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The 319 Major Industrial Accidents Since 1917

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Abstract – *In this paper 319 major industrial accidents are recorded according to well specified criteria. A reference for every accident is provided, so it can be further traced, and its total cost, wherever available, is converted to 2011 prices. Despite the fact that the number of major industrial accidents is higher in developed countries than in developing ones, the number of deaths and injuries, is considerably less. This, most likely, is a result of better enforcement of safety regulatory legislation in developed countries. Another consequence of enforcing safety regulatory legislation is the fact that during the last two decades, the number of major industrial accidents is generally decreasing.* ***Copyright © 2012 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Industrial Accidents, Explosions, Fires, Past Accident Analysis, Accidents Database*

I. Introduction

In an evolving world the expansion of industry is a necessity. Such an expansion is usually associated with an increase of industrial accidents. Unfortunately, history is destined to repeat itself and the causes are invariably the same (human error, poor regulatory enforcement, client-contractor relationship, etc.). The understanding of the causes of an accident pre-supposes a wide knowledge of other similar accidents. For these reasons many accident databases exist. Particularly, in the worldwide web, there are many online accident databases, such as ARIA [1], FACTS [2], INRS [3], MARS [4], ZEMA [5], Ility [6], CCPS [7], NTSB [8], JST [9], COSO [10], OSHA [11] etc., some with open access, but most of them unavailable to the public or subscribe only. These databases have little or no accident inclusion criteria, some of them limit their inclusions to a specified country or provide not enough data or references to review each incident. Also available in the worldwide web are online lists such as the Wikipedia list of industrial accidents or the Endgame list of major industrial accidents. The major disadvantage of these online lists is that they are user-modified and they should be further researched in order to be used. Furthermore, it should be mentioned that there are also papers that provide a list of industrial accidents according to different criteria, such as the list of Marsh [12], which is a property type list, or the list of Khan and Abassi [13] with no specific criteria or literature reference for each accident. Finally we ought to mention the extended list of accidents appearing in Lees's Loss Prevention Handbook [14] – an extended list compiled however with no specific criteria whatsoever and with limited references to the actual accident.

As already stated, in most cases there are no specific criteria that will clearly determine which accidents have been included. This absence of specific criteria makes any sort of statistics or comparisons quite difficult.

In 1993 the United Nations Environment Program [15] created a disasters database, which was originally compiled by the Organization for Economic Co-operation and Development [16] and was extended to cover the years 1990-1997. According to the UNEP database, a major industrial accident was defined by the following criteria:

- 25 deaths or more; or
- 125 injured or more; or
- 10000 evacuated or more; or
- 10000 people or more deprived of water;

We note that in this database, the following types of accidents were excluded: oil spills at sea from ships, mining accidents, voluntary destruction of ships or airplanes, and damage caused by defective products.

The aim of this work is threefold:

a) to produce a well specified major industrial accident database that conforms to the above criteria. We should however point out that one more economic criteria was added, which is:
   - 10 million USD or more cost (includes property damage, debris removal and cleanup cost).
b) to give a literature source for every accident, so that the user can trace it and collect more information, should he desires to do so.
c) to give for each accident, an estimate of its cost in 2011 Euro prices, wherever provided by the available information.

Thus, a list of 319 major industrial accidents that satisfy the above criteria (excluding transport accidents), are presented in Table I, covering the years 1917 to 2011.

The start year of 1917 was chosen, as it was close to the end of the World War I, and anyway information for accidents before that date is more scarce. We cannot possibly claim that this list is totally complete, but a great effort was made in order to obtain the best possible

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outcome. Additionally, an analysis based on this list is presented in order to evaluate the extent of such events.

II. Accidents Database

The list of accidents presented in Table I, was originally created for MInA (Major Industrial Accidents) database that exists in the Laboratory of Thermophysical Properties and Environmental Processes in the Aristotle University of Thessaloniki, Greece, and is employed only for the teaching of a Risk Analysis course [17], and not for commercial use.

This database created with Microsoft Office Access, includes to our knowledge, all the major industrial accidents from 1917 to 2011 according to the criteria discussed in the introduction.

Each case study in MInA database includes, according to availability and as it was specified in the corresponding reference:

- the date of the event;
- the type of accident and the quoted prime cause (whether it started as a fire, explosion or toxic release);
- the country and the specific place it happened (as quoted);
- the chemicals involved (substances quoted);
- the number of deaths, injuries, and people evacuated (as quoted by the specific reference);
- the total cost converted to Euros in 2011 prices (arbitrarily taken as 1 EURO = 0.7 USD), according to the Marshall and Swift [18] cost values; these are standard annual indexes that allow the conversion of cost prices from one year to another.
- the company name and the property type;
- accident summary in English and in Greek;
- photograph of the event, if available.

It should be noted, that the reference for each accident can be a paper, or a list or even a web site, but it is always a traceable valid reference. In addition to the above, there is a unique accident code for each event.

Using this code, other available documents, multimedia files or useful information are linked.

The analysis was separated into two large sections:

- a section that analyzed accidents according to their number (fifteen countries with highest number of accidents; number of accidents in developed (advanced) or developing countries; number of accidents per decade), and
- a section that analyzed them according to their consequences and total cost (ten accidents with highest number of deaths, injuries, or number of people evacuated; number of deaths and injuries in developed or developing countries; twenty accidents with the highest cost).

The distinction as to whether a specific country is defined as “developed” or “developing”, was accomplished according to the April 2007 IMF Survey [16]. This year was preferred as it was just before the onset of the recent economic deficit that has certainly changed the status of some countries. The total estimated cost includes property damage, debris removal and cleanup cost, as it is stated in the reference, and converted to 2011 Euro prices employing the Marshall & Swift cost values [18].

III. Number of Accidents Analysis

III.1. Top Fifteen Countries with the Highest Number of Accidents

Fig. 1 shows the top fifteen countries with the highest number of major industrial accidents in the period 1917-2011. The following can be noted:

- Most of the accidents are concentrated in the U.S.A., as expected, probably because major industrial activity is there. Nevertheless it is of great interest that 39% (126 out of 319) of all major accidents is concentrated in the U.S.A., while the remaining 61% (193 out of 319) is shared among 52 countries - that is an average of less than 4 major accidents per country.
- In the same figure the countries shown, concentrate more than 4 major accidents since 1917. Indeed in this case it is surprising that some countries have such a low number of major industrial accidents, but it should be reminded that, this conclusion is based on the number of accidents reported and that in some countries, due to the political, economic or social conditions, several accidents are not reported in the international databases and media.
- Finally, the fact that U.K. and Germany are second to the U.S.A., in a way it is expected, due to their high industrial activity.

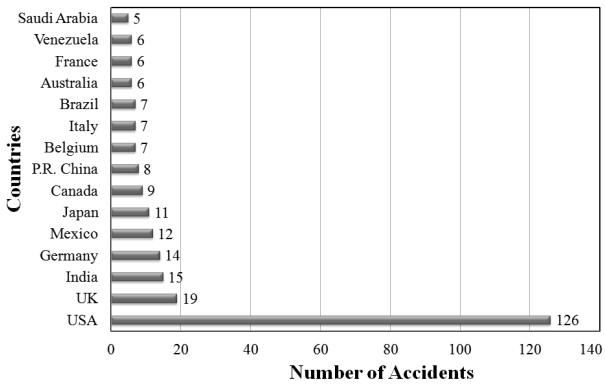

Fig. 1. The 15 countries with the highest number of accidents in the period 1917-2011

III.2. Number of Accidents in Developed and Developing Countries

In Figs. 2 and 3, the number of major accidents in developed and developing countries are shown. The countries are listed in alphabetical order in both figures.

