A COMPARATIVE STUDY OF HEALTH AND SAFETY ASPECTS IN THE UTILISATION OF COAL AND NUCLEAR ENERGY FOR POWER PRODUCTION *

by

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1. INTRODUCTION

Planning for future energy sources and the energy policy for the eighties are the topics of immense current importance, particularly in view of the rapidly declining reserves of fossil fuel and lack of proper public education on the inherent safety and potential benefits of nuclear energy systems. Therefore, it is necessary to carry out a detailed scientific analysis of risks associated with the use of different energy systems including nuclear, fossil fuel based, hydro-electric, solar and others. The study of environmental impact and economic and health aspects of the two major energy systems, i.e. nuclear and fossil fuel based, needs to be carried out on a high priority basis. Studies carried out in the past have tended to show some bias towards one or the other source of energy to make a strong case for one of the two sources. It is now being increasingly appreciated that these two major energy sources must coexist at least for the next 50 to 80 years. Therefore, risk analysis must take into consideration the current practices and future possibilities of economic power generation without appreciable risk to human health and the environment. It is also necessary to make a clear distinction between the risks associated with normal operation of a power station and those related to accidental conditions. In the case of nuclear energy, it has been amply demonstrated that risks to human health associated with normal operations are small. Probability of accidents in such stations is also extremely low. The problem of health risks associated with nuclear waste disposal has been magnified beyond proportion by some of the conservationist groups against nuclear power without adequate technical assessment. In the case of fossil fuels, risks associated with mining and movement of coal and ill effects of power plant effluents on the public health are considered to be large. For a comparative study it is necessary to specify the categories of risk associated with different stages of the fuel cycles and express these in quantitative terms. This would help not only in better planning for the future power stations but also in the optimum utilization of the two major energy sources.

In the past, studies have been made on the probability of accidental death from nuclear power stations. One of these studies concluded that the probability of death from a nuclear accident is comparable with the probability of being hit by a meteorite — we never hear of such a thing happening. Since the completion of the above study, further progress has been made in the engineering of nuclear power stations for increased safety for major reactor types. At the same time, great complexity in the evaluation of hazards of fast breeder reactors has been highlighted and extensive new studies are being carried out by different groups on the reliability of the systems involved in the production of nuclear power. Therefore this aspect of risk analysis will not be dealt with in this paper.

It is important to consider the risks to the human population associated with low levels of exposure to ionizing radiations in the long term operation of nuclear power stations, including risks associated with the waste disposal practices. There has been some evidence from the past experience of excessive human exposures to ionizing radiations that uncontrolled exposures can lead to the incidence of leukaemia and cancer amongst the exposed individuals. Although the probability of these risks is extremely small at the low levels of current exposure from the small scale use of nuclear power, it is necessary to carry out projections into the future on a sound scientific and technical basis.

Recent epidemiological studies have shown associations between the exposure to effluents from the fossil fuelled power stations and morbidity and mortality resulting from these. Although a substantial amount of epidemiological data and data on the measurement of non-radioactive pollutants is available in the literature, very few attempts have been made to use this data for quantitative estimation of risks.

2. RISK ANALYSIS

The results of recent studies on the effects of ionizing radiations on man, compiled by different national and international bodies, particularly, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the Committee on the Biological Effects of Ionizing Radiation (BEIR Committee) of the National Academy of Sciences, constitute a significant basis for risk analysis for ionizing radiations. The data on absolute risk of exposure to ionizing radiations is provided by the slope of the linear dose-effect relationship based on past human exposures. For the assessment of risk associated with the effluents from fossil fuel power stations, epidemiological data on lung cancer combined with the data on the levels of air pollution will be used. Such data is available for some of the countries in Europe, and also for several of the States in U.S.A. The data available for India is too scanty. Risk analysis can be based on both morbidity and mortality associated with the exposures.

Evidence for the induction of cancer in man by ionizing radiations has been quite unequivocal and all risk analyses are generally centred on this. The absolute risk of a particular type of cancer is generally expressed in terms of deaths per year or number of cases of cancer per year in a population of one million exposed to one rem of radiation dose (rem is a unit of radiation dose applicable to man). The quantitative risk data at lower doses is obtained by extrapolation from the human experience of exposure at high doses and dose rates. The exposed groups falling into this category are the atomic-bomb survivors of Hiroshima and Nagasaki, certain groups of patients irradiated therapeutically, and some groups occupationally exposed. Table 1 gives the estimates of absolute risk for different types of cancer, based on the incidence of death in the above groups, as compiled by the US Advisory Committee on the Biological Effects of Ionising Radiations (BEIR Committee) Ref. (1). Typical human data on dose-response used for the risk estimates of

