Journal of the Nigerian Association of Mathematical Physics
***Volume27*, (*July, 2014*), pp 607 – 622**

Comparative Analysis of Nuclear Power Generation and other Power Generation Sources together with other Social- Economic Development Sectors in Terms of Accidents Frequency and Magnitude

A.I. Oludare[1], M.N. Agu[2], L. Dim[3], P.O. Akusu[4], A.M. Umar[5] and O. E. Omolara[6]

[1]Nigerian Defence Academy, Department of Physics, Kaduna
[2] Nigeria Atomic Energy Commission, Abuja
[3]Nigerian Nuclear Regulatory Authority, Abuja
[4]Nigeria Atomic Energy Commission, Abuja
[5]Energy Commission of Nigeria, Department of Nuclear Science & Technology, Abuja
[6]Ahmadu Bello University, Department of Mathematics, Zaria, Nigeria

Abstract

This paper carried out comparative analysis of nuclear power generation and other power generation sources together with other social- economic development sectors in terms of accidents frequency and magnitude based on the past experiences from a systematic assessment of major or severe accidents. The work has been focused on the actual experience data as reflected in a number of existing databases and in numerous other sources. Through analysis of the presented data, an objective conclusion was drawn regarding the use of each energy technology for the future. The results of the comparative studied showed that nuclear power plants (NPPs) have less accident frequency and magnitude than other associated electricity generation sources together with other social- economic development sector, therefore nuclear energy is safer. Further the research showed that NPPs has more advantages over other associated electricity generation sources and therefore, has more future investment opportunities such as employment provision, industrial and educational development for economic growth than other associated electricity generation sources today.

Keywords: Risk analysis, comparism of nuclear power plants and other power generation sources, plant accidents, magnitude and frequency, safety aspects of nuclear power plants, nuclear power plants advantages.

1.0 Introduction

Risk can be seen as relating to the probability of uncertain future events. For example, according to factor analysis of information risk, risk is the probable frequency and probable magnitude of future loss. In physics the study of risk can be measure in terms of frequency and magnitude. In computer science this definition is used by the open group. Risk analysis is the systematic use of available information to identify hazards and to estimate the risk to individuals or populations, property or the environment. As in other industries, the design and operation of nuclear power plants aims to minimise the likelihood of accidents, and avoid major human consequences when they occur. In nuclear industry risk is mostly taken as fear of accident occurring. The development of Cars, Railways, Ships, Aircrafts, Guns, Nuclear Power Plants and other System with risk factor implication pose concerns about their safety and this led to the development of the classical probabilistic risk analysis. In this paper comparative analysis was conducted of nuclear energy, other energy sector and other social-economic development sectors in terms of accident frequency and magnitude and seeks for more efforts in the development of nuclear energy for national development.

Corresponding author: ***A.I. Oludare,*** E-mail: isaac_abiodun@yahoo.com, Tel.: +2347065589574

2. Aim and Objectives of the Research

The is to carry out a comparative analysis of power generating methods in terms of accident frequency and magnitude so as to find a way of changing the prevalent belief that nuclear energy is prone to accident and should not be considered as an option for energy production. The objectives are:

(i) To carry out extant literature review on accident frequency and magnitude of various energy generating systems including nuclear energy and other social- economic development sectors.

(ii) To assess energy sector and other social- economic development sectors in terms of accident frequency and magnitude

(iii) To take records of accident frequency and magnitude of various energy generating systems including nuclear energy for the generation of electricity and other social- economic development sectors.

(iv) To compare accident frequency and magnitude of various energy sources and other social- economic development sectors.

(v) To seek economic advantages of having nuclear energy as an option for national development.

(vi)To help Nigeria meet its international obligations to use nuclear technology for power generation means.

(vii) To provide a good, novel approach and method for multi-objective decision-making based on seven dissimilar objectives attributes: evolving technology, effectiveness, efficiency, cost, safety, failure and economy.

3. Motivation of the Research

The interest of this paper is to assist Nigeria and other developing nations to embrace nuclear technology in meeting their energy needs for greater economic development.

4. Research Problems

Most people develop negative opinion for development of nuclear energy sector and their perception is that nuclear plant has high risk for accident which, if it occurs can cause huge damage like loss of lives, properties and environmental hazard. But the use of nuclear power can be compared with other related sectors in terms of accident frequencies and magnitudes and it would be discovered that nuclear energy is better and safer.

5. Research Questions

In physics risk is measured in terms of frequency and magnitude. Therefore, from the research problem we have derived the following research questions:

(i) What is the accident frequency and magnitude of nuclear power plants compared to other electricity generation sources and other social- economic development sectors?

(ii) What are the economic advantages of having nuclear energy as an option to electricity production as compared with other electricity generation sources and other social- economic development sectors?

6. Nuclear Power Regulation

The International Atomic Energy Agency (IAEA) was set up by the United Nations in 1957. One of its functions was to act as an auditor of world nuclear safety, and this role was increased greatly following the Chernobyl accident. It prescribes safety procedures and the reporting of even minor incidents. Its role has been strengthened since 1996.

7. Accident Analysis of Nuclear Power Plants

There have been several reports analysis on the safety of reactors [1-6]. As in other industries, the design and operation of nuclear power plants aim to reduce the likelihood of accidents, and avoid major human consequences when they occur. In over 14,500 cumulative reactor-years of commercial operation in 32 countries, there have been only three major accidents to nuclear power plants – Fukushima, Chernobyl and Three Mile Island.

The three significant accidents in the civil nuclear power generation are presented in Figure 1.

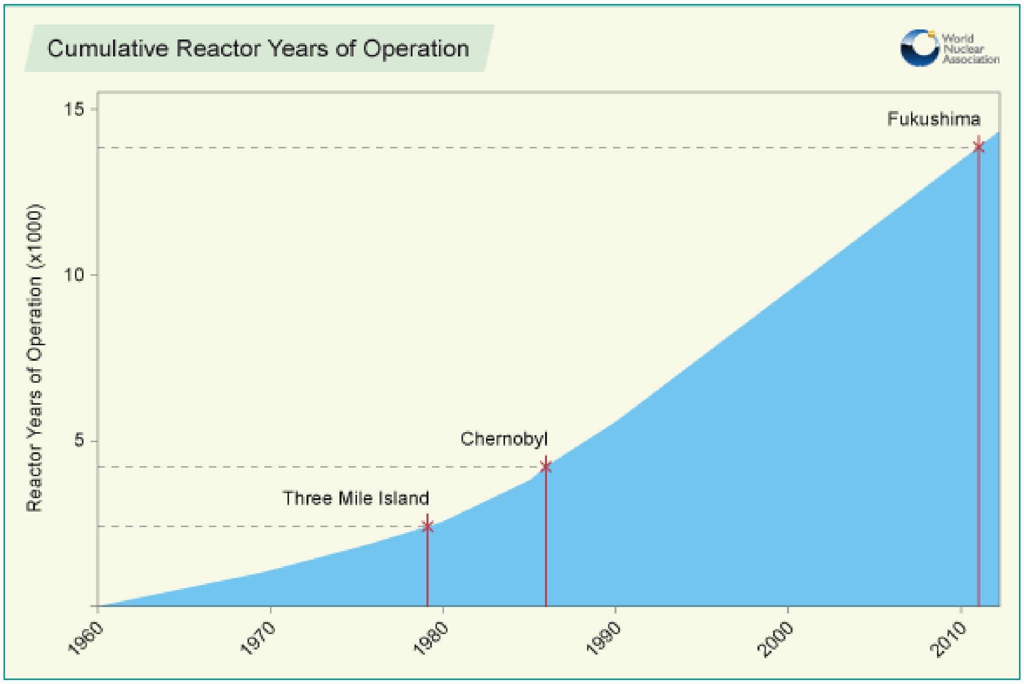


Figure 1: The Three Major Reactor Years of Operation before Accident. Source: [7]

8. Methodology

In this work, probabilistic risk analysis" (PRA), was used to assess risk of failures and comparative analyses techniques was i ntroduced to measure the accidents frequency and magnitude of the past and recent accidents in energy sectors and other relat ed sectors. The data obtained served as the instrument for results presentation.

