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Nuclear Power and Environment
Comparative Assessment of Environmental and Health Impacts of Electricity Generating Systems

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ABSTRACT

This paper deals with comparative assessment of the environmental and health impacts of nuclear and other electricity generation systems. The study including normal operations and accidents in full energy chain analysis. The comparison of the environmental impacts arising from the waste management cycles associated with non emission waste are also discussed.

Nuclear Power while economically feasible and meeting 17% of the world's demand for electricity is almost free of the air polluting gases that threaten the global climate. Comparing nuclear power with other sources for electricity generation in terms of their associated environmental releases of pollutant such as SO_2, NOX, CO_2, CH_4 and radioisotopes, taking into account the full fuel chains chains of supply option, nuclear power will help to reduce environmental degradation due to electricity generation activities. In view of CO_2 emission, the ranking order commences with hydro, followed by nuclear, wind and photovoltaic Power Plants. CO_2 emissions from a nuclear power plant are by two orders of magnitude lower than those of fossil fueled power plants.

A consequent risk comparison between different energy sourceshas toinclude al phases of the whole energy cycle. Coal mines accidents have resulted in several 1000 acute deaths over the years. Later fatalities have never been estimated. Then came hydropower, also resulting in many catastrophes and losses of human lives. Followed oil and gas energy industry, its tribute in acute fatalities is expressed in more than 1000 lifes lost. No estimate is available concerning later fatalities. latest in the list is commercial nuclearenergy, badly illustrated by the Chernobyl accident resulting officially in 31 acute fatalities, 145 latent fatalities, and 135000 evacuated individuals.

The paper offers some findings and conclusions on the role of nuclear power in protecting the global environment.

Key words: Full chain-Energy Systems – Health – Environmental Impact – Comparative Assessment.

THE ROLE OF NUCLEAR POWER

Nuclear Power can play an important role for the sustainable of energy. The resources base is large. Current estimates are that uranium resources will last some 400 to 500 years at the present rate of use. This resource base could furthermore, last some 50 times longer if breeder reactors were introduced [GTDC, 1995].

The fossil fuels such as coal, petroleum, natural gas and oil shale have made and are still making great contribution to the progress of human society (Fig. 1), however they are all non renewable energy sources. In addition they have limited reserves and uneven geographical distribution. It is estimated that the exploitable reserve of coal of the world is about 760 billion tons, petroleum 95.8 billion tons and natural gas about 9800 billion cubic meters. If calculated at the current rate of consumption, there will be decades of consumption, for the proven reserves of petroleum and natural gas and hundreds of years for coal.

A total of 443 nuclear power plants are currently operating in 32 countries around the world, During 1996, construction of three new nuclear reactors started bringing the total number of nuclear reactors reported as being under construction to 35 in 14 countries world wide in 1996, total nuclear generated electricity grew to 2300 TWh. This is more than the world's total electricity generation 1912 TWh - from all sources in 1958. Overall nuclear power plants provided approximately 17% of the world's electricity production in 1996. (Fig.1), Cumulative worldwide operating experience from civil nuclear reactors at the end of 1996 was over 8135 years, 18 countries relied upon nuclear power plants to supply at least a quarter of their total electricity needs.

Nuclear energy has played a major role in reducing the world's use of oil for electricity generation over the past two decades. Based on an evaluation of all fuels (coal, oil and natural gas) that would have been used to generate electricity if nuclear energy plants had not been built, from 1973 - 1989, nuclear energy displaces the burning of a cumulative total of 15.5 billion barrels of oil world wide. Oil generated less than 10% of the world's total electricity in the 1990's compared to more than 25% in 1973.

Advanced designs are been developed for all types of reactors. The main goals of the designers and manufactures are to: improve the economics of nuclear power, reduce the residual risk of accident, reduce the emissions and residuals, including radioactive waste from routine operation of nuclear facilities, expand the resource base and broaden the range of applicability of nuclear power.

In an increasingly competitive and international global energy market, a number of key factors will affect not only the energy choice but also the extent and manner in which different energy sources are used. These include: optimal use of available resources; reduction of overall costs; minimizing environmental impacts; convincing demonstration and safety; and meeting national and global policy needs. For nuclear energy and other options these five factors will determine the future of energy mix and strategies, at the national and global levels.

ENERGY DENSITY COMPARISONS (FUEL AND LAND REQUIREMENTS)

The quantity of fuel used to produce a given amount of energy - the energy density- determines in a large measure the magnitude of environmental impacts as it influences the fuel extraction activities, transport requirements, and the quantities of environmental releases and waste. The extraordinary high energy density of nuclear fuel relative to fossil fuels is an advantageous physical characteristic [IAEA, 1997].

One kilogram (kg) of firewood can generate 1 kilowatt-hour (kW.h) of electricity. The values for the other solid fossil fuels and for nuclear power are:

1 kg coal:	3 kW.h
1 kg oil:	4 kW.h
1 kg uranium:	50 000 kW.h
	(3 500 000 kW.h with reprocessing)

Consequently, a 1000 MW (e) plant requires the following number of tones of fuel annually [IAEA, 1997].

2 600 000 t coal:	2000 train cars (1300 t each)
2 000 000 t oil:	10 supertankers
30 t uranium:	reactor core (10 cubic meters)

The energy density of fossil and of nuclear fuel allows relatively small power plant areas of some several square kilometers (km^2). The low energy density of renewable, measured by land requirements per unit of energy produced, is demonstrated by the large land areas required for a 1000 MW(e) system with values determined by local requirements and climate conditions (solar and wind availability factors ranging from 20 to 40%):

Fossil and nuclear sites:	1-4 km^2
Solar thermal or photovoltaic (PV) parks:	20-50 km^2 (a small city)
Wind fields:	50-150 km^2
Biomes plantations:	4000-6000 km^2 (a province)

ENERGY REQUIREMENTS OF ELECTRICITY GENERATION TECHNOLOGIES

Net energy analysis in power generation has been introduced as a feasible and practical method for evaluating the engineering, economic and environmental aspects of power generation systems. It compares total direct and indirect energy investment in construction and operation of power plants with their life time energy output.

A number of studies have been performed considering net energy analysis for electricity generation technologies, including fossil fueled technologies (large scale coal, oil and natural gas fired), nuclear power and renewable energy systems (small - medium hydro, geothermal, wind, wave, tidal, ocean thermal energy conversion, solar thermal, photovoltaic, and gasified biomes power plants) [IAEA, 1994], [San Martine, R.L., 1989].

The analyzed technologies are investigated on total energy processes through their processing, transportation and use in power plants, the dismantling of power plants to management and disposal of wastes.