The following can be noted:

TABLE I
THE 319 MAJOR INDUSTRIAL ACCIDENTS SINCE 1917

Date	Country	Place	Prime Cause[+]	I[a]	D[a]	E[a]	Substance	Cost 2011 (M. €)	Ref.
03/11/2011	Japan	Fukushima	E/T	0	0	100000	Radioactive gases	175000	[19]
04/20/2010	USA	Gulf of Mexico	E	0	11	115	Oil	8154	[20]
08/16/2010	China	Harbin	E	153	20	2000	Explosives		[21]
10/29/2009	India	Jaipur	F	150	12	500000	Oil		[22]
06/03/2008	Australia	Varanus Island	E	0	0	153	Gas	111	[23]
08/26/2008	China	Guangxi Zhuang	F	60	20	11500	Polyvinyl acetate		[24]
01/07/2008	S. Korea	Icheon	F	10	40	0	Gas		[25]
03/25/2008	Iran	Arak	E	38	30	0	Detergents		[26]
--/--/2006	UK	Sunbury	F	0	0	0	Naptha	19	[27]
05/12/2006	Nigeria	Lagos City	E	60	260	0	Oil		[28]
03/23/2005	USA	Texas	E	170	15	0	Hydrocarbons	106	[29]
12/11/2005	UK	Hertfordshire	E	43	0	2000	Oil	12	[30]
11/13/2005	China	Jilin	T	60	5	10000	Benzene		[28]
01/20/2004	Algeria	Skikda	E	74	23		LNG	787	[31]
04/12/2004	USA	Dalton	T	154	0	100	Triallyl cyanurate		[32]
07/30/2004	Belgium	Ghislenghien	E	132	24	0	Natural gas		[1]
09/21/2001	France	Toulouse	E	3000	30		Ammonium Nitrate	827	[12]
03/15/2001	Brazil	Campos Basin	E		10	165	Gas	568	[12]
04/10/2001	Aruba	Aruba	F				Oil	148	[12]
04/23/2001	USA	Carson City	F				Hydrocarbons	264	[12]
05/16/2001	UK	Birkenhead	F	2			Hydrocarbons	120	[12]
04/28/2001	USA	Wood River	F				Hydrocarbons	75	[12]
09/21/2001	USA	Lake Charles	F	3			Hydrocarbons	58	[12]
08/14/2001	USA	Lemont	F				Hydrocarbons	40	[12]
02/11/2001	USA	St James	F	0	0	0	Styrene	74	[33]
05/18/2001	Taiwan	Taiwan	E	112	1	0	Gas	17	[34]
07/07/2001	USA	Tulsa	T	138	0	0	Arsenic		[35]
04/16/2001	UK	Humber River	E	185	0	0	Gas		[36]
06/25/2000	Kuwait	Mina Al-Ahmadi	E	50	5		Hydrocarbons	477	[12]
03/27/2000	USA	Pasadena	E	69	1		Butadiene	75	[12]
07/10/2000	Nigeria	Adeje, Warri	E	0	250	0	Oil		[37]
05/13/2000	Netherlands	Enschede	E	946	18	0	na		[38]
09/12/2000	Mexico	Salamanca	E	0	0	60000	Malathion		[39]
03/25/1999	USA	Richmond	E				Hydrocarbons	88	[12]
06/08/1999	Germany	Wuppertal	E	50			Potassium hydroxide	88	[12]
02/19/1999	Greece	Thessaloniki	F	0	0	0	Hydrocarbons	47	[12]
12/02/1999	Thailand	Sri Racha	E	13	8		Hydrocarbons	41	[12]
03/11/1999	India	Bombay High	F				Gas	42	[12]
01/27/1999	Canada	Taylor	E	15			Ethane	30	[12]
09/25/1998	Australia	Longford	E	8	2		Hydrocarbons	189	[40]
06/09/1998	Canada	St. John	E		1		Hydrocarbons	73	[41]
05/10/1998	Egypt	Ras Gharib	F				Oil	35	[12]
10/06/1998	France	Berre l' Etang	F				Hydrocarbons	29	[12]
10/17/1998	Nigeria	Jesse, Niger Delta	E	0	1000	0	Gasoline		[42]
12/25/1997	Malaysia	Bintulu	E	12			Gas	324	[12]
06/22/1997	USA	Deer Park	E	30			Hydrocarbons	119	[43]
--/10/1997	S. Africa	Mossel Bay	E				Hydrocarbons	41	[12]
01/21/1997	USA	Martinez	E	46	1		Hydrocarbons	27	[43]
09/15/1997	India	Visakhapatnam	E	100	60	60000	LPG	18	[44]
07/26/1996	Mexico	Cactus	E	30	6		LPG	163	[12]
10/16/1995	USA	Rouseville	F				Hydrocarbons	50	[12]
10/09/1995	UK	Wilton, Teeside	F	0	0		Propylene	24	[45]
07/15/1995	Iran	Astara	T	200	3		Chlorine		[15]
04/28/1995	S. Korea	Taegu	E/T	104	101	10000	LPG		[15]
04/10/1995	USA	Savannah	F	300		2000	Hydrogen sulphide		[46]
07/24/1994	UK	Milford Haven	E	26	0	0	Hydrocarbons	101	[47]
12/13/1994	USA	Port Neal, Iowa	E	18	4	2500	Ammonium Nitrate	155	[48]
05/27/1994	USA	Belpre	E		3	1700	Hydrocarbons	130	[49]
10/12/1994	USA	Pasadena	E				Hydrocarbons	66	[12]
02/25/1994	Japan	Kawasaki	F				Hydrocarbons	59	[12]
11/02/1994	Egypt	Donca	F		410		Oil		[12]
12/07/1994	S. Korea	Seoul	E	50	7	10000	LNG		[13]
11/26/1994	China	Shuangpai	E		61		na		[15]
05/25/1993	Venezuela	Lake Maracaibo	E		11		Propane	134	[15]
04/02/1993	USA	Baton Rouge	F				Hydrocarbons	86	[12]
--/08/1993	India	Panipat	E/T	25	3		Ammonia	24	[12]