9. Related Previous Works

Related previous works on the application of comparative analyses techniques of such accidents are available in literature [8-12].

10. Results and Discussion

Risk results are often shown in a general form similar to Table 1, "There are two useful ways to interpret risk estimation resul ts: determining expected risk values, Ri, and constructing risk profiles. Both of these methods are used in quantitative risk an alysis". The Table 1 highlighted general format of risk estimation results.

Table 1: General Format of Risk Estimation Results

Undesirable Even t	Likelihood	Consequences	Risk Level
E_1	P_1	C_1	$R_1 = P_1C_1$

The work and data gathering performed for this study are presented in this section. Although information can vary from sourc e to source, multiple sources are used to compare data and obtain an understanding of the relevant information. It's a matter o f comparison: The chances of experiencing adverse health effects from radiation are slim for both nuclear and coal-fired pow er plants—they're just somewhat higher for the coal ones.

1. Comparism of the Hazards of Using Nuclear Energy and **Some Energy - Related Accidents** in Terms of Frequency and M agnitude

In Table 2 we present the hazards of using energy in terms of accidents since 1975 to 2014

Table 2 Some energy-related accidents since 1975 to 2014. Source: [13]

S/n	**Place of Accident**	Frequency(Year)	Magnitude(Number killed)	**Comments**
1	Banqiao, Shimantan & others, Henan, China	1975	30,000 immediate 230,000 total	hydro-electric dam failures (18 GWe lost)
2	Machchu II, Gujarat, India	1979	2500	hydro-electric and irrigation dam failure
3	Ortuella, Spain	1980	70	gas explosion
4	Donbass, Ukraine	1980	68	coal mine methane explosion
5	Israel	1982	89	gas explosion
6	Guavio, Colombia	1983	160	hydro-electric dam failure
7	Nile R, Egypt	1983	317	LPG explosion
8	Cubatao, Brazil	1984	508	oil fire
9	Mexico City	1984	498	LPG explosion
10	Tbilisi, Russia	1984	100	gas explosion
11	northern Taiwan	1984	314	3 coal mine accidents
12	Chernobyl, Ukraine	1986	47+	nuclear reactor accident, massive radioactive pollution
13	Piper Alpha, North Sea	1988	167	explosion of offshore oil platform
14	Asha-ufa, Siberia	1989	600	LPG pipeline leak and fire
15	Dobrnja, Yugoslavia	1990	178	coal mine
16	Hongton, Shanxi, China	1991	147	coal mine
17	Belci, Romania	1991	116	hydro-electric dam failure
18	Kozlu, Turkey	1992	272	coal mine methane explosion
19	Cuenca, Equador	1993	200	coal mine
20	Durunkha, Egypt	1994	580	fuel depot hit by lightning
21	Seoul, S.Korea	1994	500	oil fire
22	Minanao, Philippines	1994	90	coal mine
23	Dhanbad, India	1995	70	coal mine
24	Taegu, S.Korea	1995	100	oil & gas explosion
25	Spitsbergen, Russia	1996	141	coal mine
26	Henan, China	1996	84	coal mine methane explosion
27	Datong, China	1996	114	coal mine methane explosion
28	Henan, China	1997	89	coal mine methane explosion
29	Fushun, China	1997	68	coal mine methane explosion
30	Kuzbass, Russia/Siberia	1997	67	coal mine methane explosion
31	Huainan, China	1997	89	coal mine methane explosion
32	Huainan, China	1997	45	coal mine methane explosion
33	Guizhou, China	1997	43	coal mine methane explosion
34	Donbass, Ukraine	1998	63	coal mine methane explosion
35	Liaoning, China	1998	71	coal mine methane explosion
36	Warri, Nigeria	1998	500+	oil pipeline leak and fire
37	Donbass, Ukraine	1999	50+	coal mine methane explosion
38	Donbass, Ukraine	2000	80	coal mine methane explosion
39	Shanxi, China	2000	40	coal mine methane explosion
40	Muchonggou, Guizhou, China	2000	162	coal mine methane explosion
41	Zasyadko, Donetsk, 2001 E.Ukraine		55	coal mine methane explosion
42	Jixi, China	2002	115	coal mine methane explosion
43	Gaoqiao, SW China	2003	234	gas well blowout with H2S
44	Kuzbass, Russia	2004	47	coal mine methane explosion
45	Donbass, Ukraine	2004	36	coal mine methane explosion
46	Henan, China	2004	148	coal mine methane explosion
47	Chenjiashan, Shaanxi, China	2004	166	coal mine methane explosion

S/n	Place of Accident	Frequency(Year)	Magnitude(Number killed)	Comments
48	Sunjiawan, Liaoning, China	2005	215	coal mine methane explosion
49	Shenlong/ Fukang, Xinjiang, China	2005	83	coal mine methane explosion
50	Xingning, Guangdong, China	2005	123	coal mine flooding
51	Dongfeng, Heilongjiang, China	2005	171	coal mine methane explosion
52	Bhatdih, Jharkhand, India	2006	54	coal mine methane explosion
53	Ulyanoyskaya, Kuzbass, Russia	2007	150	coal mine methane or dust explosion
54	Zhangzhuang, Shandong, China	2007	181	coal mine flooding
55	Zasyadko, Donetsk, E.Ukraine	2007	101	coal mine methane explosion
56	Linfen city, Shanxi, China	2007	105	coal mine methane explosion
57	Tunlan, Shanxi, China	2009	78	coal mine methane explosion
58	Sayano-Shushenskaya, Khakassia, Russia	2009	75	hydro power plant turbine disintegration
59	Hegang city, Heilongjiang, China	2009	108	coal mine methane explosion
60	Sangha, Bukavu, Congo	2010	235	petrol tanker accident and fire
61	Deepwater Horizon, Gulf of Mexico, USA	2010	11	Oil well blowout, over 4 million barrels of oil caused massive pollution in Gulf of Mexico
62	Pike River, New Zealand	2010	29	coal mine methane explosion
63	Taozigou, Sichuan, China	2013	28	coal mine methane explosion
64	Soma, Turkey	2014	301	coal mine methane explosion and fire

LPG and oil accidents with less than 300 fatalities, and coal mine accidents with less than 100 fatalities are generally not shown unless recent.

- **Serious Nuclear Reactor Accidents**

*Serious accidents in military, research and commercial reactors. All except Browns Ferry and Vandellos involved damage to or malfunction of the reactor core. At Browns Ferry a fire damaged control cables and resulted in an 18-month shutdown for repairs, at Vandellos a turbine fire made the 17-year old plant uneconomic to repair. The Table 3 highlights some s*erious nuclear reactor accidents between 1952 - 2014 of the reactors years.

