Accounting of Nuclear Power

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India is poised for development of nuclear power in a big way. Six additional nuclear reactors, each with a capacity of 235 megawatts, are expected to be set up during the Sixth Plan. These programmes are defended on the ground that nuclear power is indispensable for meeting the growth in demand for power in the country and that it is technically more efficient and economically cheaper than power generated from coal-based plants.

This paper subjects these claims to a critical scrutiny and brings out some of the major issues relating to nuclear technology which have wider implications for the economy.

NUCLEAR power climaxes the achievements in modern physics and is deservedly held in high admiration. Nuclear technology signifies man's mastery over the elements of nature in an important respect. It has provided mankind with incredible power to convert energy from minutest particles. One kg of natural uranium, U^{238}, can generate as much energy as it would take 35,000 kg of coal to produce. Faced with the problem of depletion of renewable resources like coal and oil, nuclear power seems to offer a breathing space for humanity before it finds alternative sources of energy. Since a nuclear plant once fed with a few tonnes of uranium oxide fuel rods can generate power for years together, it stands in sharp contrast with the coal-based power plants with their cumbrous steam generation systems and the complex infrastructure required for mining, transport and processing of coal. Finally, the nuclear power does away with the pollution created by the emissions from coal-based power plants. All these notwithstanding the problems posed by the nuclear technology seem to outweigh the gains it promises.

Among the advantages claimed for the nuclear power is that it would be cheaper than coal-based power in India and, under certain assumptions about the demand for energy, it would be indispensable for the country.[1] We would refute the arguments on both the counts. To start with, the estimates of the cost of nuclear thermal power worked out by us show the coal-based power to be more economic than nuclear power. We would like to point out in this connection certain deficiencies in the methodology of estimation which seriously affect the accounting for nuclear power.

CAPITAL COST

A nuclear power plant, with its sophisticated technology and heavy construction charges for adequate shielding of the equipment, has a high fixed cost which compares unfavourably with the fixed cost for a coal-based power plant. A nuclear power plant, therefore, costs more per kilowatt capacity than a coal-based power plant. The relative economies depend largely on the cost of fuels required to operate the respective plants. The size of nuclear plants in India has been around 200 MW. The cost for a nuclear plant for the paper is taken from a study by Sethna and Srinivasan[2] and the cost for a coal-based power plant is estimated from data available with the officials in the power industry.[3] An idea of reasonableness of the estimates can be had from a check on the ratio of the fixed costs for the two types of power plants. The ratio of the capital cost for nuclear to coal-based plants in our study comes to 1.33. The ratio compares with figures observed in the United States, ranging from 1.07 to 1.53 in respect of the light water reactors and coal-fired stations without scrubbers. The CANDU type reactor (Canadian Heavy Water Reactor) which India has adopted, however, involves higher fixed costs compared to the reactors in the US. One would, therefore, expect the ratio to be greater (that is, more favourable to the coal-fired plant) in India than in the US.

The capital charges for a power plant depend on a number of factors like the cost of the plant, the rate of interest on capital, the rate of depreciation, and the capacity factor for the plant. The capacity factor is given by the ratio of the actual hours of power generation by a plant to the hours expected from its rated capacity during a year. The estimate for capital charges per unit kWh generated, it can be seen, is highly sensitive to the variation in the capacity factor.

FUEL CYCLE

The variable cost for a nuclear plant, mainly comprising the fuel cost, is much smaller than that for the coal-based plants. Given the higher capital charges for the nuclear plant, the relative economies of the nuclear and coal-based power depend primarily on the difference between the two in respect of the fuel cost.