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Date	Country	Place	Prime Cause[+]	I[a]	D[a]	E[a]	Substance	Cost 2011 (M. €)	Ref.
12/28/1993	Venezuela	Las Tejerias	E	0	36		Natural gas		[50]
11/01/1993	Vietnam	Nam Khe	E/T	48	47		Hydrocarbons		[15]
01/11/1993	China	Baohe	E		70		Gas		[15]
08/06/1993	China	Shenzhen	E	168	12		Gas		[15]
08/04/1993	Colombia	Remeios	T		430		Oil		[15]
07/26/1993	USA	Richmond	T	6250			Sulphuric Acid		[15]
06/07/1993	China	Zhengzhou	E	32	27		na		[15]
01/07/1993	S. Korea	Chongju	F	50	27		LPG		[15]
11/09/1992	France	La Mede	E				Hydrocarbons	350	[12]
10/16/1992	Japan	Sodegaura	E	7	10		Hydrocarbons	216	[13]
10/08/1992	USA	Wilmington	E				Hydrogen	106	[12]
04/22/1992	Mexico	Guadalajara	E	1460	206	0	Gasoline	92	[51]
07/28/1992	USA	Westlake	E				Ammonia	36	[12]
09/01/1992	Greece	Elefsina	E/T	21	20		LPG		[52]
08/08/1992	Turkey	Corlu	E	64	32		Methane		[15]
04/29/1992	India	New Delhi	E	20	43		na		[15]
01/23/1992	Germany	Schkopau	T	186			Chlorine		[15]
03/24/1992	Senegal	Dakar	T	300	40		Ammonia		[15]
03/11/1991	Mexico	Coatzacoalcos	E		3		Hydrocarbons	124	[12]
03/12/1991	USA	Seadrift	E		1		Ethylene Oxide	108	[53]
06/20/1991	Bangladesh	Dhaka	E				Ammonia	97	[53]
12/10/1991	Germany	North Rhine	E				Hydrocarbons	69	[12]
08/21/1991	Australia	Coode Island	E	0	0	0	Acryl Nitrile	161	[12]
04/13/1991	USA	Sweeney	E				Hydrocarbons	172	[14]
01/12/1991	USA	Port Arthur	F				Hydrocarbons	34	[12]
03/03/1991	USA	Lake Charles	E				Hydrocarbons	34	[12]
11/03/1991	USA	Beaumont	F				Hydrocarbons	21	[12]
09/07/1991	Israel	Haifa	F				na	17	[12]
03/11/1991	Mexico	Pajaritos	E	122	3		Propane		[14]
01/05/1991	Switzerland	Nyon	T			12000	Chlorine		[14]
09/01/1991	China	Shaxi	F	350	30		Pesticide		[15]
09/24/1991	Thailand	Bangkok	E		63		Gas		[15]
09/03/1991	UK	Immingham	T	127			na		[15]
08/10/1991	Taiwan	Kaohsiung	T	600			na		[15]
05/01/1991	USA	Sterlington	E	123	8	500	Nitromethane		[15]
11/30/1990	S. Arabia	Ras Tanura	F				Hydrocarbons	44	[15]
11/25/1990	USA	Denver	F				Oil	49	[12]
11/06/1990	India	Nagothane	E	22	31		Ethane/Propane	31	[12]
11/03/1990	USA	Chalmette	E				Hydrocarbons	31	[12]
04/01/1990	USA	Warren	E				LPG	31	[12]
11/15/1990	Portugal	Porto de Leixoes	F	76	14		Propane	24	[12]
03/20/1990	UK	Stanlow	E	5	1		Chloro Fluoroaniline	12	[13]
11/05/1990	India	Maharashtra	E		35		Gas		[45]
07/25/1990	UK	Birmingham	T	60	0	75000	Phosgene		[13]
07/22/1990	S. Korea	Ulsan	E/T			10000	Butane		[45]
05/04/1990	Cuba	Matanzas	T	374	3	1000	Ammonia		[15]
04/01/1990	Australia	Sydney	F			10000	na		[15]
03/18/1990	S. Korea	Daesan	T	100		10000	Hydrogen sulphide		[15]
10/23/1989	USA	Pasadena	E	314	23	1300	Ethylene/IsoButane	959	[13]
04/10/1989	USA	Richmond	F				Hydrogen	124	[12]
03/07/1989	Belgium	Antwerp	E	11	32		Ethylene Oxide	109	[13]
12/24/1989	USA	Baton Rouge	E	12	4		Ethane/Propane	98	[13]
03/19/1989	USA	Gulf of Mexico	E				Hydrocarbons	74	[12]
09/05/1989	USA	Martinez	F				Hydrogen	68	[12]
02/14/1989	Germany	Urdingen	E				na	51	[14]
06/07/1989	USA	Morris	E				Ethylene	36	[12]
03/20/1989	Lithuania	Jonava	E/T	658	1	0	Ammonia		[54]
06/04/1989	USSR	Siberia	E	706	645	500	LPG		[45]
03/20/1989	USSR	Ionava	E	53	6	30000	Ammonia		[15]
01/05/1989	USA	Los Angeles	T			11000	Chlorine		[15]
07/06/1988	UK	Piper Alpha	E		165		Gas	1399	[12]
04/24/1988	Brazil	Enchova	F				Gas	508	[12]
05/05/1988	USA	Norco	E	48	7		LPG	371	[13]
09/22/1988	UK	North Sea	F		1		Gas	108	[12]
05/04/1988	USA	Henderson	F	350	2		Ammonium Perchloride	95	[13]
11/21/1988	Germany	Worms	E	25	3		Carbon dioxide	24	[55]

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Date	Country	Place	Prime Cause[+]	I[a]	D[a]	E[a]	Substance	Cost 2011 (M. €)	Ref.
06/08/1988	USA	Port Arthur	F				Propane	21	[14]
09/08/1988	Norway	Rafnes	E				VCM	15	[14]
11/11/1988	India	Bombay	F	16	35		Oil		[15]
10/25/1988	Singapore	Pulau, Merlimau	F				Naphtha	15	[14]
01/22/1988	China	Shanghai	E	17	25		Hydrocarbons		[15]
06/23/1988	Mexico	Monterrey	E	15	4	10000	Gasoline		[15]
01/02/1988	USA	Floreffe, PE	T				Oil	17	[14]
06/15/1988	Italy	Genoa	E	2	3	15000	Hydrogen		[15]
06/08/1988	France	Tours	F	3		200000	na		[15]
05/25/1988	Mexico	Chihuahua	E	7		15000	Oil		[15]
11/14/1987	USA	Pampa	E	43	3		Butane	317	[13]
12/20/1987	USA	Cook Inlet	F				Gas	188	[12]
03/22/1987	UK	Grangemouth	E	2	2		Hydrogen	118	[45]
08/15/1987	S. Arabia	Juaimah	E				Propane	90	[12]
07/03/1987	Belgium	Antwerp	E	20	5		Ethylene Oxide	85	[13]
10/11/1987	Canada	Fort McMurray	F				Hydrocarbons	48	[14]
06/23/1987	Canada	Mississauga	F				Hydrocarbons	24	[14]
11/24/1987	USA	Torrance	F				Hydrocarbons	20	[14]
10/29/1987	France	Nantes	F/T	28	0	38000	Ammonium Nitrate		[1]
12/12/1987	India	Maharashtra	F	23	25		Naptha		[13]
03/24/1987	USA	Nanticoke	F			15000	Sulphuric Acid		[15]
12/15/1987	Mexico	Minatitlan	T	200		1000	Acryl Nitrile		[15]
01/30/1987	USA	Texas City	T	255		4000	Acid		[15]
04/26/1986	Ukraine	Chernobyl	E	600000	31	336000	Radioactive gases	949	[56]
02/24/1986	Greece	Thessaloniki	F				Oil	343	[14]
05/19/1985	Italy	Priolo	F	11	23		Ethylene	102	[13]
11/05/1985	USA	Mont Belieu	E	13	4		Propane	67	[13]
12/21/1985	Italy	Naples	F				Oil	66	[12]
01/18/1985	Germany	Wesseling	E				Ethylene	62	[53]
07/06/1985	USA	Clinton	T	8	5		Ammonia	18	[13]
11/21/1985	USA	Tioga	E				Hydrocarbons	14	[14]
06/22/1985	USA	Anaheim	F	12		10000	Pesticide		[15]
12/04/1985	India	New Delhi	T	350	1	10	Sulphuric Acid		[57]
11/01/1985	India	Padaval	F	82	43		Gasoline		[15]
08/26/1985	USA	South Charleston	T	135			Hydrogen Chloride		[15]
02/26/1985	USA	Coachella	F	236		2000	Pesticide		[15]
12/03/1984	India	Bhopal	T	500000	20000	0	Methyl Isocyanate	461	[58]
07/23/1984	USA	Romeoville	E	76	15		LPG	303	[13]
08/15/1984	Canada	Ft.McMurray, Alberta	F				Hydrocarbons	120	[12]
12/13/1984	Venezuela	Las Piedras	F				Hydrocarbons	98	[12]
09/30/1984	USA	Basile	E				Oil	47	[12]
11/19/1984	Mexico	San Juan Ixhuatepec	E	6400	650		LPG	32	[12]
02/24/1984	Brazil	Cubatao	F	221	508		Gasoline		[14]
12/01/1984	Pakistan	Gahri Dhoda	E		60		Gas		[15]
04/07/1983	USA	Avon	F				Hydrocarbons	80	[12]
07/07/1983	USA	Newark	E		1		Oil	58	[53]
05/26/1983	USA	Prudhoe Bay	F				NGL	44	[14]
08/30/1983	UK	Milford Haven	F	6	0		Oil	20	[45]
07/01/1983	USA	Port Arthur	F				na	20	[14]
07/27/1983	UK	Dursley	F	5	0		Ammonia	20	[45]
03/08/1983	India	Kerala	E				Hydrocarbons	18	[14]
09/29/1983	India	Dhulwari	E	100	41		Gasoline		[15]
08/31/1983	Brazil	Pojuca	F	100	42	1000	Gasoline		[15]
04/14/1983	India	Bontang	E				LNG	65	[14]
06/21/1982	USA	Pennsylvania	F	0	0	0	na	155	[59]
12/19/1982	Venezuela	Tacoa, Caracas	F	500	150	40000	Oil	84	[60]
03/09/1982	USA	Philadelphia	E				Hydrocarbons	47	[12]
18/04/1982	Canada	Edmonton	F				Ethylene	36	[12]
01/20/1982	Canada	Fort McMurray	F				Hydrogen	26	[14]
05/06/1982	USA	Duluth	E				Fumaric Acid	24	[12]
10/04/1982	USA	Freeport	F				Oil	21	[14]
03/31/1982	Japan	Kashima	F				Hydrocarbons	20	[14]
02/15/1982	USA	Grand Banks	F	0	84	0	Oil		[61]
12/11/1982	USA	Taft	E			20000	Acrolein		[15]