*Table 3: S*erious nuclear reactor accidents between 1952 – 2014. Source: [14]

S/n	Nuclear Reactor	Frequency (Year)	Magnitude(Immediate Deaths)	Environmental effect	Follow-up action
1	NRX, Chalk R., Canada (experimental, 40 MWt)	1952	Nil	Nil	Repaired (new core) closed 1992
2	Windscale-1, UK (military plutonium-1957 producing pile)		Nil	Widespread contamination. Farms affected (c 1.5 PBq Entombed (filled with concrete) Being demolished. released)	
3	SL-1, USA (experimental, military, 3 MWt)	1961	Three operators	Very minor radioactive release	Decommissioned
4	Fermi-1 USA (experimental breeder, 66 MWe)	1966	Nil	Nil	Repaired and restarted, then closed in 1972
5	Lucens, Switzerland (experimental, 7.5 MWe)	1969	Nil	Very minor radioactive release	Decommissioned
6	Browns Ferry, USA (commercial, 2 x 1080 MWe)	1975	Nil	Nil	Repaired
7	Three-Mile Island-2, USA (commercial,	1979	Nil	Minor short-term radiation dose (within ICRP limits) to public, del	Clean-up program complete, in monitored storage stage of d

S/n	Nuclear Reactor	Frequency (Year)	Magnitude(Immediate Deaths)	Environmental effect	Follow-up action
	880 MWe)			ayed release of 200 TBq of Kr-85	ecommissioning
8	Saint Laurent-A2, France (commercial, 450 MWe)	1980	Nil	Minor radiation release (80 GBq)	Repaired, (Decomm. 1992)
9	Chernobyl-4, Ukraine (commercial, 950 MWe)	1986	47 staff and firefighters (32 immediate)	Major radiation release across E. Europe and Scandinavia (14 EBq or 5.2 EBq I-131 equivalent)	Entombed
10	Vandellos-1, Spain (commercial, 480 MWe)	1989	Nil	Nil	Decommissioned
11	Greifswald-5, E.Germany (commercial, 440 MWe)	1989	Nil	Nil	Decommissioned
12	Fukushima 1-3, Japan (commercial, 1959 MWe)	2011	Nil	significant local contamination (630 PBq I-131 equivalent)	Decommissioned

3. Comparism of NPPs and Coal Power Accidents in terms of Frequency and Magnitude
The magnitude of deaths in coal power is 4000 times per kWh than nuclear power. That is for every person killed by nuclear power generation, 4000 die due to coal. The Table 4 showed comparism of accident frequency and magnitude in coal power generation industry and nuclear power plants(NNPs) industry.

Table 4: Statistics of Coal Power and NPPs Accidents between 2000 to 2009. Source: [15]

S/n	**Year**	**Frequency**(Number of accidents in Coal)	**Frequency** (Number of accidents in NNPs)	**Magnitude**(Deaths in Coal)	**Magnitude**(Deaths in NNPs)	**Magnitude** (Death rate per million tons of coal power accidents)
1	2000	2,863	Nil	5,798	Nil	5.80
2	2001	3,082	Nil	5,670	Nil	5.11
3	2002	4,344	Nil	6,995	Nil	4.93
4	2003	4,143	3	6,434	Nil	4.00
5	2004	3,639	Nil	6,027	Nil	3.01
6	2005	3,341	5	5,986	Nil	2.73
7	2006	2,945	8	4,746	Nil	1.99
8	2007	1,645	Nil	3,770	Nil	1.44
9	2008	1,531	Nil	3,210	Nil	1.18
10	2009	1,616	Nil	2,631	Nil	0.89
	Total	**29,149**	Nil	**51,267**	Nil	**31.08**

4. The Major Hydroelectric Power Failures in terms of Frequency and Magnitude
The frequency and magnitude of the accident in hydroelectric power failures is higher when compared to the records of nuclear power failures. The Table 5 highlighted some major world hydroelectric power generation failures.

Table 5: List of the past world major hydroelectric power failures from 1952 – 2009. Source**:** [16]

Frequency (Year)	Plant	Location	**Magnitude** (Description of loss)	**Magnitude** (Deaths)
2009	Savano – Shushenskaya Dam	Russia	2009 Sayano – Shushenskaya hydro accident, 6 GW power generation loss, 75 fatalities, due to turbine failure	75
2009	Itaipu Dam	Brazil	18 GW power generation loss due to storm damage of transmission lines	-
2000	Biedron Hydroelectric Power Station	Switzerland	1269 MW loss, penstock rupture, three fatalities, flooding and loss of generating capacity	-

1975	Banqiao Dam	China	26,000 dead from direct flooding, 145,000 dead from subsequent famine and epidemics, 11 million homeless. Caused loss of generation, dam failed by overtopping	171,000
1956	Schoellkopf Power Station	Niagara Falls, NY	Destruction of the plant as it fell from the gorge wall and collapsed into the river, caused by water seeping into the back wall of the power station. One worker was killed and damage was estimated at $100 million USD.	-
1952	Sui-ho, Fusen, Kyosen and Choshin Dams	Korea	Due to enemy bombing, attacked during the Korean War resulting in the loss of approximately 90% of North Korea's energy generation capacity	-
1943	Herdecke	Ruhr	132 MW power generation loss, due to overtopping after failure of Mohne dam	-

Let us also see the past serious injury claims by accident types five year average in oil & gas
The Figure 2 presents oil & gas industry statistical overview (2008-2012)

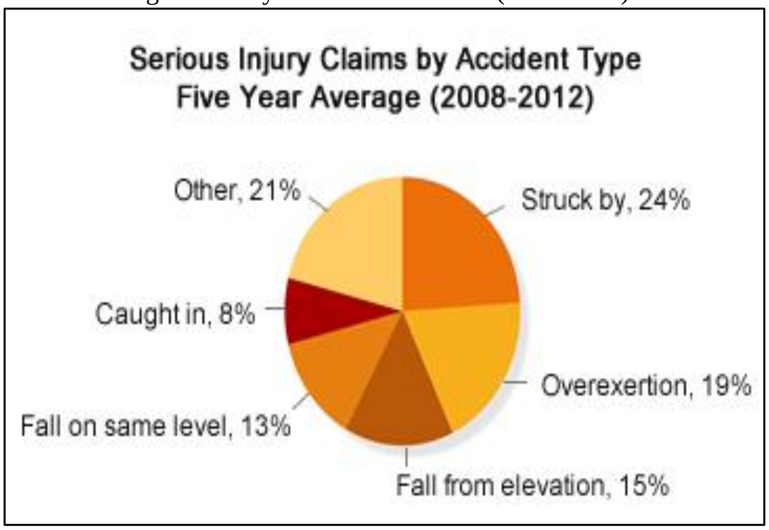


Figure 2. Oil & Gas industry statistical overview (2008-2012). Source: [17]

6. Risk of a Poison Gas Attack Using Gas Cylinders in **World War I**
Chemical weapons in World War I were primarily used to demoralize, injure and kill entrenched defenders, against whom the indiscriminate and generally slow-moving or static nature of gas clouds would be most effective. The types of weapons employed ranged from disabling chemicals, such as tear gas and the severe mustard gas, to lethal agents like phosgene and chlorine. This chemical warfare was a major component of the first global war and first total war of the 20th century. The killing capacity of gas, however, was limited – only four percent of combat deaths were caused by gas.TheTable 6 presented statistics of gas casualties in the World War I.

