The Ecologist

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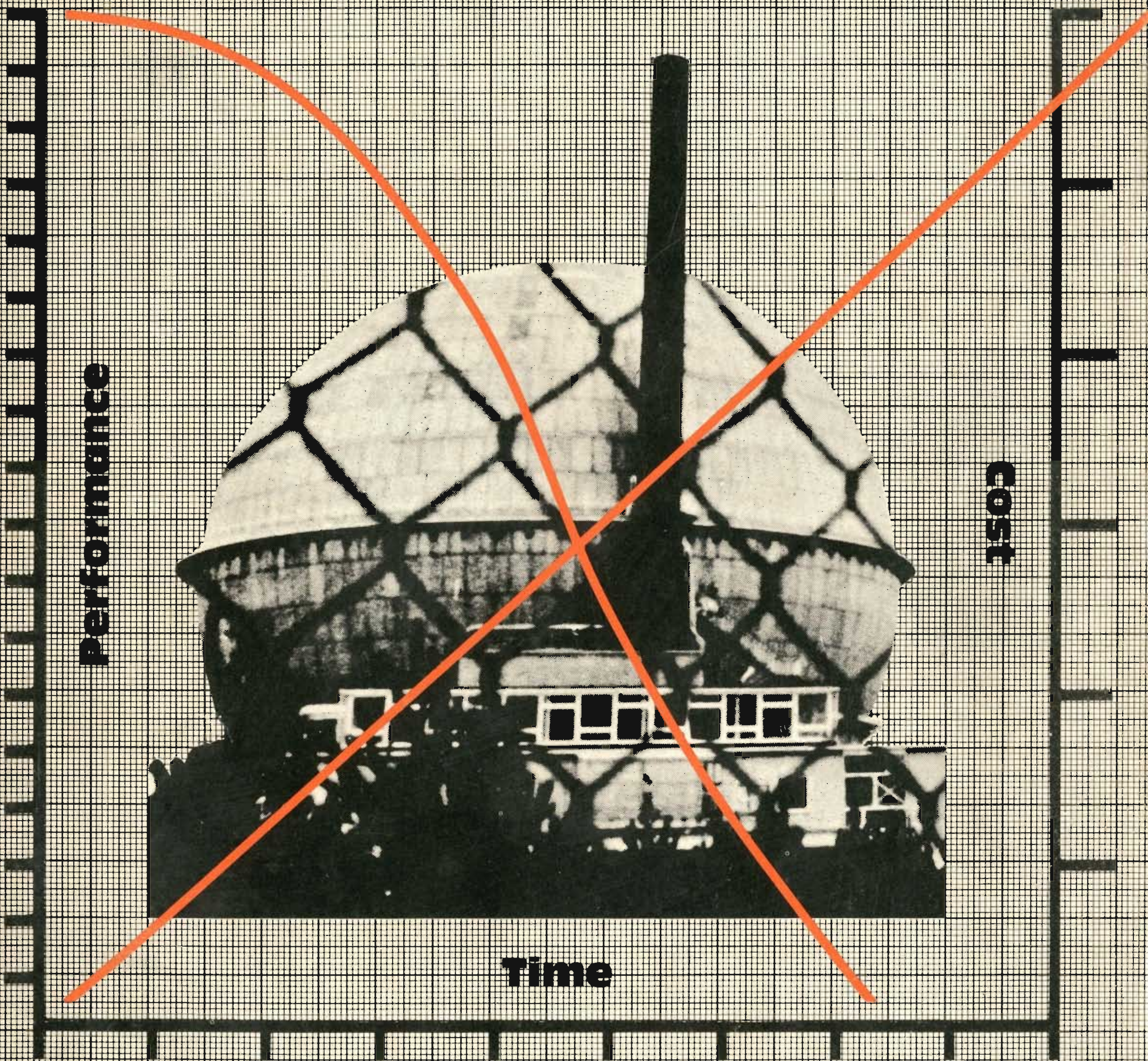

Nuclear Energy: The Real Cost

A SPECIAL REPORT

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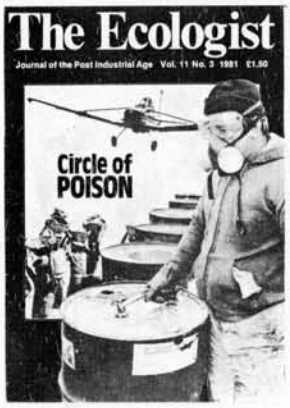

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We would like to thank John McIntyre, who is leaving our printers, for his invaluable work in laying out *The Ecologist* over the last four years.

Editorial

A State within a State

We have devoted this issue of *The Ecologist* to a detailed analysis of the economic case for and against nuclear power. We ourselves do not regard economics as the most important aspect of the nuclear constroversy. Like most responsible people, we oppose nuclear power for incomparably more important reasons — believing, as we do, that the poliferation of nuclear installations represents a serious long-term threat to life on this planet by dint of the radioactive pollution they inevitably generate. Whether or not it is actually 'economic' to threaten life on earth this way seems to us a consideration so paltry as to preoccupy only the pettiest and meanest of minds.

Nonetheless, we recognise that there are many — both within Government and without — for whom the economic arguments in the nuclear debate are the most important. For them, the only question worth asking is: "Does nuclear power generate the cheapest electricity?" It is that question which the Committee for Study of Economics of Nuclear Electricity (CSENE), whose report we publish, has attempted to answer. The Committee was set up in June 1981 under the chairmanship of Sir Kelvin Spencer, Chief Scientist at the Ministry of Power at the time when the decision was taken to commit Britian to a civilian nuclear power programme. In analysing the economic case for nuclear power, the Committee has primarily used the Central Electricity Generating Board's *own published figures.* The Committee concludes that to go ahead with the present Government's plan to build two more Advanced Gas Reactors (AGRs) and then one further large nuclear reactor every year for ten years would be sheer economic lunacy.

Undoubtedly, many of our readers will ask: Why, if nuclear power is so uneconomic, do electricity generating companies the world over insist on building more nuclear reactors? Why, too, has the claim that nuclear electricity is the cheapest gone unchallenged for so long? And how come the electricity boards of Britain and France are so blind to the implications of the figures they themselves publish?

In part the answers lie in the strong tendency of large institutions to become 'States within States', preoccupied with self-preservation, the expansion of their interests and the self-aggrandisement of their leaders. That point has been well made by Duncan Burn, the foremost historian of Britain's nuclear industry, in his book *Nuclear Power and the Energy Crisis.* "Authorities and boards", he says, "become vested interests, eager for more power, for larger staffs and large empires, anxious to conceal or explain away what has gone wrong." In effect, they become cocooned from any reality other than their own self-perpetuation.

Whether Britain is more susceptible than other countries to this 'institutional isolationism' is debatable. However, it is worth bearing in mind Professor David Henderson's observation that Britain's 'administrative culture' by emphasising "secrecy, anonymity and bureaucratic tidiness rather than accuracy and individual judgement" has made British institutions "especially liable to errors of the Concord and AGR kinds".

Be that as it may, what is certain is that once a decision has been made it is difficult for any institutions to go back on it without losing face. It is equally difficult for those involved in making a decision not to develop a psychological stake in seeing it implemented. Ally that reluctance to reconsider decisions or to tolerate critiscism with the incredible power enjoyed by the majority of large institutions and one has a perfect recipe for dangerously wrongheaded thinking.

The power enjoyed by the nuclear industry is legion. Thus, Tony Benn (when Secretary of State for Energy) publically stated that in all his political life he had never encountered "such a well organised scientific, industrial and technical lobby as the nuclear power lobby." In France, the political influence of the nuclear industry is still greater: in the last twenty-five years, at least five Government ministers (Felix Gaillard, Pierre Guillaumat, Olivier Guichard, Robert Galley and Andre Giraud) have been recruited from the top ranks of the nuclear industry, subsequently playing a decisive role in pushing (for) the implementation of France's massive nuclear power programme. The three top civil servants who presided over much of that programme enjoy such power that they have been described as 'veritable tsars'.

Although the British nuclear industry has not penetrated government circles to the same extent as its counterpart in France, the influence it wields in Whitehall is still considerable. In his evidence to the 1967 Select Committee on Science and Technology for instance Tony Benn (then Minister of Technology) testified that the Atomic Energy Authority was not only the principal source of his advice on nuclear matters but also — and perhaps more important — he saw no reason to question the advice it gave. "I regard Sir William Penney as my principal advisor on atomic energy matters" said Benn, "and it is not thought necessary, right or proper or possible for us to have within our own Ministry a complete organisation for the duplication or review and evaluation of the advice given to me by the Authority."

That situation would seem to persist even today. Certainly those government ministers at the Department of Energy with whom *The Ecologist* has had direct contact — notably David Howell and Norman Lamont, both highly intelligent men — are strongly pro-nuclear, regurgitating uncritically the propaganda of the Atomic Energy Authority. Indeed, the Department's support of nuclear power would appear so single-minded that is seems unwilling even to consider the possiblility that other forms might be more cost effective than nuclear power — an attitude for which the Department was roundly critisised by the 1980 Select Committee on Energy. "We were dismayed to find that, seven years after the first major oil price increases", said the Committee, "the DOE has no clear idea of whether investing around

Continued on page 252

Important Notice to Our Readers

The Ecologist apologises for the lateness of this issue. In order that the C.S.E.N.E. report should have maximum impact, we felt it necessary to postpone publication until after Parliament returned from its Christmas recess on January 18th 1982. This was in order that we could hold a press conference in the House of Commons and thus reach as many Members of Parliament as possible.

IMPORTANT: This is the last issue of *The Ecologist* to be sold in the shops. From issue No. 1/1982, *The Ecologist* will be sold on subscription only. To those of our readers who have been buying *The Ecologist* through their newsagents, we make an introductory offer of a year's subscription at the reduced rate of £10 (including postage). This offer closes on March 31st 1982. We would be grateful if those taking up the offer could fill in the form below and return it to: The Subscriptions Dept., *The Ecologist,* Worthyvale Manor Farm, Camelford, Cornwall.

To counter the increase in postage (coming into effect from January 1982) we are also increasing our subscription rates to £12.50 per annum for individuals: and £18.00 for institutions. The increase will take place on April 1st 1982.

Once again, we apologise for the lateness of this issue and we would like to take this opportunity of wishing all our readers a Happy New Year for 1982.

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£1,300 million in a single nuclear plant .... is as cost effective as spending a similar sum to promote energy conservation."

The allocation of funds for energy research and development reflects the pro-nuclear bias of successive governments. Thus between 1962 and 1979, Britain spent more than £500 million in research and development on the fast reactor, a technology which is proving itself to be the greatest white elephant in industrial history. By contrast, when the National Coal Board requested a mere £20 million for further development of a pressurised fluidised bed combustion plant — a British invention which would have eliminated many of the pollution problems associated with coal burning (in particular sulphur dioxide and nitrous oxide emissions) — the government flatly refused to advance the money. Now that other countries have taken the lead in developing this technology, the British government is expressing mild interest in its development.

Astonishing as it may seem, very few of the major decisions associated with Britain's nuclear programme have actually been taken for economic reasons. To be sure, economic arguments have been used to rationalise decisions but, by and large, those decisions have been determined by political expediency, considerations of national prestige and, in particular, out-and-out empire building. In this, the Atomic Energy Authority has undoubtedly been the greatest culprit. Holding the monopoly of nuclear research and development in Britain, the Authority has exerted enormous pressure on the CEGB to build reactors of AEA design — this despite protestations from the CEGB that economic interests would be better served by opting for foreign reactors.

When the first Magnox reactors were being built in the early sixties, realists within the CEGB and the AEA saw that they could not compete on economic grounds with fossil-fuel fired plant. Indeed when the reactors came on stream, it became apparent that electricity from them was costing at least 80 per cent more than originally estimated. As a result, the AEA had to come up with a design for a reactor that, on paper at least, would have cheaper generating costs than its Magnox predecessor. That reactor was the Advanced Gas-Cooled Reactor, (AGR).

Already in the United States, a number of 'commercial' Boiling Water Reactors (BWR) and Pressurised Water Reactor (PWR) were built for utilities. The manufacturers claimed that the electricity from those reactors was going to be very cheap: we now know, however, that those reactors and the ones that followed were all loss leaders. The CEGB was tempted by the figures and inevitably a serious clash broke out between those at the AEA who were pushing their own design and those who favoured adopting a light water reactor. Such was the bitterness that a mediating committee, under the chairmanship of Quentin Hogg, now Lord Hailsham, was called into being, to bring the two sides together. In the event, the AEA won the day and the AGR became the follow-up reactor to the Magnox. A major consideration that undoubtedly influenced that decision was the cancellation of the British designed TSR2 combat aircraft in favour of the American F1-11. The Wilson Government felt that the British public would resent Britain adopting yet another American technology if the AGR were abandoned for the American light water reactor.

Having lost its battle over the AGR, the CEGB performed an astonishing volte-face, producing and *Appraisal* of the AGR which bore considerable signs of AEA influence. The *Appraisal* has been described by R.F.W. Guard, later Vice-President of Canatom, as "More lavish in its praise of the AGR than a manufacturer's sales brochure." The government too went overboard, Fred Lee, the Labour Minister of Power, pronouncing the AGR to be "the greatest breakthrough of all time . . . We've hit the jackpot", a prounouncement Duncan Burn describes as ranking among the most absurd claims made by a Minister. "The advantage in cost claimed in the *Appraisal* for the "greatest breakthrough of all times" was 0.01p per KW, trivial and within the statistical margin of error", says Burn. "As competent observers pointed out quickly (unnoticed in popular discussion) the comparison involved great hazards and some bias. The design of the 600 MW AGR was extrapolated from a 30 MW prototype which involved much greater uncertainty than was involved in extrapolating from a 200 MW plant for the BWR. Recent design improvements in the BWR accepted by American utilities were rejected as unproven by the CEGB, but more recent radical and untested changes for the AGR were accepted. The *Appraisal* showed no recognition of the disadvantages of a permanent graphite core, contained inadequate data on fuel cycle costs and assumed that a 600 MW turbo alternator, of which none had been made in Britain, would stop for maintenance only once in two years, contrary to all experience."

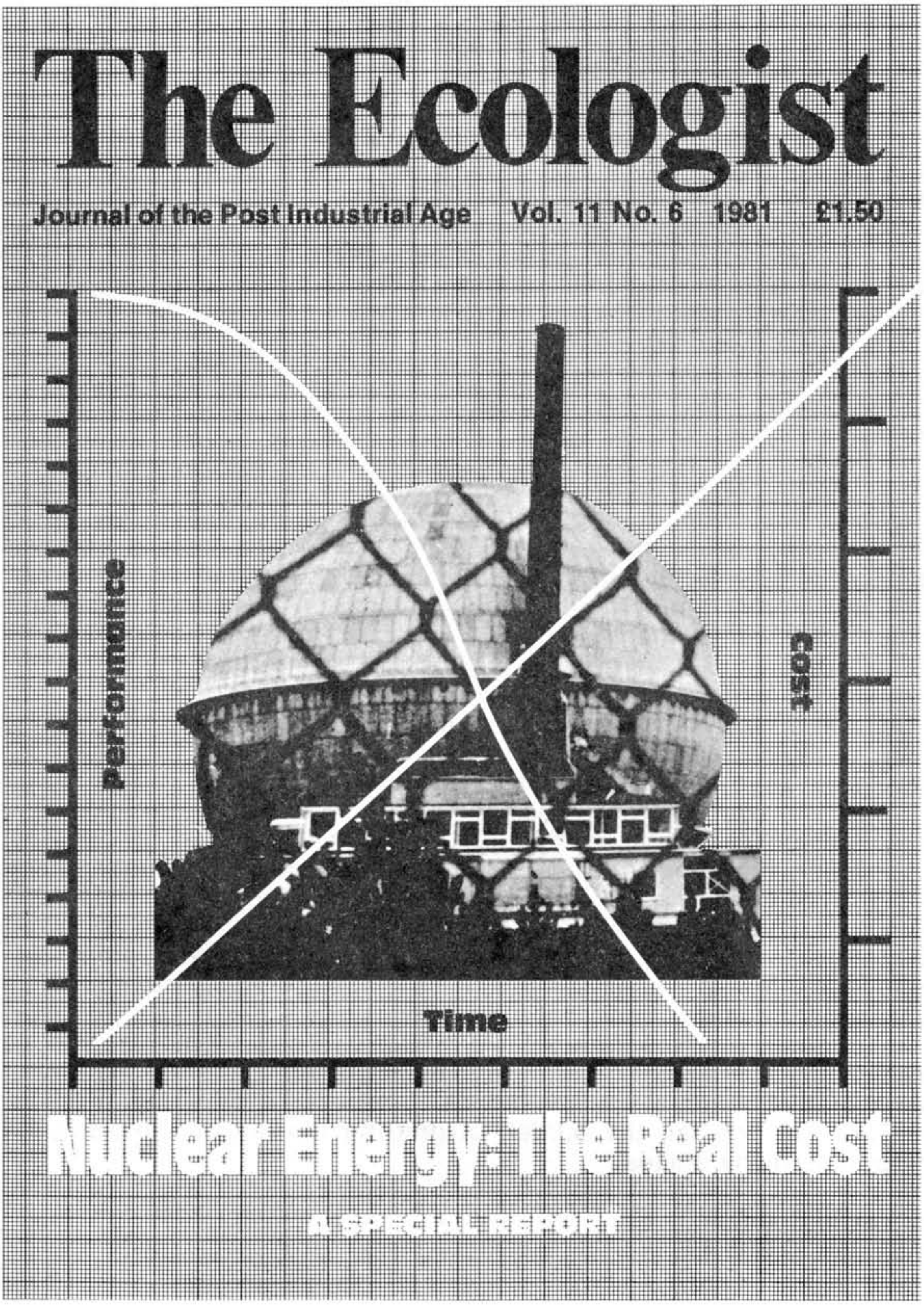
Once construction began on the AGRs all sorts of problems came to light and, as a result, there were longer and longer delays. Nonetheless, Sir William Penney, Chairman of the AEA, assured the Government that the problems associated with the AGR were inevitable and that they would soon 'melt away'. He also insisted that it would be possible during the next six years to reduce AGR generating costs by 30 per cent in terms of 1965 money. Hindsight shows those assurances to have been without foundation. "The primary source of (the) delays," notes the 1980 House of Commons Select Committee on Energy, "was that the construction was started without an appropriate prototype, without a fully detailed design, before major changes in parameters had been researched and developed and before vital engineering and metallurgical problems had been solved." In spite of the AGR experience two more AGRs are being built in Britain, one at Torness and the other at Heysham. The public have been assured that they will provide much needed and cheaper electricity.

The Committee for the Study of Nuclear Electricity has looked closely at the CEGB's figures on generating costs. It finds them grossly deceptive. Indeed, it becomes transparently clear that nuclear power has *never* provided the cheapest electricity in Britain and is most unlikely ever to do so. That the GECB still maintains the fiction that it will shows a curious capacity for self deceit — a self deceit for which we, the electricity consumers, are having to pay.

The Editors

C.S.E.N.E.

Committee for the Study of the Economics of Nuclear Electricity



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Consultant: Professor J.W. Jeffery, B.A., Ph.D.

Chairman's Foreword

This report is offered as a contribution to the analysis of the official case for nuclear power stations. It is by a small group of academics uncommitted to any particular source of primary energy. In his 1977 series of BBC talks Professor David Henderson of University College London stated "it is remarkable how little policy analysis is undertaken in Britain outside the official machine." (*Listener,* 24.11.77). We hope this effort of ours will be welcomed as an attempt, however inadequate, to remedy this.

Since 1977 there have been a few independent analyses of the sort Professor Henderson seems to have had in mind. But they have been few indeed in comparison with the many official bodies who, because of past commitments and actions, have failed to impress the reader with their impartiality.

If wise choices are to be made among a bewildering number of energy strategies the formation of policy *must* be guided not only by officialdom, acting behind closed doors, but by all competent to make a worthwhile contribution. Hence this report.

We make no claim for infallibility. On the contrary, we know our report is open to criticism at many points. Criticism, if unbiased and constructive, will be welcome. But we have no wish and no intention of being caught up in the fanatical polemics which bedevils the subject today.

Our committee mainly consists of academics wedded to the tradition of integrity in study and research which has always been the lifeblood of universities. We know we must have fallen short of this ideal in many places. In mitigation we plead that the witholding of information by the Establishment is partly to blame.

That there have been grave mistakes in energy policy is abundantly clear from the criticisms made in such reports as the First Report of the House of Commons Select Committee on Energy, and the Report on the Central Electricity Generating Board by the Monopolies and Mergers Commission. I reproduce a few of these to emphasise the need for many more studies by independent bodies of academic standing.

As chairman of the group I pay tribute to the members who gave unstintingly of their time, money, and mental energy; and this was often at considerable personal inconvenience. I especially pay tribute to Peter Bunyard. On him fell the burden of drafting the report and nurturing it through its many stages.

Sir Kelvin Spencer,
Chairman, C.S.E.N.E.

Recent Official Criticisms of Nuclear Power

From the Report on the CEGB of the Monopolies and Mergers Commission. 20 May, 1981. HC 315.

Page 290

"The inter-relationship between nationalised industries raises important issues of public policy about their respective costs and prices. Some of these issues lie beyond our immediate terms of reference, but we are bound to say that the public interest in these circumstances requires at least a fuller disclosure of costs, so that all customers will be better able to judge whether prices really represent the resource cost of supplying them, and whether one industry is subsidising another."

Page 292

"We simply conclude from the foregoing that the Board's procurement costs could have been lower. This arises not from lack of efficiency in use of its existing resources but from concern on its own or on the Government's part for the interests of major suppliers."

Page 292

(Commenting on the CEGB's planning and appraisal of new investment):

". . . we consider that there are serious weaknesses in its investment appraisal. In particular a large programme of investment in nuclear power stations, which would greatly increase the capital employed for a given level of output, is proposed on the basis of investment appraisals which are seriously defective and liable to mislead. We conclude that the Board's course of conduct in this regard operates against the public interest."

