan	Guizhou	S	Extraction	GA	13	CCIY, 2000.
23.06.1999	Shangrao	Jiangxi	S	Extraction	GA	13	CCIY, 2000.
25.06.1999	Hanyuan	Sichuan	S	Exploration	GA	13	CCIY, 2000.
29.06.1999	Chengxi	Hunan	S	Extraction	WHA	28	CCIY, 2000.
29.06.1999	Luliang	Shanxi	S	Extraction	RA	10	CCIY, 2000.
01.07.1999	Lianshao	Hunan	L	Extraction	GA	24	CCIY, 2000.
01.07.1999	Renghuai	Guizhou	S	Extraction	GA	10	CCIY, 2000.
10.07.1999	Lianyuan	Hunan	S	Extraction	GA	10	CCIY, 2000.
14.07.1999	Jiaozhuo	Henan	S	Extraction	GA	10	CCIY, 2000.
17.07.1999	Provider station	Heilongjiang	L	Extraction	GA	23	CCIY, 2000.
24.07.1999	Benxi	Liaoning	S	Extraction	GA	13	CCIY, 2000.
01.08.1999	Zezhou	Shanxi	S	Extraction	GA	14	CCIY, 2000.
02.08.1999	Guang'an	Sichuan	S	Extraction	GA	13	CCIY, 2000.
06.08.1999	Laibin	Guangxi	S	Extraction	GA	10	CCIY, 2000.
08.08.1999	Changji	Xinjiang	S	Extraction	GA	13	CCIY, 2000.
25.08.1999	Pingdingshan	Henan	L	Extraction	GA	55	CCIY, 2000.
27.08.1999	Qujing	Yunnan	S	Exploration	GA	17	CCIY, 2000.
04.09.1999	Xiangtan	Hunan	S	Extraction	GA	10	CCIY, 2000.
16.09.1999	Hegang	Heilongjiang	S	Exploration	GA	11	CCIY, 2000.
04.10.1999	Fuxin	Liaoning	S	Extraction	GA	24	CCIY, 2000.
12.10.1999	Wanshen	Chongqing	S	Exploration	GA	12	CCIY, 2000.
20.10.1999	Baotou	Inner Mongolia	S	Extraction	GA	15	CCIY, 2000.
26.10.1999	Yichuan	Henan	S	Extraction	GA	11	CCIY, 2000.
29.10.1999	Changji	Xinjiang	S	Extraction	RA	17	CCIY, 2000.
01.11.1999	Yuci	Shanxi	S	Extraction	GA	21	CCIY, 2000.
11.11.1999	Datong	Shanxi	S	Exploration	GA	13	CCIY, 2000.
11.11.1999	Jixi	Heilongjiang	L	Extraction	GA	11	CCIY, 2000.
12.11.1999	Xingren	Guizhou	S	Extraction	GA	10	CCIY, 2000.
20.11.1999	Jianshi	Hubei	S	Extraction	GA	15	CCIY, 2000.
21.11.1999	Fangzhen	Heilongjiang	S	Extraction	GA	13	CCIY, 2000.
25.11.1999	Cixian	Hebei	S	Extraction	GA	32	CCIY, 2000.
13.12.1999	Heshan	Guangxi	L	Extraction	WHA	25	CCIY, 2000.

17.12.1999	Baotou	Inner Mongolia	S	Extraction	GA	19	CCIY, 2000.
17.12.1999	Zhonglian	Hunan		Exploration	NA	9	Xinhua News
17.12.1999	Daying No. 1 mine	Henan		Exploration	NA	64	Workers
20.12.1999	Menyuan	Qinghai	SM	Exploration	GA	10	CCIY, 2000.

APPENDIX B: LIST OF SEVERE ACCIDENTS WITHIN THE CHINESE OIL CHAIN IN THE PERIOD 1969-1999

Table B.1: Severe accidents with at least five fatalities. Injured persons and economic damages were not included because this information was only available for few accidents. ACTMCLSHHA = Accident Cases of Typical and Major Casualties on Labour Safety and Health at Home and Abroad, 1995. AFSTC= Accident Files: Selected Typical Cases, 1978-1988. RDCDC = Report of the Damage caused by Disaster in China, 1949-1995. COSHY = China Occupational Safety and Health Yearbook. COY = China Ocean Yearbook. CPIY = China Petroleum Industry Yearbook.

Date	Place/Name of Unit	Energy chain stage	Max. no. fatalities	Source
02.06.1977	Shanghai	Refinery	14	ACTMCLSHHA
17.08.1979	Yangtze River/Changzhen II	Transport	11	ACTMCLSHHA
25.11.1979	Bohai Bay/Bohai II	Exploration	72	AFSTC
15.06.1980	Golf von Pohai	Exploration	70	ENSAD
10.09.1981	Zhangwu, Liaoning	Regional Distribution	6	ACTMCLSHHA
05.05.1982	Qinghuangdao, Liaoning/Shanghai	Transport	12	ACTMCLSHHA
26.10.1983	South China Sea/ACT Petro. Co.	Exploration	81	RDCDC
31.03.1984	Hebei/Baoding	Refinery	16	ACTMCLSHHA
10.12.1984	Heilongjiang/Daqing	Extraction	7	AFSTC
05.05.1987	Liaoning	Regional Distribution	8	ACTMCLSHHA.
22.10.1988	Shanghai	Refinery	25	OSH-ROM
02.01.1989	Yangtze River/Nanjing	Transport	8	COSHY, 1989.
12.08.1989	Qingdao	Distribution	19	COY, 1987-1990.
24.01.1990	Anqing, Anhui	Regional Distribution	70	MHIDAS
15.08.1991	South China Sea/ACT Petro. Co.	Exploration	18	COY, 1991-1993.
18.06.1993	Lingjiachuan tunnel, Shaanxi	Regional Distribution	8	LLP
01.07.1993	Huabei	Extraction	7	MHIDAS
23.08.1993	Shandong/Xinxian	Refinery	10	ACTMCLSHHA
28.09.1993	Zhaoxian, Hebei/Huabei	Exploration	7	ACTMCLSHHA.
12.12.1994	Unknown	N.A.	6	ENSAD
18.02.1995	Henan	Transport	29	CPIY, 1996.
27.07.1996	Hebei/Liaohe	Transport	7	CPIY, 1997.
09.08.1996	Henan/Zhongyuan	Regional Distribution	40	CPIY, 1997.
24.08.1996	Sichuan	Transport	5	CPIY, 1997.
29.12.1996	Leizhou, Guandong	Regional Distribution	9	LLP, 1997

04.06.1997	Nanjing's Qixia oil tanker anchorage	Regional Distribution	5	Reuters, 1997
15.06.1997	Xinjiang/Tuha	Transport	6	CPIY, 1998.
15.08.1997	South China Sea	Exploration	8	LLP
12.10.1997	Xinjiang	Pipe upkeep	7	CPIY, 1998.
06.11.1998	Beishan	Refinery	7	Reuters, 1998
07.12.1998	East Lamma Channel	Regional Distribution	6	Reuters, 1998
13.08.1999	Nantong, Jiangsu	Heating	9	Muzi Lateline News

APPENDIX C:
LIST OF SEVERE ACCIDENTS WITHIN THE CHINESE NATURAL GAS CHAIN IN THE PERIOD 1969-1999

Table C.1: Severe accidents with at least five fatalities. Injured persons and economic damages were not included because this information was only available for few accidents. ACTMCLSHHA = Accident Cases of Typical and Major Casualties on Labour Safety and Health at Home and Abroad, 1995.

Date	Place	Province	Energy chain stage	Max. no. fatalities	Source
12.12.1989	Shenyang	Liaoning	Regional distribution	6	MHIDAS
12.03.1991	Jidong	Hebei	Exploration	5	ACTMCLSHHA
07.08.1993	Shenzen	Guangdong	Regional distribution	70	Reuters
11.10.1993	Baohe	Heilongjiang	Exploration	70	LLP
03.01.1995		Jilan	Regional distribution	10	ENSAD
01.02.1995	Jinan	Shandong	Regional distribution	10	MHIDAS
09.02.1996	Yangzhou	Jiangsu	Regional distribution	19	Reuters
27.03.1998		Sichuan	Exploration	11	LLP

APPENDIX D:
LIST OF SEVERE ACCIDENTS WITHIN THE CHINESE LPG CHAIN IN THE PERIOD 1969-1999

Table D.1: Severe accidents with at least five fatalities. Injured persons and economic damages were not included because this information was only available for few accidents. AFSTC= Accident Files: Selected Typical Cases, 1978-1988.

Date	Place	Province	Energy chain stage	Max. no. fatalities	Source
18.12.1979	Jiling City	Jiling	Processing	36	AFSTC
22.10.1988	Gaoqiao	Shanghai	Refinery	25	AFSTC
23.06.1992		Jiangxi	Regional distribution	37	ENSAD
05.08.1993	Qingshuihe	Guandong	Heating	15	MHIDAS
20.06.1996	Shenzen	Guangdong	Heating	29	MHIDAS, LLP
18.07.1996		Shenzhen	Heating	29	Reuters
01.13.1997		Shenyang	Heating	10	Muzi Lateline News
31.07.1998	Guiyang	Guizhou	Regional distribution	80	LLP, Sigma 1999/1
03.09.1998	Xi'an	Shaanxi	Regional distribution	11	Muzi
11.12.1999		Shanghai	Heating	7	LLP
11.11.1999	Harbin	Heilongjiang	Heating	12	Muzi Lateline News

APPENDIX E:
PROBABILISTIC METHODOLOGY

The present appendix provides a summary of some past probabilistic approaches to the estimate of offsite consequences (Level 3) in full scope Nuclear Power Plant Probabilistic Safety Assessments (NPP PSAs), and suggests possible simplified extensions for sites where only scanty data is available, or for assessments for which resources would not allow a full scope Level 3 PSA. In particular, the approach used for the USNRC [1989] study is considered, and ancillary calculations use the USNRC-sponsored MACCS code [Chanin, 1993].

The latest MACCS release (i.e., version 1.5.11.1) was modified for compatibility with current PC-FORTRAN compilers, and for use on an MS-DOS platform. The modifications involve only input and output requirements, and the calculational models are unchanged. It is to be noted that the latest MACCS release makes use of the most recent ICRP recommended data base for dose conversion factors (i.e., ICRP, 90), while the versions used for the USNRC [1989] study use older data bases. Hence, the data shown here is not completely compatible with the data used in USNRC [1989].

E.1 Probabilistic approach to estimate offsite consequences

An integral part of s full scope NPP PSA is the propagation of uncertainties, from accident frequencies (Level 1), to frequencies of releases, source terms (Level 2), and offsite consequences (Level 3). Monte Carlo techniques are used for propagation of uncertainties up to the estimate of source terms, resulting in a very large number of possible radioactive releases to the environment. Typically, in USNRC [1989], the calculations arrived at 10’000 to 20’000 source terms as the result of Level 1 and Level 2 analyses for each NPP.

The calculation of conditional consequences and the overall data management for even a limited number of source terms (more than one hundred) can be prohibitive. For the Level 3 analysis, USNRC [1989] used a probabilistic model to reduce the number of source terms to be considered in further calculations. The model was called PARTITION, and is documented in Iman [1990].

In this model, the hyperspace of all the independent variables which characterize radioactive releases (activities of all radionuclides, time of release, duration of release, energy, elevation) is reduced to a two-dimensional space of average expected offsite consequences, i.e., early (immediate) fatalities, and latent cancer fatalities. To establish the expected consequences, releases are reduced essentially to I-131 and Cs-137 equivalent releases at a given time, and fixed correlation coefficients are calculated for all released radionuclides. Some of the characteristics of release are ignored (i.e., duration of release, energy, and elevation), assuming that the influence of these data is minor with respect to time and magnitude of release.

It is to be noted that correlations are established only for the two consequence measures mentioned above. On the other hand, the correlation coefficients, as detailed below, have been calculated using plant-and site-specific data.

For the establishment of the correlation coefficients, MACCS was used to calculate consequences at different distances from the plants for 100 percent release of a core inventory of each isotope, separately. In first approximation, the release was considered instantaneous, of short duration, and occurring at low elevation and low energy. These assumptions would maximize the consequences in the vicinity of the plants. Plant-specific data (population distribution, weather) was used in these calculations.

Further steps in the partitioning process included grouping all the Level 2 calculated source terms into an arbitrary small number of releases, based on the expected potential for consequences. This grouping considered radioactive decay, and first decay modes of the isotopes. Finally, specific MACCS calculations were performed for the "representative" releases.

As mentioned, the calculated correlation coefficients were site-specific. In the following sections, site specific correlation coefficients, as prescribed in the PARTITION model, are calculated, and an extension of this model is attempted, to show that correlation coefficients could be established on an inter-site basis, i.e., results could be transposed from one site to another, on the basis of simple considerations. For this purpose, correlations for two sites are calculated and compared. Also, other consequence measures (i.e., extent of land contamination) are included in the assessment. Some consideration is also given to establish correlation coefficients which would take into account other release characteristics (elevation and energy). For the purpose of this work, development of full correlation coefficients was not possible, but it would be desirable.

E.2 Calculations of correlation coefficients for the release species

In all the MACCS calculations performed, a PWR with 3600 MW(Th) operating power was used. Table E.1 shows the total initial inventories (MACCS default data) for 9 radionuclide groups. All inventories are shown normalized to 10^{15} Bq. Note that, core inventories of BWRs are not too different from those of PWRs, with few exceptions. Moreover, the MACCS data is from ORIGEN calculations for an end-of-cycle core, and is thus already uncertain to some extent.

Table E.1: Core inventories at reactor shutdown, PWR with 3600 MW(Th) operating power.

Radionuclide group	Initial activity in core (x 10^{15} Bq)
Xe	2E4
I	3E4
Cs	1E3
Te	9E3
Sr	9E3
Ru	1E4
La	4E4
Ce	9E4
Ba	7E3

Separate MACCS calculations were performed, releasing in turn 100% of the initial inventory of each group. Consequences for two possible accident sequences were calculated, one starting at two hours from scram, of short duration and occurring at 100 m, and the second starting 20 hours after scram, of relatively long duration, and occurring at 10 m. The two release sequences are called later “Early” and “Late”. In all calculations, no offsite countermeasures were considered, except for relocation if projected doses exceed 50 mSv during sixty years.

