COMPARATIVE ASSESSMENTS OF EMISSIONS FROM ENERGY SYSTEMS

# BENEFITS & BURDENS

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Uses of electricity help people meet a variety of needs, ranging from improving food production and distribution to ensuring health care and education. At the point where consumers actually use it, electricity is generally regarded as a clean and beneficial process.

Yet when electricity is produced, various substances are released into the environment. Some of them are harmful to human health. The last decade has brought greater awareness of environmental issues, including air pollution from various energy systems.

To study the impacts, analysts are using the methodology of comparative risk assessment, which has advanced considerably.

In the beginning of the 1990s, the European Commission (EC) initiated and successfully conducted a special project called ExternE. The project was aimed at determining external costs of various energy systems being borne by society (with health costs being the major contributor).

In the project's first phase, lasting to 1995, external costs for each energy system were evaluated by specialists from countries most experienced in particular systems (for example, by German and British teams in the case of coal or by Norwegians in the case of hydropower).

In the second and final phase of this project, separate analyses were made by each country for all energy systems of interest to it. Results of these studies are available today from the EC as national reports and provide the best data on comparative risk assessments of energy systems.

## AIR POLLUTION AND RADIATION RELEASES

The concentrations of classical air pollutants, such as small particulates, and sulphur and nitrogen oxides in large cities and industrialized areas, are now much higher than historical background levels generally considered as natural.

Studies have compared the measured concentrations of sulphur dioxide — a typical pollutant from fossil fuel combustion — with background concentrations in regions far away from industrial centres and with concentrations defined as admissible by the World Health Organization (WHO). *(See graph, page 20.)*

A study done by the Organization for Economic Cooperation and Development (OECD) estimated that 50% of this pollution is due to the burning of fossil fuel in energy production.

Other sources of energy also have been studied, including the burning of organic materials, mainly in developing countries, for domestic purposes like cooking and home heating.

According to the International Energy Agency of the OECD, total consumption of biomass in 1995 was 930 metric tonnes of oil equivalent (Mtoe), with at least one-third of the world population relying on biomass as its major energy source. Besides devastation of the environment from indiscriminate burning of trees and bushes, the use of biomass indoors produces very high levels of air pollution, resulting in acute respiratory infections and lung cancer. The death toll in developing countries from burning biomass is high.

For example in China, where hundreds of millions of household stoves produce heavy concentrations of indoor pollutants, the corresponding increases of chronic obstructive pulmonary diseases, lung