From the First Report of the House of Commons Select Committee on Energy, Session 1980-81. HC 114-1.

Para. 69

"We also find the Board's attitude towards comparing the costs of the AGR and PWR extremely disturbing; indeed there is very little evidence to suggest that such comparisons have been made in any but the most superficial and perfunctory way . . ."

Para. 71

"However, in view of the inevitable uncertainties surrounding many of the Board's key assumptions, the obscurity of presentation of much of the relevant information, and the Board's less than satisfactory attitude to cost comparisons, we remain unconvinced that the CEGB and the Government have satisfactorily made out the economic and industrial case for a programme of the size referred to by the Secretary of State in this statement to the House in December, 1979."

Para. 172 (XLVI)

"Enormous past nuclear investments have had exceptionally low productivity; great resources have been used with little direct return and a serious net loss."

Para. 172 (LV)

"We consider it most regrettable that the Government were not prepared to divulge the advice tendered by the Central Policy Review Staff, for it might have helped the Committee to understand better why the Government decided to continue with the two new AGRs."

Para 169

"More effort must be made, in our view, to understand and treat sympathetically the entirely natural apprehensions which follow an incident such as that at Three Mile Island. In particular, it is important to realise that much of the public concern about safety stems not so much from the statistical likelihood of an accident as from its *potentially* catastrophic consequences. Equally, the negligence and secrecy revealed by recent reports of incidents at Windscale and Dounreay are hardly conducive to a climate in which people are prepared to take on trust the arguments and statistics which favour nuclear power."

Sixth Report of the Royal Commission on Environmental Pollution. Cmnd 6618. 1976.

Para. 368

(Criticising British Nuclear Fuels Ltd. management of Windscale).

". . . it is important at such a plant that the highest standards of general housekeeping should be employed and we feel bound to say that we did not gain the impression that this was so at the time of our visit (November, 1974). We would urge that this aspect should be given more attention by the new management at the plant."

Report by the Health & Safety Executive "The Leakage of radioactive liquor into the ground". British Nuclear Fuels Ltd., 15 March, 1979.

Page III

"The circumstances of the incident indicate that the operational system was not adequate to maintain control over radioactive liquors."

Page 15, para. 48

"HMNII's investigation has revealed that BNFL has not complied with a number of licence conditions . . ."

Page 15, para. 49

"The plant management have stated that, before March 1979, they knew of no reason to treat the liquors known to arise in B701 Plant as radioactive."

Page 15, para. 50

"The attitude expressed in these statements gives us grounds for considerable concern."

Report by the Health & Safety Executive "Windscale: The Management of Safety", 1981

Page 31, para. 13.2

By the early 1970s the standard of the plants at Windscale had deteriorated to an unsatisfactory level. We consider this represented a poor base line from which to develop high standards of safety. We are strongly of the opinion that such a situation should not have been allowed to develop, nor should it be permitted to occur again."

Summary and Recommendations

1. In December 1979, the Government announced proposals for a new 15 GW nuclear programme to be comprised of ten stations. Work on one new station was to be commenced each year from 1982.

2. Even including that 15 GW, the Central Electricity Generating Board sees a shortfall of generating capacity developing by the turn of the century. That shortfall, it claims, will be the result of:

   a) A one per cent growth per annum in electricity demand between now and the year 2000.

   b) The need to retire ageing plant.

3. The CEGB is in the process of commissioning 14 GW of new generating capacity to come on stream between 1983 and 1988. At present it has a surplus generating capacity of 33 per cent. It argues that it needs a generating reserve margin of 22 per cent.

   The South of Scotland Electricity Board has a 90 per cent generating surplus. With the completion of its 1,320 MW nuclear station at Torness, its excess generating capacity will rise to more than 120 per cent. Over-estimates lead to over-investment and hence to more expensive electricity.

4. The CEGB's generating surplus is likely to increase both because of the reduction in the growth of electricity demand per annum to less than the projected one per cent, and because of the contribution of new plant coming on stream. The announced 15 GW nuclear programme reinforces the view of the Monopolies and Mergers Commission that: "It would seem that a substantial proportion of a 1,500 MW per annum programme would represent investment in advance of need."

5. Since the early 1970s the CEGB has published generating costs in which its eight Magnox nuclear stations are shown to generate the cheapest electricity.

6. In our view, the accounting techniques used by the CEGB for calculating generating costs have seriously prejudiced the results in favour of nuclear power. Most notably, by ignoring the effects of inflation, the differences between the capital costs of Magnox plant built up to 20 years ago, and those of contemporary coal-fired plant have been made to appear far smaller than they are in real terms.

   We contend that if the figures take account of the real value in modern terms of money spent as long as twenty years ago, then the apparent cheapness of nuclear power vanishes and "the fraud inherent in all inflationary finance" is revealed. Our analysis of the figures indicates that the 20 per cent generating cost advantage given by the CEGB for its Magnox stations turns into as much as a 50 per cent generating cost advantage, when compared with coal-fired plant.

7. With regard to the CEGB's AGRs, our calculations indicate that such reactors will, on being commissioned, cost the electricity consumer considerably more than if they had never been built. Thus the CEGB's published 11 per cent cost advantage of its Hinkley Point B AGR station over the contemporary Drax A, coal-fired plant, turns into a 44 per cent cost disadvantage. The 30 per cent advantage of Dungeness B, the much delayed AGR station, switches to a 70 per cent disadvantage when compared with Drax B, the coal-fired plant under construction.

   Nevertheless, the CEGB insists that investment in future nuclear plant will lead to cheaper electricity than from conventional power stations. We find the CEGB's assumptions in support of that claim to be implausible.

8. We contend that the high capital costs of building nuclear plant, their poorer than expected performance — closer to 50 per cent on design output than to the anticipated 75 per cent — as well as rapidly rising nuclear

fuel costs, have already made electricity from nuclear plant considerably more expensive than that from coal-fired plant.

We question the CEGB's assumptions that new plants will be built on schedule; that the performance of new nuclear plants will match expectations; and that nuclear fuel costs will remain low while coal costs escalate.

We consider the following assumptions more reasonable:

a) Cost overruns on construction will amount to 30 per cent, rather than the 17.5 per cent assumed by the CEGB.

b) Real coal costs will remain at 1980 levels until 1986/87 and then increase at 2 per cent per annum to the end of the century.

c) With likely increases in the cost of reprocessing, nuclear fuel costs will more than double in the period up until 1986/87. They will then increase at 2 per cent per annum until the end of the century.

On that basis we expect future nuclear plant to have a generating cost of 3.27 p/KWh compared to 2.34 p/KWh for new coal-fired plant. Thus to build just one new 1.5 GW nuclear power station rather than a coal-fired station of similar capacity, will lead to a loss over the stations lifetime of nearly £2,000 million (1980 pounds).

9. Our conclusions have been reached on the basis of the CEGB's own published figures. Our interpretations of those figures has been based on reasonable, conservative assumptions. If other considerations are taken into account — doubts about reprocessing, waste disposal, decommissioning and reactor insurance — then the economic case against nuclear power, and against the Government's proposed 15 GW programme, becomes overwhelming.

a) The reprocessing of spent nuclear fuel is fraught with problems. Discharges of radioactive wastes into the environment from reprocessing plants are already at an alarmingly high level. Meanwhile the technology for reprocessing thermal oxide spent fuel has not been mastered on an industrial scale. Ultimately plutonium losses into the various waste streams of the reprocessing plant, apart from dangerously polluting the environment, are likely to undermine any fast reactor project.

b) Doubts also remain about the safe decommissioning of obsolete reactors and the safe disposal of nuclear wastes. Vitrification of high activity wastes is still experimental and an unproven technology. A safe, acceptable repository for vitrified waste — assuming the technology works satisfactorily — has yet to be found. Only a handful of small experimental reactors have ever been decommissioned and then the expense has been considerable.

c) The nuclear industry has never had to bear the full costs of insuring its plant. Should there be a major radiation release the damage done to people and property would far exceed the provisions laid down by the Government for compensation. Nuclear reactors would make obvious targets in time of war, whether thermo-nuclear or conventional.

10. We also question the safety of pressurised water reactors in the light of evidence from the United States of embrittlement of essential components of the reactor pressure vessel, through irradiation. The cost, too, of PWRs appears to be escalating at least twice as fast as that of coal-fired plants fitted with devices for pollution-control.

11. Reasonable estimates of future electricity requirments, combined to an energy conservation programme, suggest that Britain's economy could grow and offer a higher standard of living while actual electricity consumption falls to one half or less of present requirements. The enormous capital savings associated with energy saving make a move towards such energy strategies absolutely essential, particularly in view of the impending decline of petroleum and natural gas.

12. We recommend that:

The Government should reverse its decision of December 1979 regarding the construction of 15 GW of nuclear generating plant. Work should cease forthwith on the two AGRs, at Heysham and Torness, at present under construction.

The CEGB's massive programme of prematurely decommissioning still serviceable coal-fired power stations must be halted immediately. The CEGB should embark on a programme of systematically refurbishing and modernising such plant whenever necessary.

The CEGB should embark forthwith on a programme of Research and Development aimed at making available a range of small coal-fired power stations. Those stations should be: equipped with the latest anti-pollution control devices: designed to provide combined heat and power for neighbourhood heating: and standardised in order to bring down costs and minimise the lead times between ordering and commissioning.

The CEGB should give greater consideration to the development and use of renewable energy resources.

The CEGB must adopt a proper system of current cost accounting. We recognise that this will inevitably lead to higher electricity prices if the Board is to set aside sufficient financial provisions for the future. As a consequence, we foresee electricity being used only for those purposes for which it is best suited.

The Government's Nuclear Power Programme and its Implications

In spite of a large surplus of generating capacity, the CEGB has stated its intention to embark on a large nuclear programme. The implementation of that programme, combined with new plant in the process of being commissioned, will lead to the premature retirement of existing plant. The CEGB justifies investment in nuclear power by claiming that it provides the cheapest electricity.

1.0 In December 1979, the then UK Secretary of State for Energy, David Howell, announced that Britain's electricity boards should embark on a 15 gigawatt (GW) nuclear power programme to consist of ten stations with twin 660 megawatt (MW) generating sets[1]. Work was to commence in 1982, with one new station started each year from then on. The overall cost (in 1980 figures) was to be some £15 billion.* That programme was to be in addition to the two Advanced Gas Reactor (AGR) stations—one at Torness in Scotland, the other at Heysham—agreed to by the Labour Energy Secretary, Tony Benn, in January 1978.

1.1 The present Conservative Government is clearly in favour of the programme being comprised of Pressurised Water Reactors (PWRs), in all probability based on a Westinghouse design. The site of Britain's first commercial PWR is to be at Sizewell in Suffolk. Prior to any final decision, the Government has promised a wide-ranging planning inquiry. The inquiry was to be in 1982, but is likely to be delayed until 1983, thus correspondingly shifting back the Government's proposed nuclear power programme.

1.2 Should the programme proceed as intended, by the year 2000 the UK will have 24 GW of nuclear power based on the five AGRs of the first AGR programme (now either on stream or in the process of being commissioned); the two AGRs agreed by Tony Benn; and the 15 GW of capacity proposed by David Howell[2]. The first generation reactors—the Magnox—will by then have come to the end of their lives and will presumably be in a process of decommissioning.

1.3 With just one of the four AGRs of the first programme commissioned, the Central Electricity Generating Board (CEGB) now has a capacity in excess of demand in the region of 33 per cent. The CEGB's 1980/81 declared net capability of all power stations was 56,705 MW, whereas the maximum system demand during 1980 was only 42,600 MW[3]. By 1983 the CEGB expects to have 3,840 MW of new nuclear plant commissioned and 4,960 MW of oil-fired plant. The pumped storage scheme at Dinorwic—although not itself a power station—will help meet maximum system demand by generating 1,500 MW. By 1988, the CEGB expects to have commissioned 1,320 MW of the Heysham 2 AGR and 1,980 MW of the coal-fired Drax B. The total of all new plant to be added between 1983 and 1988 thus amounts to just over 14 GW or one-third of present maximum system demand[4,5]. The South of Scotland Electricity Board (SSEB) meanwhile has an excess capacity above requirements of over 90 per cent. With the completion of the Torness AGR (1,320 MW), the SSEB's excess capacity will be 122 per cent[6].

*£15,000 million.

Forecast of Demand

1.4 Clearly the CEGB's planning margin by 1990 will depend on the level of electricity demand and on the amount of plant decommissioned. The CEGB aims to keep 4 per cent *net* surplus as its reserve margin which, in effect, means keeping a *gross* margin of at least 22 per cent[7].

The reality of electricity consumption has forced the CEGB to bring its forecasts of growth in demand down from a 1979 forecast of 1.7 per cent per annum to a 1980 forecast of 0.5 per cent per annum at least until 1988[8]. It should be noted that the CEGB did not produce a 1981 forecast of electricity growth. If it had done so, the likely growth rate might well have been zero.

Nonetheless in its evidence to the Monopolies and Mergers Commission (MMC), the CEGB made it clear that it expected a 1 per cent per annum growth in electricity demand between now and the end of the century (See Fig. 1). Indeed, the CEGB saw no more than 20 GW of all its power stations commissioned before 1980 still in operation by the turn of the century. By then, its central estimate indicated, 70 GW of capacity would be required, thus necessitating that 50 GW of new generating capacity be installed. Even including the 15 GW of nuclear plant proposed — plus the 9 GW already in the process of being built and commissioned — the CEGB therefore saw a shortfall developing.

Premature Retirement of Plant

1.5 With regard to decommissioning, the 1979-80 CEGB *Development Review* states that the minimum unavoidable level of plant closures is about 300 MW per annum[9]. Given the CEGB's stated planning margin of 28 per cent, on top of its 1 per cent forecast for electricity growth, the Board's gross requirement for new generating capacity will be about 900 MW per annum. Thus the programme to order 1,500 MW per annum from 1982 onwards will be well in excess of requirements. "It would seem that a substantial proportion of a 1,500 MW per annum programme would represent investment in advance of need", comments the Monopolies and Mergers Commission. In that respect it should be remembered too that the CEGB complained bitterly when Tony Benn called for the premature ordering of the Drax B coal-fired station[10]. The government agreed to subsidize that development[11,12].

A consequence of proceeding with the intended nuclear programme could be the premature retiring of as much as 600 MW/Yr more plant than would strictly be necessary if the CEGB built according to its needs. Should no growth take place, as would seem to be probable, then double that amount, or 1,200 MW/Yr would be retired prematurely to make way for the 1.5 GW per annum of nuclear plant[13]. In fact, any plan to retire coal-fired stations prematurely would seem to be at odds with the CEGB's own statement that the life-time of its large coal-fired plant is likely to be extended from 25 to 40 years "through enhanced levels of maintenance and replacement of components"[14].

The Real Costs

1.6 Whether the growth in electricity demand takes place as envisaged or not, the CEGB has stated its determination to proceed with its proposed nuclear power programme. As the Monopolies and Mergers Commission points out, the rationale is one of economics; the CEGB has set out to prove that the replacement of coal-fired plant prematurely by nuclear power will lead to lower electricity prices in the long run[15].

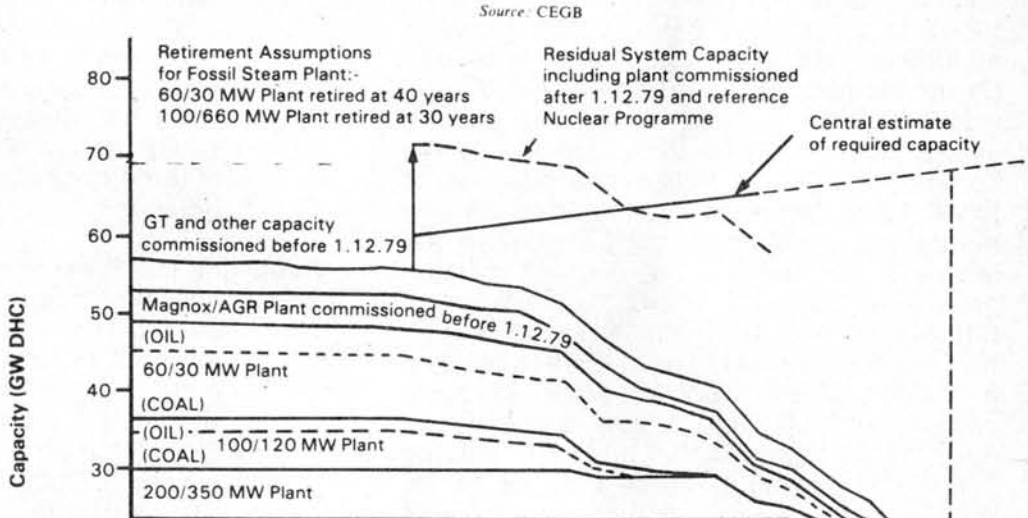
1.7 **It is our contention that the CEGB's economic case for nuclear power fails to stand up under close scrutiny. The implementation of the nuclear programme, whether in part or in its entirety, will lead to consumers having to pay considerably more for their electricity than would otherwise be the case. Indeed our calculations indicate that to build just one new 1.5 GW nuclear power station (rather than a coal-fired station of similar capacity) will lead to a loss over the station lifetime of nearly £2,000 million. A programme of ten such stations could well bankrupt the CEGB[16].**

The CEGB claims that the taking out of service of more than two-thirds of its existing plant by the year 2000, will necessitate massive investment in new plant, mainly nuclear.

Figure 1

System Capacity and Demand Estimates

Source: CEGB



MMC

Nuclear Power: The CEGB's Planning Record

The CEGB has justified the need for nuclear power on many grounds, ranging from a shortage of coal to a perceived energy gap and the necessity of replacing old plant. Those justifications have invariably been dropped when the underlying assumptions have proved unfounded. Equally, the CEGB's forecasting record has left much to be desired. Overforecasting, and an excessive planning margin have cost the electricity consumer dear.

"The Board welcomes the opportunity to safeguard future elctricity supplies by building up its nuclear capability".

2.0 Ever since the CEGB came into being in 1958, it has had to find reasons for justifying its pro-nuclear stance. At various times it has forecast shortages of coal; at others it has pointed out the necessity for maintaining a mix of fuels, so as to limit the power of British coalminers to hold the Board to ransom. In recent years, the CEGB has placed most emphasis on claims for the relative cheapness of nuclear power.

2.1 The House of Commons Select Committee on Energy thus states: "In justifying the intention to build 15 GW of nuclear plant capacity the Secretary of State for Energy, and the Chairman of the CEGB and SSEB deployed four main arguments: (a) that new nuclear plants will generate base-load electricity at costs significantly below those of additional and existing oil- or coal-fired power stations; (b) that nuclear power provides a much needed source of primary energy in meeting UK requirements in the coming decades as indigenous supplies of fossil fuels diminish and imported oil and natural gas grow increasingly expensive and insecure; (c) that a great deal of existing generating capacity has to be replaced or refurbished over the next 20 years; and (d) that the commitment is necessary to build up a viable British nuclear plant industry, capable of supplying future domestic requirements efficiently and of seizing whatever opportunity there may be to export"[17].

Coal versus Nuclear

2.2 Although not immediately appreciated by the UK coal industry, nuclear power has always been a competitor, threatening to take an increasing proportion of the electricity generating market.

The battle between coal and nuclear for generating electricity really began in the mid 1950s when the 1955 Government White Paper spoke of, "The difficulties of finding manpower for the mines . . . the provision of enough men for the mines is one of our most intractable problems and likely to remain so... Any relief that can come from other sources of energy such as nuclear power will do no more than ease the problem of finding and maintaining an adequate labour force"[18].

In March 1957, the Government foresaw a 40 million ton gap in coal availability by 1965 and hence called for a trebling of the 1.5-2.0 GW nuclear programme of the 1955 White Paper. A few years later in its 1960 White Paper, the Government anticipated that, "By 1975, power stations will be consuming the equivalent of some 125 million tons of coal a year . . . and by the 1980s their annual requirements could well reach the equivalent of 200 million tons of coal"[19].

But opinions change, as do perceived facts, and in 1963 Lord Hinton, the CEGB's chairman, stated: "The urgent need which appeared to exist in 1956 to develop nuclear power to supplement our supplies of fossil fuels has disappeared"[20]. And, in 1965, the CEGB saw; "Future supplies of fuel for electricity generation . . . (as) more than adequate"[21].

Replacing Old Plant and the Vanishing Energy Gap

2.3 The justification for nuclear power then shifted from the urgency to make up for a shortfall in fuel to the need to replace old plant. Thus in 1969, the CEGB's chairman, Sir Stanley Brown, told the House of Commons Select Committee on Science and Technology (HCSCST) that the 1968 order for an AGR at Hartlepool was "largely justified not by the increase in load estimates but by our intention to withdraw some 1,300 MW of useable but obsolescent plant"[22]. One year later, the CEGB saw a 'growing concern about coal supplies'[23], arguing that there was 'no longer a coal surplus' and that demand was 'running ahead of production'[24]. To add weight to its anxiety about coal, the CEGB warned in 1971 of, "The dangers of heavy dependence on coal, even though it is indigenous"[25].

Nevertheless the CEGB continued to rely on coal-fired generation to produce the bulk of its electricity, so much so that in August 1972, the House of Commons Select Committee on Science and Technology told of its astonishment when hearing that the CEGB did "not have any plans to order new nuclear stations"[26]. Yet in just over a year, in December 1973, the Select Committee was to hear Sir Arthur Hawkins, then chairman of the CEGB, tell how he was wanting to order eighteen new 1,200 to 1,300 MW reactors all within the space of six years, with a similar number of reactors ordered between 1980 to 1983[27]. The SSEB was also infused with the desire to build reactors and was suggesting building eight up until 1980[28].