Many offsite consequences were calculated, however, only early fatalities (resulting from immersion in the radioactive cloud and inhalation), delayed cancer fatalities (also resulting from immersion in the passing cloud and from inhalation), chronic fatalities (resulting mostly from ground contamination and ingestion of contaminated food and water), and interdicted and condemned areas were further considered. The last two measures are grouped together, as "severely contaminated area". In the calculations, interdicted area is land which can be successfully decontaminated within 20 years but which is not habitable for a long period of time, and then resettled, while condemned area is the part of land that cannot be decontaminated to safe levels within 20 years. Criteria for decontamination are arbitrary (i.e., a fixed decontamination potential per year is defined, irrespective of possible decontamination measures and their effectiveness)

The calculations have been performed for two sites, first a plant located in an European site, with relatively high population density, central European weather, and topography characterized by relatively high land mass. The second site is Surry (which is the MACCS default site), which can be characterized as having very low population density, US Southern weather, and relatively large presence of water.

The weather data for the European site was constructed from data available at PSI, augmented by Monte Carlo calculations to establish the detailed precipitation data (missing in the data base). Precipitation rates are for average European continental precipitation distributions. The population to 50 km is detailed in the plants Final Safety Analysis Reports (specifically, data for the Mühleberg site was used), and roughly estimated from 50 to 800 km on the basis of average population density for each sector and country. Note that, such a model was developed also for the ERI/HSK [1993] study, but is not publicly available, thus it was reconstructed ex-novo. The detailed procedures are, however, the same as those used in ERI/HSK [1993], and described in more detail there in an appendix.

Table E.2 shows the main characteristics of the two sites, with respect to population and land distribution. The population data shown is for different distances: for early fatalities, all the MACCS calculations show that aerosol dispersion and deposition makes it very unlikely that the lethal dose 50 (LD50), corresponding to about 3 Gy, is exceeded beyond a 8 km radius from the plants, even for very large releases. For delayed cancer fatalities, which follow immediate exposure to doses below the LD50, little effect is shown beyond a 100 km radius. For latent fatalities, data to 800 km is shown. For the Surry site, data beyond 800 km is not given in the table (the MACCS data base for Surry extends the calculations to 1600 km). However, MACCS calculates that more than 99.9% of latent fatalities would occur in the 800 km radius. Finally, for land fraction, the data to 120 km is shown, since this is the maximum distance, which is shown in the calculations where substantial land contamination is possible. The ratio of the two sets is also shown in the table.

Table E.2: Summary of population data used in the MACCS calculations.

	European site	US site	Ratio US/European site
Population to 8 km	23’000	1400	0.06
Population to 100 km	5 E+6	2.2 E+6	0.44
Population to 800 km	230 E+6	90 E+6	0.40
Land fraction to 120 km	0.96	0.74	0.77

E.2.1 Early fatalities

Tables E.3a and E.3b show the results of the calculations for early fatalities. The correlation coefficients for fatalities as a function of releases are expressed as number of fatalities per 10^{15} Bq release. Site effects are very prominent. In some cases, the coefficients differ by two orders of magnitude for the same type of release. In general, coefficients for late releases are smaller due to radioactive decay. However for some species, such as Sr and Cs, the coefficients increase due to buildup from decay from one radioisotope to another (in MACCS, first order transmutation is considered).

Table E.3c shows a comparison of the coefficients, normalized to La. The comparison between the two sites shows that the relative effectiveness of the various groups appears to be roughly site independent, and therefore results for offsite consequences would largely depend on the absolute release of activities of each group. Results could be then scaled from site to site by evaluating the ratio of population distributions in the vicinity of the sites. For instance, the ratio of health effects due to the Te specie between the two sites is approximately 0.05, while the ratio of populations within 8 km, as shown in Table E.2, is about 0.06.

Table E.3a: Early fatalities, 100% release of each group, European site.

Radionuclide group	Early release		Late release	
	Number of fatalities	Number of fatalities per 10^{15} Bq	Number of fatalities	Number of fatalities per 10^{15} Bq
Xe	0.04	2.4E-6	0.0	0.0
I	41	1.4E-3	1	3.2E-5
Cs	0.6	5.5E-4	0.8	9.1E-4
Te	107	1.2E-2	36	4.2E-3
Sr	4	4.7E-4	0.04	4.5E-6
Ru	89	7.3E-3	160	1.4E-2
La	2158	5.7E-2	1350	3.6E-2
Ce	2142	2.3E-2	1830	2.0E-2
Ba	5	7.6E-4	325	4.9E-2

Table E.3b: Early fatalities, 100% release of each group, Surry site.

Radionuclide group	Early release		Late release	
	Number of fatalities	Number of fatalities per 10 ^{15} Bq	Number of fatalities	Number of fatalities per 10 ^{15} Bq
Xe	0.0	0.0	0.0	0.0
I	3	1.0E-4	0.3	9.6E-6
Cs	0.009	8.3E-6	0.008	9.1E-6
Te	4.6	5.2E-4	3.4	4.1E-4
Sr	0.1	1.1E-5	Negligible	0.0
Ru	0.6	5.0E-5	0.4	3.5E-5
La	37	9.8E-4	16	4.3E-4
Ce	24	2.6E-4	13	1.4E-4
Ba	0.2	3.0E-5	1	1.5E-4

Table E.3c: Early fatalities, correlation coefficients normalized to La.

Radionuclide group	Early release		Late release	
	European Site	Surry	European Site	Surry
Xe	4E-5	0.0	0.0	0.0
I	2E-2	1E-1	1E-3	2E-2
Cs	1E-2	1E-2	3E-2	2E-2
Te	2E-1	5E-1	1E-1	1E0
Sr	1E-2	1E-2	1E-4	0.0
Ru	1E-1	5E-2	4E-1	1E-1
La	1E0	1E0	1E0	1E0
Ce	4E-1	3E-1	6E-1	3E-1
Ba	1E-2	3E-2	1.4	4E-1

E.2.2 Delayed cancer fatalities

Tables E.4a and E.4b show the results of calculations for delayed cancer fatalities. Differences between the two sites are less marked than those observed for the estimate of immediate fatalities, because chronic effects are calculated for very large areas, and the total population for the two sites is comparable. Also, differences between early and late releases are small, again because consequences are calculated up to relatively large distances from the plant, and hence for very long transport times, where decay in the first few hours from shutdown has little effect. The ratios of the correlation coefficients, normalized to Cs, as shown in Table E.4c, demonstrate that relative results are fairly site and weather independent.

It can be seen that the ratio of delayed health effects between the two sites, e.g. for Cs (i.e., 0.31), scales approximatelyto the ratio of populations within 100 km, shown in Table E.2.

Table E.4a: Delayed cancer fatalities from early exposure, 100% release of each group, European site.

Radionuclide group	**Early release**		**Late release**	
	Number of fatalities	Number of fatalities per 10 ^{15} Bq	Number of fatalities	Number of fatalities per 10 ^{15} Bq
Xe	36	2.3E-3	11	6.3E-4
I	2290	7.4E-2	1570	5.1E-2
Cs	1860	1.7E0	1850	1.7E0
Te	5040	5.8E-1	4470	5.2E-1
Sr	2520	2.8E-1	2260	2.5E-1
Ru	36000	3.0E0	35600	3.0E0
La	61000	1.6E0	60100	1.6E0
Ce	160000	1.7E0	158000	1.7E0
Ba	7860	1.2E0	8500	1.3E0

Table E.4b: Delayed cancer fatalities from early exposure, 100% release of each group, Surry site.

Radionuclide group	Early release		Late release	
	Number of fatalities	Number of fatalities per 10 ^{15} Bq	Number of fatalities	Number of fatalities per 10 ^{15} Bq
Xe	9	5.6E-4	3	1.9E-4
I	697	2.2E-2	499	1.6E-2
Cs	568	5.2E-1	565	5.1E-1
Te	1690	2.0E-1	1500	1.7E-1
Sr	642	7.2E-2	578	6.5E-2
Ru	9100	7.6E-1	8960	7.5E-1
La	17300	4.6E-1	11600	3.1E-1
Ce	44900	4.8E-1	44400	4.8E-1
Ba	2840	4.3E-1	2980	4.5E-1

Table E.4c: Delayed cancer fatalities, correlation coefficients normalized to Cs.

Radionuclide Group	Early Release		Late Release	
	European Site	Surry	European Site	Surry
Xe	1E-3	1E-3	4E-4	4E-4
I	4E-2	4E-2	3E-2	3E-2
Cs	1E0	1E0	1E0	1E0
Te	3E-1	4E-1	3E-1	3E-1
Sr	2E-1	1E-1	1E-1	1E-1
Ru	2E0	1E0	2E0	1E0
La	1E0	9E-1	1E0	6E-1
Ce	1E0	9E-1	1E0	1E0
Ba	7E-1	8E-1	8E-1	1E0

E.2.3 Chronic cancer fatalities

Chronic or late cancer fatalities are due to long term exposure to radioactivity, i.e., they are due for the most part to ingestion of water and foodstuff, since the population that would be exposed to contact with radioactivity would be removed from dangerous (hot) spots. This type of consequences is the most uncertain to assess, since ingestion of radioactively contaminated material is very dependent on potential long term countermeasures. Moreover, no cutoff in doses is used in the calculations for chronic fatalities, and the results shown could vary in many cases by several factors, if cutoffs were imposed.

Tables E.5a and E.5b show the results for the two sites, while Table E.5c shows the ratio of the correlation coefficients, normalized to Cs. The only large contributor to chronic fatalities is the Cs group, while the Ba and the Ru groups also show some importance. It can be seen that this type of results is completely insensitive to the time when release commences, hence radioactive decay plays no role. Also, the ratio of chronic fatalities between the two sites, e.g. due to Cs (i.e., 0.48), is close to the ratio of the populations within 800 km, as shown in Table E.2.

Table E.5a: Chronic fatalities from long term exposure, 100% release of each group, European site.

Radionuclide group	**Early release**		**Late release**	
	Number of fatalities	Number of fatalities per 10 ^{15} Bq	Number of fatalities	Number of fatalities per 10 ^{15} Bq
Xe	0	0	0	0
I	840	2.7E-2	800	2.6E-2
Cs	36200	3.3E1	36200	3.3E1
Te	1080	1.3E-1	950	1.1E-1
Sr	3800	4.3E-1	3790	4.3E-1
Ru	12000	1.0E0	11900	1.0E0
La	25600	6.7E-1	25400	6.7E-1
Ce	14600	1.6E-1	14600	1.6E-1
Ba	10200	1.6E0	10000	1.5E0

Table E.5b: Chronic fatalities from long term exposure, 100% release of each group, Surry site.

Radionuclide group	Early release		Late release	
	Number of fatalities	Number of fatalities per 10 ^{15} Bq	Number of fatalities	Number of fatalities per 10 ^{15} Bq
Xe	0	0	0	0
I	331	1.1E-2	313	1.0E-2
Cs	17600	1.6E1	17600	1.6E1
Te	395	4.6E-2	352	4.1E-2
Sr	2150	2.4E-1	2140	2.4E-1
Ru	5870	4.9E-1	5980	5.0E-1
La	9060	2.4E-1	9010	2.4E-1
Ce	6680	7.2E-2	6660	7.2E-2
Ba	4140	6.2E-1	4010	6.1E-1

Table E.5c: Chronic fatalities from long-term exposure, correlation coefficients normalized to Cs.

Radionuclide group	Early release		Late release	
	European Site	Surry	European Site	Surry
Xe	0	0	0	0
I	8E-4	6E-4	8E-4	6E-4
Cs	1E0	1E0	1E0	1E0
Te	4E-3	3E-3	4E-3	3E-3
Sr	1E-2	2E-2	1E-2	2E-2
Ru	3E-2	3E-2	3E-2	3E-2
La	2E-2	2E-2	2E-2	2E-2
Ce	5E-3	5E-3	5E-3	5E-3
Ba	5E-2	4E-2	5E-2	4E-2

E.2.4 Severely contaminated areas

Tables E.6a and E.6b show the results for the calculations of interdicted and condemned areas, combined. Results are consistent for the two sites, and the correlation coefficients mostly reflect differences in topography. Table E.6c shows the coefficients, normalized to Cs. The only contribution for long-term ground contamination is from the Cs and Sr groups. The comparison between the results for the two sites shows that land contamination does not completely scale properly to the ratio of the land areas, even though in the detailed results, maximum distance for severely affected areas is approximately the same. As can be seen, the ratio between the two sites for Cs is 0.5, while the ratio of land fractions shown in Table E.2 is 0.77.

Table E.6a: Severely contaminated area, 100% release of each group, European site.

Radionuclide group	**Early release**		**Late release**	
	Interdicted and condemned (km^2)	Interdicted and condemned (km^2) per 10 ^{15} Bq	Interdicted and condemned (km^2)	Interdicted and condemned (km^2) per 10 ^{15} Bq
Xe	0	0	0	0
I	0	0	0	0
Cs	1.4E4	1.3E1	2.2E4	2.0E1
Te	1.0E4	1.3E0	0	0
Sr	8.6E4	9.7E0	3.7E4	4.2E0
Ru	7.0E-2	0	9.0E-2	0
La	0	0	0	0
Ce	1.0E-2	0	2.0E-2	0
Ba	0	0	0	0

Table E.6b: Severely contaminated area, 100% release of each group, Surry site.

Radionuclide group	**Early release**		**Late release**	
	Interdicted and condemned (km^2)	Interdicted and condemned (km^2) per 10 ^{15} Bq	Interdicted and condemned (km^2)	Interdicted and condemned (km^2) per 10 ^{15} Bq
Xe	0	0	0	0
I	0	0	0	0
Cs	7.0E3	6.5E0	7.0E3	6.4E0
Te	0	0	0	0
Sr	4.1E4	4.6E0	4.1E4	4.7E0
Ru	2.0E-2	0	2.0E-3	0
La	0	0	0	0
Ce	7.0E-2	0	7.0E-2	0
Ba	0	0	0	0

Table E.6c: Severely contaminated area, correlation coefficients normalized to Cs.

Radionuclide group	**Early release**		**Late release**	
	European Site	Surry	European Site	Surry
Xe	0	0	0	0
I	0	0	0	0
Cs	1E0	1E0	1E0	1E0
Te	1E-1	0	0	0
Sr	8E-1	7E-1	2E-1	7E-1
Ru	0	0	0	0
La	0	0	0	0
Ce	0	0	0	0
Ba	0	0	0	0

E.3 Conclusions

The results shown in the previous sections demonstrate to a large extent that correlation coefficients for activities releases following accidents at NPPs can be used to estimate with reasonable accuracy long term offsite consequences, when compared to detailed and costly code calculations, such as can be performed using MACCS. For early offsite consequences, correlation coefficients obtained from MACCS site-specific calculations can be considered conservative, since the source terms used to calculate these weights are extreme, and mortality rate is exponential with releases.