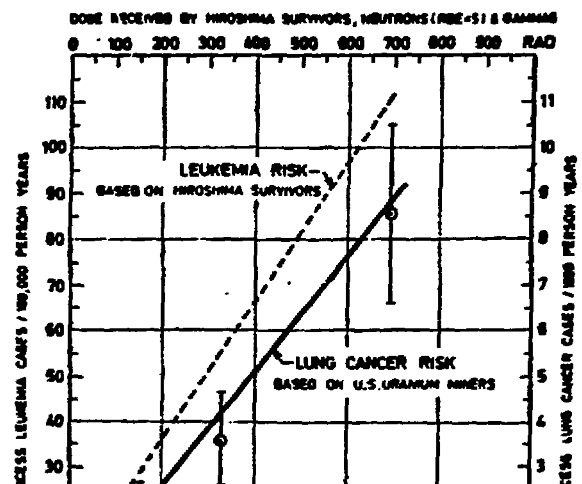

FIG. 1. TYPICAL DOSE-RESPONSE RELATIONSHIPS FOR HIROSHIMA SURVIVORS (1950 TO 1966) AND U.S. URANIUM MINERS (1951 TO 1971) [1].

Table 1 (leukaemia and lung cancer) are illustrated in *Figure 1*.

In these risk estimates, relative biological effectiveness (RBE) of the radiation involved is also taken into consideration. In extrapolating from higher doses to lower doses it is assumed that the incidence of malignancy is linearly proportional to the dose, and there is no threshold dose which does not cause cancer. Although the latter assumption seems scientifically sound, the linearity of the relationship may not be valid for all types of exposures. The risk estimates of Table 1 for single exposures can be used for calculating the number of deaths per year from continuous exposure at a rate of 1 rem/a for a lifetime. This has been calculated from the data presented in the BEIR Committee report (1) and the estimated value is 150 deaths/million per rem/a, with a most likely upper limit of 200 deaths/million per rem/a. The latter value will be used for calculating the risk of cancer deaths from continuous exposure of groups of individuals receiving doses from gaseous and liquid waste discharges from nuclear power stations, as well as for the assessment of risk in different stages of the nuclear fuel cycle. It is also useful for estimating the risks of occupational exposures in the nuclear industry and of medical exposure.

We shall now examine the doses actually received by the exposed population groups from different sources, particularly the operation of nuclear power stations, and assess the risk. The largest dose received by man still comes from natural sources including cosmic rays, terrestrial γ — radiation, ^{40}K, ^{226}Ra and ^{210}Po in the body tissue and human bone, radon daughter products deposited in the respiratory tract during normal breathing and other natural radioactive substances in the human body. Average dose from all these sources adds up to nearly 100 mrem/a, or 3 rem in 30 years. This dose is delivered continuously, at an extremely small dose rate. It consists of exposure from both high LET and low LET radiation, and involves most of the potential sites for human cancer.

Whereas natural sources give rise to exposure of the entire world population, dose from the operation of nuclear power stations relevant for risk evaluation is received only by some groups of individuals exposed to gaseous and liquid waste discharges from these stations, in addition to those occupationally exposed. The population dose from these varies with the design and operating conditions of the reactor, and is generally well below the ICRP dose limits. The average dose received by groups of individuals exposed to the discharges from a nuclear power station is estimated to be less than 5 mrem/a for a fully developed nuclear power programme with sound engineering practice. This has been amply demonstrated by a number of large stations (2, 3). This dose is nearly 5% of the natural dose of 100 mrem/a, and includes both internal and external exposures. The risk corresponds to one additional case of cancer death per year per million of the exposed group, even if we take the highest estimate of 200 cancer deaths/million per rem/a. This 'one' estimated additional case is to be considered in the light of spontaneous cancer deaths in the range of 1,000 to 2,000 persons per million per year, with an average of 1500, estimated for many parts of the world.

The exposures that do merit serious consideration are those received from medical practice, including X-ray diagnostic exposures and radiation therapy. The annual somatic dose from diagnostic practice is estimated to be in the range of 20 to 100 mrem, depending on the nature and frequency of the examination and the integrity of the diagnostic work practices. If we take 50 mrem as the average annual dose for exposed groups of patients from the medical practice, their cancer risk will be 10 per million per year, which is also small. The other miscellaneous sources of radiation exposure are fallout, use of television sets, industrial and domestic appliances, air travel, etc. Their contribution is also very small compared to the natural exposure of man.