Table 6:Statistics of Gas Casualties in the World War I. Source: [18]

Estimated gas casualties		
Nation	**Magnitude (Fatal)**	**Magnitude (Non-fatal)**
Russia	56,000	419,340
Germany	9,000	200,000
France	8,000	190,000
British Empire (includes Canada)	8,109	188,706

Austria-Hungary	3,000	100,000
USA	1,462	72,807
Italy	4,627	60,000
Total	**88,498**	**1,240,853**

7. Comparism between Nuclear Power and Transportation Accidents

The Geneva-based Aircraft Crashes Record Office (ACRO) compiles statistics on aviation accidents of **5. Statistics for Oil & Gas Industry**

aircraft capable of carrying more than six passengers, not including helicopters, balloons, or fighter airplanes. It should be not ed that ACRO is not a government or official organization. The ACRO announced in 2008 that the year 2007 was the safest y ear in aviation since 1963p; in terms of number of accidents. There had been 136 accidents registered (compared to 164 in 20 06), resulting in a total of 965 deaths (compared to 1,293 in 2006). Since then, both 2009 and 2010 saw fewer registered acci dents, 122 and 130, respectively. The year 2004 was the year with the lowest number of fatalities since the end of World War II, with 771 deaths. The Table 7 showed the statistics of aircraft accident as at 30 January 1999 to 30 December 2011.

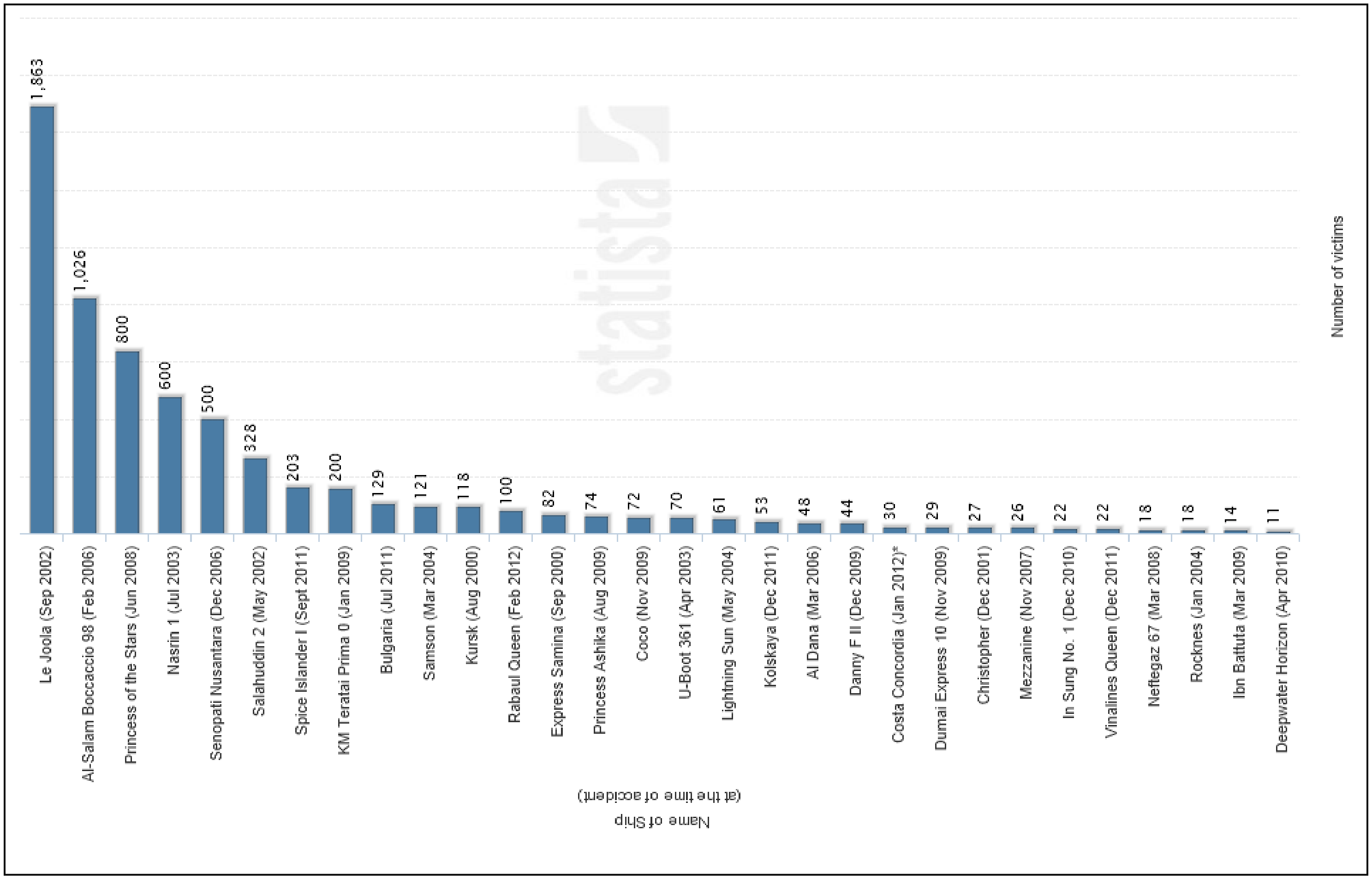
Table 7. Statistics of aircraft accident as at 30 January 1999 to 30 December 2011. Source: [19]

Year	**Magnitude** (DeathsAircraft Accident)	**Magnitude** (Deaths/LossNNPs Accident)	**Frequency** (Number of accidents in Aircraft)	**Frequency** (Number of accidents in NPPs)
2011	828	Japan nuclear accident caused displaced of thousands of people and environmental defect	117	4 number of NNPs affected
2010	1,115	Nil	130	Nil
2009	1,103	Nil	122	Nil
2008	884	Nil	156	Nil
2007	971	Nil	147	Nil
2006	1,294	Nil	166	Nil
2005	1,459	Nil	185	Nil
2004	771	Nil	172	Nil
2003	1,230	Nil	199	Nil
2002	1,413	Nil	185	Nil
2001	4,140	Nil	200	Nil
2000	1,582	Nil	189	Nil
1999	1,138	Nil	211	Nil
Total	**17,928**	Billions of dollars loss	**2,179**	4

In Table 5 it is clear that the year with most fatalities and magnitude was 2001, with 4,140 deaths. Thus, yearly aircraft accide nts fatalities are recorded in which the frequency is greater than one hundred times. Those numbers may be less than the total aircraft accidents fatalities as ACRO only considers accidents in which the aircraft has suffered such damage that it is remove d from service.

The Table 8 showed worldwide ship accidents datasheet as at September 2002 to April 2010 from various source.

Table 8. Worldwide ship accidents datasheet as at September 2002 to April 2010. Top of Form



Source: [20]

8.Compared the Magnitude of Accidents of Nuclear Power and Other Sectors

Risks from reactor accidents are estimated by the rapidly developing science of "probabilistic risk analysis" (PRA). A fuel melt-down might be expected once in 20,000 years of reactor operation. In 2 out of 3 melt-downs there would be no deaths, in 1 out of 5 there would be over 1000 deaths, and in 1 out of 100,000 there would be 50,000 deaths. The average for all meltdowns would be 400 deaths. Since air pollution from coal burning is estimated to be causing 10,000 deaths per year, there would have to be 25 melt-downs each year for nuclear power to be as dangerous as coal burning. Of course deaths from coal burning air pollution are not noticeable, but the same is true for the cancer deaths from reactor accidents. In the worst accident considered, expected once in 100,000 melt-downs (once in 2 billion years of reactor operation), the cancer deaths would be among 10 million people, increasing their cancer risk typically from 20% (the current U.S. average) to 20.5%. This is much less than the geographical variation- 22% in New England to 17% in the Rocky Mountain States.