Electricity generation systems consume fossil fuels directly and indirectly in the various activities of the full energy chain. Fig. 2 gives the rates of fossil fuel consumption associated with the direct and indirect energy consumption for generating 1 kW.h of net electricity [IAEA, 1996]. These rates were obtained by subtracting input electricity from output electricity. The consumption rates are highest for fossil-fueled power plants: 2 455; 2 518; and 2 687 kca/kWh for oil, coal and LNG power plants, resp. Fossil-fueled power plants, resp. Fossil-fueled power plants burn large amounts of fossil fuels: 96%; 95% and 85% of total amount of fossil fuel for oil, coal and LNG-fired plants. Nuclear, hydro and geothermal power plants have the lowest fossil fuel consumption: one to two orders of magnitude smaller than that of renewable energy and fossil fuel power systems.

Table (1) gives a comparison between large scale power generation technologies, output/input energy ratio, and net energy supply during the plant life of 30 years were estimated [IAEA, 1994].

From the results of the study nuclear and fossil fired power plants are net energy producers and are capable of supplying large amounts of electricity. Among renewable energy technologies, hydro and geothermal power plants are superior on the basis of energy analysis because of their higher energy density.

ENVIRONMENTAL IMPACTS

Although the use of electricity is relatively benign, its generation is one of the world's environmentally damaging activities, while the energy sector contributes 49% of greenhouse gases, electricity generation alone produces more than 25% of energy related carbon dioxide emissions. During the past 20 years, half of all increases in energy related carbon dioxide emissions were from electricity [IAEA, 1996], [Ellis, J., Peake S., 1995].

Emissions to the environment have been the principal focus of energy impact studies other significant impacts such as land disturbance and population displacement together with their economic and social implications are less emphasized. Major impacts such as depletion of natural resources and large fuel and transport requirements that influence a wide range of areas including occupational and public safety as well as national transport systems are generally ignored. The quantity of toxic pollutants and waste generated from fossil fuel plants are much more than the quantities from other energy options (Fig. 3). In general, the pollution depends on the impurity level of the fuel, with natural gas cleaner than oil and oil cleaner than coal.

A 1000 MW (e) coal plant without abatement technology produces annually an average of some 44 000 tonnes of sulphur oxides and 22 000 tonnes of nitrous oxides that are dispersed into the atmosphere. Additionally, there are 320 000 tonnes of ash containing 400 tonnes of heavy metals - arsenic, cadmium, cobalt, lead, mercury, nickel and vanadium - quantities which ignore energy chain activities such as mining and transportation [IAEA, 1997], [Pirila, P. et al., 1986], [UNDP, 1995].

Fossil fuel plants using modern abatement technology can decrease noxious gas releases as much as ten-fold, but significant quantities of solid waste can be produced in the process. Depending on the sulphur content, solid waste quantities from sulphur abatement procedures for a 1000 MW(e) plant are annually as much as 500 000 tonnes from coal, more than 300,000 tonnes from oil and some 200 000 tonnes from natural gas sweetening procedures (Fig. 3) The waste, which contains small quantities of toxic substances, is commonly stored in ponds or used for landfall and other purposes. Regulatory bodies are increasingly categorizing such waste as hazardous.

Table 1: Large Scale Power Generation Technologies [IAEA, 1994]

(plant lifetime: 30 years)

Power plant	*Coal-fired*	*Oil-fired*	*LNG-fueled*	*PWR*
Plant capacity [MW]	1000	1000	1000	1000
Capacity factor [%]	75	75	75	75
Auxiliary power in-house consumption rate [%]	7.4	6.1	3.5	3.4
Electricity generated GW. [h / a]	6084	6169	6340	6347
Fuel [Tcal / a]	14 488	14 488	14 488	16 866
Capital energy				
Fuel extraction [Tcal/a]	6.9	10.7	4.3	
Transportation [Tcal/a]	8.4	5.7	10.6	0.0
Plant [Tcal]	748.4	582.2	582.2	967.4
Operational energy [Tcal/a]				
Fuel extraction	387.4	160.7	2070.0 (liquefaction)	0.6
Oil-refining		314.2		
Milling				24.1
Conversion				12.9
Enrichment				297.5
Fabrication				4.8
Transportation	333.3	129.2	410.9	0.3
Generation	37.4	29.1	29.1	48.4
Energy payback time [a]	0.09	0.08	0.09	0.07
Energy ratio	17.15	20.75	5.61	17.40
Net energy balance [GW.h]	171 871	176 157	156 278	179 455

Note: Energy pay-back time = [capital energy for plant + operational energy x 30 years] / [electricity produced - operational energy].

Energy ratio = electricity produced x 30 years - [capital energy except for plant x 30 years + capital energy for plant + operational energy x 30 years].

Net Energy Balance = electricity produced x 30 years -[capital energy except for plant x 30 years + capital energy for plant + operational energy x 30 years].

Table (2) presents emissions in Kg/GW.h of power generating systems, for the full energy chain including the full energy chain including the fuel cycle and the construction of the plant.

Table 2: Emissions of Power Generating Systems [IAEA, 1996]

Emissions (kg/GW.h)	*Wind*	*Solar*	*Coal*	*Nuclear*
- SO2	10.9-23.5	300-380	704-709	33-50
- NOX	16.0-34.2	300-380	717-721	64-96
- dust	2.0-4.3	60-80	150	6-8

A 1000 MW (e) nuclear power plant does not release noxious gases or other pollutants and produces annually only some 30 tonnes of discharged high level radioactive spent fuel along with 800 tonnes of low and intermediate level radioactive waste. Significant reductions in the volume of low level waste to be managed can be made through compaction. In the USA, low level solid waste from nuclear power plants has been reduced ten-fold over the past decade to 30 cubic metres annually of compacted waste per plant - a total of some 3000 cubic metres from all operating plants. For perspective, industrial operations in the USA are estimated to produce annually more than 50 000 000 cubic metres of solid toxic waste [IAEA, 1997].

The fossil fuel with their combustion associated CO_2 emissions, and inherent CH_4 emissions associated with its production and transport are a separate category of high GHG emission factors, ranging from 500-1200g CO_2 equiv./kW(e).h. Future energy efficiency improvements could lower these emission factors considerably but it is unlikely that the large gap between fossil fuels and the other energy sources can be bridged. A major factor of uncertainty of natural gas is the release of gas during production and transportation.