The fuel cycle, as the system for supply of uranium to the nuclear plant is called, is much more complicated than the supply system for coal. Uranium (U^{238}) that is mined in nature contains only a small fraction (0.7 per cent) of U^{235}, an isotope of uranium, which alone is fissile and participates in the process of nuclear fission within the reactor generating the required heat. The nuclear fuel cycle starts from steps for enrichment of U^{235} in the fuel, from 0.7 per cent to 3 per cent for efficiency in operation, followed by further chemical processing and encapsulation in fuel rods for charging into the reactor.[4] When a nuclear reactor burns up the uranium it is fed with, the spent fuel rods retain fissile elements like unused U^{235} and plutonium Pu^{239}, which are obtained by conversion of the non-fissile U^{238} contained in the fuel rods. The second part of the fuel cycle costs are distinguished by whether the cycle ends with the burning of the fuel once for all, or it continues with the reprocessing of the spent fuels for recycling into the reactor. If the spent fuel is not required to be retrieved in future it has to be stored away permanently with adequate measures for safety against radiation and other hazards. When, on the other hand, the spent fuels are reprocessed, the fissile elements recovered from it are fed into the reactor leading to a net reduction in their requirement. It can thus be seen that there are alternative routes available in the fuel cycle. As the total cost of fuel per unit of nuclear energy generated is derived from all the expenditures under the fuel cycle it will differ according to the different routes chosen.

TABLE 1: COST OF POWER GENERATION

(1977-78 Prices)
(Size: 200 MW)

Capital Rs/kW			Fixed Cost (p/kWh)[a]		Fuel Cost (p/kWh)[b]		Total Cost (p/kWh)	
Thermal	Nuclear	Capacity Factor (Per Cent)	Thermal	Nuclear	Thermal	Nuclear	Thermal	Nuclear
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4500	6000	60	13.70	18.28	4.64	3.81	18.34	22.08
		65	12.64	16.86	4.64	3.81	17.28	20.68
		70	11.74	15.66	4.64	3.81	16.38	19.47
		75	10.96	14.61	4.64	3.81	15.59	18.43
		80	10.27	13.70	4.64	3.81	14.91	17.52

(a) Interest = 10 per cent, Depreciation = 3.5 per cent, and Operation and Maintenance = 2.5 per cent.
(b) (i) Coal rate = 0.58 kg/kWh, Price of coal = Rs 80/tonne.
(ii) Fuel cost for nuclear power plants is estimated for the recycle case, and shipment cost and decommissioning cost are excluded from it; burn-up = 16 MW-Day/kg, efficiency = 30.5 per cent, exchange rate: \$1 = Rs 8.50.

The estimation of the fuel cycle cost remains subject to considerable uncertainties as some of the steps in the cycle have not been standardised yet. So a firm cost for them cannot be quoted. This happens to be the case around the world with regard to fuel reprocessing and the cost of waste management. The cost of waste management poses in addition serious problems regarding the method of accounting. We deal with the subject in detail later.

There is little information available in India about the cost involved in the fuel cycle. Estimates of cost of nuclear power have been the subject of controversy between the nuclear establishment and its critiques in the advanced economies, both sides quoting widely divergent estimates. An important source of difference in the estimates is in the assumptions held and costs estimated for the fuel cycle. In view of the confusion prevailing on the subject the premier organisations of the physicists in the United States, the American Physical Society (APS) and the Institute of American Physics (IAP) recently undertook a study to provide "an independent evaluation of the technical issues in nuclear fuel cycles and waste management, together with their principal economic, environmental, health and safety implications".[5] The study, henceforth called the APS study, published in January 1978, offers extensive data for computation of the cost of the nuclear fuel cycles.

We based our calculations on the fuel cycle cost on the data provided by the APS study for heavy water reactor in the United States, which corresponded to the CANDU type reactor used in India.[6] It was presumed that the practices in India conformed to the fuel cycles described in the APS study. The operations in the fuel cycle are highly capital-intensive. Since the processing of nuclear fuels in India may be undertaken with equipment mostly manufactured in India, the APS estimates need to be adjusted appropriately. We took the ratio of the capital cost for a 200 megawatt heavy water reactor in the United States and India respectively as the factor for adjustment of the APS fuel cycle costs to Indian conditions.