The Bhopal disaster (commonly referred to as Bhopal gas tragedy) was a gas leak incident in India, considered one of the world's worst industrial catastrophes. It occurred on the night of December 2–3, 1984 at the Union Carbide India Limited (UCIL) pesticide plant in Bhopal, Madhya Pradesh, India. A leak of methyl isocyanate gas and other chemicals from the plant resulted in the exposure of hundreds of thousands of people. The toxic substance made its way in and around the shantytowns located near the plant. Estimates vary on the death toll. The official immediate death toll was 2,259 and the government of Madhya Pradesh has confirmed a total of 3,787 deaths related to the gas release. Others estimate 3,000 died within weeks and another 8,000 have since died from gas-related diseases. A government affidavit in 2006 stated the leak caused 558,125 injuries including 38,478 temporary partial and approximately 3,900 severely and permanently disabling injuries.

9. Compared Radiation Risks of Nuclear Power and Other Sectors.

The principal risks associated with nuclear power arise from health effects of radiation. This radiation consists of subatomic particles traveling at or near the velocity of light-186,000 miles per second. They can penetrate deep inside the human body where they can damage biological cells and thereby initiate a cancer. If they strike sex cells, they can cause genetic diseases in progeny. Radiation occurs naturally in our environment; a typical person is, and always has been struck by 15,000 particles of radiation every second from natural sources, and an average medical X-ray involves being struck by 100 billion. While this may seem to be very dangerous, it is not, because the probability for a particle of radiation entering a human body to cause a cancer or a genetic disease is only one chance in 30 million billion (30 quintillion).

Nuclear power technology produces materials that are active in emitting radiation and are therefore called "radioactive". These materials can come into contact with people principally through small releases during routine plant operation, accidents in nuclear power plants, accidents in transporting radioactive materials, and escape of radioactive wastes from confinement systems. Since natural radiation is estimated to cause about 1% of all cancers, radiation due to nuclear technology should eventually increase cancer risk by 0.002% (one part in 50,000), reducing life expectancy by less than one hour. By comparison, loss of life expectancy from competitive electricity generation technologies, burning coal, oil, or gas, is estimated to range from 3 to 40 days.

Robert Finkelman, a former USGS coordinator of coal quality who oversaw research on uranium in fly ash in the 1990s, says that for the average person the by-product accounts for a miniscule amount of background radiation, probably less than 0.1 percent of total background radiation exposure. According to USGS calculations, buying a house in a stack shadow—in this case within 0.6 mile [one kilometer] of a coal plant—increases the annual amount of radiation you're exposed to by a maximum of 5 percent. But that's still less than the radiation encountered in normal yearly exposure to X-rays.

There has been much misunderstanding on genetic diseases due to radiation. The risks are somewhat less than the cancer risks; for example, among the Japanese A-bomb survivors from Hiroshima and Nagasaki, there have been about 400 extra cancer deaths among the 100,000 people in the follow-up group, but there have been no extra genetic diseases among their progeny. Since there is no possible way for the cells in our bodies to distinguish between natural radiation and radiation from the nuclear industry, the latter cannot cause new types of genetic diseases or deformities (e.g., bionic man), or threaten the "human race". Other causes of genetic disease include delayed parenthood (children of older parents have higher incidence) and men wearing pants (this warms the gonads, increasing the frequency of spontaneous mutations). The genetic risks of nuclear power are equivalent to delaying parenthood by 2.5 days, or of men wearing pants an extra 8 hours per year. Much can be done to avert genetic diseases utilizing currently available technology; if 1% of the taxes paid by the nuclear industry were used to further implement this technology, 80 cases of genetic disease would be averted for each case caused by the nuclear industry.

Very high radiation doses can destroy body functions and lead to death within 60 days, but such "noticeable" deaths would be expected in only 2% of reactor melt-down accidents; there would be over 100 in 0.2% of meltdowns, and 3500 in 1 out of 100,000 melt-downs. *To date, the largest number of noticeable deaths from coal burning was in an air pollution incident (London, 1952) where there were 3500 extra deaths in one week.* Of course the nuclear accidents are hypothetical and there are many much worse hypothetical accidents in other electricity generation technologies; e.g., there are hydroelectric dams in California whose sudden failure could cause 200,000 deaths.

10. Short term severe accident fatalities

In Table 9 the risk assessments considered only short term severe accident fatalities, the reported data indicate that hydroelectric and gas fuel cycles have led to the largest single event fatality numbers. However, to draw conclusions about the relative safety of the various energy systems, fatalities and morbidity - occupational as well as public - over the longer term must be considered and this is parts of the discussion. Equally important are the maturity of the technology, the quality and maintenance of equipment and the safety and environmental controls. The Table 9 is the short-term fatalities for various energy technologies betweenyears 1970 – 1992.

Table 9: Short-Term Fatalities for Various Energy Technologies. Source: [21]

Short-Term Fatalities (1970 – 1992)					
S/n	Energy Description	Events	Fatalities		Average Facilities per GW(e) Per annum
			Range	Total	
1	Coal	133	5 - 434	6418	0.36
2	Oil	295	5 - 500	10 273	0.32
3	Natural gas	88	5 - 425	1200	0.09
4	Liquid Propane gas	77	5 - 100	2292	3.1
5	Hydro	13	10 - 2500	4015	0.8
6	Nuclear	1	31	31	0.01
The total is sum 10 times higher if accidents with less than five fatalities are included					

Nuclear power has the lowest number of short term fatalities per unit of electricity produced out of all the energy technologies studied in [22], with 0.01 average fatalities per year per GWe produced. Coal electricity generation has a value of 0.32 average fatalities per year per GWe produced. Note too that the value for coal is in the 3.0 range if accidents with less than five fatalities are included. This means that coal electricity generation results in 30 times to 300 times the average fatalities per year per unit of electricity produced as nuclear electricity generation[23].

On March 11, 2011, Japan was hit by a 9.0 magnitude earthquake followed by a 14-foot tsunami. The earthquake caused the Fukushima Daiichi nuclear power plants, owned by Tokyo Electric Power Company (TEPCO), to shut down. This is a normal response to an earthquake; the plants were in the process of safely shutting down, and the plant was receiving power from the onsite diesel generators. Future cancer deaths resulting from the radiation release during the accident are estimated to be between 100 and 1000 deaths, although statistically significant evidence of increased cancer deaths due to this event is not expected to be realized since the radiation exposure for the majority of the population living near the Fukushima site is small when compared to background radiation. In a separate study conducted by Eisenbud and Petrow[24],when comparing only radioactive emissions, assuming a 97.5% fly ash capture, it was found that coal plants released more contaminants to the atmosphere than nuclear plants. That study was later updated to account for a 99% capture of fly ash and the creation of As Low As Reasonably Achievable (ALARA) requirements. ALARA is a regulation controlling the amount of radiation that workers are exposed to. The Table 10 explained the results of that study.

Table 10: Comparing only radioactive emissions. Source: [25].

Summary of Maximum Individual Doses from Airborne Releases of a 1000 MWe Plant Energy Technology	Whole Body (Sv x 10- 5)	Bone (Sv x 10- 5)
Coal- Fired Power Plant	1.9	18.2
BWR	4.6	5.9
PWR	1.8	2.7

This study concluded that Americans living near coal combustion plants actually are exposed to higher radiation doses than those living near nuclear plants. Total expected radioactivity release from coal combustion from 1937 through 2040 is projected to be 477,027,320 millicuries. It is found that 1000 MWe coal-fired power plants expose the population to 490 person-rem/year, and 1000 MWe nuclear power plants expose the population to 4.8 person-rem/year. Figure 6 shows this comparison graphically. The Figure 3 presents radiation exposure to the public from 1000 MWe power plants.