Moreover, it is seen that, in first approximation, correlation coefficients can be extrapolated from one site to another, if the ratio of some measures tied to offsite consequences between the two sites is known. These measures are: population to 8 km for early fatalities, population to 100 km for delayed fatalities, population to 800 km for chronic fatalities, and land mass for contaminated areas.

APPENDIX F
DETAILED RESULTS

F.1 Detailed results for advanced reactors

Table F.1: Basic source terms for BWR [ERI/HSK, 1996].

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.72	1.20E-01	1.10E-01	2.80E-02	1.70E-02	2.00E-04
RC2	0.73	7.80E-03	7.60E-03	3.40E-03	2.20E-03	2.10E-05
RC3	0.74	8.80E-02	8.00E-02	3.70E-02	3.70E-02	4.30E-04
RC4	0.74	6.30E-04	2.80E-04	1.00E-04	7.80E-05	6.60E-07
RC5	0.74	5.00E-03	2.90E-03	1.30E-03	1.00E-03	1.10E-05
RC6	0.74	1.50E-03	1.40E-03	9.20E-04	4.80E-04	4.70E-06
RC7	0.78	5.90E-02	5.70E-02	2.90E-02	1.90E-02	2.60E-04
RC8	0.74	8.40E-05	3.80E-05	1.80E-05	1.40E-05	1.20E-07
RC9	0.74	6.60E-03	4.00E-03	1.80E-03	1.40E-03	1.60E-05
RC10	0.74	1.50E-03	1.50E-03	8.60E-04	4.50E-04	4.30E-06
RC11	0.74	2.50E-02	2.60E-02	8.30E-03	4.10E-04	4.80E-06
RC12	0.73	4.10E-05	1.80E-05	7.40E-06	3.50E-06	3.20E-08
RC13	0.74	2.20E-03	1.20E-03	3.40E-04	6.60E-09	2.00E-10
RC14	0.36	5.20E-05	5.30E-05	4.00E-05	4.10E-05	4.10E-07
RC16	0.37	4.00E-06	2.40E-06	1.50E-06	1.70E-06	1.50E-08
RC18	0.78	3.90E-06	4.00E-06	2.60E-06	2.70E-06	2.70E-08
RC21	0.13	1.50E-06	5.40E-07	2.80E-07	2.30E-07	1.80E-09
Core invent.[Bq]	1.60E+19	3.10E+19	1.10E+18	9.00E+18	8.60E+19	1.60E+20

Table F.2: Basic source terms for EPR [ERI/HSK, 1999].

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.91	1.80E-01	1.80E-01	1.40E-01	1.70E-02	5.80E-03
RC2	0.96	3.00E-02	3.00E-02	3.50E-02	1.00E-02	1.20E-03
RC3	0.95	6.00E-03	6.00E-03	7.00E-03	2.70E-03	2.40E-04
RC4	1.70E-03	4.20E-06	4.20E-06	6.00E-06	1.60E-06	2.90E-07
RC5	5.00E-04	7.90E-06	7.90E-06	6.00E-06	7.00E-07	5.00E-07
RC6	0.33	1.00E-01	1.00E-01	4.80E-02	1.00E-02	7.40E-03
RC7	0.37	1.60E-01	1.60E-01	1.20E-01	1.00E-02	1.20E-03
Core invent.[Bq]	1.60E+19	3.10E+19	1.10E+18	9.00E+18	8.60E+19	1.60E+20

Table F.3: Basic consequences per Bq.

	Xe	I	Cs	Te	Sr	La
Early Fatalities per Bq	0.00E+00	1.40E-18	5.50E-19	1.20E-17	5.90E-19	3.10E-17
Late fatalities per Bq	5.00E-19	3.30E-17	1.60E-15	3.40E-16	2.40E-16	1.40E-15
Delayed fatalities per Bq	0	2.70E-17	3.30E-14	1.30E-16	9.30E-16	3.60E-16
Land lost [km^2] per Bq	0.00E+00	0.00E+00	6.40E-15	0.00E+00	2.70E-15	0.00E+00

Table F.4: Core inventories (3600 MWth).

Radionuclide group	Initial activity in core (x 10^{15} Bq)
Xe	1.6E4
I	3.1E4
Cs	1.1E3
Te	9.0E3
Sr	8.9E3
Ru	1.2E4
La	3.8E4
Ce	9.3E4
Ba	6.6E3
Mo	1.2E4

Table F.5: BWR releases.

Release class	Xe	I	Cs	Te	Sr	La
RC1	1.152E+19	3.72E+18	1.21E+17	2.52E+17	1.462E+18	3.2E+16
RC2	1.168E+19	2.418E+17	8.36E+15	3.06E+16	1.892E+17	3.36E+15
RC3	1.184E+19	2.728E+18	8.8E+16	3.33E+17	3.182E+18	6.88E+16
RC4	1.184E+19	1.953E+16	3.08E+14	9E+14	6.708E+15	1.056E+14
RC5	1.184E+19	1.55E+17	3.19E+15	1.17E+16	8.6E+16	1.76E+15
RC6	1.184E+19	4.65E+16	1.54E+15	8.28E+15	4.128E+16	7.52E+14
RC7	1.248E+19	1.829E+18	6.27E+16	2.61E+17	1.634E+18	4.16E+16
RC8	1.184E+19	2.604E+15	4.18E+13	1.62E+14	1.204E+15	1.92E+13
RC9	1.184E+19	2.046E+17	4.4E+15	1.62E+16	1.204E+17	2.56E+15
RC10	1.184E+19	4.65E+16	1.65E+15	7.74E+15	3.87E+16	6.88E+14
RC11	1.184E+19	7.75E+17	2.86E+16	7.47E+16	3.526E+16	7.68E+14
RC12	1.168E+19	1.271E+15	1.98E+13	6.66E+13	3.01E+14	5.12E+12
RC13	1.184E+19	6.82E+16	1.32E+15	3.06E+15	5.676E+11	3.2E+10
RC14	5.76E+18	1.612E+15	5.83E+13	3.6E+14	3.526E+15	6.56E+13
RC16	5.92E+18	1.24E+14	2.64E+12	1.35E+13	1.462E+14	2.4E+12
RC18	1.248E+19	1.209E+14	4.4E+12	2.34E+13	2.322E+14	4.32E+12
RC21	2.08E+18	4.65E+13	5.94E+11	2.52E+12	1.978E+13	2.88E+11
Qingdao						
Early Fatalities per Bq q=2.92	0.00E+00	4.10E-18	1.60E-18	3.50E-17	1.70E-18	9.10E-17
Late fatalities per Bq q=2.00	1.00E-18	6.60E-17	3.20E-15	6.80E-16	4.80E-16	2.80E-15
Delayed fatalities per Bq q=2.61	0	7.00E-17	8.60E-14	3.40E-16	2.40E-15	9.40E-16
Land lost [km^2] per Bq q=0.67	0.00E+00	0.00E+00	4.30E-15	0.00E+00	1.80E-15	0.00E+00
Yantai						
Early Fatalities per Bq q=2.08	0.00E+00	2.90E-18	1.10E-18	2.50E-17	1.20E-18	6.40E-17
Late fatalities per Bq q=1.28	6.40E-19	4.20E-17	2.00E-15	4.40E-16	3.10E-16	1.80E-15
Delayed fatalities per Bq q=2.29	0	6.20E-17	7.60E-14	3.00E-16	2.10E-15	8.20E-16
Land lost [km^2] per Bq q=0.49	0.00E+00	0.00E+00	3.10E-15	0.00E+00	1.30E-15	0.00E+00

Table F.6: PR Releases.

Release class	Xe	I	Cs	Te	Sr	La
RC1	1.456E+19	5.58E+18	1.98E+17	1.26E+18	1.462E+18	9.28E+17
RC2	1.536E+19	9.3E+17	3.3E+16	3.15E+17	8.6E+17	1.92E+17
RC3	1.52E+19	1.86E+17	6.6E+15	6.3E+16	2.322E+17	3.84E+16
RC4	2.72E+16	1.302E+14	4.62E+12	5.4E+13	1.376E+14	4.64E+13
RC5	2.72E+16	2.449E+14	8.69E+12	5.4E+13	6.02E+13	8E+13
RC6	5.28E+18	3.1E+18	1.1E+17	4.32E+17	8.6E+17	1.184E+18
RC7	5.92E+18	4.96E+18	1.76E+17	1.08E+18	8.6E+17	1.92E+17
Qingdao						
Early Fatalities per Bq q=2.92	0.00E+00	4.10E-18	1.60E-18	3.50E-17	1.70E-18	9.10E-17
Late fatalities per Bq q=2.00	1.00E-18	6.60E-17	3.20E-15	6.80E-16	4.80E-16	2.80E-15
Delayed fatalities per Bq q=2.61	0	7.00E-17	8.60E-14	3.40E-16	2.40E-15	9.40E-16
Land lost [km^2] per Bq q=0.67	0.00E+00	0.00E+00	4.30E-15	0.00E+00	1.80E-15	0.00E+00
Yantai						
Early Fatalities per Bq q=2.08	0.00E+00	2.90E-18	1.10E-18	2.50E-17	1.20E-18	6.40E-17
Late fatalities per Bq q=1.28	6.40E-19	4.20E-17	2.00E-15	4.40E-16	3.10E-16	1.80E-15
Delayed fatalities per Bq q=2.29	0	6.20E-17	7.60E-14	3.00E-16	2.10E-15	8.20E-16
Land lost [km^2] per Bq q=0.49	0.00E+00	0.00E+00	3.10E-15	0.00E+00	1.30E-15	0.00E+00

F.1.1 Detailed results for Qingdao site, ABWR NPP

Table F.7: Qingdao ABWR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	15.252	0.1936	8.82	2.4854	2.912	29.663
RC2	0	0.99138	0.013376	1.071	0.32164	0.30576	2.703156
RC3	0	11.1848	0.1408	11.655	5.4094	6.2608	34.6508
RC4	0	0.080073	0.0004928	0.0315	0.0114036	0.0096096	0.133079
RC5	0	0.6355	0.005104	0.4095	0.1462	0.16016	1.356464
RC6	0	0.19065	0.002464	0.2898	0.070176	0.068432	0.621522
RC7	0	7.4989	0.10032	9.135	2.7778	3.7856	23.29762
RC8	0	0.010676	0.00006688	0.00567	0.0020468	0.0017472	0.020207
RC9	0	0.83886	0.00704	0.567	0.20468	0.23296	1.85054
RC10	0	0.19065	0.00264	0.2709	0.06579	0.062608	0.592588
RC11	0	3.1775	0.04576	2.6145	0.059942	0.069888	5.96759
RC12	0	0.005211	0.00003168	0.002331	0.0005117	0.00046592	0.008551
RC13	0	0.27962	0.002112	0.1071	9.6492E-07	2.912E-06	0.388836
RC14	0	0.006609	0.00009328	0.0126	0.0059942	0.0059696	0.031266
RC16	0	0.000508	0.000004224	0.000473	0.00024854	0.0002184	0.001452
RC18	0	0.000496	0.00000704	0.000819	0.00039474	0.00039312	0.00211
RC21	0	0.000191	9.504E-07	8.82E-05	0.000033626	2.6208E-05	0.00034

Table F.8: Qingdao ABWR late fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	11.52	245.52	387.2	171.36	701.76	89.6	1606.96
RC2	11.68	15.9588	26.752	20.808	90.816	9.408	175.4228
RC3	11.84	180.048	281.6	226.44	1527.36	192.64	2419.928
RC4	11.84	1.28898	0.9856	0.612	3.21984	0.29568	18.2421
RC5	11.84	10.23	10.208	7.956	41.28	4.928	86.442
RC6	11.84	3.069	4.928	5.6304	19.8144	2.1056	47.3874
RC7	12.48	120.714	200.64	177.48	784.32	116.48	1412.114
RC8	11.84	0.171864	0.13376	0.11016	0.57792	0.05376	12.88746
RC9	11.84	13.5036	14.08	11.016	57.792	7.168	115.3996
RC10	11.84	3.069	5.28	5.2632	18.576	1.9264	45.9546
RC11	11.84	51.15	91.52	50.796	16.9248	2.1504	224.3812
RC12	11.68	0.083886	0.06336	0.045288	0.14448	0.014336	12.03135
RC13	11.84	4.5012	4.224	2.0808	0.000272448	0.0000896	22.64636
RC14	5.76	0.106392	0.18656	0.2448	1.69248	0.18368	8.173912
RC16	5.92	0.008184	0.008448	0.00918	0.070176	0.00672	6.022708
RC18	12.48	0.007979	0.01408	0.015912	0.111456	0.012096	12.64152
RC21	2.08	0.003069	0.0019008	0.001714	0.0094944	0.0008064	2.096984

Table F.9: Qingdao ABWR delayed fatalities (delayed exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	260.4	10406	85.68	3508.8	30.08	14290.96
RC2	0	16.926	718.96	10.404	454.08	3.1584	1203.5284
RC3	0	190.96	7568	113.22	7636.8	64.672	15573.652
RC4	0	1.3671	26.488	0.306	16.0992	0.099264	44.359564
RC5	0	10.85	274.34	3.978	206.4	1.6544	497.2224
RC6	0	3.255	132.44	2.8152	99.072	0.70688	238.28908
RC7	0	128.03	5392.2	88.74	3921.6	39.104	9569.674
RC8	0	0.18228	3.5948	0.05508	2.8896	0.018048	6.739808
RC9	0	14.322	378.4	5.508	288.96	2.4064	689.5964
RC10	0	3.255	141.9	2.6316	92.88	0.64672	241.31332
RC11	0	54.25	2459.6	25.398	84.624	0.72192	2624.59392
RC12	0	0.08897	1.7028	0.022644	0.7224	0.004813	2.5416268
RC13	0	4.774	113.52	1.0404	0.001362	3.01E-05	119.3357923
RC14	0	0.11284	5.0138	0.1224	8.4624	0.061664	13.773104
RC16	0	0.00868	0.22704	0.00459	0.35088	0.002256	0.593446
RC18	0	0.008463	0.3784	0.007956	0.55728	0.004061	0.9561598
RC21	0	0.003255	0.051084	0.000857	0.047472	0.000271	0.10293852

Table F.10: Qingdao ABWR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	15897.92
RC2	1378.9512
RC3	17993.58
RC4	62.601664
RC5	583.6644
RC6	285.67648
RC7	10981.788
RC8	19.627272
RC9	804.996
RC10	287.26792
RC11	2848.97512
RC12	14.5729768
RC13	141.9821544
RC14	21.947016
RC16	6.616154
RC18	13.5976832
RC21	2.19992272

Table F.11: Qingdao ABWR land contamination [km^2].