TOTAL COST

The calculation of the cost of nuclear power depends on assumptions about a number of technological and economic parameters — rate of interest on capital, capacity factor for the plant, burn-up rate of the fuel, efficiency of the reactor, the route selected for reprocessing or storage of the waste. Variation in any of the parameters will affect the cost estimates significantly. It seems unavoidable that the estimation of the cost of nuclear power will remain subject to some measure of uncertainty. One can, however, state explicitly the assumptions held about the relevant parameters for the estimates made. The elaborate exercise undertaken in the APS study provides useful guidance in this respect.

The estimates of total costs for the two techniques of power generation are presented in Table 1.[7] The estimates vary over a range due to variation assumed in the capacity factor.

The figures in Table 1 show that the cost of power generation by a coal-fired plant located at the pit-head wa vary from 14.91 paise to 18.3 pa depending on the capacity factor. C parable figures for the nuclear pl with the recycling of spent fuel ra from 17.52 paise to 22.08 paise. T difference in the unit cost in favour the thermal power has to be set agai the cost of transport of coal to locati away from the pit-head. Under t present freight rates for transport coal by railways, thermal power c compete with nuclear power at a d tance of around 750 km from the p head. Only few places in India outside this range of distance from co fields. In the analysis as here the ec nomic superiority of nuclear power not established. It may also observed from Table 1 that a high capacity factor for a power plant le to a lower cost per unit of power ge rated. Nevertheless, the cost of nucle power per unit kWh remains high than the thermal power at all capaci factors.

It may be argued that a different rise in the price of the fuels may rever the relative economic position of t two techniques of power generatio There is little ground to hold such hop since the price of non-coking coal i creased between 1973 and 1978 by 10 per cent in India. The price of uranium in the international market, on the oth hand, increased from 6 to 8 dollars pe pound in 1973 to over 40 dollars pe pound in 1978, that is, by more th 500 per cent.[8]

The cost of nuclear reactors has al been rising fast over the years. Sin the capital cost of nuclear power pla is higher than that of a thermal powe plant any escalation in prices would b affecting the cost of nuclear power mor than that of thermal power. A stead increase in the capital costs of nucle reactors abroad has reduced the signific ance of fuel costs considerably. In 196 34.2 per cent of the total cost o nuclear power was accounted for by the fuel element and 49.9 per cent by capital, the remainder being the opera tions and maintenance costs. By 197 capital costs escalated to assume 77. per cent of the total cost. The fue cost declined to around 18.2 per cent The construction cost of nuclear reac tors increased by 24.4 per cent over the same period.[9]

In spite of all the detailed calculations as reflected in Table 1, the accounting for the nuclear power cost cannot be considered complete. The nuclear power plant leaves behind it a burden of liabilities to the society for a long period after it has ceased to operate. The constraints to a complete accounting of the nuclear power cost arise from the physical basis of nuclear energy.

BOTTLING THE GENIE

Uranium, the fuel for nuclear power plant, has an atomic mass of 238 with the characteristic that it has an unstable atomic structure. It has a natural tendency to eject particles from its nucleus and transform itself into other elements in the process. The process, known as radioactive decay, continues in nature over thousands of years till it attains stability in the form of lead, Pb^{206}, with an atomic mass of 206. As the radioactive decay is a slow process the release of energy accompanying it cannot be fruitfully utilised; nor does it cause concern about health hazards. The trouble arose when the nuclear physicists discovered the technique for condensing in a split second the prolonged process of transformation of the matter taking place in nature. The results, while rewarding in terms of energy gains, were not exactly the same. The laboratory process did not generate the same elements as were obtained in the natural process. Instead, entirely new elements which never occurred in nature were created as a result of human efforts. The new elements so created, include plutonium, Pu^{239}, which is the most poisonous element invented by man. Inhaling one miligram (1/1000 gram) of it would cause death within hours. Inhaling one microgram (1/1000 of a miligram) would lead to eventual lung cancer. The material remains active over 1,00,000 years. Half of the plutonium decays in 24,400 years, designated as its half life. The remaining half is reduced to one-fourth in another 24,400 years. One-sixteenth of the original substance remaining active at the end of 97,600 years. Plutonium is the ingredient of a nuclear bomb. [illegible] to 10 kilograms of plutonium are used for military bombs. But nuclear explosion can be ordered with even less quantity. Two kilograms of plutonium is considered to be the 'trigger quantity', the smallest amount to cause an explosion. This has given rise to widespread concern in the Western countries that terrorist groups can manage to remove surreptitiously such a quantity and hold a society to ransom.