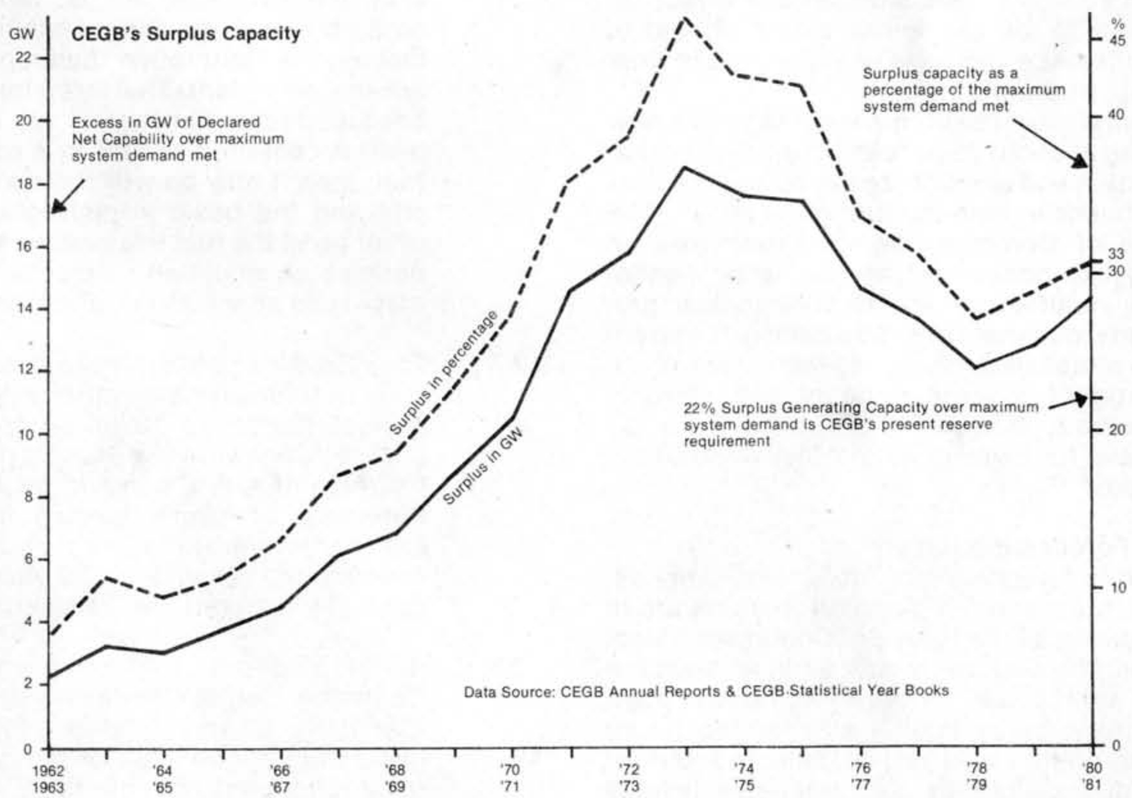
Hawkins denied that the rush to build reactors had anything to do with the 1973 Yom Kippur war[29]. Instead, the CEGB produced a chart for the Select Committee indicating an energy gap of as much as 322 million tonnes of coal equivalent by the year 2000. "The Board sees the need for some 35,000 MW of nuclear plant", was one of its statements[30].

Yet in 1975 in another change of tune, the CEGB itself stated: "The Board has no need to order any new coal- or oil-fired power stations until 1978. The Board appreciates that this will have grave repercussions for its suppliers but sees no justification for electricity consumers having to bear the extra cost of advanced orders"[31]. Thus within a few years, the 'impending' energy gap had vanished; indeed, in 1976, the Government stated in answer to a Parliamentary question, "As a country we have over-capacity in generating . . . There is over-capacity and there is a general downturn in energy demand"[32].

Over-Capacity and its Cost to the Consumer

2.4 Evidence for that over-capacity is found in the CEGB's 33 per cent surplus of generating capacity over maximum system demand[33]. That surplus is now being used by the CEGB to justify the massive decommissioning of reliable and economically viable plant. Not that the excess capacity has stunted the CEGB's plans to build nuclear plants. On the contrary, the supposed cheapness of nuclear energy is being used as a justification for decommissioning proceeding faster than it need if the CEGB held back on its future nuclear programme.

2.5 The Select Committee on Energy finds the CEGB's attitude over the high spare capacity somewhat ambivalent, especially in view of the massive investment intended for the nuclear programme. As the Committee points out, the CEGB's planning margin has been steadily increasing and is therefore incurring a cost for which the consumer has ultimately to pay. Thus before 1968 the CEGB's planning margin was 17 per cent; it was then raised to 20 per cent. Since 1977 it has been 28 per cent. "The essential reason why the planning margin was raised", says the Committee, "was to guard against the breakdown of modern plant, the risk from which is made less manageable by the trend towards larger generating units, with the resultant loss of electricity from a single breakdown . . . Indeed the further ahead one looks, the



Since the 1960s the CEGB's surplus generating capacity has been considerably in excess of its reserve margin of 22 per cent.

TABLE 1. **Forecasts of maximum electricity demand* (GW) in England and Wales and outturn (where possible)**

Date when Forecast made	*Forecast for Demand in*	*CEGB Planning Department*	*ESI Adopted*	*Outturn*	*% Over Forecast by CEGB Planners*	*% Over Forecast of ESI Adopted*
March 1969	1974-75	54.1	53.2	41.9	29.1%	27.0%
March 1970	1975-76	57.1	54.0	41.1	38.9%	31.4%
March 1971	1976-77	58.7	54.0	42.0	39.8%	28.6%
March 1972	1977-78	60.6	55.0	42.4	42.9%	29.7%
March 1973	1978-79	56.8	56.5	43.8	29.7%	29.0%
July 1974	1979-80	58.2	56.5	44.1	32.0%	28.1%
March 1975	1981-82	53.7	54.0			
March 1976	1982-83	52.5	52.0			
March 1977	1983-84	51.0	51.5			
Nov. 1977	1984-85	53.0	52.0			
Oct. 1978	1985-86	50.9	50.6			
Oct. 1979	1986-87	48.9	50.3			
Feb. 1980	1986-87	48.5	46.8			
Oct. 1980	1987-88	45.3	47.5			

Source: The CEGB

*In 'Average Cold Spell' Conditions

greater becomes the resource cost imposed on the economy by carrying a 28 per cent planning margin compared with a lower one, for it requires additional investment. For example if the estimated winter peak demand in 2000 was 71 GW, a 28 per cent planning margin would require a plant capacity of 91 GW whereas a 20 per cent planning margin would require only 85 GW. At an assumed capital cost of £1,000/KW, a 28 per cent rather than a 20 per cent planning margin would involve an additional investment of £6,000 million over the next 20 years." The Committee then recommended: "Because of the high resource costs of retaining a 28 per cent planning margin indefinitely, we believe that the generating boards should give high priority to achieving improvements in plant reliability with a view to reducing the planning margin to a much lower level as soon as practicable. This increase in overall efficiency should have a beneficial effect on the cost to the consumer, which should in turn influence the level of demand and thus the rate of ordering"[34].

Capital investment in energy supply is now running at about 25 per cent of all new capital formation and amounts to more than the total investment in manufacturing industry[35]. The House of Commons Select Committee on Energy is concerned at the large capital outlay required by the 15 GW nuclear programme, commenting: "We believe it important to stress that this outlay represents a pre-emption of a large slice of the nation's resources, which might otherwise be available for investment in other parts of the economy"[36].

The CEGB's Forecasting Record

2.6 Accurate forecasting of future electricity demand is essential if planning margins are to be reduced as the House of Commons Select Committee on Energy suggests. At least ten years are required before a large power plant can come on stream. A site for the future power station has to be selected out of several possibilities and intensive investigation carried out to test geological suitability. After a planning application and probable compulsory purchase, construction begins. The aim is to have the plant ready for operation after some six years of construction. Because of the considerable investment required to build a power plant, whether fossil fuel-fired or nuclear, the planners must be certain that within ten years the plant will be needed. In making that assessment the planners must therefore take account of likely growth in electricity demand, and of the quantity of plant to be made redundant through obsolescence or excessively expensive running costs. Even before plant has come to the end of its working life, the electricity boards may decide that the poor thermal efficiencies of the plant in question militate against its further use. The plant is therefore relegated further down the 'merit order' until the costs of keeping it operational far outweigh the advantages of having that extra generating capacity available. Nevertheless, at that point, the planners should weigh the possibilities of refurbishing the plant rather than replacing it with entirely new plant. That decision will depend on the circumstances; if for example the plant is coal-fired and there is easy access to fuel, then it may be worthwhile retaining the site and the basic infrastructure. If on the other hand the fuel lines are awkward and expensive to maintain, then the best option may be to abandon the site completely.

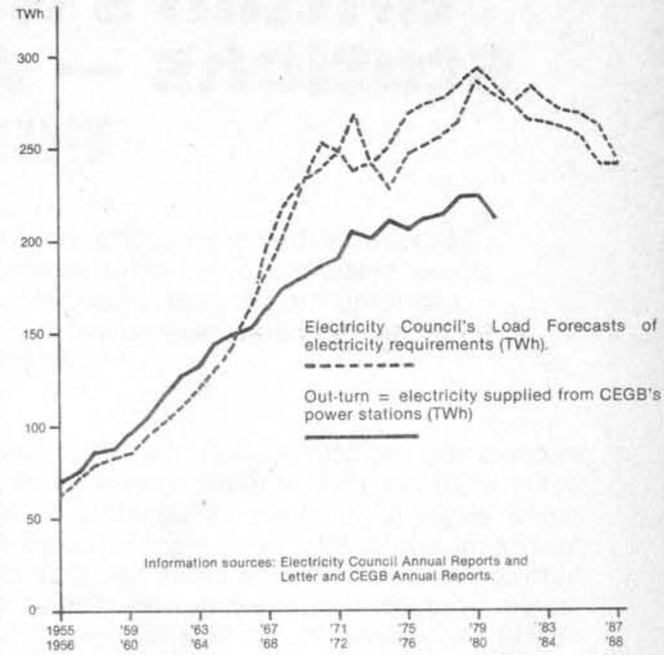
2.7 The CEGB has often emphasized the importance of forecasting electricity demand. In its Annual Report of 1978/79, for example, it states: "Central to the Board's planning is an estimate of future demand for electricity"[37]. Forecasts of future demand for electricity are made annually, if not more often, covering the period up to 12 years ahead, but generally focusing on the next seven years.

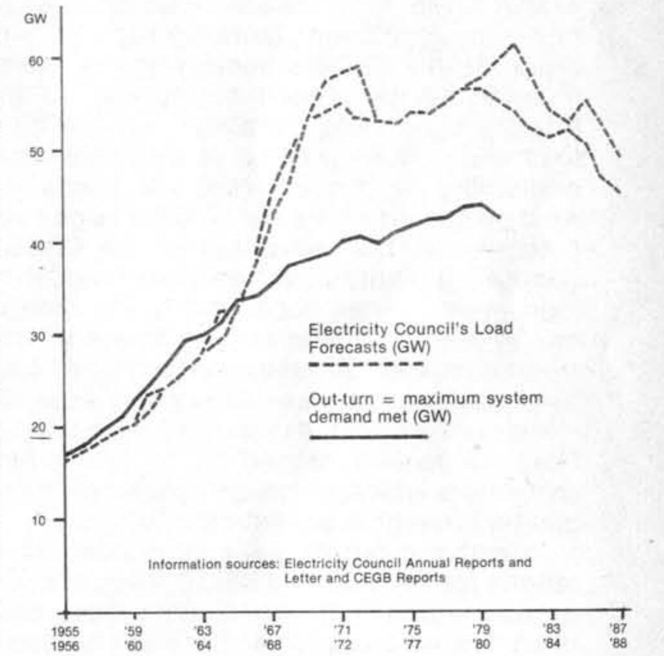
2.8 In its evidence to the recent House of Commons Select Committee on Energy, the Electricity Council stated: "The choice of basic assumptions can largely determine the final forecast"[38]. In fact, the Select Committee found itself unhappy at a number of assumptions used by the CEGB. Thus it commented: "Having examined the economic case for the policy announced by the Secretary of State, and in particular the figures supplied by the CEGB, *we have concluded that many of the underlying assumptions are open to question and that the justification for a steady ordering programme of 15 GW over ten years rests on premises which are necessarily very uncertain*"[39].

2.9 Before 1973, forecasts were made for six years ahead simply by extrapolating past trends of demand[40]. Expected increases in gross domestic product were used both by the CEGB and the Electricity Supply Industry as an indicator of the growth likely in electricity demand. Such forecasts "Consistently over-estimated the rate of GDP growth . . . with the CEGB being more optimistic than the Electricity Supply Industry"[41]. The error was substantial, amounting sometimes to as much as 40 per cent (See Table 1). Thus, in 1974, a forecast was made for 1979-80, the CEGB planning for a maximum electricity demand during the year of 58.2 GW. In the event it only needed 44.2 GW. The CEGB started to revise its forecasts downwards only as late as October 1978, having remained surprisingly optimistic about the economy's prospects until then.

2.10 Since 1974/5, the forecast Maximum System Demand has fallen, requiring the CEGB to 'need' 14.9 GW less plant. This is nearly four times the capacity of the three AGRs which (in order to satisfy the previously over-forecast demand) should have been on stream in the mid-1970s but which are not yet completed. By this reduction in its forecasts, the Electricity Supply Industry has thus 'saved' electricity consumers £14,900 million. Any further reductions in GW forecasts would 'save' further billions. In point of fact, the CEGB could have got through the 1970s without having to complete any new stations, there being sufficient capacity within the system to meet demands. Moreover with a large surplus of capacity on its hands the Board was able to decommission some 2.7 GW of plant prematurely in 1976-77[42]. **Had the AGRs come on stream when planned the CEGB would have had to explain away an even greater excess generating capacity.**

Figs. 2 and 3 show, year by year, the forecasts adopted by the Electricity Council and accepted by the CEGB, and show the 'out-turn'. On both figures, the difference between the estimates and the out-turn indicates the magnitude and consistency of the errors involved in "the best forecasts by the best people"[43], which are "central to the Board's planning"[44]. **The figures thus justify the Monopolies and Mergers Commission's conclusion that, "The forecasting record of both the CEGB and the Electricity Supply Industry have been seriously inaccurate"[45].**





Before 1965, Electricity Council forecasts of electricty demand were consistently too low. Since then, they have far exceeded actual electricity requirements. Such errors in forecasting have led to unnecessary investment in new plant.

Two examples show how the forecasting error was magnified between 1962 and 1974. Thus:

1. The estimate made in 1962/3 for 1967/68 predicted the likely increase in demand to be 57.3 terawatt-hours (TWh); the actual increase was 35 TWh. Hence the overestimate was 22.3 TWh. Prediction therefore exceeded 'out-turn' by 63.7 per cent.

2. The estimate made in 1973/74 for 1979/80 predicted the increase to be 99.2 TWh.

The actual increase was 19.2 TWh. The overestimate was 72.3 TWh. Prediction therefore exceeded out-turn by 363 per cent.

The Past Performance of Britain's Nuclear Power Stations — A Guide for the Future?

Because of their high capital cost and supposedly low running costs, nuclear power stations are run at full availability, on base-load. As such they should be providing the cheapest electricity. In fact their performance has been poor; technical problems have meant that they cannot be operated at the capacity for which they were designed.

3.0 In operating the grid system, the CEGB sets out to keep the plant with the lowest running costs working as close as possible to its maximum availability. Such plant is therefore high up the CEGB's 'merit order' list. Out of a maximum system demand during 1980/81 of 42,600 MW, some 25,000 MW is needed for continuous operation throughout most of the year (See Fig. 4)[46]. That base load is therefore met through running plants high up the merit order. All the CEGB's nuclear plants, which in total provide around 10 per cent of the Board's generating capacity[47], are on base load and hence operated at their maximum availability on the declared net capability. Also on base load are the CEGB's large coal-fired plants. The remainder of the CEGB's generating plant is used to meet fluctuating load, which varies according to the time of day and season. The largest chunk of that fluctuating load is met by medium-sized coal-fired plant and large oil-fired plant. Peak demand is met by small coal-fired and small oil-fired plants and topped up by gas-turbine generators which, although expensive to run, can be brought in at a moment's notice[48].

In carrying out its generating cost calculations for the year, the CEGB takes account of how much individual plants have been used. The extent to which the plant is used is given by the 'load factor' which, therefore, indicates its performance. Since some stops for routine maintenance and repairs are expected during the year, even for base-load plant, the load factor always falls short of 100 per cent.

3.1 Start-up time also affects output; thus a delay to the commissioning of a plant will set back a programme of planned output. In that respect the load factor on design output will be zero for every year's delay after a station should have been in operation.

The CEGB overlooks delays to the commissioning of plant in measuring load factor; indeed it is only interested in load factor after a plant has started delivering electricity to the grid. In general the load factor is calculated on the design output of the plant, but sometimes the maximum capability of the plant is deemed to be either greater* or smaller** than that for which the plant was designed. The load factor under those circumstances is sometimes given in terms of the *'declared net capability'*. Meanwhile the *'availability'* of the plant indicates what the load factor might be if the plant had been operated on base load. Thus for nuclear plants, the load factor and availability are the same[49], whereas for oil-fired plants that are used for peak-following, the load factor may be considerably lower than the availability. During 1980-81, the load factor for oil-fired plants was given as 29 per cent, whereas the availability was as high as 84 per cent[50].

3.2 Given equal 'thermal efficiencies' plants with higher load factors will generate more units of electricity for each unit of capital costs. Thus, plants operated at high load factors will have their capital charges per kilowatt-hour minimised: on the other hand, plants with higher running costs will be disadvantaged if run at lower load factors because their capital charges per kilowatt-hour will inevitably be greater than if they had been run on base load.

Derating

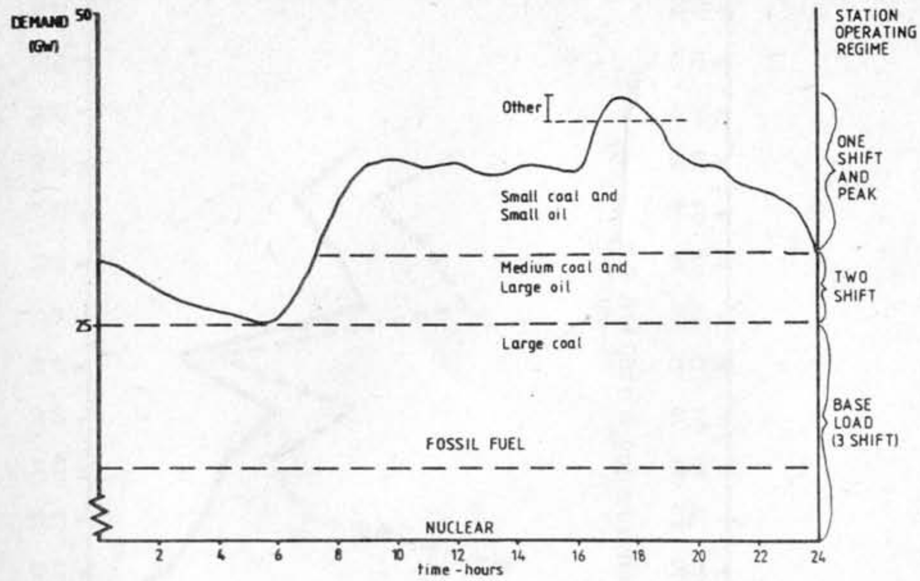
3.3 During 1966/67, Dungeness A generated 3,374 gigawatt-hours. Its load factor was given as 70 per cent. During 1971/72, Dungeness A put out 1.5 per cent less gigawatt-hours yet its load factor was given as 22.4 per cent more at 92.4 per cent. The discrepancy was the result of 'derating' the reactors for safety reasons so that declared net capability became substantially lower than the design output. The derating had the effect of bringing about lower temperatures in order to minimise the corrosion of certain components in the carbon dioxide coolant circuit.

* The CEGB's first Magnox station at Berkeley had a declared net capability of 276 MW sent-out (S-O).

** True for every CEGB nuclear power station except Berkeley.

Figure 4

Merit Order Loading Sequence to Follow Daily Demand



Source: CEGB.

Table 2.

Derating of CEGB's Nuclear Stations

Berkeley	0%
Trawsfynydd	22%
Oldbury	30.5%
Bradwell	18.33%
Dungeness A	25.5%
Wylfa	28.8%
Hinkley Point A	14%
Sizewell	27.5%
Hinkley Point B	21%

Derating can have the effect of seeming to boost a deteriorating performance: thus, purely on the strength of derating, the South of Scotland Electricity Board was able to claim that over sixteen years Hunterston A (with an 82 per cent lifetime load factor) was top of the world league. On original design output, Hunterston A was halfway down the league.

Load Factor

3.4 The definition of load factor has undergone some changes over the past 20 years. Thus in 1961, the Atomic Energy Authority stated: "Load factor is the proportion of a year in which a station is on full power." However, that criterion excludes the period of the year when the station is on partial power. The definition of load factor was then modified and in 1966 the AEA's chairman, Sir William Penney, stated that load factors were "expressed in terms of the average power level over the year divided by the maximum power level." His criterion has since been expanded by the recent House of Commons Select Committee on Energy; thus, "The load factor expresses the actual output of a plant over a given period as a proportion of output which it could theoretically have achieved over the same period if it had been available and in use at its full capacity design rating"[51].

3.5 While such a criterion of load factor may be useful in comparing stations on base-load where the aim is to keep the plant running safely for as long as it can, it loses its validity for stations that are further down the merit order and are 'load-following'. Thus, in base-load stations, low load factors are unintentional, caused in all probability by breakdowns. Indeed when a base-load plant is not running, the load factor for that period becomes zero.