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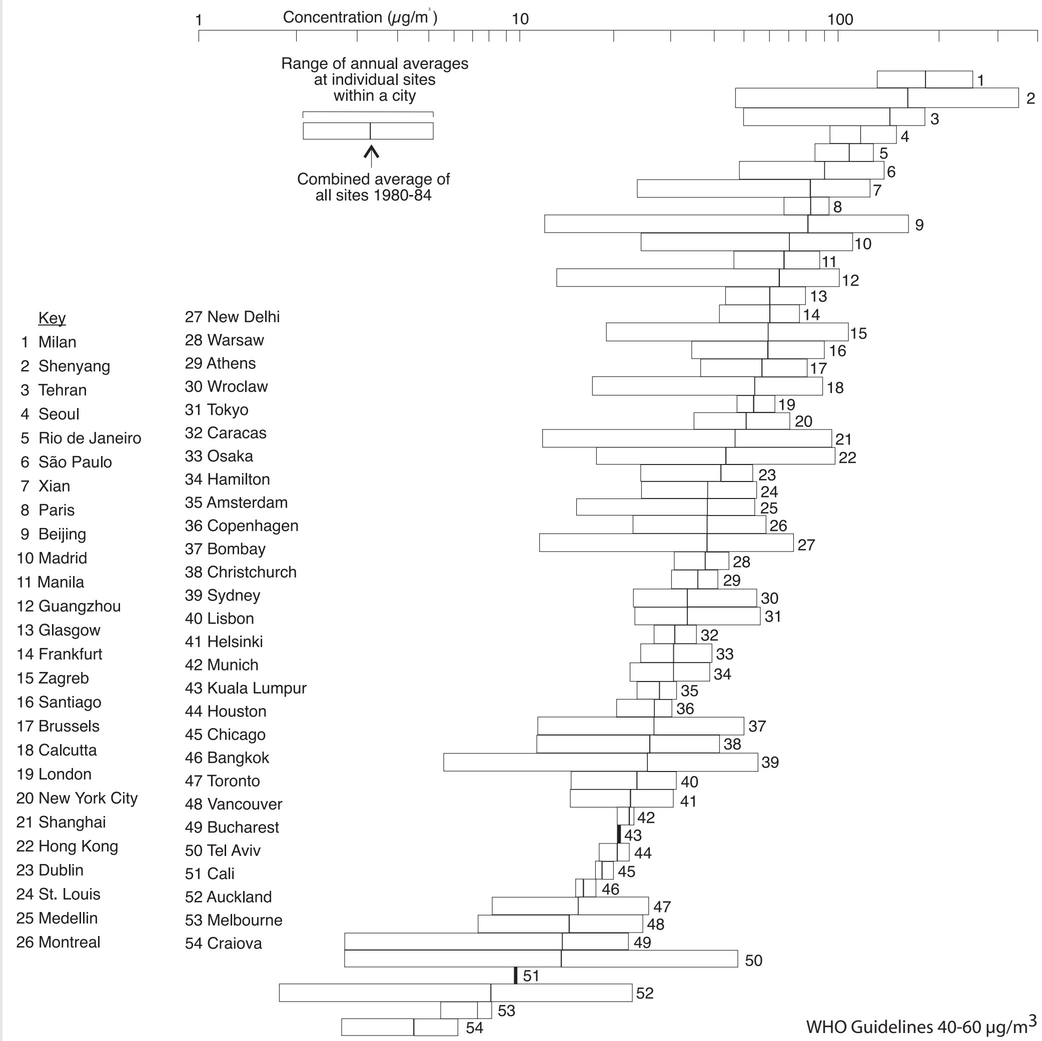
**SULPHUR DIOXIDE LEVELS IN SELECTED CITIES**




*Source: World Health Organization and United Nations Environment Programme (1987).*



cancer, coronary heart disease and childhood pneumonia are estimated to cause above 1.4 millions premature deaths every year.

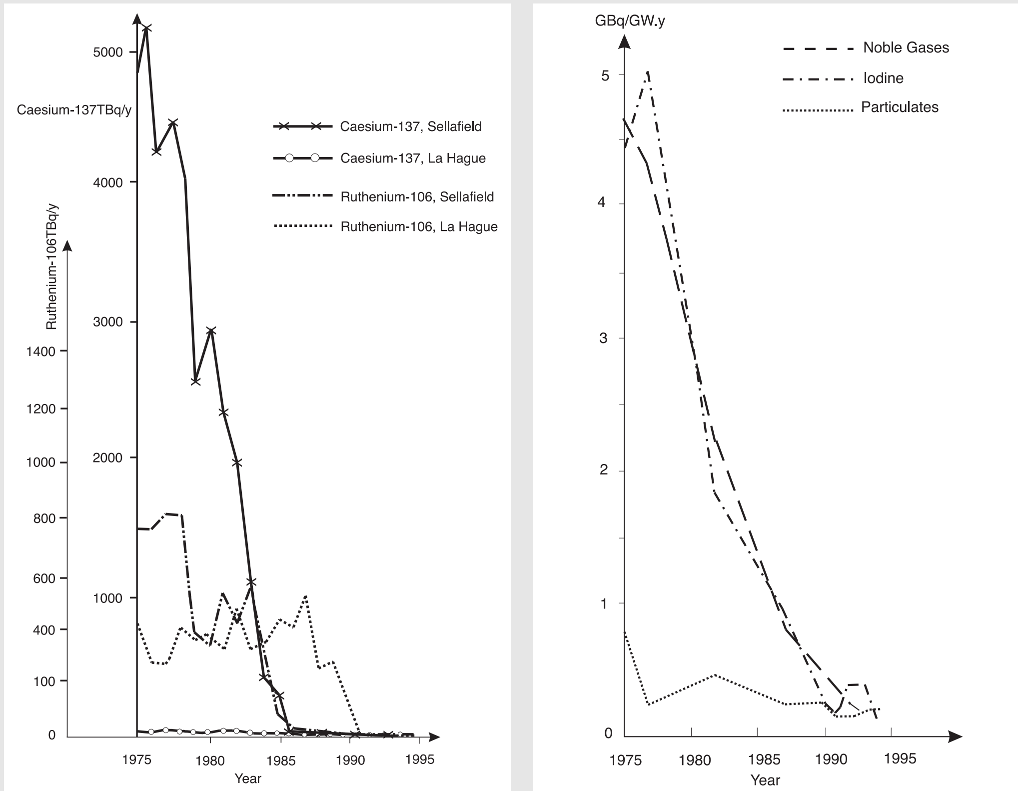
On the other hand, additional radiation doses to the population from the normal operation of nuclear power plants are only a very small part of variations of the natural background. The natural background radiation levels in many large regions vary from less than 2 millisievert per year (mSv/y) up to 5 mSv/y. The additional contributions from nuclear power are typically about 1 to 3 *microsievert* per year, or 1/1000 of the variations in levels of natural background radiation.