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	520.3	0	2631.6	0	3151.9
RC2	0	0	35.948	0	340.56	0	376.508
RC3	0	0	378.4	0	5727.6	0	6106
RC4	0	0	1.3244	0	12.0744	0	13.3988
RC5	0	0	13.717	0	154.8	0	168.517
RC6	0	0	6.622	0	74.304	0	80.926
RC7	0	0	269.61	0	2941.2	0	3210.81
RC8	0	0	0.17974	0	2.1672	0	2.34694
RC9	0	0	18.92	0	216.72	0	235.64
RC10	0	0	7.095	0	69.66	0	76.755
RC11	0	0	122.98	0	63.468	0	186.448
RC12	0	0	0.08514	0	0.5418	0	0.62694
RC13	0	0	5.676	0	0.00102168	0	5.677022
RC14	0	0	0.25069	0	6.3468	0	6.59749
RC16	0	0	0.011352	0	0.26316	0	0.274512
RC18	0	0	0.01892	0	0.41796	0	0.43688
RC21	0	0	0.0025542	0	0.035604	0	0.038158

Table F.12: Qingdao ABWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	2.97E+01	7.12E-08	1.59E+04	3.82E-05	3.15E+03	7.56E-06
RC2	4.40E-09	2.70E+00	1.19E-08	1.38E+03	6.07E-06	3.77E+02	1.66E-06
RC3	1.50E-08	3.47E+01	5.20E-07	1.80E+04	2.70E-04	6.11E+03	9.16E-05
RC4	5.90E-08	1.33E-01	7.85E-09	6.26E+01	3.69E-06	1.34E+01	7.91E-07
RC5	2.30E-08	1.36E+00	3.12E-08	5.84E+02	1.34E-05	1.69E+02	3.88E-06
RC6	2.60E-08	6.22E-01	1.62E-08	2.86E+02	7.43E-06	8.09E+01	2.10E-06
RC7	6.50E-09	2.33E+01	1.51E-07	1.10E+04	7.14E-05	3.21E+03	2.09E-05
RC8	3.20E-08	2.02E-02	6.47E-10	1.96E+01	6.28E-07	2.35E+00	7.51E-08
RC9	1.10E-08	1.85E+00	2.04E-08	8.05E+02	8.85E-06	2.36E+02	2.59E-06
RC10	1.20E-08	5.93E-01	7.11E-09	2.87E+02	3.45E-06	7.68E+01	9.21E-07
RC11	9.60E-09	5.97E+00	5.73E-08	2.85E+03	2.74E-05	1.86E+02	1.79E-06
RC12	6.40E-09	8.55E-03	5.47E-11	1.46E+01	9.33E-08	6.27E-01	4.01E-09
RC13	1.80E-08	3.89E-01	7.00E-09	1.42E+02	2.56E-06	5.68E+00	1.02E-07
RC14	2.40E-09	3.13E-02	7.50E-11	2.19E+01	5.27E-08	6.60E+00	1.58E-08
RC16	1.20E-07	1.45E-03	1.74E-10	6.62E+00	7.94E-07	2.75E-01	3.29E-08
RC18	6.10E-08	2.11E-03	1.29E-10	1.36E+01	8.29E-07	4.37E-01	2.66E-08
RC21	3.00E-09	3.40E-04	1.02E-12	2.20E+00	6.60E-09	3.82E-02	1.14E-10
TOTAL	4.12E-07	-	9.02E-07	-	4.55E-04	-	1.34E-04

F.1.2 Detailed results for Qingdao site, EPR NPP

Table F.13: Qingdao EPR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	22.878	0.3168	44.1	2.4854	84.448	154.2282
RC2	0	3.813	0.0528	11.025	1.462	17.472	33.8248
RC3	0	0.7626	0.01056	2.205	0.39474	3.4944	6.8673
RC4	0	0.000534	0.000007392	0.00189	0.00023392	0.0042224	0.006888
RC5	0	0.001004	0.000013904	0.00189	0.00010234	0.00728	0.01029
RC6	0	12.71	0.176	15.12	1.462	107.744	137.212
RC7	0	20.336	0.2816	37.8	1.462	17.472	77.3516

Table F.14: Qingdao EPR late fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	14.56	368.28	633.6	856.8	701.76	2598.4	5173.4
RC2	15.36	61.38	105.6	214.2	412.8	537.6	1346.94
RC3	15.2	12.276	21.12	42.84	111.456	107.52	310.412
RC4	0.0272	0.008593	0.014784	0.03672	0.066048	0.12992	0.283265
RC5	0.0272	0.016163	0.027808	0.03672	0.028896	0.224	0.360787
RC6	5.28	204.6	352	293.76	412.8	3315.2	4583.64
RC7	5.92	327.36	563.2	734.4	412.8	537.6	2581.28

Table F.15: Qingdao EPR delayed fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	390.6	17028	428.4	3508.8	872.32	22228.12
RC2	0	65.1	2838	107.1	2064	180.48	5254.68
RC3	0	13.02	567.6	21.42	557.28	36.096	1195.416
RC4	0	0.009114	0.39732	0.01836	0.33024	0.043616	0.79865
RC5	0	0.017143	0.74734	0.01836	0.14448	0.0752	1.002523
RC6	0	217	9460	146.88	2064	1112.96	13000.84
RC7	0	347.2	15136	367.2	2064	180.48	18094.88

Table F.16: Qingdao EPR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	27401.52
RC2	6601.62
RC3	1505.828
RC4	1.0819152
RC5	1.3633104
RC6	17584.48
RC7	20676.16

Table F.17: Qingdao EPR land contamination.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	851.4	0	2631.6	0	3483
RC2	0	0	141.9	0	1548	0	1689.9
RC3	0	0	28.38	0	417.96	0	446.34
RC4	0	0	0.019866	0	0.24768	0	0.267546
RC5	0	0	0.037367	0	0.10836	0	0.145727
RC6	0	0	473	0	1548	0	2021
RC7	0	0	756.8	0	1548	0	2304.8

Table F.18: Qingdao EPR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	1.54E+02	4.63E-08	27401.52	8.22E-06	3483	1.04E-06
RC2	4.40E-09	3.38E+01	3.38E-09	6601.62	6.60E-07	1689.9	1.69E-07
RC3	1.50E-08	6.87E+00	6.87E-10	1505.828	1.51E-07	446.34	4.46E-08
RC4	5.90E-08	6.89E-03	6.89E-12	1.0819152	1.08E-09	0.267546	2.68E-10
RC5	2.30E-08	1.03E-02	2.06E-09	1.3633104	2.73E-07	0.145727	2.91E-08
RC6	2.60E-08	1.37E+02	2.74E-07	17584.48	3.52E-05	2021	4.04E-06
RC7	6.50E-09	7.74E+01	1.55E-06	20676.16	4.14E-04	2304.8	4.61E-05
TOTAL	2.24E-07	-	1.87E-06	-	4.58E-04	-	5.14E-05

F.1.3 Detailed results for Yantai site, ABWR NPP

Table F.19: Yantai ABWR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	10.788	0.1331	6.3	1.7544	2.048	21.0235
RC2	0	0.70122	0.009196	0.765	0.22704	0.21504	1.917496
RC3	0	7.9112	0.0968	8.325	3.8184	4.4032	24.5546
RC4	0	0.056637	0.0003388	0.0225	0.0080496	0.0067584	0.094284
RC5	0	0.4495	0.003509	0.2925	0.1032	0.11264	0.961349
RC6	0	0.13485	0.001694	0.207	0.049536	0.048128	0.441208
RC7	0	5.3041	0.06897	6.525	1.9608	2.6624	16.52127
RC8	0	0.007552	0.00004598	0.00405	0.0014448	0.0012288	0.014321
RC9	0	0.59334	0.00484	0.405	0.14448	0.16384	1.3115
RC10	0	0.13485	0.001815	0.1935	0.04644	0.044032	0.420637
RC11	0	2.2475	0.03146	1.8675	0.042312	0.049152	4.237924
RC12	0	0.003686	0.00002178	0.001665	0.0003612	0.00032768	0.006062
RC13	0	0.19778	0.001452	0.0765	6.8112E-07	2.048E-06	0.275735
RC14	0	0.004675	0.00006413	0.009	0.0042312	0.0041984	0.022169
RC16	0	0.00036	0.000002904	0.000338	0.00017544	0.0001536	0.001029
RC18	0	0.000351	0.00000484	0.000585	0.00027864	0.00027648	0.001496
RC21	0	0.000135	6.534E-07	0.000063	0.000023736	1.8432E-05	0.000241

Table F.20: Yantai ABWR late fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	7.3728	156.24	242	110.88	453.22	57.6	1027.313
RC2	7.4752	10.1556	16.72	13.464	58.652	6.048	112.5148
RC3	7.5776	114.576	176	146.52	986.42	123.84	1554.934
RC4	7.5776	0.82026	0.616	0.396	2.07948	0.19008	11.67942
RC5	7.5776	6.51	6.38	5.148	26.66	3.168	55.4436
RC6	7.5776	1.953	3.08	3.6432	12.7968	1.3536	30.4042
RC7	7.9872	76.818	125.4	114.84	506.54	74.88	906.4652
RC8	7.5776	0.109368	0.0836	0.07128	0.37324	0.03456	8.249648
RC9	7.5776	8.5932	8.8	7.128	37.324	4.608	74.0308
RC10	7.5776	1.953	3.3	3.4056	11.997	1.2384	29.4716
RC11	7.5776	32.55	57.2	32.868	10.9306	1.3824	142.5086
RC12	7.4752	0.053382	0.0396	0.029304	0.09331	0.009216	7.700012
RC13	7.5776	2.8644	2.64	1.3464	0.000175956	0.0000576	14.42863
RC14	3.6864	0.067704	0.1166	0.1584	1.09306	0.11808	5.240244
RC16	3.7888	0.005208	0.00528	0.00594	0.045322	0.00432	3.85487
RC18	7.9872	0.005078	0.0088	0.010296	0.071982	0.007776	8.091132
RC21	1.3312	0.001953	0.001188	0.001109	0.0061318	0.0005184	1.3421

Table F.21: Yantai ABWR delayed fatalities (delayed exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	230.64	9196	75.6	3070.2	26.24	12598.68
RC2	0	14.9916	635.36	9.18	397.32	2.7552	1059.6068
RC3	0	169.136	6688	99.9	6682.2	56.416	13695.652
RC4	0	1.21086	23.408	0.27	14.0868	0.086592	39.062252
RC5	0	9.61	242.44	3.51	180.6	1.4432	437.6032
RC6	0	2.883	117.04	2.484	86.688	0.61664	209.71164
RC7	0	113.398	4765.2	78.3	3431.4	34.112	8422.41
RC8	0	0.161448	3.1768	0.0486	2.5284	0.015744	5.930992
RC9	0	12.6852	334.4	4.86	252.84	2.0992	606.8844
RC10	0	2.883	125.4	2.322	81.27	0.56416	212.43916
RC11	0	48.05	2173.6	22.41	74.046	0.62976	2318.73576
RC12	0	0.078802	1.5048	0.01998	0.6321	0.004198	2.2398804
RC13	0	4.2284	100.32	0.918	0.001192	2.62E-05	105.4676182
RC14	0	0.099944	4.4308	0.108	7.4046	0.053792	12.097136
RC16	0	0.007688	0.20064	0.00405	0.30702	0.001968	0.521366
RC18	0	0.007496	0.3344	0.00702	0.48762	0.003542	0.8400782
RC21	0	0.002883	0.045144	0.000756	0.041538	0.000236	0.09055716

Table F.22: Yantai ABWR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	13625.9928
RC2	1172.1216
RC3	15250.5856
RC4	50.741672
RC5	493.0468
RC6	240.11584
RC7	9328.8752
RC8	14.18064
RC9	680.9152
RC10	241.91076
RC11	2461.24436
RC12	9.9398924
RC13	119.8962518
RC14	17.33738
RC16	4.376236
RC18	8.93121
RC21	1.43265716

Table F.23: Yantai ABWR land contamination [km^2].