The Government's 1964 White Paper was explicit about the relationship between load factor and economics. "Nuclear power stations at present have a heavy capital cost, but their running costs are low. Coal and oil-fired plants have lower capital costs but higher running costs. The economics of both types of plant benefit from intensive running, but this is particularly important with nuclear power"[52].

It was realised early on that nuclear power stations would have to achieve high load factors in order to be commercially viable. Furthermore, in 1967, the AEA stated at a symposium on International Extrapolation and Comparison of Nuclear Power Costs that a 5 per cent point change in load factor—from 75 per cent to 80 per cent—would reduce generating costs by 5.6 per cent; hence from 0.36d/KWh to 0.34d/KWh[53]. In 1969, when discussing the economics of the AGR, the AEA indicated that a halving of the load factor from 87 per cent to 41 per cent would add 75 per cent to the generating cost, taking it from 0.43d/KWh to 0.795d/KWh[54].

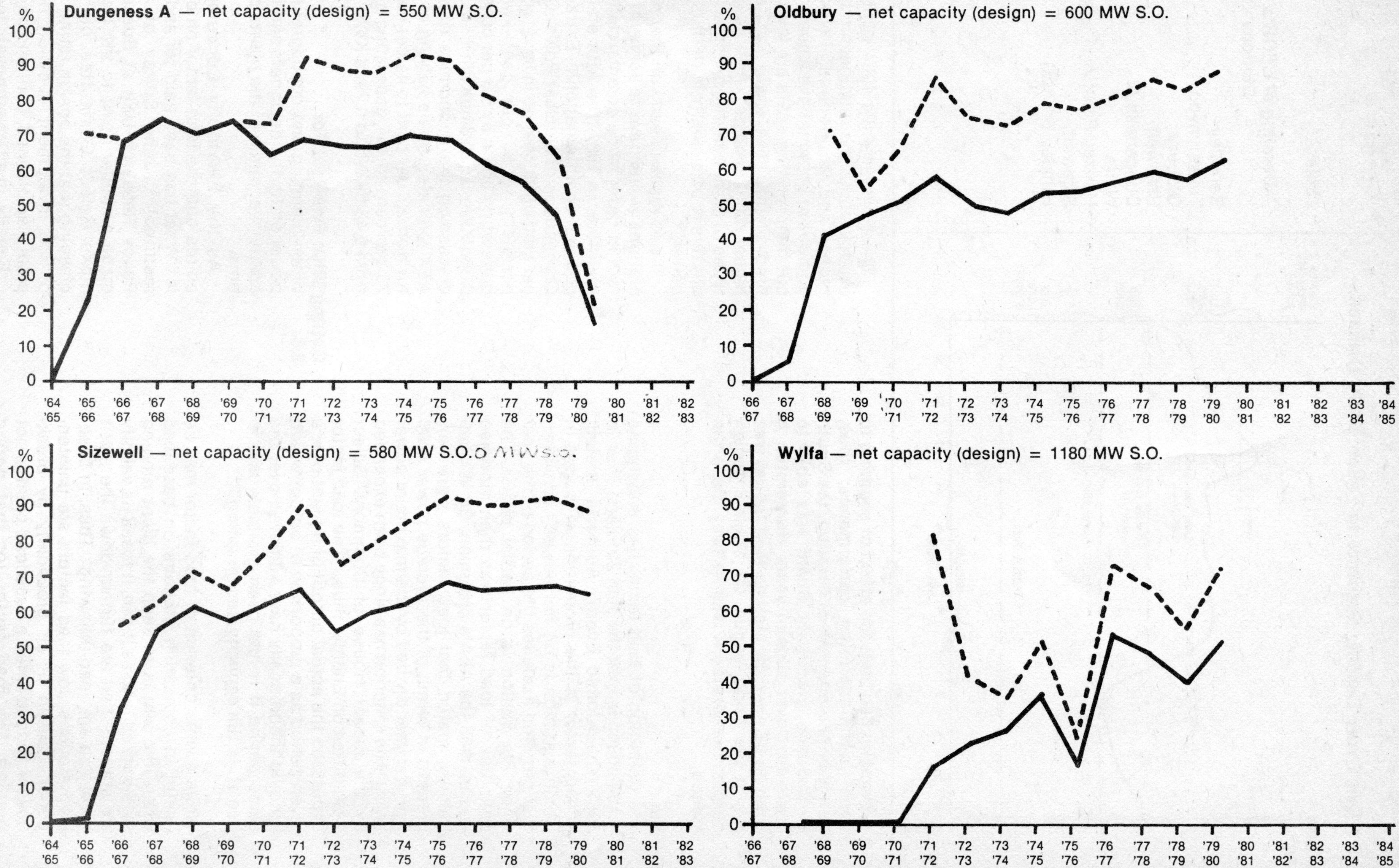
Getting What One Paid For

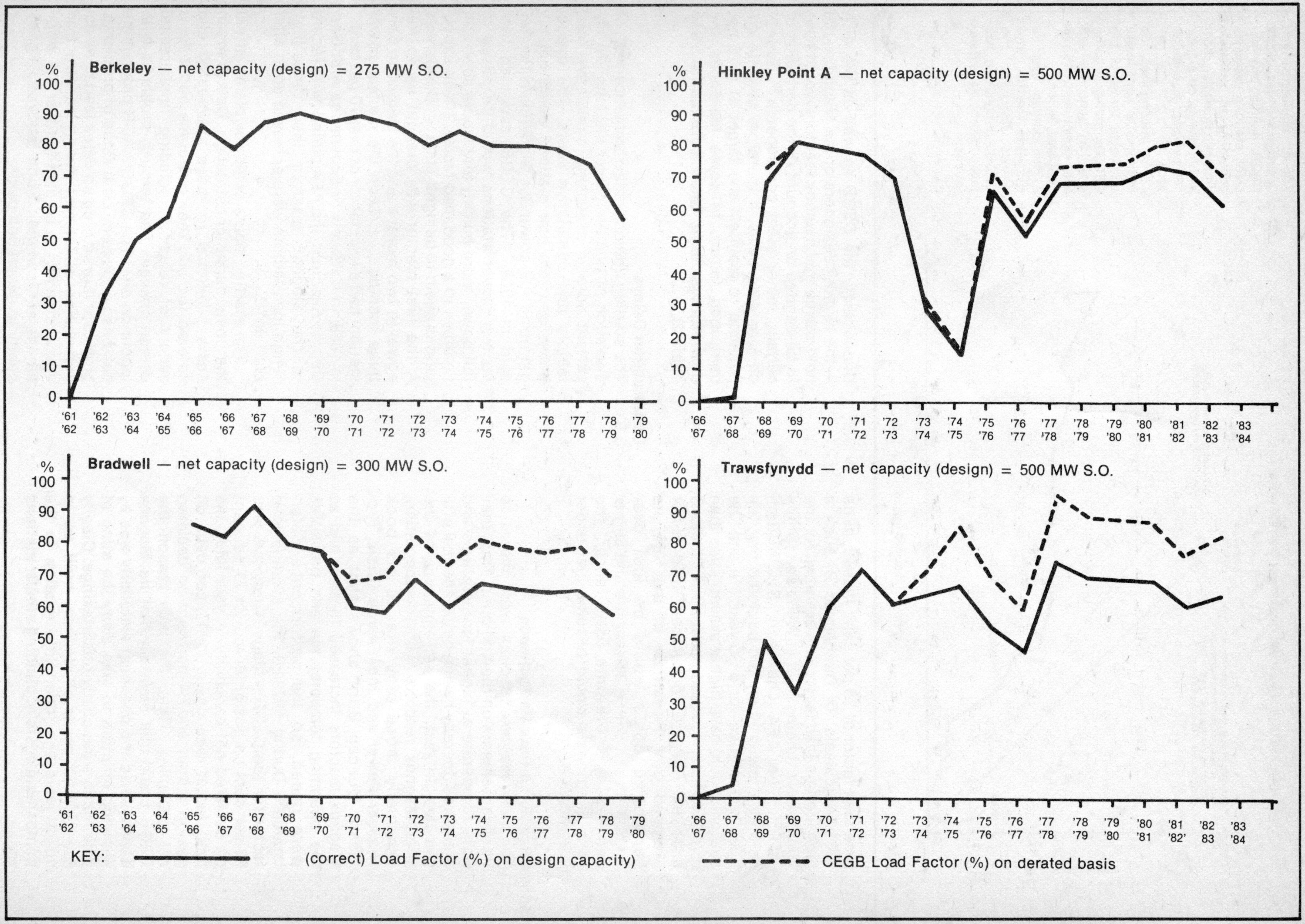
3.6 When planning and costing out an intended power plant, the designers aim for high availability over much of the plants proposed lifetime.

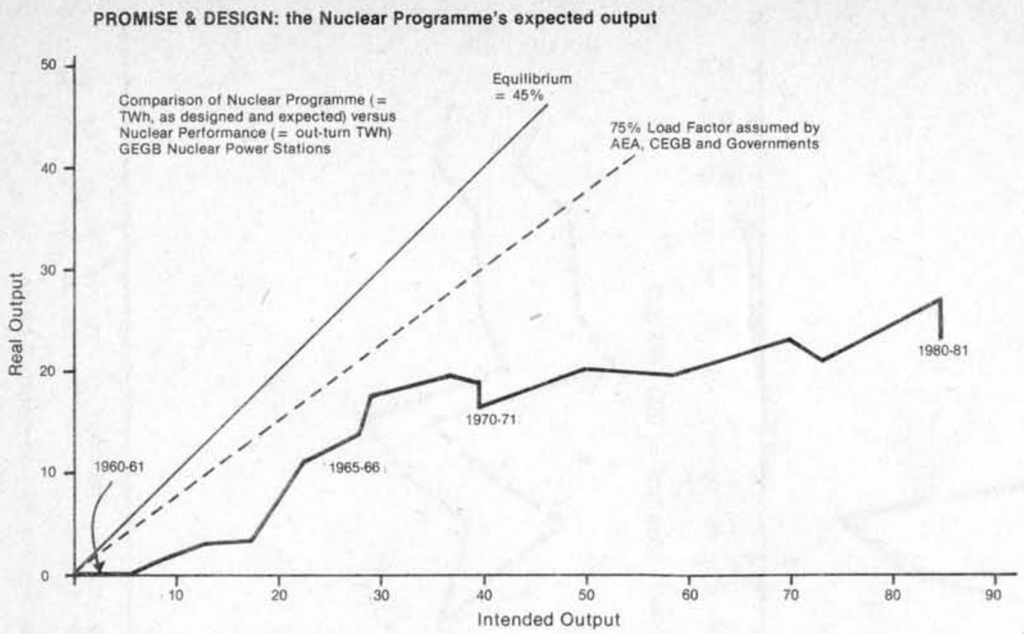
As the Electricity Consumers' Council points out, the load factor on design output is "What has been paid for and should have resulted"[55]. John Surrey of the Science Policy Research Unit at Sussex University made a similar point to the House of Commons Select Committee on Energy, proclaiming that the design rating is "The basis of the investment decision on which the plant was planned, built and paid for"[56].

Equally, in all its proposals for new nuclear plant, the CEGB planned for an average life-

THE LOAD FACTORS OF THE CEGB'S NUCLEAR STATIONS ON DESIGN OUTPUT AND AFTER DERATING




Berkeley — net capacity (design) = 275 MW S.O.
Hinkley Point A — net capacity (design) = 500 MW S.O.
Bradwell — net capacity (design) = 300 MW S.O.
Trawsfynydd — net capacity (design) = 500 MW S.O.
%
KEY:
(correct) Load Factor (%) on design capacity)
CEGB Load Factor (%) on derated basis



The 45° equilibrium line assumes the ideal of the CEGB building its nuclear stations precisely according to schedule and then operating them at full design output for 100 per cent of their lifetime.

The intermediate line indicates a supposedly attainable target of the CEGB's stations being built to schedule and then operating at 75 per cent load factor.

The bottom line indicates reality and shows how far the CEGB's programme has fallen short of expectations.

time load factor of 75 per cent; indeed, in its 1965 'Appraisals' of Dungeness B, such a high lifetime load factor was assumed for the Magnox plant being built at Wylfa and for the AGR[57]. The AEA chairman, Sir William Penney, stated: "It should be noted that the AGR is designed for a 30-year life and the station should have higher availabilities than 75 per cent . . . If we assume for Dungeness B a 30-year life and 75 per cent load factor averaged over the whole of that life, its generating costs would be just over 0.41d/KWh . . . with a 30-year life and 85 per cent average life-time load factor, the generating costs would become just under 0.38d/KWh."

Magnox Reactor: A Poor Performance

3.7 The later Magnox reactors were meant to be improvements on the first ones. Thus they were to operate at higher temperatures and pressures, thereby having better thermal efficiencies. In fact, the performances of the later Magnox reactors were disappointing, especially those of Wylfa. In his book *Nuclear Power and the Energy Crisis*, Professor Duncan Burn shows that as the Magnox reactors increased in size, and as the operating temperatures and pressures were raised, so the performance deteriorated[58]. During 1979/80, the average load factor for the CEGB's Magnox reactors was 53 per cent on design output or 71 per cent on declared net capability. A year later, the load factor was down to 47 per cent on design output and 64 per cent on declared net capability. **Thus, the only reason the CEGB could still maintain that its Magnox stations had the cheapest electricity was by allowing inflation to take away the sting of what once were costly undertakings. Clearly the historic costs of stations, built up to 10-20 years ago, bear little relation to the comparable costs of building similar stations today.**

3.8 Undoubtedly the CEGB as well as the AEA—the original designers of the Magnox—did not foresee that magnox reactors would have to be derated on account of the corrosion of certain 'minor steel components'[59]. Except on a derated basis, it therefore became impossible to maintain the target of a 75 per cent load factor. **In some instances the downratings have been substantial (See Table 2).**

Construction Delays

3.9 The starting dates for the commencement of operation of nuclear power stations are important both in assessing cumulative load factors and cumulative costs. The expectation was that new stations would quickly get up to full power. As Sir William Penney said in 1966: "The CEGB expected that nuclear power stations would be raised to full power more quickly and would soon settle down to a good load factor. These expectations seem to be right. Thus . . . Dungeness A the first reactor was brought up to full power in two months and the second in only three months . . . (Soon the nuclear power station) had a load factor of over 70 per cent." In 1968, in *A Review of Experience with Gas-Cooled Reactors*, the AEA stated (with regard to the Magnox reactors then operating): "High load factors were achieved soon after start up"[60].

The starting dates of power plants affect the costs during construction. Delays mean costs additional to those anticipated and catered for; and they can come about for a variety of reasons, including fundamental design changes and through problems with labour on site. The CEGB's AGR programme has been bugged by both kinds of problems. Moreover late starting up dates lead to an accumulation of interest during construction which then has to be paid for over the working life of the station. Such costs add significantly to generation costs.

As seen in Table 3 interest during construction becomes a major element in the generating costs of AGRs where there have been such lengthy time over-runs. In fact, the CEGB has taken practically twice as long as anticipated to get its AGR programme going[61]. **Altogether the total construction period for the four AGR stations, until start-up, should have been 55 years. On the assumption that Dungeness B, Hartlepool and Heysham 1 will start according to the CEGB's 1981 estimate, the total construction period will in reality have been 102 years.**

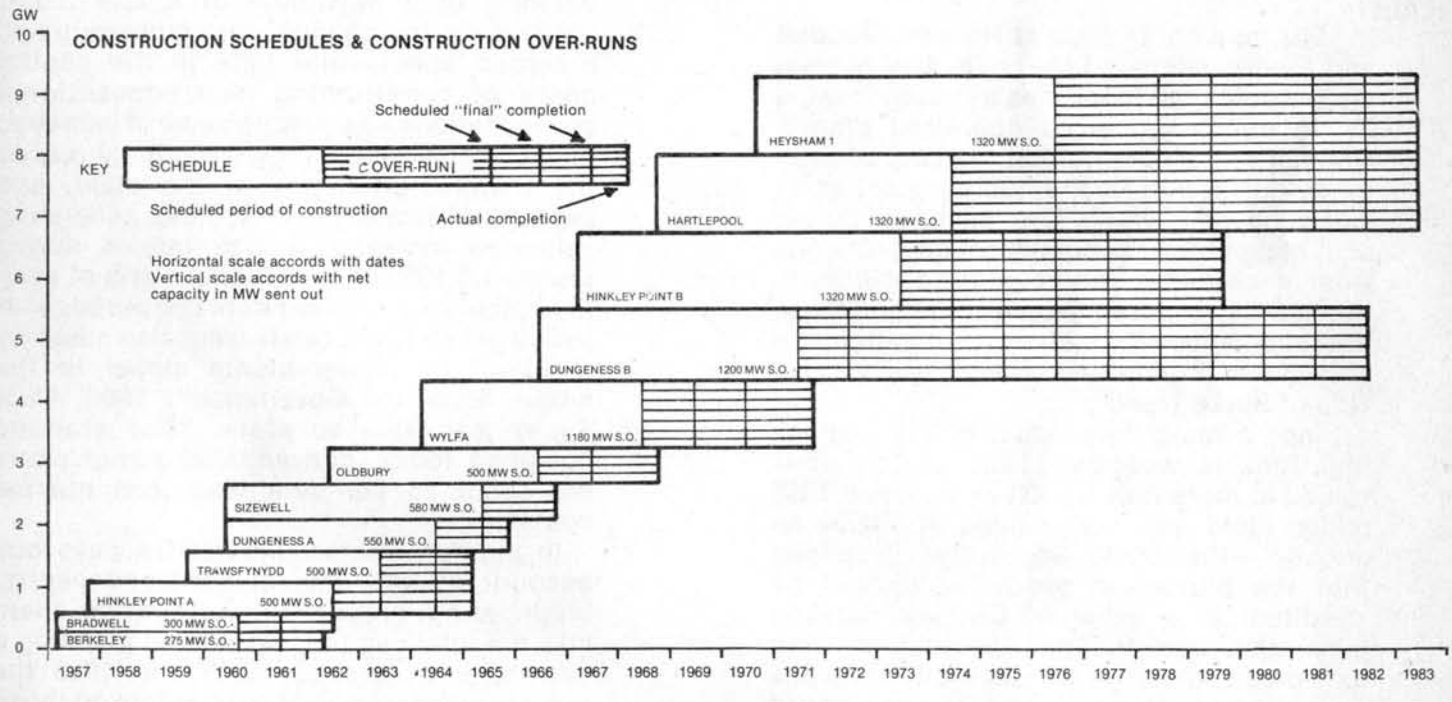
Table 3:

Interest During Construction (IDC)

Nuclear Power Stations:	IDC as % of of capital charges A	IDC as % of combination of capital charges & IDC B	IDC as % of generation costs C
Magnox	17%	15%	4%
Hinkley Point B	43%	30%	10%
Dungeness B	72%	42%	27%
Hartlepool	58%	37%	22%
Heysham 1	57%	36%	22%

Coal-fired Power Stations:	IDC as % of of capital charges A	IDC as % of combination of capital charges & IDC B	IDC as % of generation costs C
Early coal-fired power stations	25%	20%	1%
Drax A	38%	28%	3%
Drax B	60%	37%	12%

Table 3 shows, separately for nuclear power stations and coal-fired power stations, Interest During Construction (IDC) as a percentage of (A) capital charges, of (B) capital charges and IDC combined, and of (C) generation costs (see CEGB *Annual Report* 1980/81 p.65).IDC is shown to be a major factor in all costs (except where inflation has distorted the historic costs in (C) for Magnox, Hinkley Point B, early coal-fired power stations and Drax A.)



Nuclear Power: Early Uncertainties

When the CEGB's Magnox stations were built, it was realised that they would not be competitive with contemporary fossil fuel-fired plant, unless plutonium, extracted from spent reactor fuel was given an artificially high value. With fossil fuel costs rising sharply during the 1970s, nuclear power was at last expected to become competitive.

4.0 The CEGB's Magnox programme was based on the reactors built during the 1950s at Calder Hall and at Chapelcross for weapons-grade plutonium production[62]. The generation of electricity from those reactors was a by-product of plutonium production, and it helped offset the cost to Britain of building up an arsenal of nuclear weapons.

The 'Plutonium Credit' and the Economics of Magnox

4.1 In 1953, at a conference at Harwell, Goodlet and Moore estimated that a 35 MW nuclear plant would cost four times as much to build as an equivalent sized coal-fired plant[63]. Goodlet and Moore quoted the cost of electricity generation from a nuclear plant as 1d (old pence)/per unit[64]. That cost was 50 per cent higher than the equivalent cost for units from a contemporary coal-fired station[65]. Poulter, Kay and Geoghegan confirmed those figures in a report which was submitted to a government committee under the chairmanship of Burke Trend[66].

Since a major by-product of the magnox reactions is weapons-grade plutonium—valued at more than £3,000 an ounce in 1953 prices (gold was then valued at £12.50 an ounce)[67]—the Trend Committee proposed that the plutonium produced should be 'credited' at a value of 0.4d/unit against generation costs[68]. Thus, by incorporating that credit, the cost of electricity from the proposed nuclear power plants would achieve parity with that produced from coal-fired stations.

By late 1956, however, the UK government had come to the conclusion that a 'plutonium credit' of 0.4d/unit was far too high and would have to be cut to less than 0.1d/unit, thus raising at a stroke the likely cost of nuclear electricity by one-third. The reason for the lopping of the 'plutonium credit' was the possibility of importing cheap, highly enriched uranium from the United States, plus the discovery of new uranium deposits[69]. The idea that plutonium could be recycled to replace uranium was then dropped. Nonetheless, by March 1957, because of the Suez crisis and worries about the security of oil supplies from the Middle East, the government decided to expand the Magnox programme from the projected 1.5-2 GW to some 5-6 GW by 1965[70].