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Date	Country	Place	Prime Cause[+]	I[a]	D[a]	E[a]	Substance	Cost 2011 (M. €)	Ref.
05/25/1982	Italy	Todi	E	140	34		Gas		[15]
08/20/1981	Kuwait	Shuaiba	F				Hydrocarbons	80	[12]
04/07/1981	USA	Corpus Christi	E	30	9		Grain	67	[62]
02/11/1981	USA	Chicago Heights,	E				na	21	[14]
07/19/1981	USA	Greens Bayou	E				na	16	[14]
04/08/1981	Mexico	Montanas	T	50	29		Chlorine		[13]
06/01/1981	USA	Geismar	T	125			Chlorine		[14]
10/21/1980	USA	New Castle	E		5		Hydrocarbons	122	[15]
01/01/1980	USA	Borger	E				Hydrocarbons	72	[53]
02/26/1980	Canada	Brooks, Alberta	E				Gas	68	[12]
05/17/1980	USA	Deer Park	F				Fumaric Acid	39	[14]
06/26/1980	Australia	Sydney	E				Oil	28	[12]
12/31/1980	USA	Corpus Christi	F				Hydrocarbons	28	[14]
01/03/1980	USA	Avon					na	26	[14]
07/23/1980	USA	Seadrift	E				Ethylene Oxide	20	[14]
08/18/1980	Iran	Gach Saran	E	45	80		Nitroglycerine		[14]
11/29/1980	Spain	Ortuella	E		51		Propane		[14]
--/--/1980	USA	Alaska	F		51		Oil		[14]
08/16/1980	Japan	Shizuoka	E	222	15		Methane		[15]
05/28/1979	USA	Three Mile Island	T	0	0	0	Radioactive gases	1028	[15]
09/01/1979	USA	Deer Park	E				Hydrocarbons	152	[63]
07/21/1979	USA	Texas City	E				Hydrocarbons	52	[12]
01/08/1979	Ireland	Banty Bay	F		50		Oil	47	[12]
12/11/1979	Puerto Rico	Ponce	F				Hydrocarbons	36	[13]
03/20/1979	USA	Linden	E	1	1		LPG	33	[12]
12/11/1979	Australia	Geelong	F				Oil	21	[14]
07/28/1979	USA	Sauget	E				na	15	[14]
06/03/1979	Thailand	Phangnaga	E	15	50		Oil		[14]
05/30/1978	USA	Texas City	F	11	7		Butane	132	[15]
04/15/1978	SaudiArabia	Abqaiq	E				Gas	129	[12]
10/30/1978	Romania	Pitesti	E				Propylene	28	[14]
10/03/1978	USA	Commerce City	E		3		Propane	53	[53]
07/14/1978	Taiwan	Kaoshiung	F	49	33		MEKPO		[64]
02/11/1978	Mexico	Poblado Tres	E	32	40		Gas		[14]
07/07/1978	Tunisia	Manouba	E	150	3		Ammonium Nitrate		[14]
06/12/1978	Japan	Sendai	E	350	21		Oil		[15]
04/03/1977	Qatar	Umm Said	E	87	7		Propane	197	[15]
05/11/1977	S. Arabia	Abqaiq	E	15	1		Oil	153	[13]
07/08/1977	USA	Fairbanks	F		1		Oil	88	[14]
12/08/1977	Italy	Brindisi	E		3		Ethylene	73	[14]
10/17/1977	USA	Baton Rouge	E				Oil	20	[53]
12/10/1977	Colombia	Pasacabolo	E/T	22	30		Ammonia		[14]
12/23/1977	USA	Westwego	E	5	35		Grain		[13]
10/15/1976	USA	Longview	E		1		Ethylene	36	[13]
12/17/1976	USA	Los Angeles	E				Oil	25	[53]
06/04/1976	S. Arabia	Abqaiq	E				Gas	17	[14]
07/10/1976	Italy	Seveso	T	300			TCDD		[14]
12/10/1976	USA	Baton Rouge	T	3		10000	Chlorine		[13]
--/12/1976	Colombia	Carthagene	E	30	30		Ammonia		[14]
05/24/1976	USA	Geismar	E	56	0	0	Plyglycol ether	19	[15]
03/22/1975	USA	Alabama	F	0	0	0	Polyurethane	326	[14]
02/10/1975	Belgium	Antwerp	E	13	6		Ethylene	101	[65]
11/07/1975	Netherlands	Beek	E	106	14		Propylene	67	[62]
08/17/1975	USA	Philadelphia	E	20	8		Hydrocarbons	37	[66]
03/16/1975	USA	Avon	F				Oil	25	[13]
06/01/1974	UK	Flixborough	E	76	28		Cyclohexane	200	[14]
11/29/1974	USA	Beaumont	E	10	2		Hydrocarbons	52	[13]
07/19/1974	USA	Decatur	E	152	7		Iso-butane	54	[13]
05/26/1974	USA	Chicago	T	160	1	16000	Silicon Tetrachloride		[53]
--/--/1974	Romania	Pitesti	E		100		Ethylene		[14]
11/03/1974	Japan	Tokyo Bay	E		33		Naptha		[14]
07/08/1973	Japan	Tokuyama	F	16	1		Ethylene	46	[15]
02/10/1973	USA	Staten Island	E		40		LNG		[13]
10/08/1973	Japan	Goi, Ichihara City	E		4		Propylene	24	[13]
08/24/1973	Virgin Islands	St. Croix	F				Hydrocarbons	31	[14]
02/26/1972	USA	Buffalo Creek	T	1100	125	4000	Wastewater	61	[53]