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	375.1	0	1900.6	0	2275.7
RC2	0	0	25.916	0	245.96	0	271.876
RC3	0	0	272.8	0	4136.6	0	4409.4
RC4	0	0	0.9548	0	8.7204	0	9.6752
RC5	0	0	9.889	0	111.8	0	121.689
RC6	0	0	4.774	0	53.664	0	58.438
RC7	0	0	194.37	0	2124.2	0	2318.57
RC8	0	0	0.12958	0	1.5652	0	1.69478
RC9	0	0	13.64	0	156.52	0	170.16
RC10	0	0	5.115	0	50.31	0	55.425
RC11	0	0	88.66	0	45.838	0	134.498
RC12	0	0	0.06138	0	0.3913	0	0.45268
RC13	0	0	4.092	0	0.00073788	0	4.092738
RC14	0	0	0.18073	0	4.5838	0	4.76453
RC16	0	0	0.008184	0	0.19006	0	0.198244
RC18	0	0	0.01364	0	0.30186	0	0.3155
RC21	0	0	0.0018414	0	0.025714	0	0.027555

Table F.24: Yantai ABWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	2.10E+01	5.05E-08	13626	3.27E-05	2275.7	5.46168E-06
RC2	4.40E-09	1.92E+00	8.44E-09	1172	5.15E-06	271.876	1.19625E-06
RC3	1.50E-08	2.46E+01	3.68E-07	15251	0.0059	4409.4	0.000066141
RC4	5.90E-08	9.43E-02	5.56E-09	51	2.99E-06	9.6752	5.70837E-07
RC5	2.30E-08	9.61E-01	2.21E-08	493	1.13E-05	121.689	2.79885E-06
RC6	2.60E-08	4.41E-01	1.15E-08	240	6.24E-06	58.438	1.51939E-06
RC7	6.50E-09	1.65E+01	1.07E-07	9329	6.06E-05	2318.57	1.50707E-05
RC8	3.20E-08	1.43E-02	4.58E-10	14	4.53E-07	1.69478	5.4233E-08
RC9	1.10E-08	1.31E+00	1.44E-08	681	7.49E-06	170.16	1.87176E-06
RC10	1.20E-08	4.21E-01	5.05E-09	242	2.90E-06	55.425	6.651E-07
RC11	9.60E-09	4.24E+00	4.07E-08	2461	2.36E-05	134.498	1.29118E-06
RC12	6.40E-09	6.06E-03	3.88E-11	10	6.36E-08	0.45268	2.89715E-09
RC13	1.80E-08	2.76E-01	4.96E-09	120	2.15E-06	4.09273788	7.36693E-08
RC14	2.40E-09	2.22E-02	5.32E-11	17	4.16E-08	4.76453	1.14349E-08
RC16	1.20E-07	1.03E-03	1.23E-10	4	5.25E-07	0.198244	2.37893E-08
RC18	6.10E-08	1.50E-03	9.12E-11	9	5.44E-07	0.3155	1.92455E-08
RC21	3.00E-09	2.41E-04	7.22E-13	1	4.29E-09	0.0275554	8.26662E-11
TOTAL	4.12E-07	-	6.40E-07	-	3.86E-04	-	9.67721E-05

F.1.5 Detailed results for Yantai site, EPR NPP

Table F.25: Yantai EPR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	16.182	0.2178	31.5	1.7544	59.392	109.0462
RC2	0	2.697	0.0363	7.875	1.032	12.288	23.9283
RC3	0	0.5394	0.00726	1.575	0.27864	2.4576	4.8579
RC4	0	0.000378	0.000005082	0.00135	0.00016512	0.0029696	0.004867
RC5	0	0.00071	0.000009559	0.00135	0.00007224	0.00512	0.007262
RC6	0	8.99	0.121	10.8	1.032	75.776	96.719
RC7	0	14.384	0.1936	27	1.032	12.288	54.8976

Table F.26: Yantai EPR late fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	9.3184	234.36	396	554.4	453.22	1670.4	3317.698
RC2	9.8304	39.06	66	138.6	266.6	345.6	865.6904
RC3	9.728	7.812	13.2	27.72	71.982	69.12	199.562
RC4	0.017408	0.005468	0.00924	0.02376	0.042656	0.08352	0.182052
RC5	0.017408	0.010286	0.01738	0.02376	0.018662	0.144	0.231496
RC6	3.3792	130.2	220	190.08	266.6	2131.2	2941.459
RC7	3.7888	208.32	352	475.2	266.6	345.6	1651.509

Table F.27: Yantai EPR delayed fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	345.96	15048	378	3070.2	760.96	19603.12
RC2	0	57.66	2508	94.5	1806	157.44	4623.6
RC3	0	11.532	501.6	18.9	487.62	31.488	1051.14
RC4	0	0.008072	0.35112	0.0162	0.28896	0.038048	0.7024004
RC5	0	0.015184	0.66044	0.0162	0.12642	0.0656	0.8838438
RC6	0	192.2	8360	129.6	1806	970.88	11458.68
RC7	0	307.52	13376	324	1806	157.44	15970.96

Table F.28: Yantai EPR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	22920.8184
RC2	5489.2904
RC3	1250.702
RC4	0.8844528
RC5	1.1153396
RC6	14400.1392
RC7	17622.4688

Table F.29: Yantai EPR land contamination [km^2].

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	613.8	0	1900.6	0	2514.4
RC2	0	0	102.3	0	1118	0	1220.3
RC3	0	0	20.46	0	301.86	0	322.32
RC4	0	0	0.014322	0	0.17888	0	0.193202
RC5	0	0	0.026939	0	0.07826	0	0.105199
RC6	0	0	341	0	1118	0	1459
RC7	0	0	545.6	0	1118	0	1663.6

Table F.30: Yantai EPR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	1.09E+02	3.27E-08	22920.8184	6.88E-06	2514.4	7.54E-07
RC2	4.40E-09	2.39E+01	2.39E-09	5489.2904	5.49E-07	1220.3	1.22E-07
RC3	1.50E-08	4.86E+00	4.86E-10	1250.702	1.25E-07	322.32	3.22E-08
RC4	5.90E-08	4.87E-03	4.87E-12	0.8844528	8.84E-10	0.193202	1.93E-10
RC5	2.30E-08	7.26E-03	1.45E-09	1.1153396	2.23E-07	0.105199	2.10E-08
RC6	2.60E-08	9.67E+01	1.93E-07	14400.1392	2.88E-05	1459	2.92E-06
RC7	6.50E-09	5.49E+01	1.10E-06	17622.4688	3.52E-04	1663.6	3.33E-05
TOTAL	2.24E-07	-	1.33E-06	-	3.89E-04	-	3.71E-05

F.2 Detailed results for existing reactors

Non-advanced reactors are for the purpose of the report considered plants with CDF 10 times higher than CDF for advanced reactors (Appendix F.1). CDF 10 times higher means also frequency of release 10 times higher. Basic source terms, core inventories, and also the consequences per Bq are however the same. Tables F8 and F9 show the results for risks for advanced reactors with given frequencies of releases. Tables F.31 to F.34 show the results for non-advanced reactors considered in the report, with frequencies of releases increased 10 times.

Table F.31: Qingdao BWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-08	2.97E+01	7.12E-07	1.59E+04	3.82E-04	3.15E+03	7.56E-05
RC2	4.40E-08	2.70E+00	1.19E-07	1.38E+03	6.07E-05	3.77E+02	1.66E-05
RC3	1.50E-07	3.47E+01	5.20E-06	1.80E+04	2.70E-03	6.11E+03	9.16E-04
RC4	5.90E-07	1.33E-01	7.85E-08	6.26E+01	3.69E-05	1.34E+01	7.91E-06
RC5	2.30E-07	1.36E+00	3.12E-07	5.84E+02	1.34E-04	1.69E+02	3.88E-05
RC6	2.60E-07	6.22E-01	1.62E-07	2.86E+02	7.43E-05	8.09E+01	2.10E-05
RC7	6.50E-08	2.33E+01	1.51E-06	1.10E+04	7.14E-04	3.21E+03	2.09E-04
RC8	3.20E-07	2.02E-02	6.47E-09	1.96E+01	6.28E-06	2.35E+00	7.51E-07
RC9	1.10E-07	1.85E+00	2.04E-07	8.05E+02	8.85E-05	2.36E+02	2.59E-05
RC10	1.20E-07	5.93E-01	7.11E-08	2.87E+02	3.45E-05	7.68E+01	9.21E-06
RC11	9.60E-08	5.97E+00	5.73E-07	2.85E+03	2.74E-04	1.86E+02	1.79E-05
RC12	6.40E-08	8.55E-03	5.47E-10	1.46E+01	9.33E-07	6.27E-01	4.01E-08
RC13	1.80E-07	3.89E-01	7.00E-08	1.42E+02	2.56E-05	5.68E+00	1.02E-06
RC14	2.40E-08	3.13E-02	7.50E-10	2.19E+01	5.27E-07	6.60E+00	1.58E-07
RC16	1.20E-06	1.45E-03	1.74E-09	6.62E+00	7.94E-06	2.75E-01	3.29E-07
RC18	6.10E-07	2.11E-03	1.29E-09	1.36E+01	8.29E-06	4.37E-01	2.66E-07
RC21	3.00E-08	3.40E-04	1.02E-11	2.20E+00	6.60E-08	3.82E-02	1.14E-09
TOTAL	4.12E-06	-	9.02E-06	-	4.55E-03	-	1.34E-03

Table F.32: Qingdao PWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	3.00E-09	1.54E+02	4.63E-07	2.74E+04	8.22E-05	3.48E+03	1.04E-05
RC2	1.00E-09	3.38E+01	3.38E-08	6.60E+03	6.60E-06	1.69E+03	1.69E-06
RC3	1.00E-09	6.87E+00	6.87E-09	1.51E+03	1.51E-06	4.46E+02	4.46E-07
RC4	1.00E-08	6.89E-03	6.89E-11	1.08E+00	1.08E-08	2.68E-01	2.68E-09
RC5	2.00E-06	1.03E-02	2.06E-08	1.36E+00	2.73E-06	1.46E-01	2.91E-07
RC6	2.00E-08	1.37E+02	2.74E-06	1.76E+04	3.52E-04	2.02E+03	4.04E-05
RC7	2.00E-07	7.74E+01	1.55E-05	2.07E+04	4.14E-03	2.30E+03	4.61E-04
TOTAL	2.24E-06	-	1.87E-05	-	4.58E-03	-	5.14E-04

Table F.33: Yantai BWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-08	2.10E+01	5.05E-07	1.36E+04	3.27E-04	2.28E+03	5.46E-05
RC2	4.40E-08	1.92E+00	8.44E-08	1.17E+03	5.16E-05	2.72E+02	1.20E-05
RC3	1.50E-07	2.46E+01	3.68E-06	1.53E+04	2.29E-03	4.41E+03	6.61E-04
RC4	5.90E-07	9.43E-02	5.56E-08	5.07E+01	2.99E-05	9.68E+00	5.71E-06
RC5	2.30E-07	9.61E-01	2.21E-07	4.93E+02	1.13E-04	1.22E+02	2.80E-05
RC6	2.60E-07	4.41E-01	1.15E-07	2.40E+02	6.24E-05	5.84E+01	1.52E-05
RC7	6.50E-08	1.65E+01	1.07E-06	9.33E+03	6.06E-04	2.32E+03	1.51E-04
RC8	3.20E-07	1.43E-02	4.58E-09	1.42E+01	4.54E-06	1.69E+00	5.42E-07
RC9	1.10E-07	1.31E+00	1.44E-07	6.81E+02	7.49E-05	1.70E+02	1.87E-05
RC10	1.20E-07	4.21E-01	5.05E-08	2.42E+02	2.90E-05	5.54E+01	6.65E-06
RC11	9.60E-08	4.24E+00	4.07E-07	2.46E+03	2.36E-04	1.34E+02	1.29E-05
RC12	6.40E-08	6.06E-03	3.88E-10	9.94E+00	6.36E-07	4.53E-01	2.90E-08
RC13	1.80E-07	2.76E-01	4.96E-08	1.20E+02	2.16E-05	4.09E+00	7.37E-07
RC14	2.40E-08	2.22E-02	5.32E-10	1.73E+01	4.16E-07	4.76E+00	1.14E-07
RC16	1.20E-06	1.03E-03	1.23E-09	4.38E+00	5.25E-06	1.98E-01	2.38E-07
RC18	6.10E-07	1.50E-03	9.12E-10	8.93E+00	5.45E-06	3.16E-01	1.92E-07
RC21	3.00E-08	2.41E-04	7.22E-12	1.43E+00	4.30E-08	2.76E-02	8.27E-10
TOTAL	4.12E-06	-	6.40E-06	-	3.86E-03	-	9.68E-04

Table F.34: Yantai PWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	3.00E-09	1.09E+02	3.27E-07	2.29E+04	6.88E-05	2.51E+03	7.54E-06
RC2	1.00E-09	2.39E+01	2.39E-08	5.49E+03	5.49E-06	1.22E+03	1.22E-06
RC3	1.00E-09	4.86E+00	4.86E-09	1.25E+03	1.25E-06	3.22E+02	3.22E-07
RC4	1.00E-08	4.87E-03	4.87E-11	8.84E-01	8.84E-09	1.93E-01	1.93E-09
RC5	2.00E-06	7.26E-03	1.45E-08	1.12E+00	2.23E-06	1.05E-01	2.10E-07
RC6	2.00E-08	9.67E+01	1.93E-06	1.44E+04	2.88E-04	1.46E+03	2.92E-05
RC7	2.00E-07	5.49E+01	1.10E-05	1.76E+04	3.52E-03	1.66E+03	3.33E-04
TOTAL	2.24E-06	-	1.33E-05	-	3.89E-03	-	3.71E-04

APPENDIX G
SENSITIVITY ANALYSES

G.1 Basic values for increased core inventories and population

The sensitivity analysis presented in this appendix was done for both cases of 30% increase of core inventories and 20% increase of population to 800 km distance.

Table G.1: Increased core inventories.

Radionuclide group	Initial activity in core (x 10^{15} Bq)
Xe	2.08E+19
I	4.03E+19
Cs	1.43E+18
Te	1.17E+19
Sr	1.12E+20
La	2.08E+20

Table G.2: Source terms for ABWR.

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.72	1.20E-01	1.10E-01	2.80E-02	1.70E-02	2.00E-04
RC2	0.73	7.80E-03	7.60E-03	3.40E-03	2.20E-03	2.10E-05
RC3	0.74	8.80E-02	8.00E-02	3.70E-02	3.70E-02	4.30E-04
RC4	0.74	6.30E-04	2.80E-04	1.00E-04	7.80E-05	6.60E-07
RC5	0.74	5.00E-03	2.90E-03	1.30E-03	1.00E-03	1.10E-05
RC6	0.74	1.50E-03	1.40E-03	9.20E-04	4.80E-04	4.70E-06
RC7	0.78	5.90E-02	5.70E-02	2.90E-02	1.90E-02	2.60E-04
RC8	0.74	8.40E-05	3.80E-05	1.80E-05	1.40E-05	1.20E-07
RC9	0.74	6.60E-03	4.00E-03	1.80E-03	1.40E-03	1.60E-05
RC10	0.74	1.50E-03	1.50E-03	8.60E-04	4.50E-04	4.30E-06
RC11	0.74	2.50E-02	2.60E-02	8.30E-03	4.10E-04	4.80E-06
RC12	0.73	4.10E-05	1.80E-05	7.40E-06	3.50E-06	3.20E-08
RC13	0.74	2.20E-03	1.20E-03	3.40E-04	6.60E-09	2.00E-10
RC14	0.36	5.20E-05	5.30E-05	4.00E-05	4.10E-05	4.10E-07
RC16	0.37	4.00E-06	2.40E-06	1.50E-06	1.70E-06	1.50E-08
RC18	0.78	3.90E-06	4.00E-06	2.60E-06	2.70E-06	2.70E-08
RC21	0.13	1.50E-06	5.40E-07	2.80E-07	2.30E-07	1.80E-09
Core invent.[Bq]	2.08E+19	4.03E+19	1.43E+18	1.17E+19	1.12E+20	2.08E+20

Table G.3: Source terms for EPR.