Plutonium is only one among the byproducts coming out of nuclear reactors. There are others, like strontium and caesium which have half-lives of around [illegible] years. These radioactive hot wastes should pass through 20 half-lives before their radiation is brought down to a negligible level. Nuclear scientists do not yet know any means of disposing of these materials some of which continue to radiate dangerous pernicious gamma rays posing serious health hazards to the population. No method has been found after years of research to bottle up the genie which was released through the initiation of a nuclear reaction. All that is being considered now is to find the safest way to segregate them from the environment and let the sleeping dog lie. The debate is about whether the methods suggested are safe enough or not. Everybody seems reconciled to the fact that nuclear waste products have to be under protective custody for at least as many years as they remain dangerously active. Human society which is hardly more than 10,000 years old is now called upon to devise an infrastructure for preserving the nuclear wastes which should last over tens of thousand years. However, the issue is not only a philosophical one but has serious practical implications.

Besides the nuclear wastes the nuclear plants also require to be treated the same way. Apart from the spent fuels, the circulating water and much of the structural material containing the nuclear reactor would become radioactive through continuous emission of neutrons. Unlike the coal-based thermal plants, the nuclear plants cannot be sold off at scrap-value after the end of their useful life. They have to be carried over thousands of years with adequate caution that no living being trangresses into the danger zone affected by radiation. Various alternatives are being suggested for decommissioning the nuclear reactor and the associated contaminated materials. The US Department of Energy has considered mothballing, entombment, or dismantling of the reactor and other materials after the life of a nuclear plant. Mothballing would consist of removal of all fuel and radioactive fluids and wastes and putting the facility in protective storage with appropriate security measures. Entombment would need prior removal of all radioactive materials as mentioned before to a different site and sealing off all the remaining highly radioactive or contaminated components within a protective structure providing a biological shield. Dismantling would be the most expensive alternative which would require all radioactive materials above an acceptable contamination level to be removed off-site so that the plant site can be used again. The US Department of Energy provided estimates (in 1975 dollars) ranging from 2.3 million dollars to 31.2 million dollars for the three alternatives; higher decommissioning costs have been quoted by others.[10] Since only some of the research reactors and a few smaller power reactors have been decommissioned by now the estimates cannot be considered to be firm.

FAST BREEDER REACTOR

A novel way of getting rid of plutonium is to use it as the fuel in the fast breeder reactor (FBR) which has the peculiar property of reproducing more plutonium from that it is fed with. India is building an FBR unit at Kalpakkam. It is claimed that the FBR would reduce the cost of nuclear power and relieve at the same time the problem of scarcity of nuclear fuels. It is however too early to check for the economies of FBR since only a few research reactors are now in operation. The commercial operation of FBR is still year away.[11] A few points can nevertheless be made here.

Firstly, the FBR requires a full complement of plutonium before it can start operation. One needs therefore to build up adequate stock of plutonium through operation of light or heavy water reactor (known as thermal reactors) over the years as preparatory. The FBR units would similarly be required to work sufficient number of years to generate stock of plutonium for another unit. It is considered that it would take about 30 years of operation before an FBR can meet the requirements of another unit.

Secondly, the risk of a reactor accident is increased considerably with the FBR. The FBR is fed with liquid sodium as coolant which explodes immediately on coming in contact with water. The FBR has a compact core which is densely packed with fissile materials. The high degree of heat the core generates and the peculiar nature of the coolant increases the chance of core meltdown in FBR.

The plutonium for the FBR is obtained by reprocessing the product of the thermal reactors in a separate plant. The transfer of plutonium from the latter to the FBR has to be carefully organised since the leaking of a small fraction of plutonium into the environment may have serious repercussions. Further, being ingredient of nuclear bomb, there has to be an absolutely theft-proof guard over the installations connected with plutonium. All these would add to the cost for generation of power.