TABLE I (CON/D)
THE 319 MAJOR INDUSTRIAL ACCIDENTS SINCE 1917

Date	Country	Place	Prime Cause[+]	I[a]	D[a]	E[a]	Substance	Cost 2011 (M. €)	Ref.
08/04/1972	Italy	Trieste	F				Oil	36	[14]
08/14/1972	USA	Billings	E	4	1		Butane	17	[14]
03/30/1972	Brazil	Rio de Janeiro	E	53	37		Butane		[13]
09/21/1972	Brazil	Duque de Caxias	E	53	37		Butane		[68]
--/--/1972	Japan	Yokkaidi	T	978	76		na		[14]
04/06/1972	USA	Doraville	F	161	2		Gasoline		[15]
02/25/1971	USA	Longview	E	60	4		Ethylene	24	[13]
11/07/1971	USA	Morris	E	4			Ethylene Oxide	19	[14]
06/26/1971	Poland	Czechowice	E		33		Oil		[15]
12/05/1970	USA	Linden	E	40	0		Hydrocarbons	142	[62]
12/09/1970	USA	Port Hudson	E	10	0		Propane	54	[14]
--/--/1970	Germany	Kiel	E/T	18	6		Gas	11	[14]
--/--/1970	Iran	Agha Jari	E	10	29		Gas		[62]
10/01/1969	Spain	Escombreras	E		4		Propane	49	[53]
10/23/1969	USA	Texas City	E		3		Butadiene	36	[53]
09/09/1969	USA	Houston	E	9			Gas	20	[14]
03/06/1969	Venezuela	Puerto La Cruz	F				Hydrocarbons	19	[14]
12/28/1969	UK	Fawley	E		0		Naptha	11	[14]
08/12/1969	USA	Flemington	E				VCM	17	[14]
01/21/1968	Netherlands	Pernis	E	85	2		Hydrocarbons	137	[13]
01/01/1968	Germany	East Germany	E		24		VCM		[13]
08/08/1967	USA	Lake Charles	E	14	7		Iso-butane	90	[13]
--/--/1967	Brazil	Santos	E	300			Gas		[14]
01/04/1966	France	Feyzin	F	83	18		Propane	106	[13]
01/19/1966	Germany	Raumheim	E	83	3		Methane	34	[13]
10/16/1966	Canada	LaSalle	E	10	11		Styrene	15	[13]
08/25/1965	USA	Louisville	E	60	12		MVA	43	[14]
7/13/1965	USA	Lake Charles, LA	E				Ethylene	24	[14]
06/16/1964	Japan	Niigata	F		2		Hydrocarbons	69	[13]
10/25/1964	USA	Orange, Texas City	E	34	2		Ethylene	24	[14]
01/12/1964	USA	Attleboro	E	40	7		VCM	24	[13]
06/04/1964	Belgium	Antwerp	E	20	4		Ethylene Oxide	23	[14]
05/03/1963	USA	Plaquemine	E	7			Ethylene	23	[14]
04/17/1962	USA	Doe Run, Bradenburg	E	19	2		Ethylene Oxide	39	[14]
04/27/1962	USA	Marietta	E	3	1		Hydrocarbons	22	[13]
10/14/1960	USA	Kingsport	E	250	15		Aniline		[14]
05/22/1958	USA	Signal Hill	F	3	2	400	Oil	46	[13]
10/10/1957	UK	Windscale	F	0	0	0	na	99	[69]
01/29/1957	USA	Whiting	E	0	0	0	Propane	28	[70]
04/15/1957	USA	Nitro	E/T	0	0	0	Methyl Parathion	28	[71]
01/08/1957	USA	Montreal	F/T	0	1	0	Butane	12	[71]
--/--/1954	Germany	Bitburg	F	16	32		Oil		[71]
02/16/1950	Mexico	Poza Rica	T	320	22		Hydrogen sulphide		[14]
--/--/1949	USA	Nitro	T	228			TCDD		[13]
07/28/1948	Germany	Ludwigshafen	E	2500	245		Dimethyl ether	33	[13]
10/26/1948	USA	Donara	T	7000	20	0	Sulphur dioxide		[14]
11/05/1947	Finland	Rauma	T	200	19		Chlorine		[13]
02/20/1947	USA	Los Angeles	E	130	17				[72]
10/20/1944	USA	Cleveland	F	300	128		LNG	68	[13]
11/27/1944	UK	Fauld	E/T	22	68	0	Explosives		[14]
--/--/1944	USA	Brooklyn	T	208	0		Chlorine		[13]
07/21/1942	Belgium	Tessenderloo	E		200		Ammonium Nitrate		[73]
12/24/1939	Romania	Zarnesti	T		60		Chlorine		[14]
02/10/1933	Germany	Neunkirchen	E		65		Gas		[13]
--/12/1930	Belgium	Luttich	T		63				[13]
05/20/1928	Germany	Hamburg	E/T	171	11		Phosgene		[14]
01/--/1924	USA	Pekin, Illinois	E	100	35		Grain dust		[14]
09/21/1921	Germany	Oppau	E	1952	561		Ammonium Nitrate	23	[13]
01/15/1919	UK	Boston	E	40	23	0	Sugar Molasses	4	[74]
06/13/1917	UK	Ashton, Manchester	F	120	46		TNT		[1]

[+] E: explosion; F: fire; T: toxic release.
[a] I: number of injuries; D: number of deaths; E: number of people evacuated.

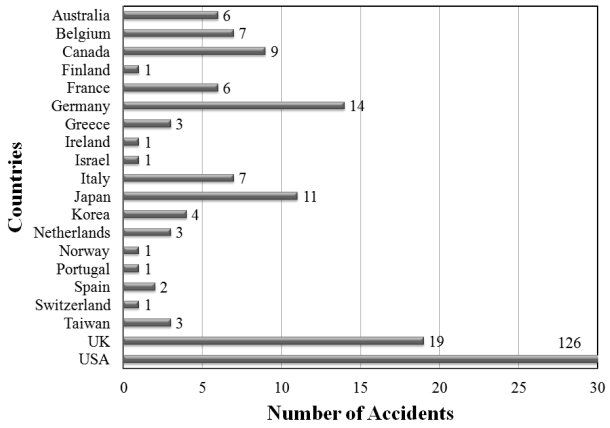

Fig. 2. Number of major accidents in developed countries in the period 1917-2011

- The 20 countries in Fig. 2, are classified as "developed" countries according to the April 2007 IMF survey [16]. These share 226 from the total of 319 major industrial accidents. Actually, if accidents that took place in the U.S.A. are not considered, the remaining 19 countries share 100 major accidents.
- On the other hand the remaining 32 developing countries, share 92 major industrial accidents, as can be seen in Fig. 3, and from them, the highest number of accidents appear in India (15), Mexico (12), P.R. China (8), and Brazil (7).

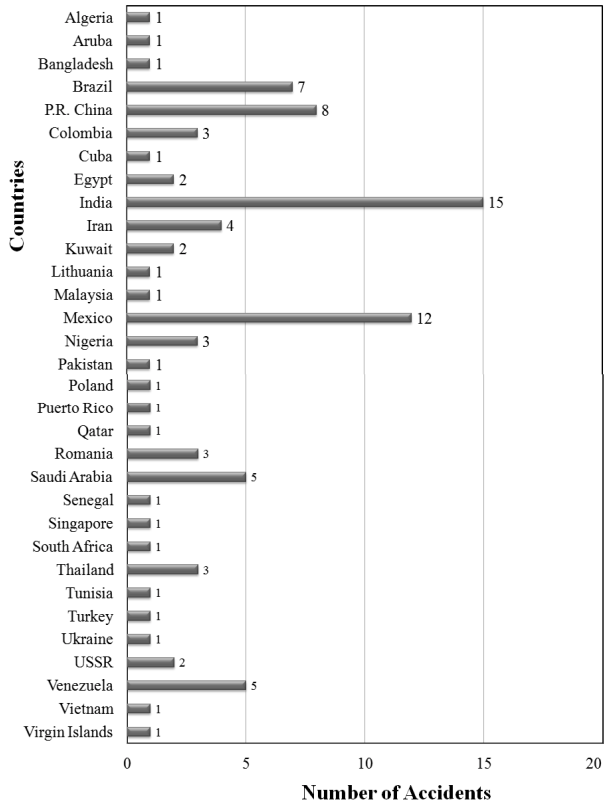

Fig. 3. Number of major accidents in developing countries in the period 1917-2011

III.3. Number of Accidents per Decade

The number of major industrial accidents per decade is shown in Fig. 4. It is interesting to note the sharp increase in the number of accidents until 1996. Probably the decline in the number of accidents that follows, can be attributed to two facts:

- The strict legislation that was introduced, following some very serious major accidents, which were concentrated in the previous decade, see Table 1 (Flixborough UK 1974, Seveso Italy 1976, Bhopal India 1984, Chernobyl Ukraine 1986, Piper Alpha UK 1988, Exxon Valdez Alaska 1989).
- Public awareness and international bodies forced industries to comply with safety regulations.

Furthermore it is obvious according to Fig. 4, that in developing countries, industrial activity began to develop after mid '70s and that is, when major industrial accidents started to happen more frequently.

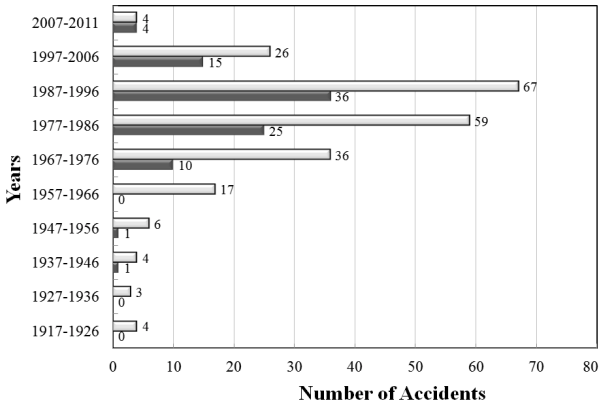

Fig. 4. Number of major accidents per decade in the period 1917-2011 (white: developed, dark: developing)

IV. Analysis According to the Accidents Causes, Consequences and Total Cost

IV.1. Main Causes of Industrial Accidents

The primary causes of the accidents included in the database have been categorized in explosions, fires or toxic releases. It should be made clear that in most cases primary causes have secondary effects, e.g., a fire can follow an explosion or the other way around. In Fig. 5 the primary causes quoted in each reference are shown. It can be seen that:

- Explosion is the primary cause of most major industrial accidents.
- It is also interesting that the trend of primary causes is similar in developed and developing accidents.
- It should also be pointed out, that the number of accidents shown in Fig. 6 have no analogy to the numbers of deaths, injuries or people evacuated (e.g., the toxic release in Bhopal affected 500,000 people).