The emission factors of non-fossil fuel energies which are mature, viz. wind, geothermal and nuclear energy, are vary low. They are in the range of 10-70g CO_2 equiv./kW (e).h. The emission factors of hydropower and sustainable biomass are uncertain due to difficulties in accounting for the emissions of CH_4 from anaerobic biodegradation from the hydropower water reservoir and in-soil biomass, (mainly roots), resp. Hydropower and sustainable biomass energy have emission factors in the range of 10-400 and 40-80g CO_2 equiv. /kW(e).h, resp. The renewable energy sources, which are still under development, viz. solar and ocean energies, show emission factors of 100-300g CO_2 equiv./kW (e). h. (Fig. 4).

Generally, accounting for methane sources in the complete fuel chain increases GHG emission factors substantially.

Table (3) shows the CO_2 emissions from selected plant types, together with their expected cost of electricity generation in the year 2000. It is clear trade-off will still often be required in 2000 between low cost and low CO_2 emitting electricity generating technologies, despite the projected fall in the cost of renewable electricity. Scatter within the emission factors from different studies of an individual energy source can be attributed to different methods and data bases. Input/output analysis from methodological weaknesses whereas process analysis suffers from the incomplete identification of GHG sources. Dota bases often are not up to date. Uncertainties in the global warming potential of CH_4 also add to the scatter in the emission factors.

Table 3: Projected Costs of and CO_2 Emissions From Selected Electricity Generating Sources [Ellis, J., Peake, S., 1995]

Electricity sources	*Net efficiency (%)*	*Cost in the year 2000 (Usc/kW.h)*	*CO_2 emissions [a] (g/kW.h)*
Pulverized coal	36-43	4.0-6.5	795-950
Atmospheric fluidized bed combustion	36-43	4.6-5.3	795-950
Pressurized fluidized bed combustion	40-45	4.9-5.1	760-850
Integrated gasification coal combustion	44-49	4.9-5.1	700-775
Combined cycle gas turbine	50-61	3.7-7.3	330-405
Light water reactor	-	5.6-7.4	0
Large hydro	-	3.8-8.7	0
Centralized photovoltaic system	-	11.3-62.8	0
Geothermal	-	2.4-4.9	0
Wind	-	4.4-7.6	0
Large biomass	-	7.5-7.8	0

[a] Emissions from generation only (life cycle emissions not included)

The direct emissions of CO_2 from nuclear power are very low. However, nuclear power releases some CO_2 if indirect processes are taken into account. The direct and indirect CO_2 emissions from nuclear Power generation was calculated. Fig. 5 gives these emissions for PWR nuclear power plant (1100 MW) itself, and the front end and for the back end processes of the nuclear fuel cycle. The total CO_2 emissions associated with the construction of the PWR power plant is given in Fig.6 for the major components of the plant. The life cycle CO_2 emission coefficient, the sum of the direct and indirect components, is about 25.7 g CO_2/KWh when the gas-diffusion process is utilized for uranium enriched. The indirect component is about 89% of the total CO_2 emission coefficient. The life cycle CO_2 emission coefficient for nuclear power is 2.7% of that of coal fired power generation.

ELECTRICITY GENERATION SYSTEMS AND WASTES

All the electricity generation systems give rise to solid, liquid and gaseous waste streams. These can be divided into emission wastes and non emission wastes. The non emission wastes, include contaminated gases and aqueous liquids, slurries, sledges, spent filters, building and dismantling rubble, non aqueous liquids, contaminated ash and soil, flue gas purification residues and other materials. In a broadly based comparison it is important to consider all the wastes arising in all aspects of the generation systems.

The following points are examined systematically when identifying wastes arising within each system: provision of the fuel or energy source; combustion or conversion of the energy source to electricity; management of conversion products; facility construction, materials manufacture; non-fuel related operational wastes, e.g. in transportation, routine maintenance wastes, abnormal maintenance wastes; spillage and clean-up; and final decommissioning wastes.

The first step in the fuel chain is extraction of the fuel and raw materials required for treatment processes, this step includes mining/ benefaction and drilling production wastes. Estimates of the amount of waste (including overburden) associates with hard coal mining/ benefaction are on the order of 600-1200 thousand T/ GW (e). a (roughly 20 - 25% of the raw coal ore) [Ellis, J., Peake, S., 1995]. For the nuclear fuel chain, less fuel is required, however the uranium/ thorium is typically present in concentrations of slightly less than 0.1% up to more than 10% in an ore body. Using uranium data from the OECD/NEA [Ellis, J., Peak S., 1995] a weighted average of roughly 100 thousand tonnes of tailings per GW (e). a are produced when conventional methods are used. The amount of waste associated with production activities for gas and oil tends to be relatively small in comparison with mining/ benefaction, but some of the wastes are classified as hazardous and in some cases radioactive.

Table 4 provides indicators of relative amounts of waste from the fuel preparation and power plant operation steps of a number of electricity generation fuel chains. During the step of plant operations, coal fired plants generate large quantities of combustion waste including fly ash and bottom ash that result from the burnt fuel, as well as gypsum and sledges from different flue gas desulfurization (FGD) techniques. Data from a number of sources suggest that the amount of ash typically ranges from 200-600 thousand t/ GW (e).a, FGD wastes range from 100-300 thousand t/ GW (e).a, and other wastes can be as much as roughly 100 thousand t/ GW (e).a [Roger Seitz, 1997].

Waste from the operation of nuclear power plants is probably the most studied waste in the world. However, as shown in Fig. 3, the amount of waste generated by nuclear power plants is very small compared with the waste generated by electricity generation systems as a whole.

Fuel and Waste Comparisons
1000-MWe electricity plant in tonnes/year

Nuclear	Coal *
Fuel: 27t (160t Natural uranium/year)	Fuel: 2.6 million t (5 trains of 1400t/day)
Wastes:	Wastes:
25t (high level)	6.5 million t CO_2
310t (intermediate)	900 t SO_2
460t (low level)	4500 t NO_x
	320,000 t Ash (with 400t toxic heavy metals)

Equipped with latest pollution abatement technology.

Table 4: Representative Quantities of Untreated Direct waste Arising from Fuel Preparation and Plant Operation Steps in Selected Fuel Chains (PER GW (E).A. Excluding Wastes from Secondary Activities Such as Facility Construction, Maintenance and Transportation [Roger Seitz, 1997].