Finally, even the FBR cannot burn up all the radioactive materials and would leave in its trail nuclear wastes for further storage.

Accounting of Liabilities

It is not difficult to understand the worry of the physicists over the effects of radioactive decay unleashed by nuclear reaction. It may not, however, be easy to appreciate that it can pose serious problem to the economists concerned with accounting of the cost of nuclear power.

Just as physicists are required for the first time to consider the physical effects expected to take place far beyond centuries, similarly the economists are also asked to account for costs that may be incurred over the centuries in future. Economists are in no better position to meet the situation than the physicists. The conventional practice in accounting, based on received theories in economics, is to reduce to present value the stream of all values relating to cost or return generated at different points of time by discounting them at appropriate rate of interest. The method of discounting consists of deflation of the values for future years by applying discount factors for the respective years. The discount factor is indicated by $1/(1+i)^t$ where i is the rate of interest and t the year to which the value refers. It can be seen that the factor continually reduces in value over the years for a given interest rate. For instance, at 15 per cent rate of interest the discount factor amounts to 0.0009 in the 50th year ($t = 50$). Applied on the value of return or cost expected in the 50th year Rs 10,000 would be taken for Rs 9 only. The discounted values for as distant years as 50 or more would be an insignificantly small figure. The higher the rate of interest, the shorter the span of years for which the same results follow.

It should be apparent from this that the existing practice of accounting for present value cannot take into cognisance any economic consequences beyond a limited number of years, the limit being determined by the rate of interest considered. Nevertheless this method of accounting has been holding its ground because in actual commercial or government project analysis, calculation of returns or costs beyond 30 or 40 years are not considered for the simple reason that the fixed capital like plants, machinery, buildings, etc, over which investments are made are expected to run down or wear out over the period. It may now be appreciated why the method of discounting for present value in respect of costs of nuclear power can be seriously misleading as it ignores the cost incurred for protective custody of the nuclear waste and the debris of decommissioned plants over practically an indefinite period.

The basic problem, however, does not arise from the method of discounting which is adopted but lies in the principles of accounting for an asset (or liability) whose life extends over years which are counted in terms of hundreds instead of the usual units of decades. Economists, like the physicists, were not required to consider such a situation before. The problem in economics is but a reflection of the real physical problem of maintaining an infrastructure for the protective custody of the nuclear waste. The received economic theory does not seem to offer any satisfactory solution.

The assumption implicit in the current practice of accounting is that the present generation can ignore the consequences of a current economic action which emerge long after during the period of a future generation and leave it to the latter to tackle them. A further anomaly in the present case is that the present generation would be reaping all the benefits and the future generation sharing only in the costs. The situation was brought out clearly by Maurice Van Nostrand, Chairman of the Iowa State Commerce Commission, during the discussion on the costing of nuclear power in a Hearing of the United States Senate Sub-Committee on Environment, Energy and Natural Resources in 1978. Referring to the cost of radioactive waste management, Van Nostrand observed: "I find it distasteful even the possibility that some of those costs are not being paid currently and that Iowans sometime in the future are going to be forced to pay not only the costs of electricity they use but some carryover costs from some electricity consumed long ago".[12]

Nuclear at the Cost of Coal

It is not often realised that the excessive emphasis now being placed on the role of nuclear energy in India has been affecting adversely the development of the alternative energy resources. Prime among them is the case of coal. India has a reserve of 85,000 million tonnes of coal. The present rate of its exploitation is a little over 100 million tonnes per annum. Even if the level of exploitation of coal was raised to 500 million tonnes per annum, the reserve could see India well through another century.

It has been suggested that India may not be able to mine as much coal as may be required to meet the increasing demand for energy by the end of the century and would, therefore, have to depend largely on the nuclear power.[13] The analysis is based on projections of demand which are highly overestimated.