Large-scale studies of various population groups exposed to low doses of radiation have been done in several countries. They include a large epidemiological study of a Chinese population including about 80,000 inhabitants of the high background radiation area of Yangjiang, and an equivalent control group from the neighbouring area having much lower levels of natural background radiation. The 1997 study found that the cancer mortality rates were lower in the high-background radiation area than in the control area. The statistical confidence of the study has been judged to be insufficient to quantify the findings. However, based on the results, no detrimental effects of low-level radiation could be observed.

Another large study was conducted in the United States

**REDUCTIONS OF ANNUAL RADIOACTIVE RELEASES (SELECTED RADIONUCLIDES)**

**REPROCESSING PLANTS** **NUCLEAR POWER PLANTS**




*Source: UNSCEAR, 1993 and 1996.*

and involved 28,000 nuclear shipyard workers who obtained doses above 5 mSv over their lifetimes.

Although the 1991 study was set up to exclude what is called the "healthy worker effect", it found that the irradiated group had 24% lower total mortality than the control group.

Further results come from the studies of 95,000 nuclear workers in the United States, Canada, and United Kingdom conducted by the International Agency for Research on Cancer. Results reported in 1995 showed that the excess relative risk for all cancer (excluding leukemia) was minus 0.07; that is, there was no increased risk. A study reported in 1997 of 115,000 Japanese nuclear workers brought similar results.

All these results were judged to be statistically inconclusive. However, these studies, as well as numerous others over the past decade, have not shown any increased incidence of cancer mortality due to exposures to low radiation doses.

The situation is quite different in the case of air pollution, where direct consequences have been seen. The relationship between the concentration of air pollutants and acute mortality has been shown dramatically in a number of cases.

The best documented case is the air pollution episode in London in 1952. It led to an overall death toll of an estimated 4000 additional deaths. Other cases in Belgium, United States, Brazil, Norway, and Germany have shown significant increases of mortality from air pollution. In China, a 1994 study found that the high concentrations of $SO_2$ in Beijing produce significant increases of mortality.

These studies evaluated air pollution effects over short time periods. The absence of long-term epidemiological studies has hampered more thorough evaluation of mortality due to air pollutants.

At the end of the 1980s, analyses of air pollution effects included as a rule only selected health hazards, arbitrarily chosen and frequently not representative enough.

Entering the 1990s, the international scientific community did not consider that available results of chronic exposures to polluted air were sufficiently proven to be used in comparative risk assessments.