COAL		NUCLEAR	
Solvent refined coal conversion to fuel oil	L	Conversion, enrichment and fuel fabrication	VS/S
Coal gasification	VL	Operations	
		- low/intermediate-level waste	S
coal-fired plant operations			
- Ashes	VL	- high-level waste (reprocessing)	VS
- Sludges and others	M/L		
- FGD (when used)	L/VL	- spent suel (once through)	VS
SOLAR		OIL	
PV cell manufacturing [2]		shale retorting	VL
- GaAs based	S[3]		
		refining crude oil	M
- $CuInSe_2$, CdS, CdZnS or CdTe based	VS/S[3]		
		oil fired plant operations	
		- Ashes (excl. FGD)	S/M
- a-Si P-I-N based	VS/S	- FGD sludge and ashes	VL
BIOMASS/ GEOTHERMAL		NATURAL GAS	
Wood fired steam electric ashes		Gas sweetening [4]	
Geothermalsludges	L/VL	-classifier/ separator sludge	L/VL
(vapour dominated)	M	-water treatment sludge	M/L
		gas fired lant operations	VS/S[5]

Scale: [Very Smal (VS) < 0.1] ; [Small (S) 0.1-1] ; [Medium (M) 1-50] ; (Large (L) 50-250]; [Very Large (VL) > 250] ; Units are 1000 tonne/GW (e)-a

Notes:

1- Ranges are based on representative averages that, in many cases, are derived using that were provided (there may be examples of specific cases that are less than or greater than the indicated ranges). The quantities from each activity cannot be added as different combinations of waste streams apply to individual cases.

2- Quantities are derived assuming the amount of waste is averaged over the lifetime of the solar cells.

3- Based only on quantity of toxic or hazardous GaAs, $CuInSe_2$ or Cd containing wastes. Other process wastes not included.

4- Based on one source, there would be a lot of variability depending on the process. Only applicable when gas sweetening is necessary.

5- Estimate based on qualitative information.

Fig. 7: illustrates the distribution of wastes generated from selected sources for five representative countries. These data should be regarded as order of magnitude indicators and comparisons between countries may not be relevant. In general, the agricultural and mining sectors tend to be among the largest sources of waste. However, as shown in Fig. 7: energy production (includes electricity, gas, steam and hot water for Sweden, United Kingdom and Germany (FRG) and is limited to power ashes/slages for Japan and Romania) and industry can also be large sources of waste. Nevertheless, the waste from operations of commercial nuclear plants is a small fraction of the total amount of waste from all sources and even from all energy production sources in each of the countries. It should be noted that Fig. 7 is intended to provide perspective on the relative amounts of waste from a variety of sources and the waste in the energy production and nuclear power plant categories are generally limited to waste from the operations step of the chain.

RISK COMPARISON OF ENERGY SOURCES

Beyond doubt the Chernobyl accident was a severe accident in all its dimensions. For comparative purposes a review of other large energy related as well as other industrial accidents is needed. While the perception of nuclear accidents may not change, such a review provides some perspective. In the industrial sector,, the well known 1984 Bhopal accident at a chemical plant in India caused some 3000 early deaths and several hundred thousand severe health effects.

In the energy sector, dam failures and overlapping have caused thousands of deaths and massive disruption in social and economic activities with displacement of entire towns - the Variant dam overlapping in Italy and dam failures in Gujarat and Orissa in India are three such examples, each with several thousand fatalities. Severe coal mine accidents causing several hundred deaths are not rare. 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 involved 500 fatalities. Energy sector accidents have also led to severe environmental damage, such as the 1989 Exxon Valdez oil tanker accident in Alaska [IAEA, 1992], [Rashad S.M., 1996], [Marshall V.C., 1988].

If risk assessments considered only short term severe accident fatalities (Table 5), the reported data would 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. Equally important are the maturity of the technology, the quality and maintenance of equipment and the safety and environmental controls.

REVIEW OF SEVERE ACCIDENTS

Given here a short review of accidents that have occurred during the last decades at the different energy sources including all phases of the whole cycle [IAEA, 1992], [Hirschberg, S., et al, 1996], [Ball, D.S., et al., 1994].

Table 5: Short term Fatalities (1970 - 1992) [Hirschberg, S., et al, 1996]

	Events	*Fatalities*		*Average fatalities*
		Range	*Total*	
Coal [a]	133	5-434	6 418	0.32
Oil	295	5-500	10 273	0.36
Natural gas	88	5-425	1 200	0.09
Liquid propane gas	77	5-100	2 292	3 .1
Hydro	13	10-2500	4 015	0.8
Nuclear	1	31	31	0.01

[a] The total is some 10 times higher if accidents with less than 5 fatalities are included.

HYDROPOWER

During the last 30 years, some few dam catastrophes have occurred throughout the world, each of them resulting in more than 1 000 deaths (Vaiont, Italy, 1963, 1189 deaths; Machhu India, 1972, 2 000 deaths; Gujarati, India, 1979, 15 000 deaths). Other accidents have occurred during the same time period resulting in several hundred deaths. Furthermore accidents have occurred where an effective warning system has resulted in early evacuation of the endangered population, thus drastically limiting the losses of human lifes (Teton, USA, 1976, only 14 deaths, 30 000 people without housing).

As a severe example of hydro-electric power risks, a brief summary of the Vaiont catastrophe is presented here. The Vaiont dam in the Italian Alps was among the highest concrete dams in the world and almost 300 m height. The dam was put in operation 1960. In September 1963 geologists noted that a large mass of land was slipping slowly toward the reservoir valley upstream the dam, due to heavy rain. On 8 October, dam engineers estimated that the land masses could reach the reservoir within a few weeks and started consequently the reduction of the dam water level. The same day warnings were send to the population drawing its attention to the danger of being on the reservoir shores. On 9 October a gigantic and sudden landslide occurred sending almost 200 millions tones of material into the reservoir. The resulting wave over topped the dam by about 125 m. The water entered the narrow Pave River valley and a wave of water, mud and rocks, 60 m high, continued downstream, devastating the town of Longhorn and several villages. The official figure of the death toll was 1 189. Higher figures have also been published. The dam remained almost intact with only minor damages to the top of its retaining wall. The accident resulted in a reduction of the reservoir by 2/3, thus rendering it useless for hydroelectric power production. The plant was consequently closed down.

NUCLEAR POWER

Comparing Chernobyl accident with the TMI-accident showed that a melt in a western light water reactor is not similar regarding environmental or human catastrophe. The highest radiation dose someone could obtain staying continuously outdoor near the TMI-plant was equivalent to one year natural radiation dose. The TMI-accident is the only core melt accident having occurred in a commercial light water reactor. Until now an operational experience of about 5 000 reactor x years has been accumulated with such light water reactors.