Release class	Xe	I	Cs	Te	Sr	La
RC1	0.91	1.80E-01	1.80E-01	1.40E-01	1.70E-02	5.80E-03
RC2	0.96	3.00E-02	3.00E-02	3.50E-02	1.00E-02	1.20E-03
RC3	0.95	6.00E-03	6.00E-03	7.00E-03	2.70E-03	2.40E-04
RC4	1.70E-03	4.20E-06	4.20E-06	6.00E-06	1.60E-06	2.90E-07
RC5	5.00E-04	7.90E-06	7.90E-06	6.00E-06	7.00E-07	5.00E-07
RC6	0.33	1.00E-01	1.00E-01	4.80E-02	1.00E-02	7.40E-03
RC7	0.37	1.60E-01	1.60E-01	1.20E-01	1.00E-02	1.20E-03
Core invent.[Bq]	2.08E+19	4.03E+19	1.43E+18	1.17E+19	1.12E+20	2.08E+20

Table G.4: Consequences per Bq

	Xe	I	Cs	Te	Sr	La
Early Fatalities per Bq	0.00E+00	1.40E-18	5.50E-19	1.20E-17	5.90E-19	3.10E-17
Late fatalities per Bq	5.00E-19	3.30E-17	1.60E-15	3.40E-16	2.40E-16	1.40E-15
Delayed fatalities per Bq	0	2.70E-17	3.30E-14	1.30E-16	9.30E-16	3.60E-16
Land lost [km^2] per Bq	0.00E+00	0.00E+00	6.40E-15	0.00E+00	2.70E-15	0.00E+00

Table G.5: ABWR releases.

Release class	Xe	I	Cs	Te	Sr	La
RC1	1.4976E+19	4.836E+18	1.573E+17	3.276E+17	1.904E+18	4.16E+16
RC2	1.5184E+19	3.1434E+17	1.087E+16	3.978E+16	2.464E+17	4.368E+15
RC3	1.5392E+19	3.5464E+18	1.144E+17	4.329E+17	4.144E+18	8.944E+16
RC4	1.5392E+19	2.5389E+16	4.004E+14	1.17E+15	8.736E+15	1.3728E+14
RC5	1.5392E+19	2.015E+17	4.147E+15	1.521E+16	1.12E+17	2.288E+15
RC6	1.5392E+19	6.045E+16	2.002E+15	1.076E+16	5.376E+16	9.776E+14
RC7	1.6224E+19	2.3777E+18	8.151E+16	3.393E+17	2.128E+18	5.408E+16
RC8	1.5392E+19	3.3852E+15	5.434E+13	2.106E+14	1.568E+15	2.496E+13
RC9	1.5392E+19	2.6598E+17	5.72E+15	2.106E+16	1.568E+17	3.328E+15
RC10	1.5392E+19	6.045E+16	2.145E+15	1.006E+16	5.04E+16	8.944E+14
RC11	1.5392E+19	1.0075E+18	3.718E+16	9.711E+16	4.592E+16	9.984E+14
RC12	1.5184E+19	1.6523E+15	2.574E+13	8.658E+13	3.92E+14	6.656E+12
RC13	1.5392E+19	8.866E+16	1.716E+15	3.978E+15	7.392E+11	4.16E+10
RC14	7.488E+18	2.0956E+15	7.579E+13	4.68E+14	4.592E+15	8.528E+13
RC16	7.696E+18	1.612E+14	3.432E+12	1.755E+13	1.904E+14	3.12E+12
RC18	1.6224E+19	1.5717E+14	5.72E+12	3.042E+13	3.024E+14	5.616E+12
RC21	2.704E+18	6.045E+13	7.722E+11	3.276E+12	2.576E+13	3.744E+11
Qingdao						
Early Fatalities per Bq q=2.92	0.00E+00	4.10E-18	1.60E-18	3.50E-17	1.70E-18	9.10E-17
Late fatalities per Bq q=2.00	1.00E-18	6.60E-17	3.20E-15	6.80E-16	4.80E-16	2.80E-15
Delayed fatalities per Bq q=3.13	0	8.50E-17	1.00E-13	4.10E-16	2.90E-15	1.10E-15
Land lost [km^2] per Bq q=0.67	0.00E+00	0.00E+00	4.30E-15	0.00E+00	1.80E-15	0.00E+00
Yantai						
Early Fatalities per Bq q=2.08	0.00E+00	2.90E-18	1.10E-18	2.50E-17	1.20E-18	6.40E-17
Late fatalities per Bq q=1.28	6.40E-19	4.20E-17	2.00E-15	4.40E-16	3.10E-16	1.80E-15
Delayed fatalities per Bq q=2.74	0	8.50E-17	1.00E-13	4.10E-16	2.90E-15	1.10E-15
Land lost [km^2] per Bq q=0.49	0.00E+00	0.00E+00	3.10E-15	0.00E+00	1.30E-15	0.00E+00

Table G.6: EPR releases.

Release class	Xe	I	Cs	Te	Sr	La
RC1	1.8928E+19	7.254E+18	2.574E+17	1.638E+18	1.904E+18	1.2064E+18
RC2	1.9968E+19	1.209E+18	4.29E+16	4.095E+17	1.12E+18	2.496E+17
RC3	1.976E+19	2.418E+17	8.58E+15	8.19E+16	3.024E+17	4.992E+16
RC4	3.536E+16	1.6926E+14	6.006E+12	7.02E+13	1.792E+14	6.032E+13
RC5	3.536E+16	3.1837E+14	1.13E+13	7.02E+13	7.84E+13	1.04E+14
RC6	6.864E+18	4.03E+18	1.43E+17	5.616E+17	1.12E+18	1.5392E+18
RC7	7.696E+18	6.448E+18	2.288E+17	1.404E+18	1.12E+18	2.496E+17
Qingdao						
Early Fatalities per Bq q=2.92	0.00E+00	4.10E-18	1.60E-18	3.50E-17	1.70E-18	9.10E-17
Late fatalities per Bq q=2.00	1.00E-18	6.60E-17	3.20E-15	6.80E-16	4.80E-16	2.80E-15
Delayed fatalities per Bq q=3.13	0	8.50E-17	1.00E-13	4.10E-16	2.90E-15	1.10E-15
Land lost [km^2] per Bq q=0.67	0.00E+00	0.00E+00	4.30E-15	0.00E+00	1.80E-15	0.00E+00
Yantai						
Early Fatalities per Bq q=2.08	0.00E+00	2.90E-18	1.10E-18	2.50E-17	1.20E-18	6.40E-17
Late fatalities per Bq q=1.28	6.40E-19	4.20E-17	2.00E-15	4.40E-16	3.10E-16	1.80E-15
Delayed fatalities per Bq q=2.74	0	8.50E-17	1.00E-13	4.10E-16	2.90E-15	1.10E-15
Land lost [km^2] per Bq q=0.49	0.00E+00	0.00E+00	3.10E-15	0.00E+00	1.30E-15	0.00E+00

G.2 Results for increased core inventories and population for Qingdao site ABWR NPP

Table G.7: Qingdao ABWR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	19.8276	0.25168	11.466	3.2368	3.7856	38.56768
RC2	0	1.288794	0.0173888	1.3923	0.41888	0.397488	3.514851
RC3	0	14.54024	0.18304	15.1515	7.0448	8.13904	45.05862
RC4	0	0.104095	0.00064064	0.04095	0.0148512	0.01249248	0.173029
RC5	0	0.82615	0.0066352	0.53235	0.1904	0.208208	1.763743
RC6	0	0.247845	0.0032032	0.37674	0.091392	0.0889616	0.808142
RC7	0	9.74857	0.130416	11.8755	3.6176	4.92128	30.29337
RC8	0	0.013879	0.000086944	0.007371	0.0026656	0.00227136	0.026274
RC9	0	1.090518	0.009152	0.7371	0.26656	0.302848	2.406178
RC10	0	0.247845	0.003432	0.35217	0.08568	0.0813904	0.770517
RC11	0	4.13075	0.059488	3.39885	0.078064	0.0908544	7.758006
RC12	0	0.006774	0.000041184	0.00303	0.0006664	0.0006057	0.011118
RC13	0	0.363506	0.0027456	0.13923	1.25664E-06	3.7856E-06	0.505487
RC14	0	0.008592	0.000121264	0.01638	0.0078064	0.00776048	0.04066
RC16	0	0.000661	5.4912E-06	0.000614	0.00032368	0.00028392	0.001888
RC18	0	0.000644	0.000009152	0.001065	0.00051408	0.00051106	0.002743
RC21	0	0.000248	1.23552E-06	0.000115	0.000043792	3.407E-05	0.000442

Table G.8: Qingdao ABWR late fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	14.976	319.176	503.36	222.768	913.92	116.48	2090.68
RC2	15.184	20.74644	34.7776	27.0504	118.272	12.2304	228.2608
RC3	15.392	234.0624	366.08	294.372	1989.12	250.432	3149.458
RC4	15.392	1.675674	1.28128	0.7956	4.19328	0.384384	23.72222
RC5	15.392	13.299	13.2704	10.3428	53.76	6.4064	112.4706
RC6	15.392	3.9897	6.4064	7.31952	25.8048	2.73728	61.6497
RC7	16.224	156.9282	260.832	230.724	1021.44	151.424	1837.572
RC8	15.392	0.223423	0.173888	0.143208	0.75264	0.069888	16.75505
RC9	15.392	17.55468	18.304	14.3208	75.264	9.3184	150.1539
RC10	15.392	3.9897	6.864	6.84216	24.192	2.50432	59.78418
RC11	15.392	66.495	118.976	66.0348	22.0416	2.79552	291.7349
RC12	15.184	0.109052	0.082368	0.058874	0.18816	0.0186368	15.64109
RC13	15.392	5.85156	5.4912	2.70504	0.000354816	0.00011648	29.44027
RC14	7.488	0.13831	0.242528	0.31824	2.20416	0.238784	10.63002
RC16	7.696	0.010639	0.0109824	0.011934	0.091392	0.008736	7.829684
RC18	16.224	0.010373	0.018304	0.020686	0.145152	0.0157248	16.43424
RC21	2.704	0.00399	0.00247104	0.002228	0.0123648	0.00104832	2.726102

Table G.9: Qingdao ABWR delayed fatalities (delayed exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	411.06	15730	134.316	5521.6	45.76	21842.736
RC2	0	26.7189	1086.8	16.3098	714.56	4.8048	1849.1935
RC3	0	301.444	11440	177.489	12017.6	98.384	24034.917
RC4	0	2.158065	40.04	0.4797	25.3344	0.151008	68.163173
RC5	0	17.1275	414.7	6.2361	324.8	2.5168	765.3804
RC6	0	5.13825	200.2	4.41324	155.904	1.07536	366.73085
RC7	0	202.1045	8151	139.113	6171.2	59.488	14722.9055
RC8	0	0.287742	5.434	0.086346	4.5472	0.027456	10.382744
RC9	0	22.6083	572	8.6346	454.72	3.6608	1061.6237
RC10	0	5.13825	214.5	4.12542	146.16	0.98384	370.90751
RC11	0	85.6375	3718	39.8151	133.168	1.09824	3977.71884
RC12	0	0.140446	2.574	0.035498	1.1368	0.007322	3.8940649
RC13	0	7.5361	171.6	1.63098	0.002144	4.58E-05	180.7692694
RC14	0	0.178126	7.579	0.19188	13.3168	0.093808	21.359614
RC16	0	0.013702	0.3432	0.007196	0.55216	0.003432	0.9196895
RC18	0	0.013359	0.572	0.012472	0.87696	0.006178	1.48096925
RC21	0	0.005138	0.07722	0.001343	0.074704	0.000412	0.15881725

Table G.10: Qingdao ABWR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	23933.4
RC2	2077.5
RC3	27184.4
RC4	91.9
RC5	877.9
RC6	428.4
RC7	16560.5
RC8	27.1
RC9	1211.8
RC10	430.7
RC11	4269.5
RC12	19.5
RC13	210.2
RC14	32.0
RC16	8.7
RC18	17.9
RC21	2.9

Table G.11: Qingdao ABWR land contamination [km^2].

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	676.39	0	3427.2	0	4103.59
RC2	0	0	46.7324	0	443.52	0	490.2524
RC3	0	0	491.92	0	7459.2	0	7951.12
RC4	0	0	1.72172	0	15.7248	0	17.44652
RC5	0	0	17.8321	0	201.6	0	219.4321
RC6	0	0	8.6086	0	96.768	0	105.3766
RC7	0	0	350.493	0	3830.4	0	4180.893
RC8	0	0	0.233662	0	2.8224	0	3.056062
RC9	0	0	24.596	0	282.24	0	306.836
RC10	0	0	9.2235	0	90.72	0	99.9435
RC11	0	0	159.874	0	82.656	0	242.53
RC12	0	0	0.110682	0	0.7056	0	0.816282
RC13	0	0	7.3788	0	0.00133056	0	7.380131
RC14	0	0	0.325897	0	8.2656	0	8.591497
RC16	0	0	0.0147576	0	0.34272	0	0.357478
RC18	0	0	0.024596	0	0.54432	0	0.568916
RC21	0	0	0.00332046	0	0.046368	0	0.049688

Table G.12: Qingdao ABWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	3.86E+01	9.26E-08	23933.416	5.74E-05	4103.59	9.85E-06
RC2	4.40E-09	3.51E+00	1.55E-08	2077.45434	9.14E-06	490.2524	2.16E-06
RC3	1.50E-08	4.51E+01	6.76E-07	27184.3754	4.08E-04	7951.12	1.19E-04
RC4	5.90E-08	1.73E-01	1.02E-08	91.885391	5.42E-06	17.44652	1.03E-06
RC5	2.30E-08	1.76E+00	4.06E-08	877.851	2.02E-05	219.4321	5.05E-06
RC6	2.60E-08	8.08E-01	2.10E-08	428.38055	1.11E-05	105.3766	2.74E-06
RC7	6.50E-09	3.03E+01	1.97E-07	16560.4777	1.08E-04	4180.893	2.72E-05
RC8	3.20E-08	2.63E-02	8.41E-10	27.1377912	8.68E-07	3.056062	9.78E-08
RC9	1.10E-08	2.41E+00	2.65E-08	1211.77758	1.33E-05	306.836	3.38E-06
RC10	1.20E-08	7.71E-01	9.25E-09	430.69169	5.17E-06	99.9435	1.20E-06
RC11	9.60E-09	7.76E+00	7.45E-08	4269.45376	4.10E-05	242.53	2.33E-06
RC12	6.40E-09	1.11E-02	7.12E-11	19.5351559	1.25E-07	0.816282	5.22E-09
RC13	1.80E-08	5.05E-01	9.10E-09	210.2095407	3.78E-06	7.38013056	1.33E-07
RC14	2.40E-09	4.07E-02	9.76E-11	31.9896356	7.68E-08	8.591497	2.06E-08
RC16	1.20E-07	1.89E-03	2.27E-10	8.7493731	1.05E-06	0.3574776	4.29E-08
RC18	6.10E-08	2.74E-03	1.67E-10	17.91520887	1.09E-06	0.568916	3.47E-08
RC21	3.00E-09	4.42E-04	1.32E-12	2.88491879	8.65E-09	0.04968846	1.49E-10
TOTAL	4.12E-07	-	1.17E-06	-	6.85E-04	-	1.75E-04