Since then, two extensive studies in the United States have become internationally recognized. One of them, reported in 1993, considered 6000 inhabitants of six US communities, and the other, in 1995, evaluated 552,000 adults residing in 151 US metropolitan areas. Both studies showed that chronic exposure mortality factors from long-term cases of air pollution are much higher than those derived from shorter episodes.

In 1997, the results of the 1995 US study were incorporated in the EC's ExternE project as the basis for evaluation of mortality and loss of life expectancy due to chronic air pollution.

Moreover, the ExternE project in 1997 took into consideration the influence of sulphur dioxides and nitrogen oxides. These pollutants were shown to produce secondary particulates that are considered highly dangerous to human health because their small size facilitates their penetration into lungs, where their effects are the most detrimental.

The independent EC findings are in good agreement with guidelines prepared by the IAEA on comparative risk assessment and issued in 1997 *(General Guidelines for the Comparative Assessment of Health and Environmental Impacts of Electrical Energy Systems).*

The guidelines further indicate the necessity of performing comprehensive analyses of health risks for all important stages of energy production, not only for the stage of power plant operation. This has been taken into account in the ExternE project with one important exception. The project does not consider back-up systems that will be needed for wind and solar power, if they should become significant contributors to energy supply. Neglecting these external costs considerably improves the situation of solar and wind power plants.

Nevertheless, the project has included front-end stages in evaluating the costs of renewable energy sources, and this has been an important step forward in comparative risk assessments of energy systems.

In the case of nuclear power, analysts have found that the radiation releases at the stage of plant operation are very small. The allowable additional radiation doses from nuclear power plants are regulated in various countries at levels ranging from 0.08 mSv/y in the United States to 0.3 mSv/y in Germany. However, the actual yearly doses are much less, generally around 0.001 to 0.003 mSv/y, and in some cases up to 0.03 mSv/y.

The doses attributed to other stages of the nuclear fuel cycle are also small. For example, the doses arising from French reprocessing plants are below 0.02 mSv/y. This finding reflects a trend of decreasing releases of radioisotopes from nuclear plants and fuel cycle facilities. *(See graphs, page 21.)*

Similarly, radon releases from uranium mill tailings have been significantly reduced —to the point where a 1998 study found that their integrated health effects were about 150 times smaller than the levels estimated in 1993 by the United Nations Scientific Committee on the Effects of Atomic Radiation.

Radioactive releases from reprocessing plants are very small, sometimes not measurable. However, some released radioactive isotopes have very long decay times, and the integration of their effects over long time periods (100,000 years) can lead to significant collective doses.

## ASSUMPTIONS & APPROACHES

Comparative risk assessment studies should apply comparable methodologies for various energy systems. This has not been the case, however, and studies have been based on different sets of assumptions and approaches.

For example, studies have discarded the illnesses of coal miners due to pneumoconiosis (better known as "Black Lung") or to radon inhalation, although the numbers of victims reach hundreds of thousands; this has been done because analysts considered that improvements in mining safety promise to get rid of these health burdens. On the other hand, studies do account for radon exposure of uranium miners, although the collective radiation doses (per GWe.y) are smaller for uranium than for coal.

Other examples should also be pointed out.

■ Various air pollutants are frequently neglected – for example, sulphur dioxide or nitrogen oxides, while in the case of nuclear power, all possible pathways of radiological hazards are followed. Only the latest ExternE study considers all important air pollutants.

■ The calculations of health effects from air pollutants typically are limited to 80 km or to one country, with the largest study (ExternE) covering the area of Europe. The effects of ionizing radiation, however, are calculated for the entire world.

■ The time horizon in studies of air pollutants frequently is limited to the present time, while for ionizing radiation it is becoming longer and longer, reaching 100,000 years in the latest ExternE study.

Often too easily dismissed is the fact that radioactive products decay and finally disappear, while chemical pollutants remain toxic forever. One reason may be that there are good data on decay of radioactive substances and on the ways of their possible filtration through the biosphere. On the other hand, there is very little or no data on long-term behaviour of toxic waste from non-nuclear fuel cycles.

The lack of data on non-nuclear health burdens often has been used to justify exclusion of some external health costs for other types of energy systems. A typical example is the front-end costs of renewables.