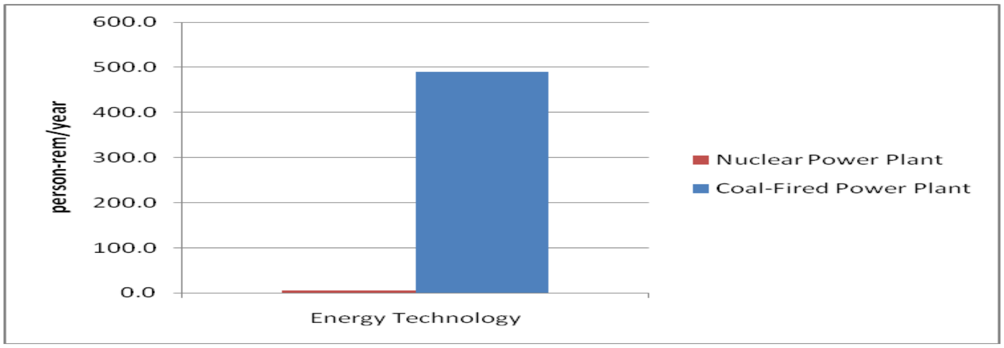


Figure 3: Radiation Exposure to the Public from 1000 MWe Power Plants

The radiation exposure to the public from a coal-fired power plant is an order of magnitude higher than the radiation exp osure to the public from a nuclear power plant. Additionally, the total population dose for the complete nuclear fuel cycle is o nly 136 person-rem/years. This includes mining, reactor operation, and waste disposal. The total population dose for the com plete coal fuel cycle is unknown [26]. Report found that the external health and environmental costs are much higher for coal-fired power plants than nuclear power plants [27]. It can be inferred from this conclusion that coal-fired power plants are mor e detrimental to the environment and public health than nuclear power plants.

Studies have shown that in the absence of a nuclear power plant accident, the coal-fired plant industry has a higher leuke mia incidence risk when compared to the nuclear industry [28]. It would require an additional 40 nuclear reactors in the US f or the nuclear industry to expose the public to the same risk of leukemia incidence as the US coal industry back in the late 19 80s. A concern of nuclear power plants is the potential for nuclear accidents, such as the Three Mile Island (TMI) and Fukush ima accidents. Studies on the TMI accident indicated an increased cancer rate of 2 lifetime cancer incidences for the 2.2 milli on people within 50 miles of the plant. However, the additional 2 lifetime cancer incidences are indiscernible from the expect ed 540,000 incidences of cancer for 2.2 million people.

In the energy sector, dam failures and overlapping have caused thousands of deaths and massive disruptions in social and economic activities with the displacement of entire towns — the Variant dam overlapping in Italy and dam failures in Gujara t and Orissa in India are three such examples, each with several thousand fatalities. Explosions and major fires in the oil and gas industry have involved both occupational and public fatalities and injuries. A pipeline gas leak explosion in the Urals inv olved 500 fatalities. Energy sector accidents have also led to severe environmental damage, such as the 1989 ``Exxon Valdez' ' oil-tanker accident in Alaska.

11. Deaths from energy-related accidents per unit of electricity

The main metric used to assess reactor safety is the likelihood of the core melting due to loss of coolant. These new desig ns are one or two orders of magnitude less likely than older ones to suffer a core melt accident, but the significance of that is more for the owner and operator than the neighbours, who - as Three Mile Island and Fukushima showed - are safe also with older types. The Figure 4 explained the deaths from energy-related accidents per unit of electricity considering 1943 accident s with more than five fatalities.

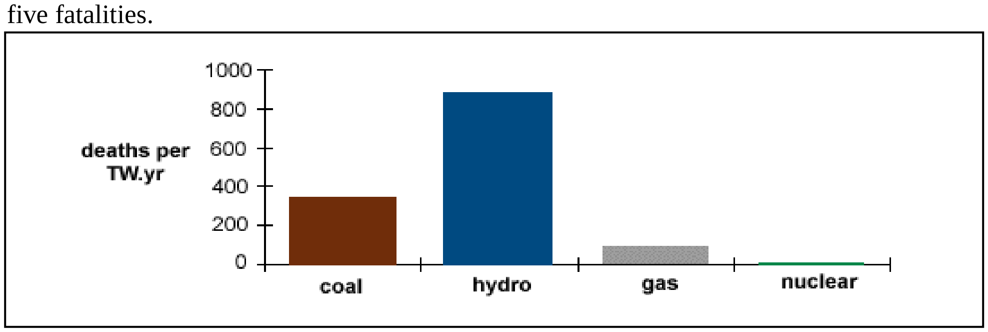


Figure 4: Deaths from energy-related accidents per unit of electricity

One TW.yr is the amount of electricity used by the world in about five months. Coal-fired power generation has chronic, rather than acute, safety implications for public health. It also has profound safety implications for the mining of coal, with th ousands of workers killed each year in coal mines.

with 18 GWe lost. In 1979 and 1980 in India some 3500 were killed by two hydro-electric dam failures, and in 2009 in Russia 75 were killed by a hydro power plant turbine disintegration.

A major reason for coal's unfavourable showing is the huge amount which must be mined and transported to supply even a single large power station. Mining and multiple handling of so much material of any kind involves hazards, and these are reflected in the statistics. The Table 11 is the summary of severe accidents in energy chains for electricity 1969-2000.

Table 11: Summary of severe accidents in energy chains for electricity 1969-2000. Source: [29]

S/n				D	
1	Energy chain	Fatalities	Wy		Wy
2	Coal	2259	157	18,000	597
3	Natural gas	1043	85	1000	111
4	Hydro	14	3	30,000	10,285
5	Nuclear	0	0	31	48

In Table 12 present a compassing of accident statistics in primary energy production

Table 12: Comparison of accident statistics in primary energy production. Source: [30]

S/n	**Fuel**	**Immediate fatalities 1970-92**	**Who?**	**Normalised to deaths per TWy electricity**
1	Coal	6400	workers	342
2	Natural gas	1200	workers & public	85
3	Hydro	4000	public	883
4	Nuclear	31	workers	8

Basis: per million MWe operating for one year, not including plant construction, based on historic data which is unlikely to represent current safety levels in any of the industries concerned. In the UK, Friends of the Earth commissioned a study by the Tyndall Centre, which drew primarily on peer-reviewed academic literature, supplemented by literature from credible government, consultancy and policy sources. It concluded in January 2013 that "Overall the safety risks associated with nuclear power appear to be more in line with lifecycle impacts from renewable energy technologies, and significantly lower than for coal and natural gas per MWh of supplied energy."

12. The Advantages of Having Nuclear Power Plants

Advantages of civil nuclear power have made it a significant part of the energy mix in most industrialized countries since the 1960s. U.S. government statistics show that in 2009, nuclear reactors produced 20.2% of the nation's electricity, worldwide, it was 13.8 percent. The following are the advantages of NPPs.

(a)Environmental Friendliness

Under normal accident-free conditions, nuclear power generation is comparatively friendly to the environment and is reliable as regards both fuel supply and power delivery**.** Nuclear power plants can help preserve the environment by lessening the dependence on fossil fuels as a source of energy. The burning of gas, oil and coal is believed by some environmentalists to contribute to atmospheric problems such as global warming and acid rain. Since nuclear plants produce power without relying on these resources, they can help create cleaner air for plants and animals especially. Increased awareness of global climate change and fossil-fuel dependence issues brought increased favorable attention to civil nuclear power in the decade before the 2011 nuclear power plant accident in Japan.