For a complete analysis of the nuclear fuel cycle risk, it is necessary to consider the hazards associated with each stage of operation, including uranium mining, milling and processing, fuel fabrication, reactor operation and fuel reprocessing. Based on the estimated mean dose from each of the operations, it is possible to estimate the risk of cancer for each operation, again using the rate of 200 deaths/million per year/rem estimated by the BEIR Committee for continuous or continual exposure. The data is given in Table II, in which risk is estimated in terms of cases per 10,000 workers. The last column gives the risk of spontaneous induction of cancer. In the case of uranium miners, the current risk is only one per 10,000, against the excess death rate of 15 per 10,000 found from a survey carried out for the period 1950-1967 (4). For all the stages of the fuel cycle, the risk is less than one. The risk analysis for the fast breeder fuel cycle may be based on the release of ^{239}Pu and other transuranic elements in fuel reprocessing for these reactors. The population dose from releases from a fuel reprocessing plant for a 1,000-MWe fast breeder is only 10^{-8} of the natural α -dose, giving an exceedingly small risk estimate on the scale considered (5).

3. RISK ANALYSIS FOR CHEMICAL POLLUTANTS AND COMPARISON

Although several chemical pollutants have been known to give rise to cancers of different type, there is no systematic human data which can be used for numerical risk analysis, as in the case of ionizing radiations. In addition to cancer, chemical pollutants also cause death from heart diseases, emphysema, chronic bronchitis and several other ailments. The overall risk analysis should include death from all such causes. During the last 20 years there has been a rapid rise in the incidence of deaths from cancer and heart diseases, and chemical pollutants probably account for a major part of this increase. It is estimated that nearly 50% of all deaths are caused by cancer and heart diseases (6).

Several of the pollutants in the environment that can cause cancer have been identified. These include inorganic substances like asbestos, arsenic, chromium, nickel, and organic substances such as benzo(a)pyrene, benzidine, vinyl chloride and coal tar. Benzo(a)pyrene is produced in substantial quantities in the burning of coal, and is also present in automobile exhausts. Risk analysis based on large scale epidemiological studies can provide very useful information on the risk of such pollutants in large groups of population. This has been done on the basis of recently available data showing the increasing trend in lung cancer attributed to air pollution. Fig. 2 gives the number of deaths from lung cancer in some West European countries (7), U.S.A. (8) and India (9, 10). The figure shows a continuous increase in the incidence of lung cancer from 1950 to 1970. Such an increase may be associated with continuous increase in the production of power from coal and oil, although there may be several other factors also involved.

It is well known that lung cancer is caused by air pollution as well as by cigarette smoking. In order to establish the contribution of air pollution, methods of regression analysis have been used with the data on mortality due to lung cancer, and available information on smoke pollution and cigarette smoking (11) to find out the increase in the incidence of cancer due to pollutants from coal burning in the fossil fuelled power stations. This analysis showed an increment of nearly 142 cases of lung cancer deaths per million per year, per ton of coal consumed per person, in a population with a total age-sex-specific lung cancer death rate of 750 per million from all causes (England and Wales, 1958-59). Although there are limitations in the model used for analysis, the estimates show orders of magnitude of higher lung cancer risk due to coal fired stations compared to the nuclear power stations. The regression analysis also showed 15% increment in the average lung cancer death rate from cigarette smoking (for 10^3 cigarettes per year). The overall risk of pollutants from coal fired power stations, including death from causes other than lung cancer, would be even higher. A similar analysis was carried out for lung cancer deaths due to inhalation of the specific carcinogen benzo(a)pyrene from coal burning, on the basis of extensive data on concentration of this carcinogen from 48 states in U.S.A., and total incidence of lung cancer (11). The analysis showed an increment of nearly 48 cases of lung cancer deaths per million, per ng/m^3 of benzo(a)pyrene, in a population with total lung cancer death rate of nearly 867 per million. This corresponds to a contribution of 5.5% to the lung cancer deaths from benzo(a) pyrene in the air.

If we now consider the increase in total number of deaths from lung cancer during the last 20 years (Fig. 2) and attribute an estimated 85% increase

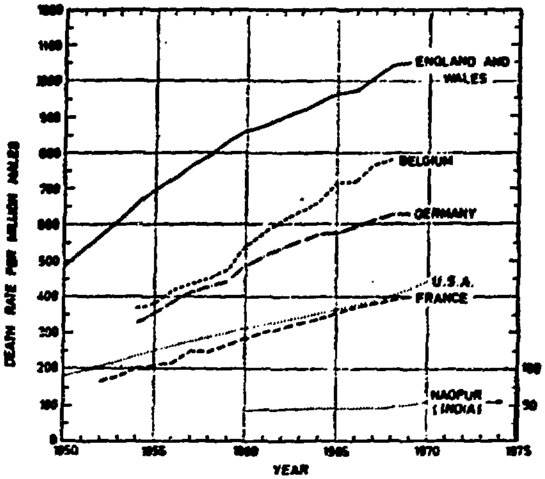

FIG. 2. INCREASING TREND OF LUNG CANCER DEATH RATE IN MALES FOR SOME WEST EUROPEAN COUNTRIES, UNITED STATES AND NAGPUR (INDIA).