It is argued, for instance, that if the per capita energy consumption in India levelled off by the end of the century to about one half of the per capita energy consumption prevailing in Europe around 1977, the output of coal would have to be raised by a factor of 10. Considering that the level of coal production in 1977 was about 101 million tonnes it would indeed appear to be a formidable task. The unrealism in the assumption would, however, be apparent if one referred to the figure for per capita commercial energy consumption for the European countries, which was about 4,200 kg of coal equivalent during 1977. While the same for India stood only at 178 kg of coal equivalent.[14] It may be noted also that the Working Group on Energy Policy set up by the Planning Commission estimated more modest figures ranging from 427 to 531 million tonnes for the production of coal by 2001.[15]

Hazards of Coal

It has, however, to be acknowledged that coal also contributes to environmental pollution and health hazards. The burning of coal produces dust, chemicals and smoke containing noxious elements like sulphur, phosphorous and traces of radioactive element like Radium 226 which emits beta rays with a half-life of 1,620 years. These induce various types of diseases among the population.

While a coal fired plant of 500 MW capacity would produce about 30,000 truck loads of ash per year, the discharge of fuel by a nuclear power station of similar size would amount to only 5 truck loads for the nuclear waste. There is, however, a difference between the flyash and the nuclear waste. The flyash from a thermal plant is distributed over wide areas not only in the ash-ponds adjacent to the power stations but also in productive use over wide areas. The intensity of radiation from the flyash has not been as high as to call for special protective measures.

The flyash from a thermal plant is nowadays being increasingly used for productive purposes like manufacture of bricks, use as road binding material and manufacture of pozzolona cement. Being absorbed in productive use, any possibility of increase in the intensity of radiation due to continued accumulation of the flyash in ash-ponds adjacent to the power stations is reduced. The danger from nuclear waste arises primarily from the high degree of radiation emitting from its concentrated mass of heavy metals.

Coal has yet other problems. It emits smoke consisting of sulphur dioxide and phosphorous and nitrogen oxides. Increasing use of coal in the industries and the power stations all around the world had been raising the carbon dioxide content of the atmosphere to a dangerous level. The scientists are worried about the carbon dioxide screen around the world preventing dissipation of the heat generated on the planet earth leading to what is termed as the greenhouse effect. There is the danger of the earth gradually warming up. The consequences of the greenhouse effect are yet to be assessed fully. It is acknowledged that the pollution from the chimney stacks are deleterious to public health and means should be found to contain it.

ADVANCES IN COAL TECHNOLOGY

Fortunately, research on ameliorative measures for pollution from coal has achieved some positive results. Electrostatic precipitators and scrubbers now being fitted to chimney stacks in the Western countries have proved well in controlling the emission of particulates and chemical elements. However, these go to increase the cost of burning coal. The research on a radical alternative to the existing practice of burning coal in the boilers with its attendant problems of smoke emission is now fairly advanced in the form of fluidised bed combustion (FBC) system.

Fluidised bed combustion is the burning of fossil fuel in a hot bed of granular particles held in suspension in an air stream.[17] Placed at the bottom of a combact unit replacing the large conventional boiler, hot air with high velocity at a temperature between 750°C and 950°C is charged through the bed making it 'boil' as it were. As the stream-carrying tubes can also pass through the bed; heat is transferred not only by radiation and conviction but also by conduction. The combustion temperature being lower than that in a conventional firebox, the chance of damage to the material is reduced significantly. Fed with suitable proportion of limestone or dolomite the fluidised bed absorbs the noxious sulphur dioxides and controls their emission. It also minimises the formation of nitrogen oxides, a major pollutant produced by the burning of coal. Virtually any combustible material can be burnt on the hot bed of FBC unit. Since coals with high ash content can be used the requirements of coal preparation can be reduced. Because of the reduced heat transfer area requirements, an FBC unit is smaller and lighter. Hence its construction cost is reduced. Grainger shows that an FBC unit would be cheaper than nuclear power units at all practical load factors in the UK.[18] FBC units are now in commercial operation for raising steam for industrial use. An experimental unit with 10-tonne capacity has been put to industrial use in India recently. The units for the power plant are now in the laboratory stage in the UK, the US, USSR and the Scandinavian countries.