TABLE II
THE 10 MAJOR INDUSTRIAL ACCIDENTS WITH THE HIGHEST NUMBER OF PEOPLE KILLED, INJURED OR EVACUATED

Country	Place	Date	Prime Cause[+]	Substance involved	People Killed
India	Bhopal	12/03/1984	T.R	Methyl isocyanate	20,00
Nigeria	Jesse, Niger Delta	10/17/1998	E	Gasoline	1,00
Mexico	San Juan Ixhuatepec	11/19/1984	E	LPG	65
USSR	Siberia	06/04/1989	E	LPG	64
Germany	Oppau	09/21/1921	E	Ammonium Nitrate	56
Brazil	Cubatao	02/24/1984	F	Gasoline	50
Columbia	Remeios	08/04/1993	T.R	Oil	43
Egypt	Donca	11/02/1994	F	Oil	41
Nigeria	LagosCity	05/12/2006	E	Oil	26
Nigeria	Adeje Warri	07/10/2000	E	Oil	25

Country	Place	Date	Prime Cause[+]	Substance involved	People Injured
Ukraine	Chernobyl	04/26/1986	E	Radioactive gases	600,00
India	Bhopal	12/03/1984	T.R	Methyl Isocyanate	500,00
USA	Donara	10/26/1948	T.R	Sulphur dioxide	7,00
Mexico	San Juan, Ixhuatepec	11/19/1984	E	LPG	6,40
USA	Richmond	07/26/1993	T.R	Sulphuric Acid	6,25
France	Toulouse	09/21/2001	E	Ammonium Nitrate	3,00
Germany	Ludwigshafen	07/28/1948	E	Dimethyl ether	2,50
Germany	Oppau	09/21/1921	E	Ammonium Nitrate	1,95
Mexico	Guadalajara	04/22/1992	E	Gasoline	1,46
USA	Buffalo Creek	02/26/1972	T.R	Wastewater	1,10

Country	Place	Date	Prime Cause[+]	Substance involved	People Evacuated
India	Jaipur	10/29/2009	F	Oil	500,000
Ukraine	Chernobyl	04/26/1986	E	Radioactive gases	336,000
France	Tours	06/08/1988	F	Na	200,000
Japan	Fukushima	03/11/2011	E/T.R	Radioactive gases	100,000
UK	Birmingham	07/25/1990	T.R	Phosgene	75,000
India	Visakhapatnam	09/15/1997	E	LPG	60,000
Mexico	Salamanca	09/12/2000	E	Malathion	60,000
Venezuela	Tacoa, Caracas	12/19/1982	F	Oil	40,000
France	Nantes	10/29/1987	F/T.R	Ammonium Nitrate	38,000
USSR	Ionava	03/20/1989	E	Ammonia	30,000

[+] E: Explosion; F: Fire; T.R: Toxic Release

IV.2. Top Ten Countries with the Highest Number of People Killed, Injured or Evacuated

Table II shows the countries with the highest number of people killed, injured or evacuated. The following can be noticed:

- The two major industrial accidents with the highest number of deaths are the toxic release of methyl isocyanate in Bhopal, India in 1984, and the gasoline explosion in Jesse, Nigeria in 1998.
- In the case of people injured, the worst accidents are the nuclear accident at Chernobyl, Ukraine in 1986, and the Bhopal, India accident in 1984.

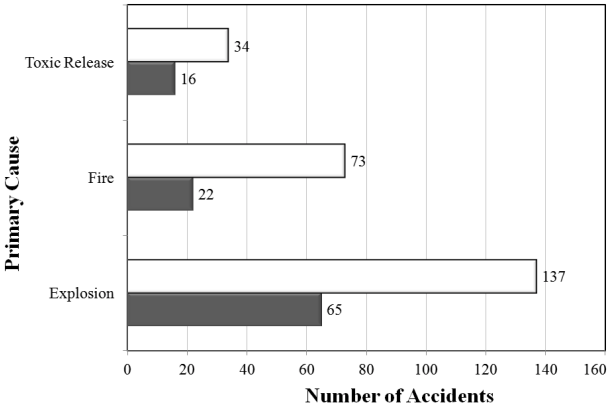

Fig. 5. Primary causes of industrial accidents in developed (white) and developing (dark) countries

- In the case of highest number of people evacuated the two worst industrial accidents are, the oil fire in Jaipur, India, in 2009, and again the nuclear accident in Chernobyl, Ukraine, in 1986.
- The worst accidents did not happen in the U.S.A., but rather in India, Nigeria or Ukraine, probably indicating a more relaxed application or lack of legislation measures.

It should be noted that in accidents like Chernobyl or Bhopal, it is very difficult to calculate the actual number of people killed or injured, so the numbers quoted, are the numbers given in each specific reference.

IV.3. Number of Deaths and Injuries in Developed and Developing Countries

In Table III, the total number of deaths and injuries resulted from accidents in developed and developing countries is shown. The following can be noted:

- The number of deaths in developed countries is much smaller than the equivalent in developing countries. If we further consider that out of the 319 recorded major industrial accidents, 227 are in developed countries, an average of about 14 deaths per accident in developed countries, and 254 deaths per accident in developing countries (even if we exclude the Bhopal accident, in developing countries we still count 47 deaths per accident) can easily be derived. It is our belief that this is most likely attributed to the strict industrial safety legislation that is enforced in developed countries, who also have better infrastructure and contingency plans to deal with such events.

IV.4. Top Twenty Accidents with Highest Total Cost

In Fig. 6, the twenty accidents with the highest cost are shown. The following can be noted:

- The most expensive accident in terms of cleanup cost and property damages is, as in a way expected, the Fukushima accident in 2011 in Japan, followed by the accident in the Gulf of Mexico in 2010, and the Piper Alpha accident in 1988.

TABLE III
TOTAL NUMBER OF DEATHS AND INJURIES IN DEVELOPED AND DEVELOPING COUNTRIES

Developed Countries			Developing Countries		
Country	Deaths	Injuries	Country	Deaths	Injuries
Australia	2	0	Algeria	23	74
Belgium	334	196	Argentina	0	0
Canada	12	25	Aruba	0	0
Finland	19	200	Bangladesh	0	0
France	48	3114	Brazil	634	727
Germany	950	5001	P.R. China	209	540
Greece	14	21	Colombia	490	52
Ireland	50	0	Cuba	3	374
Israel	0	0	Egypt	410	0
Italy	63	453	India	20329	500888
Japan	162	1573	Iran	142	293
S.Korea	67	160	Kuwait	5	50
Netherlands	220	1766	Lithuania	1	658
Norway	0	0	Malaysia	0	12
Portugal	14	76	Mexico	758	7646
Spain	55	0	Nigeria	280	60
Switzerland	0	0	Pakistan	60	0
Taiwan	34	761	Poland	33	0
UK	332	592	Puerto Rico	0	0
USA	730	19104	Qatar	7	87
			Romania	160	0
			Saudi Arabia	1	15
			Senegal	40	300
			Singapore	0	0
			South Africa	0	0
			Thailand	121	28
			Tunisia	3	150
			Turkey	32	64
			Ukraine	31	600000
			USSR	651	759
			Venezuela	197	500
			Vietnam	47	48
			Virgin Islands	0	0
TOTAL	3106	33042	TOTAL	24667	113325

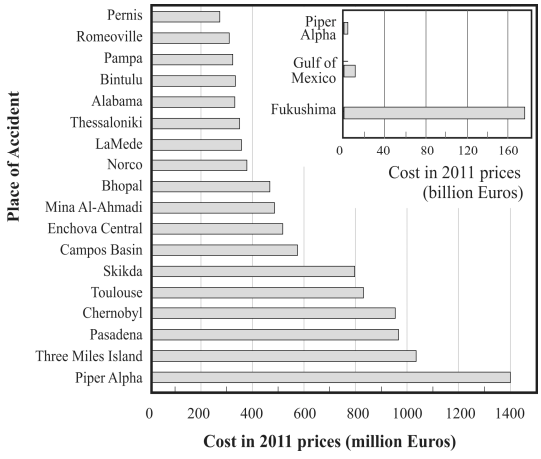

Fig. 6. Top twenty accidents with the highest total cost

V. Conclusion

In this work, 319 major industrial accidents were recorded according to the UNEP specified criteria. This allows proper comparison and analysis of the accidents.