About seven years after TMI occurred the catastrophe in the graphite moderated, light water cooled reactor Chemobyl 4 happened. Important contributing causes to the accident were major deficiencies in the reactor construction (unstable physical properties in combination with ineffective shut down system) and in the safety philosophy (lack of tight and strong containment). Soviet officials confirmed in April 1991 in Paris that the total death toll is 31 (these persons died within two months after the accident). 145 persons show sign of radiation induced illness (later injury can be expected for these persons). 135 000 persons were evacuated in 6 days after the accident. Some more local evacuations have been actual. A land area with a radius of 30 km is commonly inhabitable for decades. The psychological consequences are important into the public due to radiophobia (not only in the contaminated areas but also in countries outside USSR). The total economical consequences of the accident have been estimated at 25 billins roubles including the relocation of about 200 000 people Table 6. Shows the Long Term Health Effects of Chernobyl.

Table 6: Long Term Health Effects of Chernobyl

	Number of people	*Cancer deaths from other causes*	*Cancer deaths from radiation (increase)*
Emergency workers	1 000	180	20 (2.0%)
Liquidates (nation-wide)	650 000	90 000	2 000 (0.3%)
Evacuated 1986	115 000	17 000	400 (0.3%)
Residents in the high zone	300 000	40 000	1 000 (0.3%)
Infants 1986 (up to 4 years)	1 000 000	a	b

a Fiffy thyroid cancers (treatable).

b Several thousand thyroid cancers (treatable).

Source: *One Decade after Chernobyl: Summarizing the Consequences of the Accident (Proc. Conf. Vienna, 1996), IAEA, Vienna, (1996).*

COAL

Unlike hydropower and nuclear power, it is the daily operation of coal fired power plants which constitutes the most significant health and environmental risks. Accident risks in a coal fired power plant are, from the health point of view, limited to the plant personnel (i.e. death risk in connection to fire or explosion). For the environment, the consequences of an accident will affect only the plant's vicinity.

The three worse mining accidents recorded in the openly published literature count more than 1000 deaths each (Couriers, France, 1906, 1 060 deaths; Fushun, China, 1931, 3 000 deaths; Honkeiko, China, 1942, 1 549 deaths). Relatively often the death toll of mining accidents exceeds 100 victims. The number of non-fatal injuries in coal mining accidents is about 10 times higher than the respective death toll. American statistics shows that coal mining accidents in the USA have contributed to half the death toll in working accidents until year 1960. The coal mining industry still constitutes today the most injuries affected industry in the USA. The same is probably valid for all countries mining coal below ground.

Later health risks for miners are well documented. The mean life expectancy for miners is significantly lower, up to decades, than the one for the average person living in respective country.

Another risk with coal mining is related to the wastes, as depicted in the following. Waste generated at coal mines is generally piled into huge slag tips. Occasionally there are landslides on these tips. One such slip occurred at Aberdeen, South Wales, October 1966. A large part of a slag tip, lubricated by groundwater and heavy rains, slipped down a 200 m slope and engulfed a primary school and eight other buildings. 144 people died in this accident, 116 of them were young children.

NATURAL GAS

The acute health risks resulting from the widespread use of natural gas are dominated by catastrophes during extraction (exploration / drilling/production), important gas leakages in the distribution network, compressor and monitoring stations, fire and explosion in areas with high population density. The last issue includes potentially very significant risks in harbor cities due to ship transport of Liquefied Natural Gas (LNG).

With the development of off-shore exploration, especially at sites distant from land, large exploration and accommodation platforms were built, often located in adverse environment, as the North Sea. Two accidents are summarized below, illustrating the potential severity of off-shore catastrophes.

The capsizing of Alexander Kielland in March 1980 is probably the worse accident having affected an accommodation platform. It capsized in storm force weather in the Ekofisk field, and was found upside-down. Of the 225 persons on board, 123 died, many of the bodies were never recovered [IAEA, 1992].

In July 1988, the Piper Alpha platform was totally destroyed by fire and explosion. This platform was an oil production installation. As a result of a major gas leakage in the compressor system, a fire started and explosions occurred disabling among other both the control room and all electrical power supply. The fire fighting system was ineffective and the fire escalated rapidly. The main gas pipeline to land failed without any possibility of isolating the natural gas leakage. Gigantic gas bubbles went to the sea surface and caught fire. The subsequent fire balls enveloped the entire platform, leading to its collapse and total destruction. This catastrophe resulted in 167 deaths. The economical loss exceeded billion US dollars.

In October 1949 occurred a LNG-leakage at the Ears Ohio Gas Company, Cleveland, Ohio, USA. The leakage was 2 900 m^3 LNG. The gas cloud ignited promptly and deflagrated. Some gas entered the sewage system and ignited there. The flames reached 900 m in altitude and a fire ball 300 m in diameter formed. The whole installation was destroyed. 128 persons died and 400 suffered severe injuries. As a consequence of the Cleveland catastrophe a massive opinion ground up in USA against the use of natural gas. Use of similar installations was stopped for almost 30 years.

Year 1973 occurred in USA a new catastrophe during reparation work on an empty 95 000 m^3 large LNG-storage tank in the New-York state. The tank had been drained one year earlier and had also been flushed inflammable gas. 42 persons were working inside the storage tank, some of them doing welding reparation works. Suddenly an explosion occurred which blowed off the steel and concrete tank top. Its subsequent fall and the explosion killed altogether 40 workers. The most credible cause of the accident was that some natural gas was still present in the tank despite the earlier flushing. This fact was never officially recognized against the background of the Cleveland catastrophe and the prevailing opinion.

During the severe winter 1987, several accidents occurred in Europe due to leaking gas pipelines being torn by earth movements because . the cold weather. The resulting leak points were difficult to localize in the densely populated cilies. Explosions and fires resulted in several deaths.

Finally an indication is provided below of the huge amounts of energy contained in the pressurized gas transportation pipelines. This indication refers to the catastrophe in June 1989, in Ural, USSR, when a leaking gas pipeline resulted in the worse train catastrophe ever in USSR. A gas leakage had been in progress for 5 hours. The gas escaped up to some kilometers from the leakage point. A spark, from one out of two trains circulating some kilometer from the pipeline, ignited the gas cloud. The following explosion overturned the wagons. The heat resulting from the gas burning was so intense that two wagons melted partly and became welded together. Between 600 and 800 persons died, a majority of the offers being children on the way to vacation centers. All trees were wrecked inside a radius of 4 km. The explosion has been calculated as equivalent to 10 kilotons TNT, or the strength of a small atomic bomb [IAEA, 1992].

OIL

The health and environmental risks connected to the extraction, transportation and storage of oil are dominated by the risk for explosions and fires, and significant oil leakages. What has been said above for natural gas, including some hundred of totally lost platforms, is also valid for oil extraction. An environmental risk which is rarely touched upon is the risk for uncontrollable oil leakages during prospecting or extraction. Disregarding such leakages caused by acts of war, like in the Persian Gulf this year, there was the important oil leakage in the Mexican Gulf, in the late seventies. Almost six months were needed to stop the leakage which finally amounted to about 300 000 tonnes of crude oil released into the aquatic environment.