Another breakthrough in the power technology has been made by the introduction of magneto hydro dynamic (MHD) method for power generation.[19] In MHD technology, gas from coal is raised to high heat and passed through a magnetic core under high pressure. The elements of the gas are ionised and the charges from the electromagnetic field are collected by electrodes to generate electricity, thus eliminating the need for the generator and the turbine. As the coal is gasified for use in MHD, its composition with regard to ash and chemicals assumes less significance. The Soviet Union, the pioneer in the MHD technology, has scaled up from a 20 Megawatt generator in 1971 to 100 MW capacity at present. They aim to develop 2,000 MW units by the year 2000.[20]

MISALLOCATION OF RESOURCES ON R AND D

The development in coal technology has, however, not been as fast as one would have expected. An important reason for this can be ascribed to the exaggerated hopes raised by the emergence of nuclear technology which its advocates claimed could substitute largely for coal in power generation. This has been largely responsible for diversion of resources for research and development away from coal to nuclear technology for power generation both in India and in other parts of the world.

The concern for pollution from the burning of coal in the power plants can be appreciated. It needs, however, be pointed out that coal will continue to be burnt for industrial use even if the nuclear plants take over the task of power generation entirely. In India the industrial use of coal, exclusive of power generation, amounts to about 70 per cent of the total. One cannot afford to do away with coal. It becomes incumbent, therefore, that scientists are encouraged to find suitable means for controlling if not eliminating the damaging consequences arising from the burning of coal. This would, however, call for a major shift in the policy pursued by the government regarding the R and D on energy resources in the country. If the allocation of resources for research on the alternative energy resources is any guide then the government would appear to be heavily biased in favour of nuclear technology and taking a rather dim view about the prospects of coal technology.

The successive union governments have failed to accord coal its rightful place in the allocation of priorities for research and development of energy resources. The figures for outlays on science and technology in the revised draft for the Sixth Plan (1978-83) revealed a strong bias in favour of nuclear technology and a narrow view for the prospects of coal technology. It is difficult to interpret otherwise the amounts of Rs 220 crore and Rs 18 crore allotted to the two sectors respectively under S and T for the five years. There is no indication yet of any significant change in the approach to science and technology by the present government.

Notwithstanding the assertions to the contrary India will have to depend on coal as the bridge fuel during the stage of transition from dependence on non-renewable to renewable or virtually inexhaustible resources. It is coal which has been providing us with the breathing space required for development of alternative energy resources. Improvement in the technology of combustion of coal and its other uses can help extend the period of transition and protect the environment from pollution from coal. There is a singular lack of urgency among the decision-makers about the need for concerted efforts towards the end. The stance of the nuclear scientists has only encouraged the adoption of such an attitude.

CONCLUSION

Nuclear energy has raised in its wake a host of problems which need be solved before a nation can proceed to adopt it for power generation on a large scale. The peculiar characteristic of nuclear power, effects of which have to be considered for accounting even for periods when the nuclear plant has long ceased to operate, vitiates comparability with competing energy resources like coal-based power. Overplaying the promise of nuclear power has been at the cost of the development of coal technology.

Considering that coal will remain indispensable in industrial production and will continue to generate power in India for yet another century, serious research efforts should be made to find more economic and environmentally more acceptable way of burning coal. At present, because of our overconfidence in nuclear technology, only a fraction of the resources devoted to research and development of nuclear technology is allocated for research on coal.

Notes

1 R Ramanna, 'Inevitability of Atomic Energy in India's Power Programme', *Commerce*, Annual Number, 1977, pp 89-94.

2 H N Sethna, and M R Srinivasan, "India's Nuclear Programme and Constraints Encountered in Its Implementation", *Nuclear Power and its Fuel Cycle*, Volume 6, IAEA-CN-36/385, International Atomic Energy Agency, Vienna, 1977.

3 The capital cost per unit KW capacity for 120 MW units supplied by BHEL to different power projects ranged between Rs 2,000 and Rs 3,000 at 1976 prices. Our figure for 200 MW coal-based unit is likely to err on the higher side.