Furthermore, a reference for every accident was provided, so it can easily be traced by the user.

From the analysis of these accidents some important conclusions do arise:

a) Although the number of major industrial accidents is higher in developed countries than in developing ones, the number of deaths and injuries, is considerably less. This most likely is a result of better enforcement of safety regulatory legislation in developed countries.
b) Another effect of better enforcement of safety regulatory legislation is the fact that it seems that during the last two decades, the number of major industrial accidents is decreasing in general.

References

[1] ARIA Database, *Analysis, Research and Information on Accidents*. (2012). French Ministry of Ecology, Energy, Sustainable Development. Available at: http://www.aria.developpement-durable. gouv.fr/index_en.html. Last accessed: 08.13.2011

[2] FACTS Hazardous materials accidents knowledge base, (2012). Available at: http://www.factsonline.nl/browse-chemical-accidents-in-database. Last accessed:03.25.2011

[3] INRS Database, *Institut National de Recherche et de Securite*. (2012). Available at: http://en.inrs.fr/. Last accessed: 05.10.2012.

[4] MARS Database, *Major Accident Reporting System*. (2012). Available at: http://mahb.jrc.it/ index.php?id=39. Last accessed: 02.18.2012.

[5] ZEMA Database, *Zentrale Melde- und Auswertestelle für Störfälle und Störungen in verfahrenstechnischen Anlagen*. (2012). Available at: http://www.umweltbundesamt.de/nachhaltige-produktion-anlagensicherheit-e/zema/index.html. Last accessed: 01.16.2012.

[6] Ility Datase, *Ility Engineering*. (2012). Available at: http://www.saunalahti.fi/ility/. Last accessed: 03.12.2012.

[7] CCPS Database, *Center for Chemical Process Safety*. (2011). Available at: http://www.aiche.org/ccps. Last accessed: 04.25.2011.

[8] NTSB Database, *National Transportation Safety Board*. (2012). Available at: http://www.ntsb.gov/investigations/databases.html. Last accessed: 06.25.2012.

[9] JST Database, *Japan Science and Technology Agency*. (2012). Available at: http://sciencelinks.jp/j-east/. Last accessed: 07.15.2012.

[10] COSO Database, *Czech Occupational Safety Office*. (2011). Available at: http://www.cubp.cz/. Last accessed: 06.15.2011.

[11] OSHA Database, *Occupational Safety and Health Administration*. (2012). Available at: http://www.osha.gov/pls/imis/accidentsearch.html. Last accessed: 01.25.2012.

[12] Marsh, *The 100 largest losses 1972-2001: large property damage losses in the hydrocarbon-chemical industries*. (2003). Available at: www.equityeng.com/sites/default/files/reports/M&M-article_452602.pdf. Last accessed: 10.23.2011

[13] F. I. Khan, S. I. Abassi, Major accidents in process industries and an analysis of causes and consequences. *J. Loss Prev. Process Ind.* 12 (1999) 361-378.

[14] F. P. Lees *Loss prevention in the process industries – Hazard identification assessment and control*. Oxford: (Butterworth-Heinemann, 1996)

[15] United Nations Environmental Programme Awareness & Preparednes for Emergencies at Local Level, *UNEP Apell Disasters Database,*. (2006). Available at: http://www.unep.fr/scp/sp/disaster/database/. Last accessed: 05.20.2011.

[16] Organisation for Economic Co-operation and Development (OECD), (2011). Available at: http://www.oecd.org/home/ Last accessed: 02.04.2011.

[17] M. J. Assael, K. E. Kakosimos, Can a cause on the calculation of the effects of fires, explosions and toxic gas dispersions, be