G.3 Results for increased core inventories and population for Qingdao site EPR NPP

Table G.13: Qingdao EPR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	29.7414	0.41184	57.33	3.2368	109.7824	200.5024
RC2	0	4.9569	0.06864	14.3325	1.904	22.7136	43.97564
RC3	0	0.99138	0.013728	2.8665	0.51408	4.54272	8.928408
RC4	0	0.000694	9.6096E-06	0.002457	0.00030464	0.00548912	0.008954
RC5	0	0.001305	1.80752E-05	0.002457	0.00013328	0.009464	0.013378
RC6	0	16.523	0.2288	19.656	1.904	140.0672	178.379
RC7	0	26.4368	0.36608	49.14	1.904	22.7136	100.5605

Table G.14: Qingdao EPR late fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	18.928	478.764	823.68	1113.84	913.92	3377.92	6727.052
RC2	19.968	79.794	137.28	278.46	537.6	698.88	1751.982
RC3	19.76	15.9588	27.456	55.692	145.152	139.776	403.7948
RC4	0.03536	0.011171	0.0192192	0.047736	0.086016	0.168896	0.368398
RC5	0.03536	0.021012	0.0361504	0.047736	0.037632	0.2912	0.469091
RC6	6.864	265.98	457.6	381.888	537.6	4309.76	5959.692
RC7	7.696	425.568	732.16	954.72	537.6	698.88	3356.624

Table G.15: Qingdao EPR delayed fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	616.59	25740	671.58	5521.6	1327.04	33876.81
RC2	0	102.765	4290	167.895	3248	274.56	8083.22
RC3	0	20.553	858	33.579	876.96	54.912	1844.004
RC4	0	0.014387	0.6006	0.028782	0.51968	0.066352	1.2298011
RC5	0	0.027061	1.1297	0.028782	0.22736	0.1144	1.52730345
RC6	0	342.55	14300	230.256	3248	1693.12	19813.926
RC7	0	548.08	22880	575.64	3248	274.56	27526.28

Table G.16: Qingdao EPR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	40603.862
RC2	9835.202
RC3	2247.7988
RC4	1.59819946
RC5	1.99639427
RC6	25773.618
RC7	30882.904

Table G.17: Qingdao EPR land contamination [km^2].

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	1106.82	0	3427.2	0	4534.02
RC2	0	0	184.47	0	2016	0	2200.47
RC3	0	0	36.894	0	544.32	0	581.214
RC4	0	0	0.0258258	0	0.32256	0	0.348386
RC5	0	0	0.0485771	0	0.14112	0	0.189697
RC6	0	0	614.9	0	2016	0	2630.9
RC7	0	0	983.84	0	2016	0	2999.84

Table G.18: Qingdao EPR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	3.00E-10	2.01E+02	6.02E-08	40603.862	1.22E-05	4.53E+03	1.36E-06
RC2	1.00E-10	4.40E+01	4.40E-09	9835.202	9.84E-07	2.20E+03	2.20E-07
RC3	1.00E-10	8.93E+00	8.93E-10	2247.7988	2.25E-07	5.81E+02	5.81E-08
RC4	1.00E-09	8.95E-03	8.95E-12	1.598199	1.60E-09	3.48E-01	3.48E-10
RC5	2.00E-07	1.34E-02	2.68E-09	1.9963943	3.99E-07	1.90E-01	3.79E-08
RC6	2.00E-09	1.78E+02	3.57E-07	25773.618	5.15E-05	2.63E+03	5.26E-06
RC7	2.00E-08	1.01E+02	2.01E-06	30882.904	6.18E-04	3.00E+03	6.00E-05
TOTAL	2.24E-07	-	2.44E-06	-	6.83E-04	-	6.69E-05

G.4 Results for increased core inventories and population for Yantai site ABWR NPP

Table G.19: Yantai ABWR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	14.0244	0.17303	8.19	2.2848	2.6624	27.33463
RC2	0	0.911586	0.0119548	0.9945	0.29568	0.279552	2.493273
RC3	0	10.28456	0.12584	10.8225	4.9728	5.72416	31.92986
RC4	0	0.073628	0.00044044	0.02925	0.0104832	0.00878592	0.122588
RC5	0	0.58435	0.0045617	0.38025	0.1344	0.146432	1.249994
RC6	0	0.175305	0.0022022	0.2691	0.064512	0.0625664	0.573686
RC7	0	6.89533	0.089661	8.4825	2.5536	3.46112	21.48221
RC8	0	0.009817	0.000059774	0.005265	0.0018816	0.00159744	0.018621
RC9	0	0.771342	0.006292	0.5265	0.18816	0.212992	1.705286
RC10	0	0.175305	0.0023595	0.25155	0.06048	0.0572416	0.546936
RC11	0	2.92175	0.040898	2.42775	0.055104	0.0638976	5.5094
RC12	0	0.004792	0.000028314	0.002165	0.0004704	0.00042598	0.007881
RC13	0	0.257114	0.0018876	0.09945	8.8704E-07	2.6624E-06	0.358455
RC14	0	0.006077	0.000083369	0.0117	0.0055104	0.00545792	0.028829
RC16	0	0.000467	3.7752E-06	0.000439	0.00022848	0.00019968	0.001338
RC18	0	0.000456	0.000006292	0.000761	0.00036288	0.00035942	0.001945
RC21	0	0.000175	8.4942E-07	8.19E-05	0.000030912	2.3962E-05	0.000313

Table G.20: Yantai ABWR late fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	9.58464	203.112	314.6	144.144	590.24	74.88	1336.561
RC2	9.71776	13.20228	21.736	17.5032	76.384	7.8624	146.4056
RC3	9.85088	148.9488	228.8	190.476	1284.64	160.992	2023.708
RC4	9.85088	1.066338	0.8008	0.5148	2.70816	0.247104	15.18808
RC5	9.85088	8.463	8.294	6.6924	34.72	4.1184	72.13868
RC6	9.85088	2.5389	4.004	4.73616	16.6656	1.75968	39.55522
RC7	10.38336	99.8634	163.02	149.292	659.68	97.344	1179.583
RC8	9.85088	0.142178	0.10868	0.092664	0.48608	0.044928	10.72541
RC9	9.85088	11.17116	11.44	9.2664	48.608	5.9904	96.32684
RC10	9.85088	2.5389	4.29	4.42728	15.624	1.60992	38.34098
RC11	9.85088	42.315	74.36	42.7284	14.2352	1.79712	185.2866
RC12	9.71776	0.069397	0.05148	0.038095	0.12152	0.0119808	10.01023
RC13	9.85088	3.72372	3.432	1.75032	0.000229152	0.00007488	18.75722
RC14	4.79232	0.088015	0.15158	0.20592	1.42352	0.153504	6.814859
RC16	4.92544	0.00677	0.006864	0.007722	0.059024	0.005616	5.011436
RC18	10.38336	0.006601	0.01144	0.013385	0.093744	0.0101088	10.51864
RC21	1.73056	0.002539	0.0015444	0.001441	0.0079856	0.00067392	1.744744

Table G.21: Yantai ABWR delayed fatalities (delayed exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	411.06	15730	134.316	5521.6	45.76	21842.736
RC2	0	26.7189	1086.8	16.3098	714.56	4.8048	1849.1935
RC3	0	301.444	11440	177.489	12017.6	98.384	24034.917
RC4	0	2.158065	40.04	0.4797	25.3344	0.151008	68.163173
RC5	0	17.1275	414.7	6.2361	324.8	2.5168	765.3804
RC6	0	5.13825	200.2	4.41324	155.904	1.07536	366.73085
RC7	0	202.1045	8151	139.113	6171.2	59.488	14722.9055
RC8	0	0.287742	5.434	0.086346	4.5472	0.027456	10.382744
RC9	0	22.6083	572	8.6346	454.72	3.6608	1061.6237
RC10	0	5.13825	214.5	4.12542	146.16	0.98384	370.90751
RC11	0	85.6375	3718	39.8151	133.168	1.09824	3977.71884
RC12	0	0.140446	2.574	0.035498	1.1368	0.007322	3.8940649
RC13	0	7.5361	171.6	1.63098	0.002144	4.58E-05	180.7692694
RC14	0	0.178126	7.579	0.19188	13.3168	0.093808	21.359614
RC16	0	0.013702	0.3432	0.007196	0.55216	0.003432	0.9196895
RC18	0	0.013359	0.572	0.012472	0.87696	0.006178	1.48096925
RC21	0	0.005138	0.07722	0.001343	0.074704	0.000412	0.15881725

Table G.22: Yantai ABWR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	23101.2276
RC2	1986.7181
RC3	25934.6652
RC4	82.421209
RC5	833.1606
RC6	403.85341
RC7	15830.7859
RC8	20.440096
RC9	1152.1303
RC10	406.89811
RC11	4152.72522
RC12	13.2799559
RC13	198.4425345
RC14	27.748775
RC16	5.6179738
RC18	11.34223945
RC21	1.79455247

Table G.23: Yantai ABWR land contamination [km^2].

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	487.63	0	2475.2	0	2962.83
RC2	0	0	33.6908	0	320.32	0	354.0108
RC3	0	0	354.64	0	5387.2	0	5741.84
RC4	0	0	1.24124	0	11.3568	0	12.59804
RC5	0	0	12.8557	0	145.6	0	158.4557
RC6	0	0	6.2062	0	69.888	0	76.0942
RC7	0	0	252.681	0	2766.4	0	3019.081
RC8	0	0	0.168454	0	2.0384	0	2.206854
RC9	0	0	17.732	0	203.84	0	221.572
RC10	0	0	6.6495	0	65.52	0	72.1695
RC11	0	0	115.258	0	59.696	0	174.954
RC12	0	0	0.079794	0	0.5096	0	0.589394
RC13	0	0	5.3196	0	0.00096096	0	5.320561
RC14	0	0	0.234949	0	5.9696	0	6.204549
RC16	0	0	0.0106392	0	0.24752	0	0.258159
RC18	0	0	0.017732	0	0.39312	0	0.410852
RC21	0	0	0.00239382	0	0.033488	0	0.035882

Table G.24: Yantai ABWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	2.73E+01	6.56E-08	2.31E+04	5.54E-05	2.96E+03	7.11E-06
RC2	4.40E-09	2.49E+00	1.10E-08	1.99E+03	8.74E-06	3.54E+02	1.56E-06
RC3	1.50E-08	3.19E+01	4.79E-07	2.59E+04	3.89E-04	5.74E+03	8.61E-05
RC4	5.90E-08	1.23E-01	7.23E-09	8.24E+01	4.86E-06	1.26E+01	7.43E-07
RC5	2.30E-08	1.25E+00	2.87E-08	8.33E+02	1.92E-05	1.58E+02	3.64E-06
RC6	2.60E-08	5.74E-01	1.49E-08	4.04E+02	1.05E-05	7.61E+01	1.98E-06
RC7	6.50E-09	2.15E+01	1.40E-07	1.58E+04	1.03E-04	3.02E+03	1.96E-05
RC8	3.20E-08	1.86E-02	5.96E-10	2.04E+01	6.54E-07	2.21E+00	7.06E-08
RC9	1.10E-08	1.71E+00	1.88E-08	1.15E+03	1.27E-05	2.22E+02	2.44E-06
RC10	1.20E-08	5.47E-01	6.56E-09	4.07E+02	4.88E-06	7.22E+01	8.66E-07
RC11	9.60E-09	5.51E+00	5.29E-08	4.15E+03	3.99E-05	1.75E+02	1.68E-06
RC12	6.40E-09	7.88E-03	5.04E-11	1.33E+01	8.50E-08	5.89E-01	3.77E-09
RC13	1.80E-08	3.58E-01	6.45E-09	1.98E+02	3.57E-06	5.32E+00	9.58E-08
RC14	2.40E-09	2.88E-02	6.92E-11	2.77E+01	6.66E-08	6.20E+00	1.49E-08
RC16	1.20E-07	1.34E-03	1.61E-10	5.62E+00	6.74E-07	2.58E-01	3.10E-08
RC18	6.10E-08	1.94E-03	1.19E-10	1.13E+01	6.92E-07	4.11E-01	2.51E-08
RC21	3.00E-09	3.13E-04	9.39E-13	1.79E+00	5.38E-09	3.59E-02	1.08E-10
TOTAL	4.12E-07	-	8.32E-07	-	6.54E-04	-	1.26E-04

G.5 Results for increased core inventories and population for Yantai site EPR NPP

Table G.25: Yantai EPR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	21.0366	0.28314	40.95	2.2848	77.2096	141.7641
RC2	0	3.5061	0.04719	10.2375	1.344	15.9744	31.10919
RC3	0	0.70122	0.009438	2.0475	0.36288	3.19488	6.315918
RC4	0	0.000491	6.6066E-06	0.001755	0.00021504	0.00386048	0.006328
RC5	0	0.000923	1.24267E-05	0.001755	0.00009408	0.006656	0.009441
RC6	0	11.687	0.1573	14.04	1.344	98.5088	125.7371
RC7	0	18.6992	0.25168	35.1	1.344	15.9744	71.36928

Table G.26: Yantai EPR late fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	12.11392	304.668	514.8	720.72	590.24	2171.52	4314.062
RC2	12.77952	50.778	85.8	180.18	347.2	449.28	1126.018
RC3	12.6464	10.1556	17.16	36.036	93.744	89.856	259.598
RC4	0.02263	0.007109	0.012012	0.030888	0.055552	0.108576	0.236767
RC5	0.02263	0.013372	0.022594	0.030888	0.024304	0.1872	0.300988
RC6	4.39296	169.26	286	247.104	347.2	2770.56	3824.517
RC7	4.92544	270.816	457.6	617.76	347.2	449.28	2147.581

Table G.27: Yantai EPR delayed fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	616.59	25740	671.58	5521.6	1327.04	33876.81
RC2	0	102.765	4290	167.895	3248	274.56	8083.22
RC3	0	20.553	858	33.579	876.96	54.912	1844.004
RC4	0	0.014387	0.6006	0.028782	0.51968	0.066352	1.2298011
RC5	0	0.027061	1.1297	0.028782	0.22736	0.1144	1.52730345
RC6	0	342.55	14300	230.256	3248	1693.12	19813.926
RC7	0	548.08	22880	575.64	3248	274.56	27526.28

Table G.28: Yantai EPR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	38190.9
RC2	9209.4
RC3	2103.60
RC4	1.47
RC5	1.83
RC6	23638.44
RC7	29673.86

Table G.29: Yantai EPR land contamination [km^2].