Coal Hits Back

4.2 It soon changed its mind, lengthening the time over which the programme would come into being by three years—to 1968—and sticking to a maximum of 5 GW[71]. The reasons for the change were numerous and included spectacular falls in the capital costs of constructing new conventional power stations—largely because of improved coal-burning technology, which increased the thermal efficiency of the plant, and because of economies of scale as generating sets were increased in size. Indeed, during the period 1955-65, the capital costs of coal-fired plants were halved from £60 per kilowatt to £30 per kilowatt. Costs were also saved by building the power plants closer to the mines. Thus, the Government's 1960 *White Paper* was able to state: "For stations designed today, conventional power costs are about 25 per cent less than nuclear costs"[72].

In addition, whereas the CEGB always took account of site development and central engineering charges, incorporating them into the total capital costs, when planning a new coal or oil-fired facility, in 1953 the nuclear planners somehow overlooked those costs which amounted to between 5 and 10 per cent of total station capital costs. Interest charges on capital borrowed were also up on the 4 per cent used in 1954 and had increased to 6 per cent by 1961. The higher rate, together with the price inflation running at 2 per cent per year, affected the nuclear power plants with their comparatively high construction costs more than it did conventional power plants.

The Economics of Magnox under Attack: Early Criticisms

4.3 By the early 1960s, the CEGB's Magnox programme was already under criticism on economic grounds. Far from giving Britain cheap electricity, the Magnox programme was costing the electricity consumer and the taxpayer £20 million per year more than they would have had to pay had the generating plants been coal-fired. In 1967, the Chairman of the National Coal Board, Lord Robens, told the National Union of Mineworkers that the Magnox programme had led to the loss of 28,000 jobs in the mines because of the electricity generating board's diminished demand for coal[73]. Furthermore, the Magnox programme was costing £750 million; £525 million more in capital costs than would have been required by an equivalent-sized coal-fired programme[74]. When actual generation costs were published, they indicated that nuclear power at 1.06 old pence/KWh cost 35 per cent more than coal-fired plant at 0.786 old pence/KWh[75].

4.4 The nuclear industry answered criticisms of the high costs of nuclear generated electricity by claiming that the economies of scale that were bringing down the costs of coal-fired plant could also be expected to reduce the costs of nuclear power. Thus the last two Magnox stations to be built, Oldbury and then Wylfa, were to have higher operating temperatures, higher pressures and larger generating capacities per reactor. A major departure in design was the use of a pre-stressed concrete, steel-lined pressure vessel instead of the all steel pressure vessel used in earlier reactors. The innovation was to bring the capital costs down from £185 per kilowatt for Berkeley (the CEGB's first Magnox reactor), to £101 per kilowatt for Oldbury and Wylfa[76]. The assumption then was that Wylfa would have a twenty year life; a fuel-burn up of 3,000 megawatt-days per tonne on average; and interest on capital borrowed at 7.5 per cent[77]. Its generating cost was then expected to come out at 0.66 old pence per kilowatt-hour—thus costing less than that of contemporary coal-fired plant.

Later Criticisms

4.5 Even prior to the Yom Kippur War of 1973, the CEGB was claiming that its best Magnox plants were producing power more cheaply than the best coal or oil-fired plants. In fact it had always been the rationale of nuclear power that, although capital costs were higher compared with conventional plant, the fuel costs (and hence operating costs) were considerably lower[78]. The economic case for nuclear power, therefore, rests on the difference in fuel costs between nuclear and coal being sufficiently great over the year's operation to offset the higher capital charges of nuclear.

Once a power station has been built and the capital charges made, the temptation is to overlook the initial investment and to be guided instead by the actual operating costs. In making its claims for the relative cheapness of nuclear power, the CEGB has constantly succumbed to that temptation. Thus, when it made its claims for Dungeness A and Sizewell A at the end of 1971, the CEGB was incorporating historic cost figures into the actual production costs and not taking inflation into account. At that time the Department of Trade and Industry criticised the CEGB for muddling historic costs. The Department provided the 1972 House of Commons Select Committee on Science and Technology with a comparison of generating costs based on January 1972 prices. As a consequence, the figures were completely reversed; Magnox came out considerably more expensive than either coal or oil-fired generation[79]. On the other hand, the Department of Trade and Industry was in agreement with the CEGB that on estimated generating costs, the AGRs being built would give slightly cheaper electricity than either coal or oil at an 8 per cent interest rate. At a 10 per cent interest rate, nuclear would be less competitive than coal but still more competitive than oil.

Yom Kippur War: Nuclear Comes into its Own?

4.6 Those official criticisms of Magnox generating costs would seem to have evaporated, however, in the upheaval following the Yom Kippur war and the rapid escalation in the price of non-nuclear fuels. Indeed it was claimed nuclear power had at last come into its own. France and the United States, in particular, embarked on ambitious nuclear construction programmes, France aiming to have more than 50 per cent of its electricity generated by nuclear power in the mid 1980s[80]. Speculation that such nuclear programmes would lead to a rush on supplies of uranium led, during the 1970s, to sharp rises in uranium prices[81]. Nonetheless the nuclear industry argued that such rises were easily accommodated, with only a marginal effect on the economics of nuclear generating costs. The reasoning was that the cost of uranium comprised less than one fifth of total generating costs. By comparison as much as 80 per cent of coal-fired generating costs were comprised of fuel costs[82,83].

The CEGB's contention that nuclear is the best buy would *appear* to be borne out by the figures it publishes annually. Thus Magnox generating costs are stated to be cheaper than coal or oil-fired generating costs. In 1979/80, for example, Magnox generating costs in pence per kilowatt-hour were given as 1.30 compared to 1.56 for coal-fired and 1.93 for oil-fired[84]. In 1980/81, the respective costs were given as 1.65 for Magnox, 1.85 for coal-fired and 2.62 for oil-fired[85]. The CEGB expects the differences between the comparative costs to become more glaring with the new stations, nuclear, coal and oil, coming on line. As we shall see in Section 5, however, the CEGB's figures are based on accounting practices which are hard to justify and which, unquestionably, favour nuclear power.

Historic Costs: "The Fraud Inherent in all Inflationary Finance"

When inflation is taken into account and historic cost figures are given a proper value, the CEGB's figures, indicating the present-day relative cheapness of nuclear power compared to coal-fired plant, are completely reversed. Nuclear power is considerably more expensive.

5.0 The CEGB presents the figures in such a way as to obscure the reality of the economic performance of its nuclear power stations. Indeed over the past decade, the figures presented in the CEGB's annual reports (as well as in answers to Parliamentary questions) indicate that nuclear power provides the cheapest electricity being generated in the UK.

5.1 **We contend that if the figures take account of the real value in modern terms of money spent as long as twenty years ago, then the apparent cheapness of nuclear power vanishes and "the fraud inherent in all inflationary finance" is revealed.**

Prejudiced Accounting

5.2 The CEGB itself is well aware that money spent yesterday gives a false impression of its value today. In its 1973/74 *Annual Report*, it stated: "The price of electricity should fully reflect the cost so that consumers' decisions will bring electricity consumption to the level that makes the most effective use of national resources . . . Otherwise a low price stimulates demand for an underpriced product which in turn increases unnecessarily the amount of generating plant that has to be built . . . Acceleration in the rate of inflation raises the question of whether the Board is making sufficiently clear in its published accounts the extent to which income covers its real costs. At present, it charges revenue account with depreciation based on the historical costs of assets and with interest on accumulated borrowings. This means that the charge to revenue account for the use of assets in production is too low, at least by the extent to which today's pound (sterling) is less in value than what it was when they were installed"[86].

Despite that frank statement, the CEGB has used the avowed cheapness of nuclear power—based on past investments—to gain support on economic grounds for its intended nuclear power programme.

5.3 By evaluating capital and running costs at historic prices, nuclear power receives a double advantage: first because the differences between its capital costs and those of contemporary coal-fired plant are made to appear far smaller they are in real terms: second, because in contrast to fuel for coal-fired plant, nuclear fuel will have been paid for in the more distant past, when costs were lower.

5.4 Moreover, the CEGB proposed in its 1980/81 *Annual Report* that the lifetimes of its Magnox plants be extended by five years and of its larger coal-fired plant by 15 years. Although not yet incorporated in the generating cost figures, such an extension would again favour nuclear. In historic costs the proposed extension would bring nuclear generating costs down by 0.03 p/KWh and coal-fired costs by 0.01 p/KWh[87]. In current costs, the advantage of extending Magnox lifetimes is emphasised, with a reduction in generating costs for nuclear of 0.12 p/KWh and for coal-fired plant of 0.06 p/KWh. In view of the corrosion problems coming to light in Magnox reactors, we seriously wonder whether the proposed stretching of Magnox lifetimes can, even for accounting purposes, have any validity. In fact, four Magnox reactors are now shut down, their futures uncertain. Should their lifetimes be shortened, nuclear generating costs must take that loss in account[88].

5.5 A first requirement of any valid economic appraisal of different kinds of generating plant is that any prejudiced assumptions should be eliminated from the calculations. Although the CEGB has itself stated over the past few years that its generating costs should not be used as a basis of future planning because they incorporate historic figures, the apparently cheaper generating costs of its Magnox reactors are bound to be persuasive.

In fact the CEGB has studiously avoided asking the right questions. What the Board should be asking itself is: If coal-fired stations had been built instead of Magnox stations and the value of money had been stable, or the accounts properly corrected for inflation, would electricity have been cheaper or dearer?[89]

A New Analysis

5.6 Essential information on the capital costs of individual nuclear and coal-fired stations commissioned between 1965 and 1979—in prices current in the year of expenditure and hence in historic costs—became available in response to a Parliamentary question. The question was put by Frank Hooley MP on February 2nd, 1981, but the reply was only received in mid-May. Professor J. W. Jeffery of Birkbeck College, London, has analysed that data in an article, *The Real Costs of Nuclear Electricity in the UK*, to be published in early 1982 *in Energy Policy*[90]

His conclusions are that the 20 per cent generating cost advantage of Magnox given by the CEGB switches to a 30 to 50 per cent disadvantage when the generating costs are properly converted into 1979/80 pounds.[91].

Getting to the Real Cost

5.7 As Jeffery explains at length in his article, there is more to current cost accounting than simply transforming historic costs into up-to-date figures. The load factors and availability of the plant in question must be determined; the interest during construction assessed; and, for nuclear plant, the date when the initial fuel was purchased must be inferred. An annuity, incorporating a 5 per cent rate of return and operating much like a mortgage, must then be calculated over the supposed lifetime of the plant, given in 1979/80 as 25 years for coal-fired plant and 20 years for nuclear plant[92]. As previously mentioned, those lifetime estimates have now been extended.

5.8 In principle the conversion of historic costs into current costs must take account of inflation and incorporate an interest rate that is generally accepted. The decline in the value of money is best represented by the Retail Prices Index (RPI). As for the interest rate, Professor Jeffery uses 5 per cent per annum—the required rate of return laid down by the government. The adjustment for load factors is more complicated since it depends on the expected availability should the generating plant have been operated on base-load. On the other hand a plant might be used on base-load but have a poor availability on design output.

Being nuclear, the CEGB's Magnox stations were all run at full availability[93]; therefore no load factor adjustment was necessary, even though their performance during 1979/80 was poor with a load factor on design output of no more than 56 per cent. The coal-fired plants, on the other hand, had an availability of 69 per cent on declared net capability, but were operated at a load factor of 64 per cent. Without nuclear plants, the coal-fired stations would have had to take on the full burden of meeting base-load requirements and load factors would therefore have matched availability. To adjust the generating costs of the coal-fired system to match up with availability, the fixed costs, comprised of capital plus running costs, must be multiplied by $\frac{64}{69}$.

The capital cost, and interest during construction (IDC), are annuitised over the specified lifetimes of the respective plants—thus 20 years for Magnox and 25 years for coal[94]. The annuities can then be divided by the number of kilowatt-hours produced in the year to give the capital cost in pence per kilowatt-hour. Meanwhile the CEGB allows for a decommissioning cost for nuclear plant of £2/KW per annum in March 1980 prices. Without disputing that figure, Jeffery adds it to the capital cost.

5.9 No coal-fired station has more than a few months store of coal on site and the CEGB purchases coal during the year when it is to be used. Hence the inclusive fuel costs for coal-fired plant published in the *Annual Report* need no adjustment for inflation. The same is not true of nuclear fuel costs. The initial fuel, for example is fabricated, during the construction of the power plant, and should there be delays in construction, then obviously the fuel will have to be kept in hand. Typically the initial fuel may be held in reserve for a number of years before use, and consequently the price paid for that fuel will not represent an up-to-date price[95]. Replacement fuel will also have been manufactured as much as four years or more before the mid-point of its life in the reactor.

The Real Escalation in Nuclear Fuel Costs

5.10 The Magnox fuel cost is given as 0.60p/KWh in Table 1 of Appendix 3 in the 1979/80 CEGB's *Annual Report*. As Professor Jeffery estimates, that fuel cost comprises: 'initial fuel cost' in 1965/66 prices; fuel fabrication costs in 1975/76 prices; and reprocessing costs in 1979/80 prices. The task then is to disentangle which part of the 0.60 p/KWh overall fuel price belongs to which category.

The CEGB gives 'initial fuel cost' in March 1980 prices as £4 per KW per annum. In pence per kilowatt-hour, 'initial fuel' therefore comes out in March 1980 at 0.081 p/KWh, which must then be converted into 1965/66 prices by multiplying by 0.235, the retail price index adjustment. The answer, 0.019 p/KWh, has then to be subtracted from 0.60 to give the fuel cost remaining for reprocessing and fuel fabrication.

Jeffery deduced from the reprocessing payments recorded in the CEGB accounts that about two-thirds of Magnox fuel costs—minus 'initial fuel' in 1965/66 prices—are taken up by current reprocessing requirements. In a reply to a letter from Jeffery, the CEGB did not contest this approximate figure. Therefore reprocessing costs account for two thirds of 0.60—0.019, the answer coming to 0.387 p/KWh in 1979/80 prices. The remainder, 0.194 p/KWh, gives the cost of fuel fabrication in 1975/76 prices.

All the three cost items must then be converted to 1979/80 prices; reprocessing costs coming out at 0.387 p/KWh, fuel fabrication at 0.320 p/KWh and 'initial fuel' at 0.075 p/KWh. **The total fuel cost in 1979/80 prices thus comes to 0.387 + 0.320 + 0.075 = 0.78 p/KWh, 30 per cent up on the 0.60 p/KWh given in the *Annual Report* and presented to Parliament.**

5.11 According to evidence given to the Monopolies and Mergers Commission, the CEGB stated that it expected Magnox fuel costs to rise in real terms by 50 per cent primarily because of increases in reprocessing costs[96]. Meanwhile, British Nuclear Fuels Ltd. expected a threefold rise in reprocessing costs between 1979/80 and 1986/87[97]. **To reflect some of those real fuel cost increases, Jeffery assumes a doubling of reprocessing costs. On that basis the 1979/80 fuel cost would be 1.17 p/KWh and therefore nearly double the published figure.**

Coal Comes Out On Top

5.12 **When all the figures are put together, Jeffery finds that the CEGB's publicised 17 per cent advantage of Magnox over contemporary coal-fired plant during 1979/80 (See Table 4, col. 3 & 4) turns into a considerable generating cost disadvantage. Thus when just the capital and IDC costs are corrected for inflation, coal has an 18 per cent advantage. When all costs are corrected for inflation coal's advantage increases to 29 per cent. With the likely increases in reprocessing costs added, coal's advantage becomes 51 per cent, (See Table 4).**

A similar treatment of the CEGB's figures for the generating costs of AGRs and contemporary coal fired plant turns nuclear power's apparent generating cost advantage into a substantial disadvantage. Thus as seen from Table 5 (col. 2), the CEGB gives 1.35 p/KWh as the generating cost for its AGR at Hinkley Point and 1.52 p/KWh for its Drax A coal-fired plant. Elsewhere in its 1979/80 Annual Report (Appendix 3, Table 3), the CEGB assesses the generation costs for those three AGR stations of its first AGR programme still awaiting completion, and for the second half of Drax. Despite the incredible delays and cost-overruns on the AGR stations, and in particular Dungeness B, coal-fired comes out considerably more expensive at 3.59 p/KWh compared with Dungeness B's 2.62 p/KWh. The oil-fired plants have generation costs of around 7 p/KWh—hardly surprising in view of their being immediately relegated to load following.

Converting historic costs for the four AGR reactors into current costs and assessing generation costs in a similar way as he performed for Magnox, Jeffery has found the comparative advantage of AGRs completely reversed with coal coming out considerably cheaper.

Thus, Jeffery shows (See Table 5) that a seeming 11 per cent advantage for Hinkley Point B over Drax A turns into as much as 44 per cent disadvantage once both capital costs and fuel costs are corrected for inflation, and a probable escalation of reprocessing costs is included. Meanwhile depending on which plant is considered, with Dungeness B the worst, the 30 per cent plus advantage of nuclear over coal-fired turns into as much as a 70 per cent disadvantage, (See Table 6 Col. 3).

Table 4: Results of inflation correction applied to the stations considered in Table 1, Apendix 3 of the CEGB's 1979/80 Annual Report.

	COAL FIRED					NUCLEAR					
	£m	Ann-20yrs @ 5% £m	Output TWh	Cost in p/kWh	LF Corrections 64/69	£m	Ann-25yrs @ 5% £m	Output TWh	Cost in p/kWh	Decommissioning (see para. 5.8)	Total
Historic Capital Costs	964.1					476.9					
1979/80 Capital Costs	3640.9	258.3	100.5	0.257	0.24	2042.0	163.8	18.21	0.900	0.038	0.94
1979/80 IDC @ 5%	1084.9	77.0		0.077	0.07	508.7	40.8		0.224		0.22

Columns 3 & 4 indicate figures as presented in Table 1, Appendix 3 of CEGB's 1979/80 Annual Report.

Total 1979/80 Costs in p/kWh

	COAL-FIRED				NUCLEAR (Magnox)			
	1	2	3		4	5	6	7
Capital Charges (and provisions for decommissioning)	0.26	0.24	0.09		0.34	0.94	0.94	0.94
Interest During Construction	0.08	0.07	0.02		0.06	0.22	0.22	0.22
Inclusive fuel costs	1.29	1.29	1.29		0.60	0.60	0.79	1.18
Other Costs of Operation	0.16	0.15	0.16		0.30	0.30	0.30	0.30
Total	1.79	1.75	1.56		1.30	2.06	2.25	2.64
Nuclear/Coal(2)%					83**	118	129	151

1. Costs corrected for inflation
2. Costs corrected for inflation and Load Factor
3. Figures from Table 1, Appendix 3, CEGB's Annual Report 1979/80
4. Figures from Table 1, Appendix 3, CEGB's Annual Report 1979/80
5. Capital and IDC costs corrected for inflation, no fuel cost correction.
6. All costs corrected for inflation
7. As 6 but probable reprocessing cost increases added (See para. 5.11)

**Both uncorrected, ie, 4/3

Table 5: Total Cost of Electricity in p/kWh (1979/80 prices) from Drax A (coal) and Hinkley Pt. B (AGR nuclear) station

	Drax A		Hinkley Pt. B				
Notes	1	2	2	3	4	5	6
Capital charges and provision for decommissioning	0.25	0.12	0.37	0.70	0.70	0.70	0.70
Interest during construction	0.08	0.04	0.18	0.30	0.30	0.30	0.30
Inclusive fuel costs	1.25	1.25	0.55	0.55	0.97*	1.07*	1.19*
Other Costs of operation	0.11	0.11	0.25	0.25	0.25	0.25	0.25
Total	1.69	1.52	1.35	1.80	2.22	2.32	2.44
Nuclear/Coal(1)%			89**	107	131	137	144

1. Corrected for inflation
2. Figures from Table 2, Appendix 3, CEGB's 1979/80 Annual Report
3. Capital and IDC costs corrected for inflation; no fuel costs correction
4. All costs corrected for inflation
5. As 4, but minimum likely escalation of real reprocessing costs added
6. As 5, but probable escalation of reprocessing costs

*Corrected from figures of paras. by the factor 1.08 to give 1979/80 prices

**Both uncorrected (ie, Coal(2))

Table 6: Results of Inflation Corrections applied to the stations considered in Table 3, Appendix 3, of the CEGB's Annual Report, 1979/80

	DRAX B	DUNGENESS B	HARTLEPOOL	HEYSHAM
Settled down LF	73	54	54	54
Design output in GW	1.98	1.2	1.32	1.32
Assumed output in TWh*	12.66	5.68	6.24	6.24
Annuity of capital costs, £mpa	58.7	66.9	57.2	54.0
Annuity of IDC, £mpa	12.8	38.2	26.0	17.7
Capital cost in P/kWh	0.464	1.178	0.917	0.865
Decomissioning, p/kWh		0.042	0.042	0.042
IDC in p/kWh	0.101	0.673	0.417	0.284
Table 3, LF corrections **				
Capital costs	0.52	0.88	0.77	0.79
IDC	0.35	0.72	0.52	0.53
Other costs	0.09	0.23	0.23	0.23

Total 1979/80 Costs in p/kWh

	DRAX B		DUNGENESS B			HARTLEPOOL			HEYSHAM		
	1	2	1	2	3	1	2	3	1	2	3
Capital charges and provision for decommissioning	0.52	0.46	0.88	1.22	1.22	0.77	0.96	0.96	0.79	0.91	0.91
Interest during construction	0.35	0.10	0.72	0.67	0.67	0.52	0.42	0.42	0.53	0.28	0.28
Inclusive fuel costs	1.35	1.35	0.59	0.59	1.28	0.59	0.59	1.28	0.59	0.59	1.28
Other Costs of Operation	0.09	0.09	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
TOTAL	2.31	2.00	2.42	2.71	3.40	2.11	2.20	2.89	2.14	2.01	2.70
Nuclear/Coal(2)%			121	136	170	106	110	145	107	101	135

1. Table 3, Appendix 3, corrected for Load Factor and use of lifetime fuel cost

2. Capital costs and IDC corrected for inflation, fuel costs as 1

3. As 2 but nuclear fuel costs corrected for inflation and probable escalation of real costs of reprocessing

*The assumed output in TWh = design output in GW x 87.60 x LF/1000

**LF corrections for the figures of Table 3, Appendix 3 are : for AGR stations — 49/54 = 0.91; for Drax B — 56/73 = 0.77

Current Cost Accounting

The change to current cost accounting by the CEGB has given a more realistic value to the CEGB's assets. Nevertheless to reduce the large losses that have been revealed, the CEGB has written off some £3,000 million of old plant. That 'writing-off' provides the CEGB with another justification for investing in new nuclear plant.