The oil industry has also caused disasters, both to man and the environment, during the transportation and loading/unloading of its products. A serious accident occurred in Eire, January 1979, and involved the supertanker "Betelgeuse" moored at a jetty at Whiddy Island and unloading its crude oil. A fault in-pumped ballast caused the tanker to break mid-ship. Due to unknown reason the tanker caught fire and several explosions followed. The entire crew, two passengers and the shore staff on the jetty lost their lives, with a final death toll of 50. The tanker was totally destroyed, the jetty severely damaged. An indication of the energy released during the explosion was obtained when a 500 kg heavy steel plate from the tanker was found 600 m from the accident point.

The transportation of crude oil with supertankers has recorded a significant number of castrophes where very large quantities of oil leaked and resulted in severe ecological damages. At the end of the sixties the crude oil tanker Torrey Canyon ran aground in the English channel. 100 000 tonnes of crude oil were spilt. About ten years later, in 1978, the crude oil tanker Amoco Cadiz ran aground of Bretagene, France. 250 000 tonnes of crude oil were spilt and swept more than 350 km of the coastline, ruining the marine ecosystem for decades. More recently, in 1989, the crude oil tanker Exxon Valdez grounded in the Prince William Sound, Alaska. About 40 000 tonnes of crude oil were spilt contaminating about 1 600 km of coastline.

FINDINGS AND CONCLUSIONS

The extraordinary high energy density of nuclear fuel relative to fossil fuels is an advantageous physical characteristic. The energy density of fossil and of nuclear fuel allows for relatively small power plant sites of a few square kilometres. The low energy density of renewables results in high land requirements.

Full energy chain analyses show that there are a wide variety of significant issues and impacts linked to energy options. These analyses demonstrate the significant greenhouse gas emissions that can be related to significant fuel extraction, transport, manufacturing and construction activities. Nuclear power and wind are on the low side of full chain emissions.

Managing nuclear power waste has distinct advantages as the quantities are remarkably small relative to the energy produced. The small quantities permit a confinement strategy, with the radioactive material, beginning with the nuclear fission process through to waste disposal, essentially isolated from the environment.

All energy sources represent some risks, highly depending on different countries culture and economics. These risks have to be assessed and minimized, and should part of an integrated view on the risks in the society.

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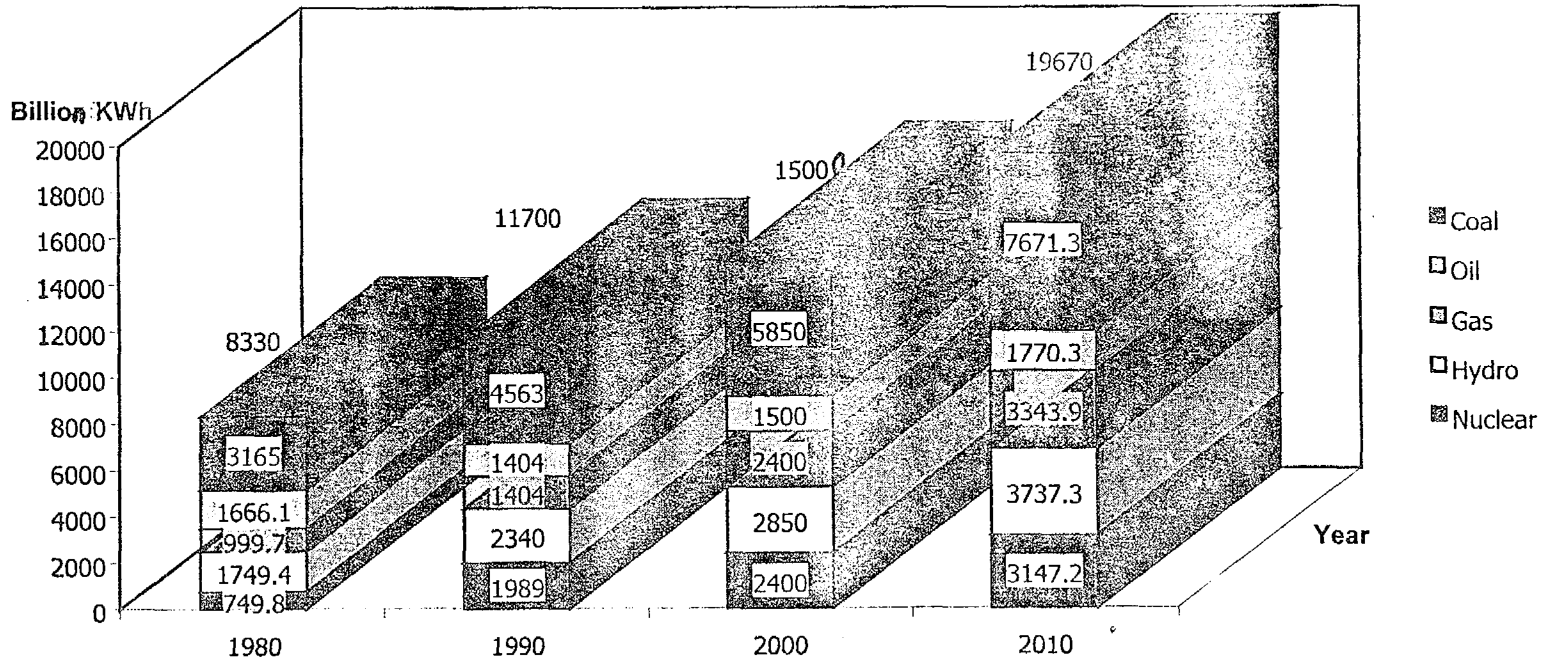