Renewable energy sources indeed are environmentally friendly during power plant operation, yet their development involves huge outlays of material and energy before the plant is built.

### EXTERNAL IMPACTS OF FOSSIL FUEL POWER PLANTS IN GERMANY

| PLANT TYPE | COAL* | LIGNITE* | OIL* | GAS* |
|---|---|---|---|---|
| Sulphur content of fuel | 0.9% | 0.3% | 0.2% | 0% |
| **EMISSIONS** (milligrams per kilowatt-hour) | | | | |
| Power plant, $SO_2$ | 288 | 411 | 1088 | 0 |
| Total cycle , $SO_2$ | 326 | 425 | 1611 | 3 |
| Power plant, $NO_x$ | 516 | 739 | 814 | 208 |
| Total cycle, $NO_x$ | 560 | 790 | 985 | 277 |
| Plant particulates (TSP) | 57 | 82 | 18 | 0 |
| Total cycle, TSP | 182 | 511 | 67 | 18 |
| **EXTERNAL COSTS IN POWER GENERATION** (cost in milli- ECU per kilowatt-hour) | | | | |
| Health damages due to power plant/total cycle | 11.9/13.4 | 15.2/16.0 | 25.7/33.3 | 2.8/4.3 |
| Accidents | not quantified | | | |
| Global warming | 3.0-110.5 | 3.9-143.1 | 3.3-120.4 | 1.3-48.5 |
| Other impacts | 0.16 | 0.23 | 0.64 | 0.04 |
| Global warming total cycle | 3.4-125 | 4.0-149 | 3.5-132 | 1.5-56 |
| Other impacts | 0.16 | 0.23 | 0.64 | 0.04 |
| **TOTAL EXTERNAL COSTS** (per TWh) | 17-138 | 20.2-165 | 37.5-166 | 5.8-60 |
| **TOTAL LOST LIFE EXPECTANCY** (years of life lost per TWh) | 141.5 | 165 | 359 | 46 |

**Coal =pulverized coal, flue gas desulphurization (FGD), reduction of nitrogen oxides ( denox), dust removal systems (dedusting) ; lignite=pulverized lignite, FGD, denox, dedusting; oil=peak load power plant; gas=gas turbine, combined cycle*

*Source: European Commission ExternE Project 1997.*

### COLLECTIVE DOSES FROM VARIOUS STAGES OF THE NUCLEAR FUEL CYCLE

***Collective doses for closed nuclear fuel cycle (manSv/TWh)***

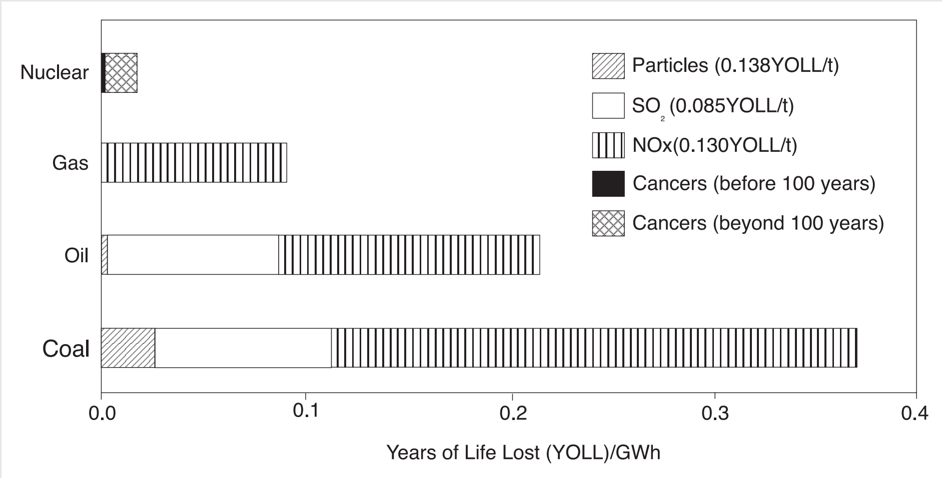
| STAGE | FRANCE | GERMANY | UK |
|---|---|---|---|
| **MINING & MILLING** | | | |
| public | 0.177 | *0.1* | *0.1* |
| workers. | 0.112 | 0.0058 | 0.7 |
| **POWER GENERATION** | | | |
| public | 1.88 | 0.63 | 0.407 |
| workers. | 0.352 | 0.39 | 0.028 |
| **SEVERE ACCIDENT** (dose per reactor year) | | | |
| public | 0.019 to 2.9* | 0.019 | |
| **REPROCESSING** | | | |
| public | 10.3 | 3.3 | 0.448 |
| **WASTE DISPOSAL** | | | |
| public | 0.166 | 0.14 | |
| Total collective dose | 13.0 | *4.6* | *1.7* |
| Lost Life Expectancy (years of life lost per TWh) | 9.8 | *3.0* | *1.3* |