6.0 In Appendix 3 of its 1980/81 *Annual Report*, the CEGB has for the first time introduced current cost accounting, its intention being to reflect fully 'the effects of inflation on replacement costs'. The CEGB recognises that: "In a period of relatively high inflation, allowance has to be made for the fact that the cost of replacing plant and equipment is increasing and the cost of using material from stock is not the price originally paid for it, but the higher price which usually has to be paid to replace it . . . The most significant aspect of the Board's approach to current cost accounting is the valuation of power stations. Their value is not related to their original cost but to the energy and power output of which they are now capable, to the energy cost of that output, and to the cost of replacing the output with new generating plant which, because of technological change, will not have the same characteristics. Consequently the Board, with the concurrence of its Auditors, has devised a method of calculating the value to the business of the total generating system in terms of 'Modern Equivalent Assets' . . ."[98]

As the Board points out in its report, the move to current accounting reveals a net loss after interest of £281 million during 1980/81: the loss during 1979/80, using the same accounting technique, was £287 million[99].

6.1 **The change from the CEGB's past accounting practice to current cost accounting has a dramatic effect on the figures. Thus, as Professor Jeffery shows, between March 31st 1980 and April 1st 1980 the overall losses shot up more than sixfold from £47 million prior to midnight to £287 million the next morning, (See Table 7).[100]**

6.2 According to the CEGB, their current cost accounting techniques 'whilst not a system of accounting for general inflation' allow 'for price changes specific to the business when reporting assets employed and profits thereon . . .'[101]

In fact, through not applying constant purchasing power accounting (and hence correcting fully for inflation), the CEGB is able to make the dramatic increases appear less than they are in reality. Jeffery calculates that, with full correction for inflation, the 200 to 600 per cent increases shown in Table 7 might be up to half as big again.

6.3 In its use of the Modern Equivalent Asset concept, the CEGB is able to minimise the net MEA value and hence the charge for depreciation. This the CEGB does by restricting the total capacity of plant recognised as having a positive value "to the total required for system operational purposes, i.e. 22 per cent above the demand expected to be met. Plant outside this total, likely in practice to be subject to early retirement or put into reserve, is considered to have zero value"[102]. In effect, the CEGB is writing off some 10 per cent of its generating capacity.

Jeffery is particularly critical of this aspect of the CEGB's current cost accounting. Not only is the CEGB casually writing off valuable publicly owned property but also the method of accounting provides the possibility 'for substituting new nuclear plant for effective and more economical older coal-fired plant, with no financial penalty to the CEGB for scrapping such older stations.'

6.4 Through applying the CEGB's criteria of what is an asset to the figures published in its 1980/81 *Annual Report*, Jeffery shows exactly how the Board has, on the one hand, written off plant without putting a value to it and, on the other hand, justified the immediate need to begin constructing nuclear power stations. His figures are shown in Table 8.

"Even supposing the 12.3 GW surplus to requirements is on average 75 per cent amortized," says Jeffery, "the remaining book value will be about 1000 x 12.3 x 0.25 = £3075 million (taking the present day value of a 1 GW station as about £1,000 million. It is dif-

ficult to understand how an accounting system can allow around £3,000 million of public assets to be written off without the auditors even commenting on it. It is even more difficult to understand how the Department of Energy can allow the premature retirement of coal-fired stations, almost all of which under similar load conditions can produce electricity whose Works Cost is less than the total cost of new nuclear stations built to replace them"[103].

Table 7: The Effect on the CEGB's Accounts of Switching from Historic to Current Cost Accounting. Figures in £ million.

	31/3/80	1/4/80	Increase %
Fixed Assets	4353	17785	409
Depreciation	303	577	190
Nuclear PS Initial Fuel	124	482	389
Generating Reserve	486	1955	402
Current Cost Reserve	0	12769	—
Loss	47	287	611

Table 8: The CEGB's Writing Off Of Capacity

	GW
Maximum system demand (MSD) forecast for 1982/3	44.8
22% more than MSD	54.7
Declared net capability (DNC) of all stations (1981)	56.7
Stations due for commissioning by 1983	10.3
Total DNC (1983)	67.0
Stations surplus to requirements, written off as of no value and closed or put into reserve: 67.0 — 54.7	12.3
Stations left operating (1983)	54.7
Forecast MSD in 1988/9 (at least)	49.0
28% more than MSD	62.7
Requirements for additional stations by 1988/9: 62.7 — 54.7	8.0

Conclusion: Seven new nuclear stations must be started by 1983.

Fuel Costs: Coal Stays Steady, Nuclear Rises

In justifying future investment in nuclear power, the CEGB claims that coal prices will rise rapidly in real terms over the next few years, while nuclear fuel costs will remain steady and even decline. Those assumptions are highly questionable. Present indications are that the reverse will be true.

7.0 A main plank of the CEGB's advocacy for nuclear power has been its supposed cheap fuel costs compared with those for coal-fired plants. Moreover, it has been claimed that, whereas nuclear fuel costs are unlikely to rise in real terms, coal costs will show a continuing real price increase. Thus, in its evidence to the House of Commons Select Committee on Energy and to the Monopolies and Mergers Commission, the CEGB stated that it expected the real price of National Coal Board (NCB) coal to increase by as much as 2 per cent per year over the next seven years until 1987/88[104]. In addition it expected that the Government grants to the coal industry would come to a stop during the 1980s and that, therefore, the NCB would be forced to achieve a measure of profitability[105]. Consequently, the CEGB expected that the pithead price of coal would be likely to rise by more than 4 per cent per year during those seven years[106]. From then on until the end of the century, coal prices were expected to rise by 2 per cent per year in real terms[107].

In its *1979/80 Development Review*, the CEGB expected imported coal to be as much as 5 per cent cheaper than the NCB pithead price[108]. A year later, it had changed its mind—stating that the falling value of the pound against the dollar could lead to a substantial price differential in favour of NCB coal by the turn of the century[109]. And, just to make life doubly difficult for itself, the CEGB anticipated that supplies of NCB coal would fall short of demand by the end of the century, thus forcing the electricity board to have to take in the more expensive imports. In its evidence to the Monopolies and Mergers Commission, the CEGB assumed that by 1986/87 the NCB would be able to provide it with no more than 70 million tonnes of coal compared with 78 million tonnes in 1979/80[110]. By the year 2000, according to the CEGB, the NCB's supply would have fallen to 55 million tonnes, whereas the CEGB's coal burn was expected to be 63 million tonnes[111]. The shortfall would have to be made up by imports.

One of the assumptions the CEGB made in its forecasting was that industry's demand for 'steam coal' would increase between now and the end of the century, thus absorbing a greater proportion of NCB supply[112]. In view of the continuing economic recession and the slump in industrial output, together with considerable technical improvements in the efficiency of use of energy, the CEGB's expectation of a growth in industrial demand for steam coal would seem to be off the mark.

As the Monopolies and Mergers Commission points out, "The Board's view on the future output of the NCB and availability of NCB coal are somewhat more pessimistic than those expressed by the Department of Energy, whom we consulted. The Department's last published projections give a range of United Kingdom coal output around the turn of the century of 137-155 million tonnes per annum. Since the projections were published in 1979, short term prospects for economic growth have worsened. This is likely to have at least some effect on the development of demand for coal and the level of supply required. The Department have also told us that, on current prospects, they do not expect the availability of coal to the CEGB from the NCB to be significantly less than the present volume up to the turn of the century"[113].

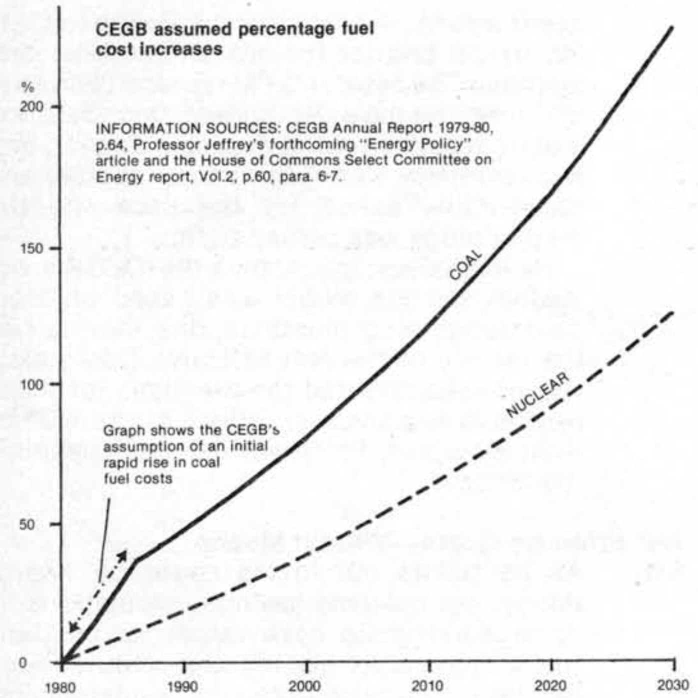
Coal—The Real Price Falls

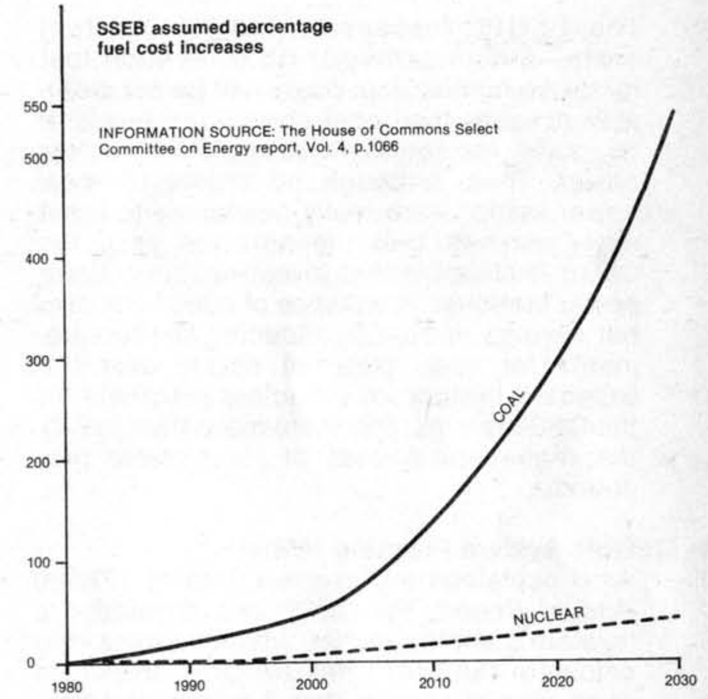
7.1 If forecasting is to have any value, then at least it must be seen to be accurate in the short-term. When forecasting in the short-term fails to match up with reality, then any decisions taken on long-term forecasting must be wholly suspect. The CEGB's forecasting of the short term increases in the price of coal has proved a gross overestimate. Instead of a five per cent real price increase per annum for NCB coal since 1979, the CEGB has found itself paying slightly less for its coal than the increase in the retail price index[114]. Thus in real terms, the cost of the CEGB's coal remained stable. In fact the CEGB has agreed to take 75 million tonnes of coal per annum for five years between 1980 and 1986 provided that coal prices to the CEGB remain constant in real terms.

Nuclear Fuel Costs Rising

7.2 But if coal prices in real terms have been remaining stationary in recent years, the same cannot be said of nuclear fuel costs which have more than doubled in real terms since 1975. And, as pointed out by the Monopolies and Mergers Commission, the escalation in nuclear fuel costs is by no means over[115]. Reprocessing costs in particular have been rising rapidly, and between 1975 and 1987 are expected to rise tenfold with a threefold increase from 1980-87.[116] According to the CEGB, Magnox reprocessing costs are likely to add 0.36 p/KWh on a discounted basis to present total fuel costs[117]. **Using Jeffery's calculation that reprocessing costs at present amount to 0.387 p/KWh, then that additional 0.36 p/KWh reprocessing cost will bring total reprocessing costs to 0.779 p/KWh in 1980 prices, 5 per cent greater than the CEGB's stated 'inclusive fuel costs' of 0.74 p/KWh in 1979/80[118].**

At such a rate of escalation Magnox fuel costs are fast approaching coal-fired fuel costs, and the rationale of nuclear power — that its high capital costs are offset by much cheaper fuel — no longer has substance to support it.

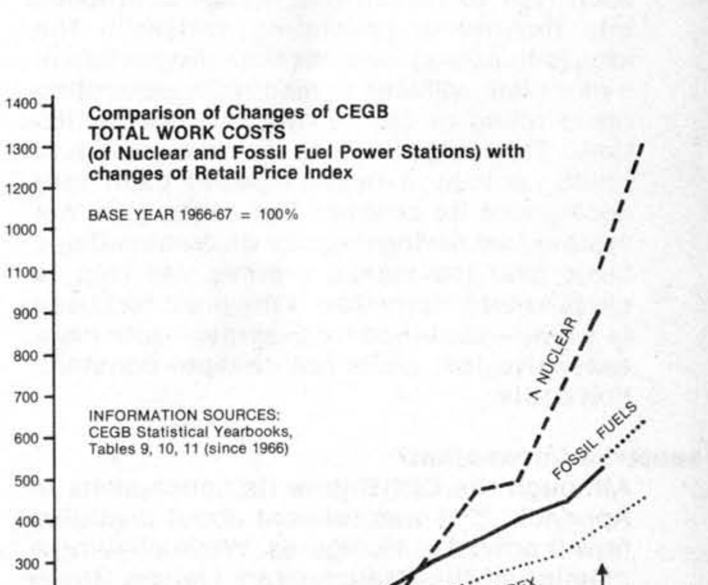




As the graphs demonstrate, the CEGB has based its case for nuclear power on rather different assumptions of future fuel costs for coal and nuclear than has the SSEB. Note that the scale indicating percentage increases in the two graphs differs by a factor of three.

In relative terms the total works costs of the CEGB's nuclear stations have escalated at a rate far higher than have the total works costs of coal-fired stations.

The provisions for reprocessing spent fuel have been largely responsible for the sudden change in nuclear's costs, beginning around 1974.



Net Effective Cost and the Rationale for Nuclear Power

The CEGB has presented a systems analysis of its generating plant, in which it calculates the "Net Effective Cost" of introducing new plant. The CEGB claims that the introduction of new nuclear plant will lead to electricty prices being cheaper in the future than if new coal-fired plant is built or old plant is refurbished.

8.0 The CEGB's assessment of future fuel costs—and in particular its contention that inclusive nuclear fuel costs will be considerably cheaper than coal costs—is critical to its plans for future investment in nuclear power. Thus, although no orders for new power stations are really necessary to meet likely demand over the next ten yars, the CEGB is claiming that investment in nuclear power stations "in advance of need" will give net savings in cost by reducing the requirements for coal. This net saving over the expected lifetime of a nuclear plant will, in the CEGB's eyes, therefore more than justify the high capital cost of its nuclear programme.

The CEGB's System Planning Model

8.1 As it explained in Appendix 3 of its 1979/80 *Annual Report*, the CEGB has developed a 'system planning model' which enables it to calculate the 'Net Effective Cost' (NEC) for each type of station that it might introduce into the overall generating system[119]. The idea is to assess whether the introduction of a new plant will lead to electricity generating costs rising or falling over the plant's lifetime. Thus a plant that is more costly to build, such as a nuclear power plant may because of its cheaper fuel costs give 'net system fuel savings' which on an annuitised basis over the plant's lifetime will lead to cheaper electricity than if the plant had been of a type—coal-fired for example—with more expensive fuel costs but cheaper construction costs.

Freedom of Information?

8.2 Although the CEGB gave its conclusions in Appendix 3, it was reticent about divulging how it arrived at its figures. While chairing a meeting of the Parliamentary Liaison Group for Alternative Energy Strategies during March 1980, Mr David Widdicombe QC asked the CEGB whether it would comply with requests from several members of the audience for more information on its Net Systems Savings planning model. The request was for the data that was being fed into the model and for the actual computer programme. The senior CEGB representatives at that meeting gave assurances that the information would be made available. In fact, Professor Jeffery who was at that meeting and specifically asked for the data and the methodology was denied both.

Nevertheless, given that the CEGB's net system savings model was based on standard accounting practices, and that he had the results of the Net Effective Cost calculations plus some of the premises for those results in Appendix 3, Table 4 of the 1979/80 *Annual Report*, Professor Jeffery unravelled the model.*

Net Effective Costs—What it Means

8.3 As he points out in his paper on *Energy Policy*, net systems savings calculations involve working out cash values for past and future payments (both expenditures and receipts) from the date of commissioning, since then outgoings start to be balanced by income. The cash values are called 'present values' and they are annuitised over the expected lifetime of the plant—25 years for a nuclear plant. Thus, the present value of a future payment is calculated through the notion of investing a sum at the present time which at *r* per cent compound interest will accumulate sufficiently to cover the cost *n* years in the future.

Likewise a 'present value' can be calculated for income. Comparisons between different sizes of plant can be made through dividing all payments by the design output of the station in kilowatts. The algebraic sum of all the present values gives the Net Effective Cost of the station in £/KW per annum. **A positive NEC indicates that constructing the station will involve an economic loss; a negative NEC indicates a likely profit**[120].

* *In the Real Costs of Nuclear Electricity in the UK,* Jeffery states that his calculations "have been checked and agreed with the CEGB."

8.4 In assessing the Net Effective Cost, the CEGB must account for:

a) *Capital costs and interest during construction.* Hence it must make a judgement on the likely duration of construction:

b) *The cost of decommissioning, dismantling and disposal of the station, net of scrap value if any.* Such costs are likely to be extended over more than 50 years for nuclear power plants, and an assessment at this stage cannot be more than guesswork since no large nuclear power station has yet been properly dismantled either in Britain or elsewhere (see para. 10.5).

c) *Fuel costs.* For a coal-fired station these occur during the year of use, but for a nuclear plant they are complicated by the need to fabricate the fuel elements and later to dispose properly of the radioactive waste products. Thus fuel elements may be manufactured some years before use in the reactor[121]. Radioactive waste products may not be disposed of in a final fashion for many decades, surveillance and maintenance of extremely expensive high activity waste tanks being essential in the meantime. In order for its planning technique to have any relevance to the future, the CEGB must make accurate judgements on the likely overall fuel costs of both nuclear and coal-fired stations. An underestimate of the total nuclear fuel cycle costs (including all the stages from procuring uranium from abroad to uranium enrichment, fuel fabrication, storage and reprocessing and ultimate waste disposal) and an exaggeration of coal costs over the next twenty to thirty years can alter the net effective cost of a station from one which indicates savings to one which indicates substantial losses. Since the capital investment of each new nuclear station is likely to exceed one billion pounds, the risk involved in getting the figures wrong is considerable.

d) *Direct operating costs, other than fuel costs, and encompassing repair and maintenance as well as other administrative costs.* Clearly a plant that operates with a high load factor during the year will have cheaper running costs per unit of output relative to one which is load-following.

The CEGB's Results

8.5 Table 4 of the CEGB's Appendix 3 compares the net effective cost of future nuclear and coal-fired stations at March 1980 prices[122]. The annuities, including fixed and variable costs, for a nuclear power station amount to £123/KW per annum: for a coal-fired station the figure is £159/KW per annum. Since both plants will displace less efficient plant, there will be considerable fuel savings—the assumption being that nuclear power with its higher load factor of 63 per cent will save considerably more fuel than coal-fired with its 54 per cent lifetime load factor. Thus the fuel savings for nuclear through displacing less efficient plant amount to £148/KW per annum and for coal-fired to £143/KW per annum. The Net Effective Cost for nuclear thus becomes £ − 25/KW and for coal-fired £ + 16/KW, meaning that there will be overall savings if the CEGB proceeds with investment in new nuclear plant while there will be losses (or heavier electricity bills) should it proceed with new coal-fired plant.

Sensitivity of the Model

8.6 The cost of coal, and the efficiency with which it will be used, have a considerable bearing on the net effective cost of nuclear power. In its 1980/81 *Development Review*, the CEGB estimates a range of Net Effective Costs should the coal price change up or down from its current central estimate of National Coal Board prices for the year 2000/01. The delivered price is then expected to be 216p/GJ[123]. The nuclear plant is taken to be an Advanced Gas Reactor with an NEC of − 18, and the coal-fired plant with an NEC of + 22. Should the marginal coal price be 40 per cent higher than forecast—the figure chosen by the CEGB—the NEC for the nuclear plant improves by − 26 £/KW per annum to become − 44 £/KW per annum. The coal-fired plant NEC also improves because the introduction of more efficient coal-fired plant leads to a reduction in the amount of coal burnt. By the same token, should coal-fired fuel prices be lower, the NECs of both coal-fired and nuclear plant deteriorate. Thus, a 15 per cent lower marginal coal price than that forecast takes the nuclear NEC from − 26 to + 3 and increases the coal-fired NEC by three points to + 25 £/KW per annum[124].

8.7 The electricity consumer might be forgiven for welcoming lower than forecast coal prices. But, according to the model, if the CEGB had gone ahead with its programme for constructing new power plants — be they nuclear or coal — then there would be less net savings than there might have been had coal costs remained high. With lower than forecast coal prices, the CEGB's calculations make it clear that it would have been better not to have proceeded with such constructions. Thus, should the CEGB get its coal price forecasting wrong and exaggerate it, the justification for its construction programme would evaporate.