Fig 1. Development of Gross Power Generation WorldWide by Energy Sources

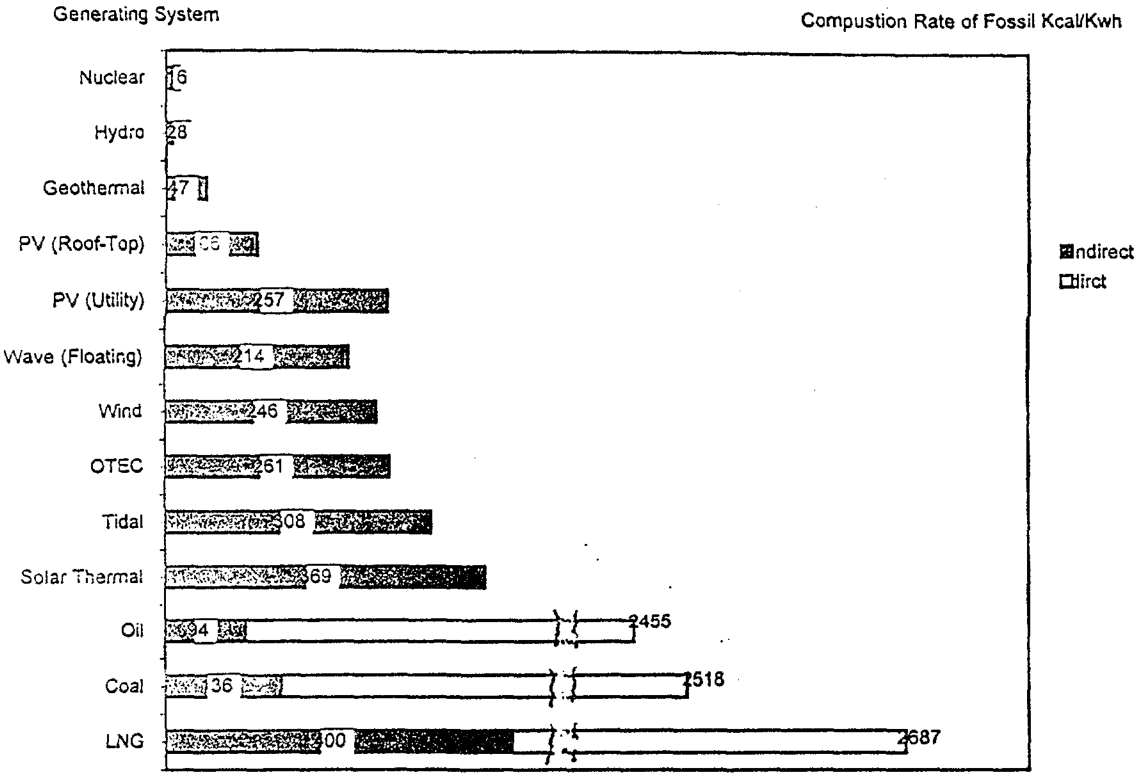

Fig.2 Rate of Fossil Fuel consumption of Different Power Generating Systems

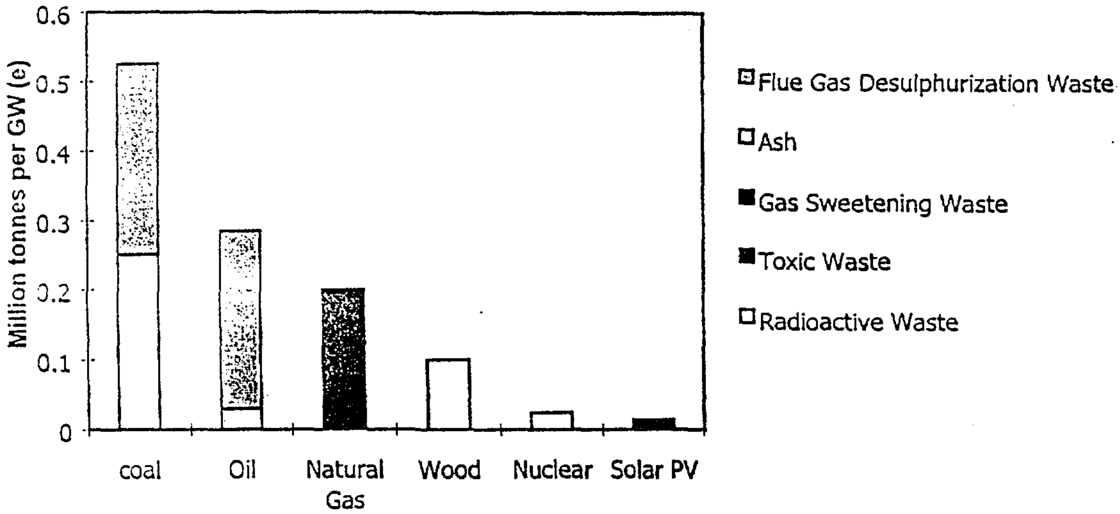

Fig 3.Waste Generated annuallyin fuel Preparation and Plant Operation (IAEA)