**Estimated upper value for nuclear power plants (not included in estimates for EU countries). Source: European Commission ExternE 1997 study and SENES, UK, 1998. Data in italics corrected from the EC study using SENES results for uranium mining and milling.*

Recent comparisons show that the amounts of steel and non-ferrous metals needed per GWe.y for solar systems are between 30 to 150 times larger than for nuclear power, and even the amount of concrete and cement is six times larger for solar than for nuclear technologies.

Moreover, the electricity requirements to produce all

**COMPARISONS OF HEALTH RISKS FOR ENERGY SYSTEMS**




Note: Comparisons based on damage costs per ton of pollutant assessed in EC ExternE Project; graph provided by A. Rabl, France.

these materials and build the solar power plant are very large, reaching up to 30% of the total electricity that would be produced in the plant's lifetime. The production of this electricity involves health and environmental damages as well, so that altogether solar power plants contribute to environmental pollution even before they start to produce electricity. This aspect was frequently left out of considerations. As noted, the latest ExternE study has in most cases corrected many of these errors.

In the interests of improving comparative risk assessments, various teams of specialists participating in IAEA technical committee meetings have made a number of proposals. One proposal is the introduction of a certain level of risk, below which individual hazards could be considered to be too small to integrate them for risk comparison purposes. Such a cut-off point for health effects of all power systems would provide better consistency and comparability of evaluation than the present practice. The present practice cuts off the effects at various distances and time periods, or neglects some stages of the fuel chain.

## RESULTS OF STUDIES

Although technological improvements make it possible to significantly decrease the environmental burdens of the coal fuel cycle, the emissions of existing and planned coal-fired power plants remain high. The 1995 ExternE study acknowledges that further abatement of emissions is technically possible. However, it notes that such reductions are connected with large increases of construction costs and with operational losses; consequently, utilities are expected to build plants conforming to actual regulations rather than to technical possibilities.

In the case of the nuclear fuel cycle, important contributions to radiological burdens were determined in studies done in France, Germany, Sweden and the UK. *(See table, page 23.)*

In these studies, all radiological hazards were integrated over the entire world population and over very long time periods, up to 10,000 or even 100,000 years. Significant contributions are due to mining and milling, nuclear plant operation, and fuel reprocessing. The radiological burdens due to other stages of the nuclear fuel cycle were calculated as well, though they were very small.

Although the comparisons include much more conservative assumptions for nuclear than for fossil power systems, results indicate that the health burdens connected with electricity generation are the smallest for nuclear power. These are calculated to be about 100 times smaller than for coal or oil and several times smaller than for gas. *(See graph, this page.)*

In conclusion, international studies over the past decade illustrate the importance of assessing external health costs for the full cycle of energy production systems. In general, more conservative approaches are followed with respect to assessments of radiological hazards than to air pollution from other energy systems. Nevertheless, results indicate that under normal operating conditions, nuclear power has lower health and environmental burdens than fossil fuels. Estimates for renewable sources of energy remain incomplete; depending on the assumptions of the study, the estimated effects are either slightly below or above those for nuclear power. ❐