8.8 As pointed out (paras 7.0-7.2), the CEGB's premise in carrying out its NEC calculation is that nuclear fuel costs will remain low—at worst keeping abreast of inflation but not rising in real terms. That premise is critical. The whole exercise is undermined if, as Jeffery argues, nuclear fuel costs are rising in real terms. Indeed using his figures, nuclear fuel costs at 1.17 p/KWh are not much less than coal fuel costs at 1.29 p/KWh (1979/80 prices).

The Validity of the Assumption

8.9 The CEGB's planning system would be a valid technique as long as the figures fed into the model were reasonable assumptions. In fact, the robustness of the conclusions of net effective cost calculations are entirely a product of the data fed in. As the Monopolies and Mergers Commission points out, the CEGB's case for nuclear power rests very largely on extravagant hopes for the future[125,126].

Thus, the CEGB expects to achieve the construction of its nuclear power plants on schedule—that is within six years from start to finish. If the CEGB can construct its power stations within that time-schedule it will obviously keep the fixed costs down.

Yet the CEGB's construction record has hardly been a happy one. The first four AGRs were scheduled to take 72 months each to construct, but the average expected construction overrun on each of the four stations is 85 months, giving a total of 157 months—more than double that planned for[127,128].

The CEGB's record for building the first group of large coal-fired plants is considerably better, the average delay being 27 months for each—thus giving a total construction time of around 100 months[129].

The CEGB has assessed the effect of time overruns on Net Effective Cost. Thus a two year delay in commissioning—bringing the total construction time to 8 years—takes the NEC of −18 £/KW per annum for an AGR up to −5 £/KW per annum[130]. A fifteen per cent increase in cost over that anticipated, in addition to the two year delay, makes the NEC positive at +7 £/KW per annum[131]. Under similar circumstances, the NEC for coal-fired plant increases from +22 to +32[132]. Thus a nuclear plant is more than two and a half times as sensitive to a construction delay as a coal-fired station. Consequently, the seven year average time overrun on the first four AGRs must have had a devastating effect on their net effective costs. Undoubtedly the CEGB will have difficulty recouping the costs of such plants.

Indeed it will be the Board's coal-fired stations—which at present generate 80 per cent of the Board's electricity[133]—that will have to absorb those extra costs, and the electricity consumer who will have to pay for them.

The Effect of Load Factor and Availability

8.10 In Appendix 3, Table 4 of its 1979/80 *Annual Report*, the CEGB gave its future nuclear plant an average lifetime load factor of 63 per cent and the coal-fired plant one of 54 per cent[134]. Yet the figures for nuclear plants are optimistic, especially in the light of the actual performances of the CEGB's Magnox reactors. Thus, as we have seen, the CEGB has had difficulty keeping its Magnox reactors running at 70 per cent of a derating which on average is 25 per cent less than the original design output (see Table 2).

Large coal-fired plants have also had to be derated, the average for the CEGB's seven stations amounting to a total of some 3 per cent[135]. In its 1979/80 *Development Review*, the CEGB assumed that its first four AGRs would achieve no more than 80 per cent of their design rating[136]. In the same *Review*, however, the CEGB considered the possibility that the AGRs may not achieve more than 50 per cent of their original design rating—a performance that will undoubtedly put up their generating costs still further[137].

The average availability of generating plant tends to be less than the current rating. In its evidence to the Monopolies and Mergers Commission, the CEGB told that it had altered estimates of annual average availabilities in preparing Net Effective Cost calculations for its 1980/81 *Development Review*[138]. Thus it reduced the annual average availabilities from 68 per cent to 66 per cent for AGRs and from 67 per cent to 64 per cent for PWRs[139]. The reason for reducing the availabilities of AGR plant came about because of difficulties in achieving on-load refuelling[140]. The 68 per cent annual average availability was based on the CEGB managing to achieve 30 per cent on-load refuelling[141].

Nuclear plant is far more sensitive to derating and poorer availability in economic terms than is coal-fired plant. Thus a 10 per cent derating will bring nuclear's net effective cost up 9 points to −9 £/KW per annum[142]. A loss of three percentage points on average availability, in addition to the derating and an expectation that it will take four years to bring the plant to full power on current rating, will bring the NEC to −2 £/KW per annum[143].

Reinterpreting Net Effective Costs

Realistic assumptions on likely construction times of nuclear plant, and on nuclear fuel and coal fuel costs, indicate that the building of a single 1.5 GW nuclear plant will lead to a loss of £2,000 million over the cost of buildings and running a new coal-fired plant. For the cheapest electricity, the CEGB should maintain and refurbish coal-fired plant that would be prematurely retired should the nuclear programme go ahead.

9.0 The CEGB's evidence to the Monopolies and Mergers Commission exposed the sensitivity of its Net System Planning model to its underlying assumptions[144]. Indeed, in its 1980/81 *Annual Report*, the CEGB made no further reference to Net Effective Cost calculations[145]. Perhaps the discarding of such calculations indicates the CEGB's awareness that the economic advantages of nuclear power do not stand up to close scrutiny.

Professor Jeffery, having unravelled the CEGB's Net System Planning model and broadly determined its assumptions, has re-analysed the CEGB's projections using assumptions that are more in keeping with current events and likely trends, as well as with the CEGB's past record.

Jeffery's results indicate that nuclear generated electricity will be 35 to 53 per cent more expensive than that generated by modern coal-fired stations. Moreover, both the modern nuclear and the modern coal-fired stations will produce electricity at a much higher cost than the 1.63 p/KWh fuel cost of the existing coal-fired stations that will be displaced[146].

The CEGB's Assumptions

9.1 From the CEGB's 1979/80 *Annual Report* Jeffery has deduced that the hypothetical nuclear power station on which the CEGB's Net Effective Cost calculations are based will be commissioned in 1986/87; that the nuclear fuel costs, after including 0.072 p/KWh for initial fuel, will amount to 0.50 p/KWh; and that other operating costs are similar to those of Hinkley Point B in 1979/80 (corrected to 63 per cent load factor and March 1980 prices)[147]. After 1986/87, the total costs for fuel follow those specified for 1990/91 and 2000/01 in the CEGB's evidence to the House of Commons Select Committee on Energy with some increases in 'other costs'. Similarly for coal, the costs are those specified by the CEGB in its evidence to the Select Committee with the addition of 0.06 p/KWh for handling charges[148]. After 2000, coal costs too remain constant. Jeffery also deduces that cost overruns of nuclear plant will be limited to 17.5 per cent, although the CEGB admitted to the Monopolies and Mergers Commission that such an assumption was 'a conscious underestimate'[149].

9.2 Professor Jeffery estimated that the CEGB had assumed a 29 per cent thermal efficiency for the coal-fired plant to be replaced by nuclear plant. Given that the CEGB anticipates that coal costs will increase by 36 per cent from 1980 to 1986/87, the coal fuel cost of the coal-fired plant displaced will be 2.22 p/KWh.

Injecting Realism into the Model

9.3 Having got the basis of the CEGB's Net Effective Cost calculations, Professor Jeffery is able to substitute the CEGB's figures with others that are more likely to prevail over the next decade and even longer. Thus, instead of assuming an increase in coal costs of 36 per cent in real terms over the next few years, Jeffery assumes that coal costs remain stable in real terms, at their 1980 level, from 1980 to 1986/87. Since coal costs have in fact remained stable for the past two years, such an assumption is not a particularly bold one.

On that basis, the Net Effective Cost of nuclear plant swings from £ − 25/KW per annum to £ + 31.5/KW per annum, a total reversal.

9.4 The CEGB's assumptions on nuclear fuel costs are as dubious, if not more so, than those on coal. **Thus, whereas real nuclear fuel costs more than doubled between 1973 and 1980, the CEGB has assumed for its Net Effective Cost calculations that nuclear fuel costs will be almost exactly *half* those for 1979/80 for all nuclear stations and only 85 per cent of the cost attributed to Hinkley Point B in 1979/80[150].**

The CEGB undoubtedly hopes that the cost of reprocessing irradiated AGR fuel will prove cheaper than it has for Magnox fuel. But that hope is little more than an act of faith: in France, which has more experience of reprocessing thermal oxide irradiated fuel, the price has been escalating rapidly. As yet no industrial plant for reprocessing thermal oxide fuel exists in the world. In France, the official figure for such reprocessing has been put at more than £360 per kilogram (1981 prices) and therefore similar to the figure used in the UK: unofficial but well informed sources, however, expect thermal oxide reprocessing to cost at least £600 per kilogram—and maybe as much as £1000 per kilogram.

From the CEGB figures available to him, Professor Jeffery has attempted to calculate the real cost of nuclear fuel, choosing the AGR at Hinkley Point as a likely example. His assessment of all the fuel cost ingredients (in March 1980 figures) comes to 1.05 p/KWh[151].

In view of the major changes now taking place in the design of British Nuclear Fuel's Thermal Oxide Reprocessing Plant—the consequence of unforseen technical problems and a drop in demand for reprocessing[152] —Professor Jeffery is in agreement with French opinion that reprocessing thermal oxide fuel will cost at least double that anticipated by the CEGB. That doubling of reprocessing costs will add 0.226 p/KWh to the AGR fuel costs, thus bringing total nuclear fuel costs up to 1.28 p/KWh[153].

Nuclear Power: An Economic Disaster?

9.5 To make a more realistic comparison with a coal-fired station and a more probable Net Effective Cost calculation for a nuclear station, Jeffery assumes:

a) Cost overruns on construction will amount to 30 per cent:
b) Real coal costs will remain at March 1980 levels until 1986/87, increasing at 2 per cent per annum to the end of the century and then remaining constant:
c) A real nuclear fuel cost of 1.28 p/KWh in 1986/87, increasing at 2 per cent per annum until 2000 and remaining constant thereafter.

9.6 Such assumptions lead to a generation cost of 3.27 p/KWh for nuclear and 2.34 p/KWh for coal. Meanwhile, the Net Effective Cost calculation for a nuclear plant under such circumstances comes out at £+88/KW per annum, a dramatic change from the £−25/KW per annum published by the CEGB. Thus to build a 1.5 GW nuclear station on that basis would create a present value loss of nearly £2000 million.

We contend that, on the above economic grounds alone, it would be an act of irresponsible folly for the CEGB to build one such station, let alone the ten proposed by the Government.

Table 9: Comparison of the assumptions used to calculate the NEC's of nuclear and coal fired power stations commissioned in 1986-7 for calculations performed in 1979-80(1)

	CEGB	JWJ
Capital cost and Construction time(2)	Stations built to time and cost	30% cost overun
Interest rate(3)	5%	5%
Load Factor(4) : nuclear Coal Factor(5) : coal	63% 54% Real increase of 36% by date of commissioning and at 2% per annum thereafter.	63% 63% No real increase to date of commissioning and at 2% per annum thereafter.
Nuclear Costs(6)	15% less at date of commissioning than at date of calculation, then increase at 2% per annum.	Inflation corrected present cost of Hinkley Pt. B and estimated increase in real cost of reprocessing at date of commissioning and then increase at 2% per annum.
Life Times(7) : nuclear coal	25 years 30 years	25 years 30 years

Notes

1. Specifically the nuclear station is taken to be an AGR. Present indications are that PWR costs will be higher.
2. Typically £1000/KW and 6 years.
3. Given by the Treasury. Also known as the Test Discount Rate.
4. Unit cost fall as Load Factor rises. Thus fair comparison needs the same Load Factor for both types. In effect these are Load Factors on Design Output. Experience shows derating effects nuclear stations more than coal stations. LFDO falls with derating.
5. Coal costs have hardly risen in real terms since 1975. The understanding between the CEGB and NCB is that there will be no increase at all between 1980 and 1985.
6. Real costs have more than doubled since 1975. Because nuclear fuel costs comprise past and future expenditure inflation correction and estimates of future real cost increases are essential.
7. Coal station lifetimes have recently been extended to forty years.

Other Considerations

When such unknown costs as the true price of decommissioning nuclear stations or burying their waste are taken into account, nuclear power's future becomes bankrupt.

10.0 Much of the data and conclusions we have presented in the report has so far been based on information provided by the CEGB, whether in its annual reports, or in evidence to the House of Commons Select Committees, and more recently to the Monopolies and Mergers Commission. In interpreting those official figures and statements we have employed straightforward, unprejudiced methods, such as the use of the retail price index to indicate the effects of inflation on historic costs. Any extrapolations into the future, particularly of fuel costs, have been based on reasonable, indeed conservative assumptions, in accordance with evidence given both to the House of Commons Select Committee on Energy and to the Monopolies and Mergers Commission. We claim that our conclusions are therefore those to which anyone could come, who had recourse to the same background material.

10.1 Until now we have left out of the discussion a number of other considerations, which although extremely important in any evaluation of the pros and cons of nuclear power, are far more difficult to evaluate in terms of cost.

As we have pointed out, the generating costs of nuclear power stations in the U.K., based on conventional criteria are, and have always been greater than those of contemporary coal-fired plant. Add to those costs of nuclear power the costs of ensuring that obsolete plants are properly dismantled; that environmental contamination with the radioactive wastes is kept to an acceptable minimum; that adequate steps are taken to ensure that accidents involving major releases of radioactivity are avoided; that full insurance costs are taken into account, then clearly nuclear power becomes wholly uneconomic.

Pollution Control

10.2 Comparisons of the costs of different electricity generating systems must take into account the pollution caused by each and the cost of pollution control. Because of the potency of radioactive wastes, the operators of nuclear installations have had no other choice but to aim for complete containment of the products of the nuclear fuel cycle, and to minimise gamma and neutron radiation emissions into the working environment. Nevertheless total containment is impossible to achieve in practical terms, and certain wastes are released routinely into the environment from nuclear installations.

The uranium mine is another, major source of environmental contamination, particularly of radium and its decay products. Britain, through having no uranium mining of its own as yet, is fortunate in avoiding such hazards.

The reprocessing of spent reactor fuel, to extract uranium and plutonium, is by far the largest radioactive polluter of the environment in Britain.

Increasing concern over the quantities of radionuclides discharged from Windscale — for example a hundredfold increase in caesium-137 between 1961 and 1977 — has led to BNFL refurbishing its Magnox reprocessing plant at Windscale at a cost of over £1 billion[154]. As a consequence the cost of reprocessing Magnox fuel is likely to increase several fold, as we have seen, (para 5.11) and that does not include paying for the backlog of spent Magnox fuel that is awaiting reprocessing. Meanwhile, the reprocessing of thermal oxide fuel has never been successfully achieved on an industrial scale anywhere in the world. Apparent problems with the design of the new thermal oxide reprocessing plant at Windscale (THORP) and of equivalent plants in France, indicate that such reprocessing technology has yet to be mastered[155].

Reprocessing and the Fast Reactor

10.3 Fast reactor fuel has to be reprocessed for the large quantities of plutonium that pass through the system. The rationale of the system is to use uranium-238 — the most ubiquitous isotope of uranium — and hence to increase the potential energy of uranium sources by at least 60 fold. Indeed some 20,000 tonnes of depleted uranium — the uranium high in uranium-238 after enrichment — stand in rusting containers outside BNFL's Capenhurst enrichment plant in Cheshire. The promise of the energy in those containers has given rise to enthusiastic support for the fast reactor.

Fast reactor fuel, with its high burn-up — some three times higher than PWR fuel and 20 times higher than Magnox fuel — is likely to prove even more troublesome to process than thermal oxide fuel. Aside from dangers of criticality owing to the large quantities of plutonium passing through the system — one GW fast reactor requires some 4 tonnes of plutonium as fuel — one of the greatest headaches associated with reprocessing is the perpetual loss of plutonium into all the various waste streams. Those losses of plutonium are assessed at anywhere between 0.5 per cent and 12 per cent, and for fuel reprocessed to date are more likely to lie somewhere between 4 and 6 per cent. A six per cent loss of plutonium from fast reactor fuel would stretch the doubling time for plutonium breeding into infinity; hence every fast reactor would be dependent on thermal reactors for its initial fuel inventory. Since it takes some 20 years of light water reactor operation to produce the plutonium necessary for starting-up a fast reactor, the question arises whether sufficient reasonably high-grade resources of uranium exist in the world for establishing an all-embracing fast reactor programme[156].

Indeed, assessments of total world recoverable reserves of uranium put the energy yield obtainable from thermal reactors at no more than one-fifth of that in remaining reserves of petroleum. With that perspective in mind, the energy left in the depleted uranium outside Capenhurst has more the qualities of 'will-o-the-wisp' than future power for sustaining the industrial world.

Vitrification

10.4 Reprocessing gives rise to high activity wastes that are kept in solution in continuously stirred and cooled stainless steel tanks. Clearly such tanks have a limited life, and the pressing problem is what to do with the contents.

Vitrification, and then burial of the resulting glass blocks, has been up until now the nuclear industry's proposal, yet uncertainties remain whether the glass blocks will stand up to centuries of irradation and the relatively high temperatures generated through radioactive decay. Even the technology of vitrification is in doubt, and Britain, after years of research into the 'Harvest' method has abandoned it for the French AVM method developed at Marcoule. That method has its critics in France.

Meanwhile even greater doubts exist concerning the burial of the vitrified wastes in 'geologically sound' deposits. Popular resistance to such burial is fogging the issue even more, but it demonstrates public apprehension at the notion of using the environment as a radioactive waste dump.

Decommissioning

10.5 Although the CEGB has been operating its Magnox stations since the early 1960s, it only began making financial provision for decommissioning those plants since April 1976[157]. In 1978/79 the CEGB set £20 million aside to cover all its nine stations (including Hinkley Point B) but increased the sum to £30 million in 1980/81. The Board itself admists to uncertainty in estimating "the long term costs associated with decommissioning", but nevertheless believes the costs will be no more than a few percentage points in real terms of the total construction costs.

No large commercial reactors have yet been dismantled, consequently there is a large element of guesswork in estimating the likely costs of complete demolition of a nuclear station.

A small, 20 MW, boiling water reactor at Elk River in Minnesota, was completely dismantled after four years of operation, as was the Sodium Reactor Experiment Facility near Los Angeles. **In both instances the cost of dismantling approached one quarter of the original costs of construction — adjusted for inflation. Large reactors are not simply bigger than those small reactors; their containment structures are much thicker, moreover they will presumably have operated for at least 20 years and hence will be far more radioactive. It would be surprising therefore if their dismantling costs would be proportionately any less.**

Nevertheless, in the United States, General Public Utilities carried out a study on the likely decommissioning costs of its Three Mile Island units. That 1978 assessment — prior to the accident at Unit 2 — indicated that the costs were likely to be \$125/KW in 1979 dollars — an amount which the United States Department of Energy found to be "representative of the most current dismantlement assessments"[158].

To estimate a figure that he considers more realistic, Komanoff applies a one per cent real cost escalation from 1979 to 1988 to the \$125/KW decommissioning figure, and then holds the cost steady in real terms. Assuming that the reactor has a lifetime load factor of 60 per cent, and applying an 8 per cent fixed charge rate — thus 2.3 per cent points lower than the rate applied to nuclear capital costs — Komanoff finds that the projected decommissioning cost comes to 2.1 mills/KWh — "slightly less than 4.5 per cent of total projected nuclear generating costs of new plants."

Komanoff's results indicate that decommissioning costs fall within acceptable limits. Time will tell whether the basis of those figures is largely correct. **In the meantime the cost of decontaminating the Three Mile Island No. 2 reactor as a consequence of the 1979 accident, is running into figures that in real terms are comparable to those of constructing a brand new reactor. The present estimate is that more than one billion dollars will be required.**

Coal-burning — Pollution Problems

10.6 Coal-burning gives rise to pollution problems of its own, and it is reasonable to expect that any coal-burning by the electricity board should be made to comply with rigorous standards of pollution control. In the United States, increasingly stringent standards are being introduced, and according to Komanoff in *Power Plant Cost Escalation,* coal-fired plants built in 1988 will emit less than 10 per cent of the main pollutants — sulphur dioxide, particulates and nitrogen oxides — compared with plants completed in 1971. Already plants being built today in the United States have to comply with significantly more rigorous standards than those built in 1978. Moreover, unlike nuclear plants where doubts always remain whether increasingly stringent safety standards will guarantee reactor safety, the new pollution-control standards applied to coal-fired plants take effect immediately.

The result of all the improvements in the emission of pollutants from a coal-fired plant "to a level cleaner than existing plants burning low sulphur oil would", says Komanoff, "enable utilities significantly to expand coal-generated electricity without exacerbating acid rain and most other emission-related effects of burning coal[159]."

Comparative Costs of Improving Safety and Emissions: Nuclear and Coal-Fired Plant

10.7 Improvements in reactor safety that have been deemed necessary in the light of operating experience in the United States, have led to the capital costs of nuclear plants rising 142 per cent in real terms between 1971 and 1978. That escalation in cost therefore took place before the accident at Three Mile Island. During the same period, average capital costs for coal-fired plant increased by 66 per cent — "less than half the percentage cost increase for nuclear plants."

Komanoff concludes that new nuclear plants coming into operation in the United States in the late 1980s are likely to cost at least 75 per cent more to construct than new coal plants with advanced pollution control. Consequently electricity generated from the reactors will cost at least 25 per cent more than power from new coal plants.

The Case for a PWR in Britain

10.8 Komanoff's study of the cost escalation for power plants cannot be ignored in Britain. On the contrary, it appears that certain bodies — namely the Nuclear Installation Inspectorate and the CEGB itself — are concerned that the radiation exposure to PWR operators in the United States, are too high for British standards. Thus a reactor operator in the United States typically receives 10 times more radiation than his counterpart in Britian operating a Magnox. The aim appears to bring operating exposures in a British PWR to one half those of present American PWRs Growing concern that a British PWR might cost as much, if not more than an AGR, led to Walter Marshall, chairman of the UKAEA, being appointed in mid 1981 as head of a task force to resolve differences between the Atomic Energy, the National Nuclear Corporation, the CEGB and the Nuclear Installations Inspectorate. The hope is that the different parties will settle on a design that, as well as being considerably cheaper to build than an AGR, will satisfy the Inspectorate's and the CEGB's safety demands. Whether such hopes can be fulfilled is by no means certain.