(b) Safety

Despite well-publicized accidents such as Three Mile Island and Chernobyl, nuclear plants have proven to be relatively safe. According to Ecolo.org, the chances of dying as the result of a nuclear power plant disaster is lower than dying from heart disease, fire, homicide or motor vehicle accident. The website also indicates that the burning of coal could lead to a widespread virus due to the chemicals produced and set free in the environment.

© Energy Supply

Since the energy produced by nuclear power plants is man-made, it means that there is less of a need to depend on natural resources. This eliminates the concern about running out of energy due to exhausting the world's resources.

Uranium, which is the primary source of nuclear fuel is used for no other primary purpose and exists in abundant quantities, enough to last for billions of years.

(d) Cost Savings

Nuclear power plants can produce energy in a more cost-effective manner. According to Public Broadcasting Service (PBS.org), the cost per kilowatt-hour of nuclear electricity is N192. By comparison, natural gas costs N268 and the cost of oil is N377. Nuclear electricity is only slightly more expensive than coal-fired electricity, which costs N188 per kilowatt-hour.

(e) Waste Disposal

Though nuclear waste can be dangerous if not disposed off properly, it has the advantage of being small in quantity and can be buried deep under the ground. This virtually eliminates the danger caused by possible exposure. Nuclear power plants consume uranium, which differs from coal energy production which produces uranium as a waste product that stays at the surface.

(f) Environmental Impacts

An overwhelming advantage of civil nuclear power is that, except during severe accidents, there is almost no release of pollutants into the environment. A comparative assessment of alternate energy sources by the International Atomic Energy Agency (IAEA) enumerates comparative advantages of civil nuclear power over other fuel sources. Coal-fueled power plants continuously release huge amounts of pollutants that degrade air quality, acidify lakes and produce slag heaps that must be remedied. *Hydroelectric developments submerge large areas of land under water, causing population displacements and ecosystem changes.*

(g) High Energy Density

The IAEA assessment cites the statistic that 30 tons of uranium and 2.6 million tons of coal contain equal amounts of energy. The extremely high energy content of nuclear fuel brings many advantages. Large rail transport networks for fuel delivery, or pipelines cutting across environmentally fragile areas are not needed. The volume of waste produced is minute compared with the other alternatives; this leads to one of the principal cited advantages of civil nuclear power -- waste is confined rather than dispersed. Since transport of fuel -- or waste -- is easy, civilian nuclear reactors can be built close to where the power is to be used, eliminating the need for long transmission lines.

(h) Reliability

According to the IAEA assessment, the world's proven uranium reserves would last well past year 2060 at the current consumption rate. The largest deposits are in reliable and politically stable Canada and Australia. These nuclear energy reserves can be extended far into the future with the use of advanced technologies such as reprocessing of used fuel or the introduction of thorium as an alternate to uranium. Civil nuclear power plants produce very large amounts of electricity with almost perfect reliability, a primary requirement for heavy industry. *Solar and wind power lack this advantage*.

(i) District Heating, Propulsion and Desalination

Civil nuclear power has applications other than production of electricity. Low-temperature heat, a byproduct of nuclear power plants, is used in many countries for directly heating buildings and supplying process heat to industry; it is also used for desalinating sea water in many arid regions. Russia operates a fleet of about a half-dozen nuclear-powered icebreakers: they require refueling only about once every four years. Russia is also considering smaller "floating" nuclear power reactors, which can be moved to smaller coastal settlements to provide electricity.

13. Conclusion

The research aim to carry out comparative analysis of power generating methods in terms of accident frequency and magnitude so as to find a way of changing one negative believed that nuclear energy is pro to accident and should not be consider as an option for energy production and in line with the objectives, the following have being achieved;

(i) Extant literature review has been carried out on accident frequency and magnitude of various energy generating system including nuclear energy and other social- economic development sectors.

(ii) Assessment of energy sector and other social- economic development sectors in terms of accident frequency and magnitude

(iii) Record taken of accident frequency and magnitude of various energy generating system including nuclear energy for the generation of electricity and other social- economic development sectors.

(iv) Accident frequency and magnitude of various energy sources and other social- economic development sectors have been compared

(v) Economic advantages of having nuclear energy as an option have been highlighted.

(vi) This study provides a good, novel approach and method for multi-objective decision-making based on seven dissimilar objectives attributes**:** evolving technology, effectiveness, efficiency, cost, safety, failure and economy.

In almost every aspect, nuclear power plants appear to be the more desirable technology for the future when compared to coal-fired power plants, hydro energy chains, natural gas, oil and others. As it is better safe in terms of accident frequency and magnitude, especially when taking into consideration the rate of a death and loss in of failure; if future government regulations are ever enacted to control radiation release for coal-fired power plants, electricity generation from nuclear power plants would become an even more attractive option. coal-fired power plants physically produce more waste per unit of electricity produced than nuclear power plants; nuclear power plants have been shown to be much safer to the environment, to the workers, and to the surrounding population than coal-fired power plants. The safe operation of a nuclear power plant is generally acknowledged as contributing to society's success and promoting economic performance within those member states that have a nuclear electricity generation capacity. No technology that is perfectly safe. Chasing perfection can cause us to ignore just im proving and trading worse for a lot better. Non-roof installations of solar are safer than roof installation. Nuclear, wind, solar and hydro energy chains is a lot safer than coal and oil. Natural gas is safer but not as much as nuclear and those others. The f ocus needs to be on getting rid of the most dangerous energy sources which are coal and oil first.

Developing country like Nigeria will require a secure electricity supply to meet expected future demand which is an essential requirement for economic development as envisaged under the government's growth and poverty reduction strategy. Althoug h preparatory works to attain Milestone 2 are being put in place, it is evident that the government has shown some commitme nt at least to an extent in the actualisation of the nuclear power programme given its short time from 2006 when NAEC beca me operational. Nigeria is presently in phase two of the development of the infrastructure for a nuclear power programme get ting ready to invite bids. With the signing of international and bilateral agreements with countries like Russia and South Kore a and the signing and ratification of treaties, conventions and protocols, it shows that the country means it to use nuclear pow er for peaceful socio-economic purposes only. NAEC, NNRA and ECN are putting in place programmes to relate with the pu blic on its various activities in order to address public perception during the successful implementation of the nuclear power p rogramme.

Suggestions for Overcoming Risk Challenges:

Nuclear option is needed in the energy sector not only for power generation but for socio-economic development, industr ial revolution and educational development of the nuclear technology. Nigeria and other developing nations need awareness i n the following areas of nuclear power development strategy;

Selection of type of reactor for nuclear power plant, Human resource needs, Extent of the uranium resources in the coun try and impact on the fuel policy, Public Acceptance of Nuclear Power Plant, Nuclear Security and Safety Assurance and Ins urance, Life and Environmental Protection, Radiation Protection.

Comparing the use of nuclear power with other related sectors in terms of accident frequencies and magnitudes it was dis covered that nuclear is safer. So while electricity production through hydro energy chains, natural gas, petroleum, coal-fired p lants and others may be necessary due to the sheer magnitude of global energy requirements, it is clear that nuclear power sho uld play a much larger role in the future energy development.