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	797.94	0	2475.2	0	3273.14
RC2	0	0	132.99	0	1456	0	1588.99
RC3	0	0	26.598	0	393.12	0	419.718
RC4	0	0	0.0186186	0	0.23296	0	0.251579
RC5	0	0	0.0350207	0	0.10192	0	0.136941
RC6	0	0	443.3	0	1456	0	1899.3
RC7	0	0	709.28	0	1456	0	2165.28

Table G.30: Yantai EPR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	3.00E-10	1.42E+02	3.82E+04	1.15E-05	3.27E+03	9.82E-07
RC2	4.40E-09	1.00E-10	3.11E+01	9.21E+03	9.21E-07	1.59E+03	1.59E-07
RC3	1.50E-08	1.00E-10	6.32E+00	2.10E+03	2.10E-07	4.20E+02	4.20E-08
RC4	5.90E-08	1.00E-09	6.33E-03	1.47E+00	1.47E-09	2.52E-01	2.52E-10
RC5	2.30E-08	2.00E-07	9.44E-03	1.83E+00	3.66E-07	1.37E-01	2.74E-08
RC6	2.60E-08	2.00E-09	1.26E+02	2.36E+04	4.73E-05	1.90E+03	3.80E-06
RC7	6.50E-09	2.00E-08	7.14E+01	2.97E+04	5.93E-04	2.17E+03	4.33E-05
TOTAL	2.24E-07	-	1.42E+02	-	6.54E-04	-	4.83E-05

G.6 Results for increased source terms for Qingdao ABWR NPP

Sensitivity results presented in the Appendix G.6 are provided for increased source terms; the increase is by 10 times for small releases, and 2 times for large releases.

Table G.31: Qingdao ABWR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	Total
RC1	0.00	30.50	0.39	17.64	4.97	29.12	82.62
RC2	0.00	9.91	0.13	10.71	3.22	3.06	27.03
RC3	0.00	22.37	0.28	23.31	10.82	62.61	119.39
RC4	0.00	0.80	0.00	0.32	0.11	0.10	1.33
RC5	0.00	6.36	0.05	4.10	1.46	1.60	13.56
RC6	0.00	1.91	0.02	2.90	0.70	0.68	6.22
RC7	0.00	15.00	0.20	18.27	5.56	37.86	76.88
RC8	0.00	0.11	0.00	0.06	0.02	0.02	0.20
RC9	0.00	8.39	0.07	5.67	2.05	2.33	18.51
RC10	0.00	1.91	0.03	2.71	0.66	0.63	5.93
RC11	0.00	6.36	0.09	26.15	0.60	0.70	33.89
RC12	0.00	0.05	0.00	0.02	0.01	0.00	0.09
RC13	0.00	2.80	0.02	1.07	0.00	0.00	3.89
RC14	0.00	0.07	0.00	0.13	0.06	0.06	0.31
RC16	0.00	0.01	0.00	0.00	0.00	0.00	0.01
RC18	0.00	0.00	0.00	0.01	0.00	0.00	0.02
RC21	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G.32: Qingdao ABWR late fatalities.

Release class	Xe	I	Cs	Te	Sr	La	Total
RC1	11.52	491.04	774.4	342.72	1403.52	896	3919.2
RC2	11.68	159.588	267.52	208.08	908.16	94.08	1649.108
RC3	11.84	360.096	563.2	452.88	3054.72	1926.4	6369.136
RC4	11.84	12.8898	9.856	6.12	32.1984	2.9568	75.861
RC5	11.84	102.3	102.08	79.56	412.8	49.28	757.86
RC6	11.84	30.69	49.28	56.304	198.144	21.056	367.314
RC7	12.48	241.428	401.28	354.96	1568.64	1164.8	3743.588
RC8	11.84	1.71864	1.3376	1.1016	5.7792	0.5376	22.31464
RC9	11.84	135.036	140.8	110.16	577.92	71.68	1047.436
RC10	11.84	30.69	52.8	52.632	185.76	19.264	352.986
RC11	11.84	102.3	183.04	507.96	169.248	21.504	995.892
RC12	11.68	0.83886	0.6336	0.45288	1.4448	0.14336	15.1935
RC13	11.84	45.012	42.24	20.808	0.002	0.000896	119.9036
RC14	5.76	1.06392	1.8656	2.448	16.9248	1.8368	29.89912
RC16	5.92	0.08184	0.08448	0.0918	0.70176	0.0672	6.94708
RC18	12.48	0.079794	0.1408	0.15912	1.11456	0.12096	14.09523
RC21	2.08	0.03069	0.019008	0.017136	0.094944	0.008064	2.249842

Table G.33: Qingdao ABWR delayed fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	520.8	20812	171.36	7017.6	300.8	28822.56
RC2	0	169.26	7189.6	104.04	4540.8	31.584	12035.284
RC3	0	381.92	15136	226.44	15273.6	646.72	31664.68
RC4	0	13.671	264.88	3.06	160.992	0.99264	443.59564
RC5	0	108.5	2743.4	39.78	2064	16.544	4972.224
RC6	0	32.55	1324.4	28.152	990.72	7.0688	2382.8908
RC7	0	256.06	10784.4	177.48	7843.2	391.04	19452.18
RC8	0	1.8228	35.948	0.5508	28.896	0.18048	67.39808
RC9	0	143.22	3784	55.08	2889.6	24.064	6895.964
RC10	0	32.55	1419	26.316	928.8	6.4672	2413.1332
RC11	0	108.5	4919.2	253.98	846.24	7.2192	6135.1392
RC12	0	0.8897	17.028	0.22644	7.224	0.048128	25.416268
RC13	0	47.74	1135.2	10.404	0.013622	0.000301	1193.357923
RC14	0	1.1284	50.138	1.224	84.624	0.61664	137.73104
RC16	0	0.0868	2.2704	0.0459	3.5088	0.02256	5.93446
RC18	0	0.08463	3.784	0.07956	5.5728	0.040608	9.561598
RC21	0	0.03255	0.51084	0.008568	0.47472	0.002707	1.0293852

Table G.34: Qingdao ABWR latent fatalities (early + delayed exposure).

Release class	Total latent (late+delayed)
RC1	28822.56
RC2	12035.28
RC3	31664.68
RC4	443.60
RC5	4972.22
RC6	2382.89
RC7	19452.18
RC8	67.40
RC9	6895.96
RC10	2413.13
RC11	6135.14
RC12	25.42
RC13	1193.36
RC14	137.73
RC16	5.93
RC18	9.56
RC21	1.03

Table G.35: Qingdao ABWR land contamination [km^2]

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	1040.6	0	5263.2	0	6303.8
RC2	0	0	359.48	0	3405.6	0	3765.08
RC3	0	0	756.8	0	11455.2	0	12212
RC4	0	0	13.244	0	120.744	0	133.988
RC5	0	0	137.17	0	1548	0	1685.17
RC6	0	0	66.22	0	743.04	0	809.26
RC7	0	0	539.22	0	5882.4	0	6421.62
RC8	0	0	1.7974	0	21.672	0	23.4694
RC9	0	0	189.2	0	2167.2	0	2356.4
RC10	0	0	70.95	0	696.6	0	767.55
RC11	0	0	245.96	0	634.68	0	880.64
RC12	0	0	0.8514	0	5.418	0	6.2694
RC13	0	0	56.76	0	0.0102168	0	56.77022
RC14	0	0	2.5069	0	63.468	0	65.9749
RC16	0	0	0.11352	0	2.6316	0	2.74512
RC18	0	0	0.1892	0	4.1796	0	4.3688
RC21	0	0	0.025542	0	0.35604	0	0.381582

Table G.36: Qingdao ABWR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	8.26E+01	1.98E-07	32741.76	7.86E-05	6303.80	1.51E-05
RC2	4.40E-09	2.70E+01	1.19E-07	13684.392	6.02E-05	3765.08	1.66E-05
RC3	1.50E-08	1.19E+02	1.79E-06	38033.816	5.71E-04	12212.00	1.83E-04
RC4	5.90E-08	1.33E+00	7.85E-08	519.45664	3.06E-05	133.99	7.91E-06
RC5	2.30E-08	1.36E+01	3.12E-07	5730.084	1.32E-04	1685.17	3.88E-05
RC6	2.60E-08	6.22E+00	1.62E-07	2750.2048	7.15E-05	809.26	2.10E-05
RC7	6.50E-09	7.69E+01	5.00E-07	23195.768	1.51E-04	6421.62	4.17E-05
RC8	3.20E-08	2.02E-01	6.47E-09	89.71272	2.87E-06	23.47	7.51E-07
RC9	1.10E-08	1.85E+01	2.04E-07	7943.4	8.74E-05	2356.40	2.59E-05
RC10	1.20E-08	5.93E+00	7.11E-08	2766.1192	3.32E-05	767.55	9.21E-06
RC11	9.60E-09	3.39E+01	3.25E-07	7131.0312	6.85E-05	880.64	8.45E-06
RC12	6.40E-09	8.55E-02	5.47E-10	40.609768	2.60E-07	6.27	4.01E-08
RC13	1.80E-08	3.89E+00	7.00E-08	1313.26144	2.36E-05	56.77	1.02E-06
RC14	2.40E-09	3.13E-01	7.50E-10	167.63016	4.02E-07	65.97	1.58E-07
RC16	1.20E-07	1.45E-02	1.74E-09	12.88154	1.55E-06	2.75	3.29E-07
RC18	6.10E-08	2.11E-02	1.29E-09	23.656832	1.44E-06	4.37	2.66E-07
RC21	3.00E-09	3.40E-03	1.02E-11	3.2792272	9.84E-09	0.38	1.14E-09
TOTAL	4.12E-07	-	3.84E-06	-	1.31E-03	-	3.70E-04

G.7 Results for increased source terms for Qingdao site EPR NPP

Sensitivity results presented in the Appendix G6 were provided for increased source terms by 10 times for small releases, and 2 times for large releases.

Table G.37: Qingdao EPR early fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	22.878	0.3168	44.1	2.4854	84.448	154.2282
RC2	0	3.813	0.0528	11.025	1.462	17.472	33.8248
RC3	0	0.7626	0.01056	2.205	0.39474	3.4944	6.8673
RC4	0	0.000534	0.000007392	0.00189	0.00023392	0.0042224	0.006888
RC5	0	0.001004	0.000013904	0.00189	0.00010234	0.00728	0.01029
RC6	0	12.71	0.176	15.12	1.462	107.744	137.212
RC7	0	20.336	0.2816	37.8	1.462	17.472	77.3516

Table G.38: Qingdao EPR fate fatalities.

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	14.56	368.28	633.60	856.80	701.76	2598.40	5173.40
RC2	15.36	61.38	105.60	214.20	412.80	537.60	1346.94
RC3	15.20	12.28	21.12	42.84	111.46	107.52	310.41
RC4	0.03	0.01	0.01	0.04	0.07	0.13	0.28
RC5	0.03	0.02	0.03	0.04	0.03	0.22	0.36
RC6	5.28	204.60	352.00	293.76	412.80	3315.20	4583.64
RC7	5.92	327.36	563.20	734.40	412.80	537.60	2581.28

Table G.39: Qingdao EPR delayed fatalities (early exposure).

Release class	Xe	I	Cs	Te	Sr	La	Total delayed
RC1	0	345.96	15048	378	3070.2	760.96	19603.12
RC2	0	57.66	2508	94.5	1806	157.44	4623.6
RC3	0	11.532	501.6	18.9	487.62	31.488	1051.14
RC4	0	0.008072	0.35112	0.0162	0.28896	0.038048	0.7024004
RC5	0	0.015184	0.66044	0.0162	0.12642	0.0656	0.8838438
RC6	0	192.2	8360	129.6	1806	970.88	11458.68
RC7	0	307.52	13376	324	1806	157.44	15970.96

Table G.40: Qingdao EPR Latent fatalities (early + delayed exposure)

Release class	Number of latent fatalities
RC1	22920.8184
RC2	5489.2904
RC3	1250.702
RC4	0.8844528
RC5	1.1153396
RC6	14400.1392
RC7	17622.4688

Table G.41: Qingdao EPR land contamination [km^2]

Release class	Xe	I	Cs	Te	Sr	La	TOTAL
RC1	0	0	613.8	0	1900.6	0	2514.4
RC2	0	0	102.3	0	1118	0	1220.3
RC3	0	0	20.46	0	301.86	0	322.32
RC4	0	0	0.014322	0	0.17888	0	0.193202
RC5	0	0	0.026939	0	0.07826	0	0.105199
RC6	0	0	341	0	1118	0	1459
RC7	0	0	545.6	0	1118	0	1663.6

Table G.42: Qingdao EPR risks.

Release class	Frequency of release	Early fatalities		Latent fatalities		Land contamination	
		Number	Risk	Number	Risk	km^2	Risk
RC1	2.40E-09	1.09E+02	3.27E-08	2.29E+04	6.88E-06	2.51E+03	7.54E-07
RC2	4.40E-09	2.39E+01	2.39E-09	5.49E+03	5.49E-07	1.22E+03	1.22E-07
RC3	1.50E-08	4.86E+00	4.86E-10	1.25E+03	1.25E-07	3.22E+02	3.22E-08
RC4	5.90E-08	4.87E-03	4.87E-12	8.84E-01	8.84E-10	1.93E-01	1.93E-10
RC5	2.30E-08	7.26E-03	1.45E-09	1.12E+00	2.23E-07	1.05E-01	2.10E-08
RC6	2.60E-08	9.67E+01	1.93E-07	1.44E+04	2.88E-05	1.46E+03	2.92E-06
RC7	6.50E-09	5.49E+01	1.10E-06	1.76E+04	3.52E-04	1.66E+03	3.33E-05
TOTAL	2.24E-07	-	1.33E-06	-	3.89E-04	-	3.718E-05