to air pollution (excluding 15% from smoking), we can calculate the total lung cancer risk of air pollution. Fig. 2 shows nearly 500 additional cases per million for England and Wales, of which 425 can be attributed to air pollutants, in a population with total lung cancer death rate of 1050 per million in the year 1970. This corresponds to a contribution of 19% to the lung cancer deaths for the effluents from coal fired power stations. For the effluents from a well established nuclear power programme (with a dose of 5 mrem per year), the contribution to all types of cancer including leukaemia is only 0.066% (on the basis of one additional death in an average of 1500 cancer death per million per year).

COMPARISON OF RADIOLOGICAL HAZARDS FUELLED AND NUCLEAR POWER PLANTS

It has also been suggested that the natural radioactive content of coal contributes a greater radiological hazard than the effluents from nuclear power stations. We shall consider this question in some detail. Eisenbud and Petrow (12) were probably the first to estimate the radioactive effluents to the atmosphere from fossil-fuelled power plants. In these plants the source of radioactivity is the normal radioactive content of coal, particularly Radium-226 and Radium-228. These radioactive substances are contained in the fly ash, and stay in the air as suspended particles. In addition to these, radon and daughter products are also present in the plumes of coal fired power stations. The daughter products of radon are electrically charged at the time of formation and tend to attach themselves to natural aerosols normally present in the atmosphere. The atmospheric residence time of these radioactive particulates would be of the same order as that of other suspended particulate matter, and lies in the range of 6 to 30 days. Polonium-210, the longest lived alpha emitting daughter product of radon is also known to be present in the plumes in significant concentration. This isotope is probably in equilibrium with the long lived parent Radium-226 in the coal.

It may be assumed that radioactive substances are released in the atmosphere in the same percentage as fly ash is released from the stack. On the basis of this assumption the radioactivity released exceeds the permissible levels by a factor of 3 to 4 However the actual radiological health significance of this release must be assessed on the basis of particle size and dose delivered to the lung and other body organs. This assessment must await future research on this aspect of the problem.

Under normal operating conditions the nuclear power plants emit, primarily radioactive noble gases. It has been estimated that the concentrations of noble gases under normal operation of a nuclear power station are well below the tolerance levels, often lower by more than an order of magnitude. Besides this, the lung dose delivered by inhalation of noble gases is extremely small since no particulate matter gets deposited in the lung.

Schikarski (13) had carried out a detailed analysis of comparative radiological hazards of the two types of power stations and concluded that the nuclear energy systems with boiling water reactors are at least 60 times better than coal, and the systems with pressurised water reactors is 400.000 times better than coal. He has further concluded that on the whole, from the point of view of risk potential, nuclear energy is better than coal by a factor of 180. If we combine the radiological and chemical hazards of coal burning, the factor of safety for nuclear power is very large indeed. However, as pointed out earlier, much further research is necessary to compare the radiological hazards of the two systems.

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TABLE I

Estimates of absolute risk of leukaemia and all other cancers (deaths per million per year per rem) for different age groups. Risk estimates are for whole life following the latent period

Age group	Type of cancer	Absolute risk
0 — 9 years	Leukaemia	2.0
0 — 9 years	All other cancers	1.0
Above 10	Leukaemia	1.0
,,	Breast cancer	1.5
,,	Lung cancer	1.3
,,	G.I. including stomach	1.0
,,	Bone	0.2
,,	All other cancers	1.0
Total for 0 — 9 age group		3
Total for above 10 age group		6

TABLE II

Occupational risk estimates for different stages of the nuclear fuel cycle, for whole body exposures

Stage of the fuel cycle	Average individual exposure (mrem/year)	Estimated risk, cases/10,000	Risk of spontaneous cancers/10,000
Mining	500	1	15
Milling & Processing	100	0.2	15
Reactor Operations	200	0.4	15
Fuel Transport	50	0.1	15
Reprocessing Plants	200	0.4	15

Explanatory Notes:

1. Estimated risks are for 10,000 persons employed in each of the operations. For actual numbers employed, risks tend to be negligible compared to spontaneous incidence.
2. Risk estimates for miners are only for external whole body dose.
3. Individual exposures are the best estimates available from different sources. See reference (14) for reactor operations.