4 The enrichment of uranium is not necessary for the heavy water reactors, now in use in India, since they operate with natural uranium only.

5 Study Group on Nuclear Fuel Cycles and Waste Management, "Report to the American Physical Society", *Reviews of Modern Physics*, Volume 50, Number 1, Part II, January 1978.

6 The APS study, it may be mentioned, found nuclear power to be cheaper than coal-based power in the US.

7 D K Bose, and S Mohan, "The Cost of Nuclear Power in India" Technical Report No ERU/3/80, October 24, 1980, Economic Research Unit, Indian Statistical Institute, Calcutta. The methodology of cost estimation is explained in the paper.

8 Committee on Government Operations, US House of Representatives, "Nuclear Power Costs", Ninety Fifth Congress, Second Session, House Report No. 95-1090, April 1978.

9 Barry Commonor, "The Poverty of Power", Knopf, New York, 1976. The estimated capital cost in the APS study (1978) also came to be around 78 per cent of the total cost of nuclear power. The Committee on Government Operations reported a ten-fold increase in the capital cost over 10 years between 1968 and 1978, rising from 2 to 4 mills (1/10th of a cent) to 20 to 40 mills per kWh.

10 Committee on Government Operations, *op cit*, p 97, p 131.

11 I C Bupp, "The Nuclear Stalemate: Energy Future', Report of the Energy Project at the Haward Business School edited by R Stobaugh and D Yergin, Random House, 1979.

12 Committee on Government Operations, *op cit*, p 16.

13 Ramanna, *op cit*, p 90.

14 World Energy Supplies, 1973-78, Series J 22, United Nations, New York, 1979, Table 4.

15 Report of the Working Group on Energy Policy, Planning Commission, Government of India, New Delhi 1979, pp 83-84.

16 Ramanna, *op cit*, p 90.

17 W Patterson, 'To Bed Betimes', *New Scientist* July 20, 1978, pp 180-181.

18 L Grainger, 'Energy Conversio Technology in Western Europe' Proceedings of Transactions o the Royal Society, London, A 278 527-539 (1974). Reproduced *Energy in the 1980s*, The Roy Society, London, 1974.

19 A E Sheindlin, W D Jackso W S Brzozowski and L H T Rietjens, 'Magneto Hydro Dynam Power Generation', Natural R sources Forum, Volume 3, No January 1979.

20 *Ibid*.

DISCUSSION

On Measurement of Poverty

P V Sukhatme

TO be told that I am wrong in my assessment is not a new experience to me. Only ten years ago, I was told that I was wrong in my inference that energy (food) and not protein was the limiting factor in our diet. The words used were much stronger than the words used by V M Dhandekar in his Kale Memorial Lecture [1]. The interest of food industries were apparently hurt by my conclusion and perhaps justified in their fury. Nonetheless, the view I put forward came to be accepted and now generally prevails. I have even stronger grounds to believe that my assessment on poverty linked with undernutrition will also come to be accepted notwithstanding what Dandekar has said. I will examine his principal arguments one by one and show how and where he goes wrong.

POVERTY AND UNDERNUTRITION

Dandekar asserts that poverty and undernutrition are two different phenomena and there is a difference between half the population having energy intake less than the average requirement and half the population living on a level of expenditure below the level corresponding to the average energy requirement. I agree. In be quotes me approvingly when makes the point "as income increa the energy intake increases rapidly start with and gradually therea indicating that an appreciable num of people remain undernourished want of adequate income". But if two phenomena are different but lated in the above sense, what is rationale of using the average cal requirement in calculating the po ty line? He answers it in terms average consumer behaviour. I ask, it conceivable that a man who is un nourished for lack of income have higher priorities other than food? Does average behaviour m sense when the relationship betw income and intake is curvilinear?"

Does Dandekar see the differe between undernutrition as measu by energy requirement and under rition based on clinical examinat There is ample evidence to show a man can meet his energy needs a range of intakes. Studies [2,3,4 the variation in daily energy bal show that man's intake is regu in auto-regressive manner to meet needs and imply that man adapts requirements over a wide range