topical, enjoyable and meaningfull? *IChemE J: ECE* 5 (2010) E33-E54.
[18] Chemical Engineering Journal, Marshall & Swift cost index. 119 (January 2012) 56.
[19] R. Yoshioka, K. Iino, *Technical report: Fukushima accident summary (Aug. 19, 2011)* (2011). Association for the Study of Failure. Available at: http://www.shippai.org/eshippai/html/. Last accessed: 03.17.2012
[20] C. Cleveland, *Deepwater Horizon oil spill*. (2011). The Encyclopedia of Earth. Available at: http://www.eoearth.org/ article/Deepwater_Horizon_oil_ spill. Last accessed: 06.11.2011
[21] Xinhuanet English News, *Death toll from fireworks factory explosion rises to 20 in NE China*. (2010). Xinhuanet English News. Available at: http://news. xinhuanet.com/english/. Last accessed: 08.27.2011
[22] A. Vindhani, *Half a million people evacuated as deadly fire rages through Jaipur oil depot*. (2009). Mail Online. Available at: http://www.dailymail.co.uk/news/article-1224018/Five-killed-150-injured-massive-rages-Indian-oil-depot.html. Last accessed: 09.15.2011
[23] Standing Committee on Economics, *Matters relating to the gas explosion at Varanus Island, Western Australia*. (2008). Available at: http://www.aph. gov.au/. Last accessed: 05.24. 2011
[24] CNN, *20 dead in chinese chemical plant explosion*. (2008). CNN Available at: http://articles.cnn.com/2008-08-27/world/ china.blast_1_chemical-plant-explosion-morning-blast?_s=PM: WORLD. Last accessed: 05.10.2011
[25] CNN, *Warehouse blaze claims 40 lives*. (2008). CNN. Available at: http://articles.cnn.com/2008-01-07/world/skorea.fire_1_ware house-massive-fire-toxic-fumes?_s=PM:WORLD. Last accessed: 05.13.2010
[26] BBC, *Chemical blaze kills 30 in Iran*. (2008). BBC News. Available at: http://news.bbc.co.uk/2/hi/ middle_east/7419555 .stm. Last accessed: 11.11. 2010
[27] G. Frederic, Frozen steam condensate results in pipe rupture and fire in a refinery. *IChemE J. LPB* 190 (2006) 28-31.
[28] BBC, *Lagos pipeline blast kills scores*. (2006). BBC News. Available at: http://news.bbc.co.uk/ 2/hi/africa/6209845.stm. Last accessed: 11.10.2010
[29] M. P. Broadribb, Lessons from Texas city, a case history. *IChemE J. LPB* 192 (2006) 3-12.
[30] M. Smith, *Review of reports on Buncefield*. (2007). Available at: http://www.linkassociates.com/pdf_downloads/Review% 20of%20reports%20on%20Buncefield.pdf. Last accessed: 12.10.2010
[31] BBC, *Four killed in Algeria gas blast*. (2004). BBC News. Available at: http://news.bbc.co.uk/1/hi/world/africa/3411651 .stm. Last accessed: 09.21. 2010
[32] AristaTek, *Industrial accidents involving chemical reactors*. (2004). Aristatek. Available at: http://www.aristatek.com/ newsletter/0603march/techspeak.pdf. Last accessed: 12.10.2010
[33] A. H. Tullo, Styrene bounces off the bottom. *Chem. Eng. News* 80 (2002) 27-28.
[34] T. Tzoua, D. Edwardsa, P. Chungb, An explosion accident - causes and safety information management lessons to be learned. *IChemE J. LPB* 178 (2004) 18-25.
[35] ActionPA, *Toxic gas leak in Oklahoma*. (2001). Available at: www.actionpa.org/fluoride/chemicals/catoosa.html. Last accessed: 09.06.2011
[36] J. Carter, P. Dawson, R. Nixon, Explosion at the Conoco Humber refinery - 16th April 2001. *IChemE J. LPB* 188 (2006) 14-20.
[37] T. Johnson, *More than 250 feared dead in Nigerian pipeline explosion*. (2000). World Socialist Web Site. Available at: http://www.wsws.org/articles/2000/jul2000/nig-j14.shtml. Last accessed: 10.10.2009
[38] P. Hendrik, *Netherlands fireworks factory explosion - the downside of the Dutch model*. (2000). World Socialist Web Site. Available at: http://www.wsws.org/articles/2000/may2000/neth-m31.shtml. Last accessed: 04.18.2010
[39] P. Cryan, Victims of mexican pesticide disaster left to fend for themselves. *Global Pestic. Camp.* 11 (2001) 14-15.
[40] State Coroner Victoria, *Longford*. (1998). Coroners Court of Victoria. Available at: http://www.coronerscourt. vic.gov.au. Last accessed: 08.09.2009
[41] WHSCC, *Accident investigation report on the explosion and fire at the irving oil refinery saint john, New Brunswick*. (1999). Available at: http://ncsp.tamu.edu. Last accessed: 07.20.2011
[42] B. Klein, *Nigerian gas line fire*. (1999). Linguistic Data Consortium. Available at: http://projects.ldc.upenn.edu/ TDT3/topic.research/topic3014.html. Last accessed: 12.11.2012
[43] EPA, *Tosco Avon refinery Martinez, California*. (1998). Available at: http://www.epa.gov/osweroe1/docs/chem/tosco.pdf Last accessed: 06.15.2011
[44] A. Rodante, Analysis of an LPG explosion and fire. *Process Saf. Prog.* 22 (2004) 174-181.
[45] R. Fewtrell, A. Walsh, A review of UK and overseas major industrial accidents since Flixborough 1974. Report No AM5088/2.2.97 prepared for and on behalf of HSE. (1997).
[46] EPA, *Powell Duffryn Terminals, Inc. Savannah, Georgia*. (1998). Available at: http://www.epa.gov/osweroe1/docs/ chem/pdtirept.pdf. Last accessed: 06.15.2011
[47] G. Newsholme, Some thought on the explosion of Milford Haven in 1994. *IChemE J. LPB* 193 (2007) 15-16.
[48] D. Shockey, J. Simons, T. Kobayashi, Cause of the Port Neal ammonium nitrate plant explosion. *Eng. Fail. Anal.* 10 (2003) 627-637.
[49] Los Angeles Times, *Blast at Ohio plant forces evacuation: explosion: At least one worker is killed and two are missing and presumed dead after nine-hour fire. The cause is unknown.* (1994). Los Angeles Times. Available at: http://articles.latimes. com/1994-05-28/news/mn-63228_1_ohio-river. Last accessed: 10.15.2010
[50] New York Times, *Gas blast kills 36 near caracas*. (1993). New York Times. Available at: http://www.nytimes.com/1993/ 09/29/world/gas-blast-kills-36-near-caracas.html. Last accessed: 10.15. 2010
[51] Suburban Emergency Management Project, *The Guadalajara 1992 sewer gas explosion disaster*. (2006). Available at: http://www.semp.us/publications/biot_reader.php?BiotID=356. Last accessed: 12.15.2010
[52] E. Iliopoulou, A. Lochaitis, E. Komninakis, L. Poulikakos, S. Asfour, S. Chalkitis, C. Tzortzis, Mass disasters in greece. *J. Ann. Burns Fire Dis.* 7 (1994) 36-40.
[53] E. M. Lenoir, Davenport, J. A., A survey of vapor cloud explosions: second update. *Process Saf. Prog.* 12 (1993) 12-33.
[54] A. Banks, Consequences of overpressure in a refrigerated ammonia tank. *IChemE J. LPB* 156 (2000) 15-20.
[55] E. Clayton, M. Griffin, Catastrophic failure of a liquid carbon dioxide storage vessel. *IChemE J. LPB* 125 (1994) 3-10.
[56] UNSCEAR, *Annex J: Exposures and effects of the Chernobyl accidents*. (2009). United Nations Scientific Committee on the Effects of Atomic Radiation. Available at: http://www. unscear.org/docs /reports/annexj.pdf. Last accessed: 03.15.2012
[57] Environmental Law Alliance Wordwide, *India -- M.C. Mehta v. Union of India, WP 12739/1985 (1986.02.17) (Oleum gas leak case)*. (2009). Environmental Law Alliance Wordwide. Available at: http://www.elaw.org/node/2719. Last accessed: 11.19.2010
[58] E. Broughton, *The Bhopal disaster and its aftermath: a review*. (2004). National Center for Biotechnology Information. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC 1142333/. Last accessed: 10.11.2010
[59] L. R. Best, *Storage fire (K Mart)*. (1983). Available at: http://www.nfpa.org/assets/files/MbrSecurePDF/FIFallsTown-ship.pdf. Last accessed: 09.25.2011
[60] R. Schiller, *Inferno at Tacoa*. (2009). Industrial Fire World. Available at: http://www.fireworld.com/Archives/tabid/93/article Type/ArticleView/articleId/86994/Inferno-at-Tacoa.aspx. Last accessed: 01.20.2010
[61] C. D. Heising, W. S. Grenzebach, The ocean ranger oil rig disaster: A risk analysis. *Risk Anal.* 9 (1989) 55-62.

[62] A. A. Pekalski *Review of preventive and protective systems for explosion risk in the process industry*. (TU Delft Internal Report, Delft, 1997)
[63] World Nuclear Association, *Three Mile island accident*. (2001). World Nuclear Association. Available at: http://www.world-nuclear.org/info/inf36. html. Last accessed: 10.21.2009
[64] T.-C. Ho, Y. S. Duh, J. R. Chen, Case studies of incidents in runaway reactions and emergency relief. *Process Saf. Prog.* 17 (1998) 259-262.
[65] IChemE, Fire at Browns Ferry nuclear power station. *IChemE J. LPB* 047 (1982) 13-14.
[66] A. L. M. Van Eijnatten, Explosion in a naphtha cracking unit. *Plant Loss Prev.* (1977) 11-14.
[67] West Virginia Division of Culture and History, *Buffalo Creek*. (2011). West Virginia Division of Culture and History. Available at: http://www.wvculture.org/history/buffcreek/ bctitle.html. Last accessed: 09.14.2011
[68] T. Kletz *What went wrong? Case histories of process plant disasters*. 4th ed. Houston: (Elsevier, 1999)
[69] S. Beitler, *Long beach, CA oil refinery fire, May 1958*. (2009). GenDisasters. Available at: http://www3.gendisasters.com/ california/12917/long-beach-ca-oil-refinery-fire-may-1958. Last accessed: 02.20. 2010
[70] Lakestay, *The 1957 Windscale fire*. (2011). Lakestay. Available at: www.lakestay.co.uk/ 1957.htm. Last accessed: 03.03.2012
[71] F. Manuelle, One hundred largest losses - A thirty year review of property damage losses in the hydrocarbon - chemical industries. *IChemE J. LPB* 071 (1986) 1-12.
[72] D. Hess, *Donora smog of 1948*. (2007). Donora Fire Company. Available at: http://www.donora.fire-dept.net/1948smog.htm. Last accessed: 10.06.2010
[73] IChemE, The largest explosion in the UK Fauld, 1944. *IChemE J. LPB* 103 (1992) 17-18.
[74] S. Beitler, *Pekin, IL Corn products refining starch plant explosion, Jan 1924*. (2007). GenDisasters. Available at: http://www3.gendisasters.com/illinois/1083/pekin,-il-corn-products-refining-starch-plant-explosion,-jan-1924. Last accessed: 03.11.2012
[75] V. C. Marshall, The Boston mass., incident of January 15th 1919. *IChemE J. LPB* 082 (1988) 27-32.

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