Acknowledgments

We thank Department of Physics, Nigerian Defence Academy (NDA) Kaduna, Nigeria Atomic Energy Commission, Ene rgy Commission of Nigeria, Nigerian Nuclear Regulatory Authority, Energy Commission of Nigeria and the Department of Mathematics, Ahmadu Bello University (ABU) Zaria, Nigeria, for the human and material support during the research work. Finally, we thank the authors and establishments that we used their material and intellectual property in the course of this pap er.

References

[1] IAEA, 2008. Analysis of Severe Accidents in Pressurized Heavy Water Reactors [pdf] Available at: <http://*www-pub.iaea.org/MTCD/publications/PDF/te_1594_web.pdf*>

[2] Hiroshi Sekimoto 2007 Nuclear Reactor Theory and Reactor Analysis"Innovative Nuclear Energy Systems for Sustainable Deve lopment of the World" (COE-INES) Tokyo Institute of Technology. Copyright © 2007. The 21st Century Center of Excellence Program

[3]U.S.NRCLibrary, 2013**.** Backgrounder on the Three Mile Island Accident.Availableat: <http://www.nrc.gov/reading-rm/doc-coll ections/fact-sheets/3mile-isle.html>

[4]F. Mayinger 1997, Status of thermohyraulic research in nuclear safety and new challenges. Eight international tropical meeting o n nuclear reactor thermo hydraulic kyolo, Japan September 30 to October 4, 1997, Proceedings Volume 3. Lehrstuhl a fur ther modyn Technische Universitat Mur Boltzmannstrabe 1585748 Garching Germany.

[5] U.S. Atomic, Energy Commission Regulatory Directorate of Regulatory Standards 1974. Regulatory Guide 1.77"Assumptions Used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors" May 1974 Guide

[6] Farhad pour farhad-Ali. 1976. The unsteady state operation of chemical reactors. Ph.D. University of London Ramsay memorial laboratory department of chemical engineering university college London Torrington place London WC1 December 1976

[7] WNA 2014. Safety of Nuclear Power Reactors. World Nuclear Association updated April 2014. Available at http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Safety-of-Nuclear-Power-Reactors/

[8]Yuji M. 2012, Summary and evaluation of cost calculation for nuclear power generation by the cost estimation and review comm ittee. IEEJ May 2012

[9] Nils S. and Carl-Erik W. Economic Analysis of Various Options of Electricity Generation - Taking into Account Health and Env ironmental Effects. Örnbogatan 41 SE 167 66 Bromma Sweden.

[10] Fortum Power and Heat Oy 2007. Safety assessment of the Loviisa nuclear power plant. Statement regarding the licence applic ation concerning the operation of the Loviisa nuclear power plant. Radiation and Nuclear Safety Authority.STUK-B 81 / Octob er 2007.
[11] Stephen J. 2011. Comparative Assessment of Coal-Fired and Nuclear Power Plants. Master of Engineering in Mechanical Engi neering, December 2011
[12] OECD 2010 NEA No. 6861. Comparing nuclear accident risks with those from other energy sources. Nuclear Development IS BN 978-92-64-99122-4.Available at:
www.oecd-nea.org/ndd/reports/2010/nea6862-comparing-risks.pdf
[13] WNA 2014. The hazards of using energy Updated May 2014. World Nuclear Association, registered in England and Wales, nu mber 01215741. Registered office: 22a St James's Square London SW1Y 4JH United Kingdom. Available at: http://www.worl d-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Appendices/Safety-of-Nuclear-Power-Reactors---Appendix/
[14] WNA 2014. Serious nuclear reactor accidents Updated May 2014.. World Nuclear Association, registered in England and Wale s, number 01215741. Registered office: 22a St James's Square London SW1Y 4JH United Kingdom. Available at: http://www. world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Appendices/Safety-of-Nuclear-Power-Reactors---Appendix/
[15] Coal Accident 2014. Statistics of Coal Power Accidents, updatedJanuary 2014. China state administration of work safety. Avai lable at: http://en.wikipedia.org/wiki/Coal_in_China
[16] Wikipedia 2013. List of hydroelectric power failures, last modified on 11 December 2013. Available at: http://en.wikipedia.org /wiki/List_of_hydroelectric_power_station_failures
[17] WorkSafeBC Business Information & Analysis 2013. Oil & Gas industry statistical overview (2008-2012), July 2013. Availabl e at:
http://batuaksoy.wordpress.com/2013/09/12/statistics-for-oil-gas-industry-oil-gas-industry-statistical-overview-2008-2012/
[18] Haber, Ludwig Fritz (1986). The poisonous cloud: chemical warfare in the First World War. Oxford University Press. p. 70. IS BN 0-19-858142-4.
Available at: http://www.wzaponline.com/PoisonGas.pdf
[19] ACRO 2012. Statistics of aircraft accident as at 30 January 1999 to 30 December 2011. Source: Geneva-based Aircraft Crashes Record Office (ACRO) Retrieved 7 May 2012.
http://en.wikipedia.org/wiki/Aviation_accidents_and_incidents
[20] "Transport Accident Investigation Commission". TAIC. Retrieved 9 May 2012.
[21] Short-Term Fatalities for Various Energy Technologies. Available at: http://www.iaea.org/Publications/Booklets/Development/ devseven.html
[22] S. M. Rashad, and F.H. Hammad 2000. Nuclear power and the environment: comparative assessment of environmental and he alth impacts of electricity-generating systems. National Centre for Nuclear Safety and Radiation Control, Atomic Energy Auth ority, 3, Ahmed El Zomer, Journal of Applied Energy 65 (2000) 211- 229. Available at: www.elsevier.com/locate/apenergy
[23] Eisenbud M. and Petrow H. 1964. Radioactivity in the Atmospheric Effluents of Power Plants That Use Fossil Fuels. *Science*, 1964.
[24] McBride, J. et al. 1978. Radioactive impact of airborne effluents of coal and nuclear plants. ScienceMagazine. December *1978*: Vol. 202 no. 4372 pp. 1045-1050.
[25] Gabbard A. 1993. “Coal Combustion: Nuclear Resource or Danger,” Oakridge National Laboratory Review, 1993. ***ORNL Revi ew*** Vol. 26, No. 3&4, ***1993***
[26] EUR 20198. 2003. “External Costs: Research results on socio-environmental damages due to electricity and transport”. Publica tions European Commission Community Research, 2003. ISBN 92-894-3353-1.Information and Communication Unit, B-1049 Brussels
Available at: http://ec.europa.eu/research/energy/pdf/externe_en.pdf
[27] Prybutok, Victor R., and Gold, Leonard M. 1987. Modeling for comparison of leukemia incidence risk between nuclear and co al power industries. Journal of Hazardous Materials, 26(1991), Elsevier Science Publishers B.V., Amsterdam 319-33. Availabl e at:http://www.ewp.rpi.edu/.pdf
[28] Ad Hoc Population Dose Assessment Group, 1979. “Population Dose and Health Impact of the Accident at Three Mile Island Nuclear Station (A Preliminary Assessment for the Period March 28 Through April 7, 1979),” U.S. Nuclear Regulatory Commi ssion (May 10, 1979).
[29] OECD 2010. European Commission takes part in the work of the *OECD* an impressive collection of *data* assembled by the *Pau l Scherrer Institute* (PSI). Available at:
http://www.oecd-nea.org/ndd/reports/2010/nea6862-comparing-risks.pdf
[30] Ball, Roberts & Simpson, 1994. Safety of Nuclear Reactors - World Nuclear Association
Available at: www.world-nuclear.org/info/...of.../Safety-of-Nuclear-Power-Reactors/