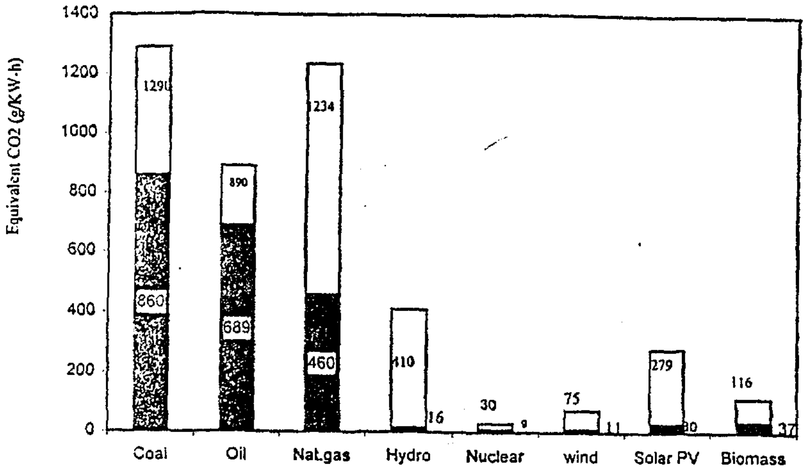

Fig.4 Full Energy Chain CO2 Equivalent Emission Factors

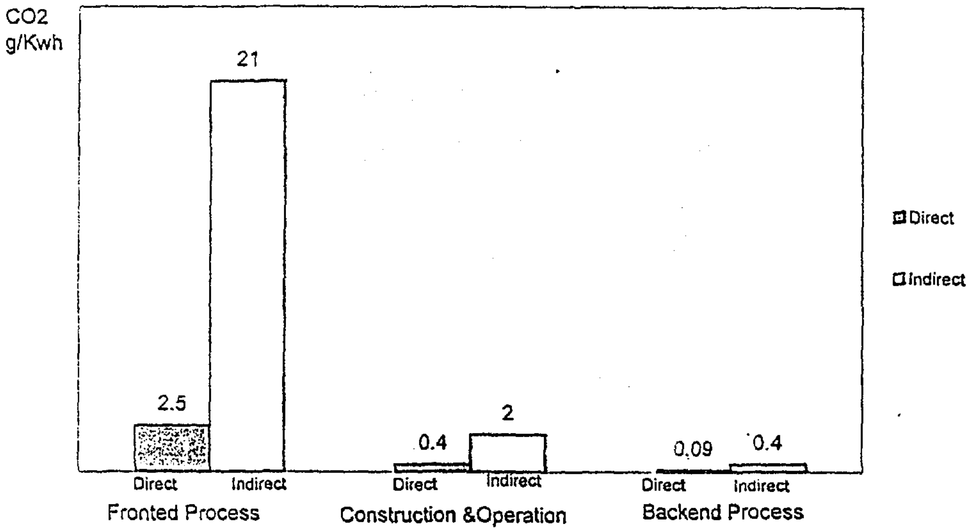

Fig.5 CO_2 Emission from Nuclear (PWR)r Generation

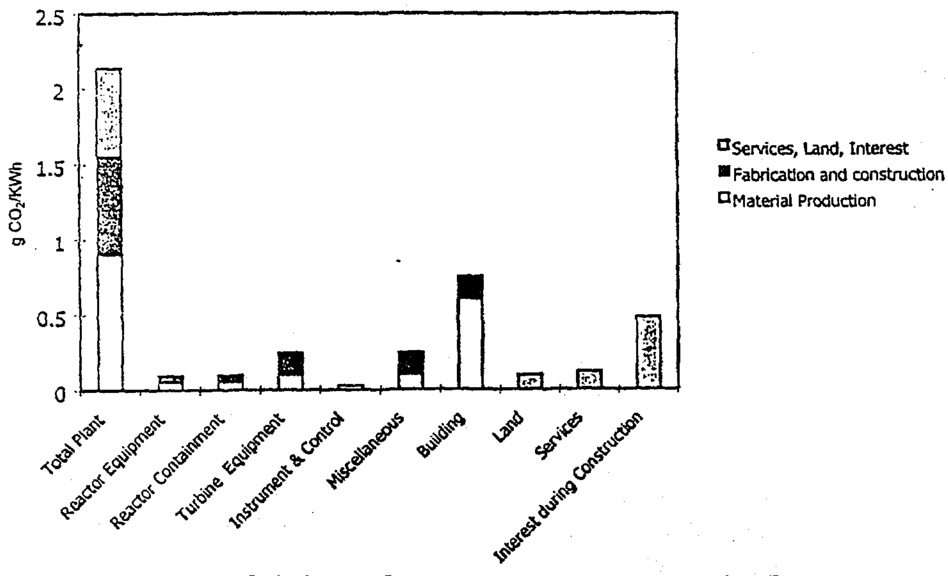

Fig 6 Indirect CO2 Emission per Component of 1100 MWe PWR Nuclear Power Plant

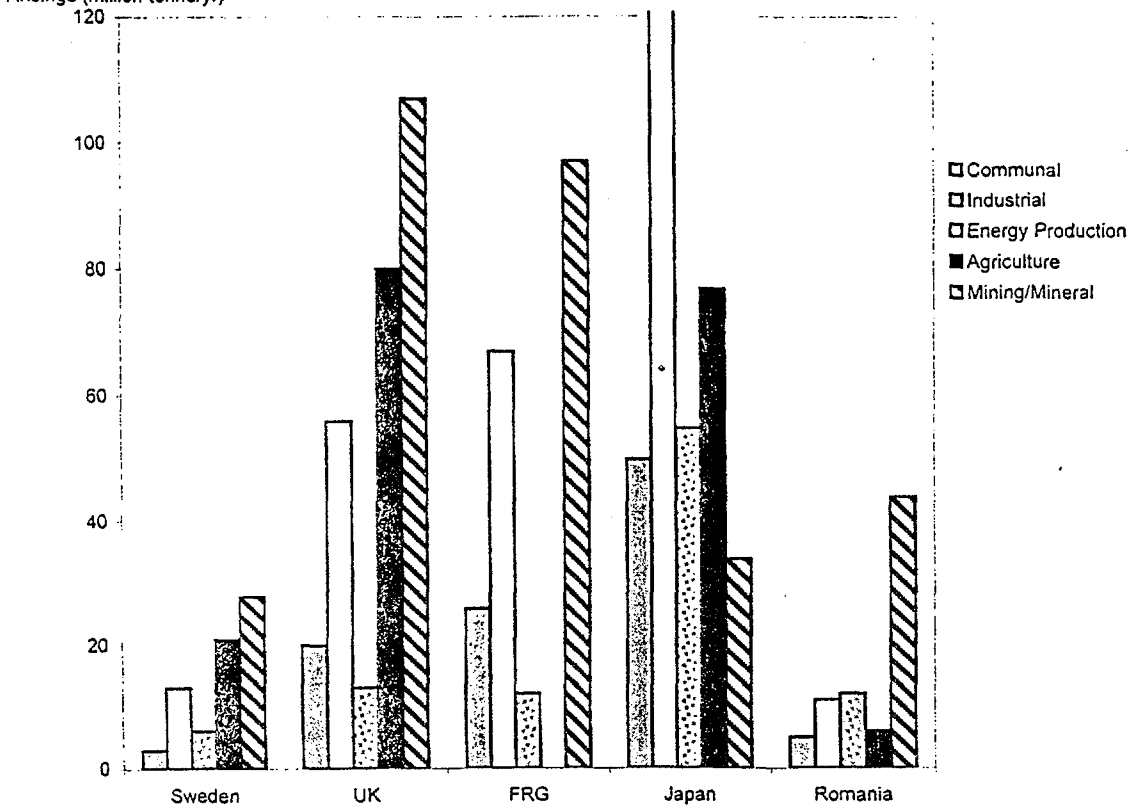

Fig.7 Estimated Annual waste arising from Different Industries for 5 Countries

	Communal	*Industrial*	*Energy Production** *(Nuclear Reactors**)*	*Agriculture*	*Mining / mineral*
Sweden	3	13	0.6 (0.0087)	21	28
UK	20	56	13 (0.06)	80	107
FRG	26	67	12 (0.02)	Not reported	97
Japan	50	395	55 (0.02)	77	34
Romania	5	11	12 (n/a)	6	44

* Data include waste from electricity, gas steam and hot water for Sweden UK and Germany and "Power plant ash/slag" for Japan and Romania.

** Commercial nuclear reactor waste data (shown in Parentheses) obtained form several sources as documented in Chan-Sands and Seitz, Worldwide Overview of Inventories of Radioactive Waste, in proceedings from GTDC Workshop on Toxic Waste, 4-6 Sept. 1996 Vienna (1996).

Notes: Values should be considered order of magnitude estimates and are not necessarily comparable between countries due to different definitions and counting methods that may be used. The energy production data do not include mining / beneficiation waste and also do not account for waste associated with imported fuel.