Actual Performance of Light Water Reactors

10.9 In general, the performance of light water reactors in operation in the Western world is extremely poor, especially of the more recent, large reactors. Thus in the United States — which has the greatest experience in terms of reactor-years of operation — the 62 licensed commercial-size reactors (over 400 MW capacity) had a cumulative average load factor of 60 per cent. Out of the 62 reactors, 39 were large plants, over 800 MW; their performance was by far the worst, and their load factors averaged only 51 per cent between January 1979 to mid 1968[160].

Since load factors of 80 per cent were envisaged for light water reactors in the early 1970s, the poorer performance has led to generating costs being at least 25 per cent worse than bargained for.

In France, the PWRs are working marginally better than the comparably large US plants, having load factors close to 55 per cent. Japan has 21 nuclear plants with a total generating capacity of 15 GW, the Japanese government planning to double nuclear generating capacity by 1985 and triple it by 1990. The performance of its present reactors and public opposition are likely to make this very difficult. Japanese experience with nuclear power has been dismal; indeed the reactors have been plagued by accidents and the load factors on average have been extremely poor. Thus the average load factor of light water reactors is below 54 per cent, and appears to decrease as the reactors age. The average load factor for reactors that have been in operation for more than three years is 41 per cent, and for reactors in operation more than seven years is only 26.7 per cent.

The poor performance of large light water reactors should be giving the CEGB second thoughts at introducing the PWR into this country. The likely cost escalation should be another reason. Indeed even Komanoff's estimate that a PWR of the lates 1980s might cost $1,400/KW (1980 dollars) to build has already been far exceeded in Washington State where five 1200 MW reactors have been under construction. There the costs of the five plants have escalated from a 1976 estimate of $6.67 billion — thus $1,100/KW — to $23.9 billion in mid-1981. The cost in today's prices is therefore just under \$4,000/KW, and, by anyone's standards, astronomical. In order to cut losses, the owners, the Washington Public Power Supply System, have been advised to put two of the plants 'into mothballs' and accordingly the reactor vessels have been enshrouded in plastic.[161, 162]

Meanwhile construction errors at the new Diablo Canyon power station in California have held up licensing, and doubt remains whether the plant will ever come on stream.

PWR safety

10.10 The intregity of the pressure vessel of light water reactors, and in particular of PWRs, is essential if major accidents are to be avoided. Controversy over cracks in the pressure vessel and coolant legs of the reactor has not been resolved; although such lack of resolution has not stopped EDF in France from operating PWRs known to have cracks both in the reactor vessel and in the heat exchanger plates of the primary coolant circuit. Recent evidence from the United States suggests that the steel used in making the pressure vessel and other essential components of the reactor is becoming brittle through irradiation. According to the US Nuclear Regulatory Commission some plants may become unsafe to operate within a year[163].

Insurance

10.11 Accidents to nuclear installations can cause devastation on a hitherto unknown scale, and not surprisingly commercial insurance companies do not have the financial resources to take on the comprehensive cover of nuclear power stations. In the United States, in order that the electricity utilities would accept the risk of building civilian nuclear reactors, an act was passed in 1957 — the Price Anderson Act — which committed the Federal Government to providing the bulk of the cover in the event of an accident. The act set an absolute ceiling of \$560 million on the damages which could be recovered after a nuclear accident; out of that the private utilities would have to be responsible for \$60 million and the federal government, the remaining \$500 million.

The Price Anderson Act was updated in 1975, with private utilities having to pay a great contribution. Thus, in 1977, the utility carried insurance up to \$140 million; should there be a major accident, then each utility that operated nuclear reactors would have to pay a retrospective premium of \$5 million per plant. Any shortfall below \$560 million would again be made up by the government: thus the ceiling had remained the same.

In fact the Rasmussen Reactor Safety Study of 1975 concluded that a reactor accident could cause \$14 billion in property damage alone. The deaths and injuries from a major accident would run into the hundreds of thousands. The Rasmussen study was criticised by a number of scientists for underestimating the risk of accident and the final toll of damage. Nevertheless it is clear that the total insurance cover is a pittance of that which would be required. Indeed the Three Mile Accident, which apparently caused no deaths and damaged no property outside the plant, will cost at least one billion dollars.

In Britain, under the 1965 Nuclear Installations Act, the operators of nuclear plant are required to pay up to £5 million damages per plant. Should claims exceed that sum then the government is expected to step in with total compensation up to £50 million. That sum could well be wholly inadequate.

Future Uncertainties

10.12 One of the most persistently voiced reasons for Britain having nuclear power is to make up for the shortfall in energy supplies that is expected sometime around the turn of the century when petroleum and natural gas supplies begin to dwindle. Meanwhile conventional thinking has it that growth in gross national product will continue to take place and will demand proportionate growth in overall energy demand. Thus nuclear power will substitute for oil and natural gas and will fill the forecast 'energy gap'.

The Department of Energy's forecasts have been classics of their kind in foreseeing energy gaps and in creating the apparent need for a massive substitution of conventional energy sources with nuclear power. For example, in its 1978 *Energy Commission Paper (5),* the Department of Energy saw total electricity demand doubling by the turn of the century. Thus, the Department considered that electricity would make inroads into areas that traditionally had been served by other 'primary fuels'.

In 1982, such forecasts of growth in energy demand and in particular of electricity demand, seem most unlikely. Primary energy demand has not yet regained its high of 353 millions of tons of coal equivalent (m.t.c.e.) of 1973. In 1980, primary energy demand was some 25 m.t.c.e. down from 1973, and the demand for energy has fallen still further. At the same time the efficiency of energy use has marginally improved—a greater quantity of GNP being generated for a given quantity of energy.

Various independent assessors of the energy scene, and in particular Gerald Leach's group at the International Institute of Environment and Development (IIED), believe that energy efficiency can be carried much further by introducing a range of energy-saving techniques. Smaller, lightweight cars for example, could consume half the petroleum they do today; meanwhile in the home, proper insulation combined with heat pumps could reduce domestic demands for energy considerably[164].

Other groups have gone further than the IIED by emphasising the potential of the renewable energy sources. The Centre for Alternative Technology, for example, suggests that delivered energy supply can remain as it is, but that the contribution of electricity falls to less than a third of its present value. Instead greater use is made of heat recycling, solar heating and heat pumps. Meanwhile the Friends of the Earth have combined the approaches of both the IIED group and the Centre for Alternative Technology. Thus, Friends of the Earth pushes both energy conservation and the renewables in reaching a figure of primary energy demand that is under half its level today.

Energy Conservation

10.13 In Britain, the Association for the Conservation of Energy has estimated that a comprehensive programme for improving the thermal characteristics of housing at a rate of half a million homes per year, could lead to a three per cent saving in UK primary energy demand. Furthermore per £1 investment, the householder would get a three to seven fold better energy return on draught proofing and insulating his house than he would in paying for the electricity (via nuclear generation) to keep his still draughty house warm.

At present Britain does not need to increase its supplies of energy. It has vast coal reserves, and we are faced today with the greatest world oil glut in history. At the same time, Britain is undergoing a substantial decline in industrial output. The question thus arises whether, during a period when Britain has such a large electricity overcapacity, we should be contemplating the spending of £15 billion on nuclear power stations? Moreover if such capital were spent it would undoubtedly limit the output of production and employment. As the Monopolies and Mergers Commission remarks: **"A large programme of investment in nuclear power stations, which would greatly increase the capital employed for a given level of output, is proposed on the basis of investment appraisals which are seriously defective and liable to mislead. We conclude that the Board's course of conduct in this regard operates against the public interest."**[165]

Power plant size

10.14 Except for its gas turbine plants, the CEGB has opted for large power stations with multiple 660 MW generating sets. Such large plants are certainly required for nuclear power stations because of the savings that can be obtained through having a large production of power within a single containment structure. It has not been shown that such economies of scale prevail for other systems of electricity generation. Thus, as Michael Prior points out "Relatively small (say 200 MW) coal-fired units, possibly using combined-cycle systems, utilising waste heat, and installed in refurbished urban sites may have a lot more going for them than is currently acknowledged by the supply authorities[166]." An additional advantage is that they could be mass-produced which would considerably reduce their cost.

Also, the pressurised fluidised-bed coal-fired plant has not yet been developed for commercial use in Britain. Yet when it does reach the point of being exploited, it may well be that it will function better in combination with small generating sets than the 660 MW sets currently used by the CEGB.

An electricity generating system that employs a large number of small units rather than a small number of large units is in fact less sensitive to breakdowns in plant, inasfar as a small proportion of generating capacity is lost at any one time. The size of generating sets therefore dictates the amount of reserve margin that the generating boards need to keep on hand. By the same token, the use of smaller generating plant means that planning margins can be brought down considerably.

10.15 **All these considerations are of utmost relevance in calculating the real medium to long-term economics of nuclear electricity. Indeed if one takes them into account, rather than choosing to ignore them because they cannot immediately be translated into the quantitative language of accountancy, then electricity derived from nuclear power will be seen to be prohibitively expensive. Some 142,000 people had their electricity cut off in 1977 because they could not pay their electricity bills. How many one wonders will have the like done to them in the year 2000, if the nuclear lobby is allowed to have its way?**

Conclusions and Recommendations

11.0 Nuclear power is totally uneconomic. Each 1.5 GW power station built will cost the electricity consumer £2,000 million pounds more than the cost of building and operating an equivalent coal-fired power station for the same period of time. To arrive at this figure, only a few of the relevant factors have been taken into account — those that are quantifiable today.

If other factors, that are equally relevant but more difficult to quantify (see paras 10.0 to 10.15) are taken into account, this figure might have to be increased very significantly, perhaps even by several times.

11.1 If our calculations are correct, and our conclusion justified then the following recommendations are inescapable:

11.2 The Government should reverse its decision of December 1979 regarding the construction of 15 GW of nuclear generating plant.

11.3 Work should stop on the two AGRs (Heysham and Torness) at present under construction, since the capital invested so far in these undertakings is paltry in comparison to the money these plants would lose were they to operate for their expected lifetime (see 9.0-9.6).

11.4 The CEGB's massive programme of prematurely decommissioning still serviceable coal-fired power stations should be stopped forthwith. Instead, the CEGB should embark on a programme of systematically refurbishing and modernising such plant whenever necessary (see 10.14-10.15).

11.5 The huge waste of energy and in particular electricity, both at a domestic and industrial level — that has so far been encouraged by the CEGB so as to expand the demand for its services — should be eliminated. An appropriate body should be set up to organise, for this purpose, a massive nationwide campaign of energy, and in particular electricity, conservation. If this is properly done, it should, as we have seen, reduce by at least a factor of two the electricity generating requirements in this country — with immense savings to the electricity consumer.

11.6 The CEGB should embark forthwith on a programme of Research and Development aimed at making available a range of small coal-fired power stations having the following principal features:

a. They should be equipped with latest anti-pollution control devices. The fluidised bed system should be thoroughly investigated as it may provide the most effective means of reducing SO_2 emissions to a minimum.

b. They should be designed to provide combined heat and power for neighbourhood heating when possible, thereby making full use of heat energy, which, a present, is simply released into the environment.

c. They should be small, and maximum standardisation should be achieved so as to bring down the cost to a minimum, and to minimise the lead-time between ordering and commissioning. This way, generating capacity would be quickly and cheaply adjustable to the large fluctuations in electricity demand that can be expected in the age of uncertainty in which we now live.

11.7 The CEGB should give greater consideration to the development and use of renewable energy resources i.e. sun, wind and waves — whose potential is probably greater than is generally accepted. In that respect the CEGB must be commended for proceeding with the construction of a prototype windmill in Camarthen Bay. The prototype is to be followed by the construction of larger windmills of megawatt size, on other sites.

11.8 Those appointed to the Board of the CEGB should be chosen for their wide experience of public affairs. Technicians who have spent most of their professional lives in the electricity generating industry should be a small minority on the Board. Electricity supply is too important for our national well-being to be under the control of bigotted specialists.

11.9 The Select Committee on Energy should be properly financed so that it may engage the necessary permanent staff and acquire the services of the academics required to permit a thorough examination of these issues. It should be asked, among other things, to verify our findings and seriously consider our recommendations.

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85. CEGB, *Annual Review,* 1980/81, p.37, Table 21.
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91. Professor Jeffery, as well as others of the public, had been requesting such information for several years. Indeed in a letter to *Nature* in which he gave approximate calculations of the relative costs of nuclear and coal-fired electricity, Jeffery stated: "The full calculation can only be undertaken when the CEGB decides that its present policy of withholding the detailed data . . . is counterproductive." (*Nature,* 287, 23.10.80, p.674.).
92. CEGB, *Annual Report,* 1979/80, Appendix 3. Early coal-fired = 25 years; Drax + future coal-fired plant = 30 years; Magnox = 20 years; AGR = 30 years.
93. CEGB, *Annual Report,* 1979/80, Appendix 3, Tables 1 and 2: Also CEGB *Annual Report* 1980/81, Appendix 4, Tables 1 and 2.
94. CEGB, *Annual Report,* 1980/81, p.63.
95. Atomic Energy Authority, *Annual Report* 1970/71, Chapter 1 states: "The initial charges for the two Dungerness B reactors were completed" i.e. some 12 years before completion of Dungerness B station. *(Atom* 180 p.224). In the interim, prices (per the Retail Price Index) have more than trebled.
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113. MMC, *Report on the CEGB,* p.73, para. 5.38.
114. MMC, *Report on the CEGB,* p.165, para. 7.30.
115. MMC, *Report on the CEGB,* pp. 181-182.
116. MMC, *Report on the CEGB,* p.181, para. 7.96 and p.182, Table 7.10.
117. MMC, *Report on the CEGB,* p.182, para. 7.98.
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120. CEGB, *Annual Report,* 1979/80, Appendix 3.
121. Eg. for Dungeness B, the initial fuel charges were completed in 1970/71 (AEA *Annual Report* 1970/71) but the power station is not not expected to be completed until 1982 (CEGB *Statistical Yearbook* 1980/81, p.14).
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123. MMC, *Report on the CEGB,* p.74, para. 5.36.
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125. MMC, *Report on the CEGB,* p.108, para. 5.134.
126. MMC, *Report on the CEGB,* p.83, para. 5.67, p.92, para. 5.95, and p.112, para. 5.153.
127. MMC, *Report on the CEGB,* p.83, para. 5.68.
128. MMC, *Report on the CEGB,* p.84, para. 5.72.
129. MMC, *Report on the CEGB,* p.84, para. 5.72.
130. MMC, *Report on the CEGB,* p.85. Table 5.6.
131. MMC, *Report on the CEGB,* p.85, Table 5.6.
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136. MMC, *Report on the CEGB,* p.86, para. 5.78.
137. MMC, *Report on the CEGB,* p.86, para. 5.78.
138. MMC, *Report on the CEGB,* p.87, para. 5.81.
139. MMC, *Report on the CEGB,* p.87, para. 5.81.
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France — Country of the Atom

by
Peter Bunyard and Edward Goldsmith

If nuclear power seems cheap in France, it is because half the costs have been ignored.

France's nuclear power programme is the most ambitious in the western world; held up by the nuclear lobby as a shining example for others to emulate. It is no coincidence that Mrs Thatcher decided on her own ambitious programme of nuclear construction in the UK after a visit to various French nuclear installations in 1979. What particularly impressed her, it seems, was the sheer size and breadth of the French nuclear programme and claims for its incredible cheapness.

Such blind acceptance makes it particularly important that the French nuclear costings should be looked at closely — a difficult undertaking since Electricite de France (EDF) has shown itself extremely reluctant to divulge information other than for PR purposes. Nevertheless by piecing together bits of information that have been made available over the last few years, it is possible to get an idea of the true cost of nuclear electricity in France. Particularly useful in this respect is an unpublished report on the subject undertaken by a group working in the field of alternative energy, *Ecologie, Energie et Survie,* headed by Ferone de la Selva. From the information contained in this report we offer the following comments on the French nuclear costings.

The Cost of Delivered Electricity

According to the chairman of EDF, Marcel Boiteux (*Liberation* 23.9.80) the price of nuclear generated electricity was then 13 centimes/KWh and thus considerably lower than that of coal or oil-fired generating plant. Yet the figures published in the EDF's Annual Report for 1979, hence for the preceding year, indicated a much higher figure for nuclear power. Thus total production from nuclear generation was then 36,200 million kilowatt-hours at a cost of 6,813 million francs; that puts the cost at 18.82 centimes/KWh.

Given that inflation in France is running at approximately 13 per cent, Boiteux's figure of 13 centimes/KWh becomes 11.5 centimes/KWh for 1979. Thus the cost of nuclear generated electricity in France appears to be underestimated by Boiteux to the extent of 7.3 centimes/KWh. On that basis the cost of nuclear electricity comes out at 63 per cent higher than the cost quoted by the EDF chairman.

The EDF Annual Report for 1979 also indicates the cost of electricity generated from fossil fuel fired plant to be 14.72 centimes/KWh (total production 96,000 million kilowatt-hours; total cost 14,134 million francs). Similarly hydroelectric electricity will have cost 7.05 centimes/KWh, having taken the output of 61,700 million kilowatt-hours at a cost of 4,352 million francs. With those figures in mind it is clear that nuclear generated electricity during 1979 was considerably more expensive than that generated by either fossil fuel or hydroelectric plant.

On 5th December 1980, Mr Bergogneaux, assistant director of general economic studies of the EDF, stated that the price of nuclear electricity in 1990 would be 15 centimes/KWh, taking into account financial charges of 8.10 centimes, fuel 4.00 centimes and running costs of 2.90 centimes/KWh. Meanwhile, he said, the price of electricity derived from coal would be 25.80 centimes/KWh comprised of 6.2 centimes for financial charges, 14.00 centimes for fuel, 2.90 centimes for running costs and 2.70 centimes/KWh for desulphurisation.

The EDF has used various expediencies to mask the true cost of nuclear electricity; when such expedients are taken into account, the cost of nuclear electricity turns out to be much higher than admitted, and far higher than the price of electricity derived from coal.

The Cost of Research and Development

The budget of the Commissariat de l'Energie Atomique for research and development into civilian as opposed to military uses of nuclear power was 4,980,400,000 francs in 1980 and was increased to 5,674,900,000 francs in 1981.

Of those sums, 3,048,600,000 francs for 1980 and 3,478,100,000 for 1981 were paid for by government subsidies. Moreover the CEA does not bill the EDF for the results of its research and development; these are provided free with the result that the costs of research and development are not incorporated in the cost of nuclear electricity. We have here an obvious hidden subsidy paid by the French tax payer to the nuclear industry.

Capital Costs

In its report of 1980, entitled *Energy in Developing Countries,* the World Bank estimated the capital costs of large nuclear reactors at $1,600/KW. On the basis of a rate of exchange of 4.75 francs/dollar the World Bank figure translates into 7,600 francs/KW. The World Bank estimated a coal-fired plant to cost $1,000/KW. EDF expects the cost of a PWR to be exactly one half that of the World Bank's. Its coal-fired plant costs 40 per cent less than the World Bank estimate.

Undoubtedly EDF's estimate is for the perfect PWR — one that is built exactly according to specification and schedule with no account taken for likely cost overruns.

Cost Overruns

Most nuclear power stations take longer to build than was originally foreseen and budgeted for. Moreover, according to the EDF, each extra day's delay in commissioning a nuclear plant costs a million francs (*Valeurs Actuelles* 7th July 1977). The Fessenheim PWRs took 22 months more to build than predicted leading to added costs of 68 million francs in 1977 values. Since contractors normally pay only a small indemnity for each day's delay, EDF absorbs most of the extra cost; yet it makes no allowance for cost overruns in its estimates of the cost of nuclear electricity.

Another nuclear station at Gravelines comprising two reactors of 900 MW each incurred a cost overrun estimated at 7 billion francs; a sum which the EDF again failed to take into account despite it involving on its own figues an extra capital expenditure of 3,889 francs/KW.

Such cost overruns are particularly significant in a period of high inflation, when much of the money to meet the massive capital costs of nuclear installations has to be borrowed. In fact EDF is heavily subsidised by the government; the extent of the subsidy coming to light in a debate in the House of Commons on the 21st January 1981 (see HC 78.1 Pricing Policy 21.1.81 pp. 82-3). Mr Stoddart MP asked the Secretary of State for Energy if it were true that the French government had written off £1.4 billion of EDF's debts relating to capital expenditure and had suspended until 1985 interest charges on borrowings for the construction of nuclear installations. The Secretary of State for Energy Mr David Howell admitted that "Broadly similar things have been done."

Correction for Inflation

The EDF applies a correction for inflation on its capital costs (taux d'actuellisation) of 10 per cent. That value underestimates the inflation rate, which in France over the last few years has been closer to 13 per cent. Use of the latter, more realistic figure, would lead to a considerably higher figure for the capital costs of a nuclear power station. Thus, on a starting value of 100, a 10 per cent inflation rate over ten years would yield a figure of 259.36: a 13 per cent inflation rate over ten years would yield a figure of 339.38 — more than 30 per cent higher.

Because of the much lower capital costs of fossil-fuel fired plant, that underestimate of the true cost of inflation does not have such a pronounced effect on its overall generating costs compared with the effect on nuclear power generated electricity.

Load Factor

A further technique for underestimating the capital costs of nuclear electricity is to calculate them on the basis of an unrealistically high load factor. The World Bank assumes that a nuclear power station will function for 7,000 hours per year; the EDF is marginally more realistic in assuming a figure of 6,600 hours per year therefore a load factor of 75 per cent. Mr Paul Quilles, a nuclear specialist who acts as energy spokesman for the French Socialist Party, stated on the 23rd December 1980, in *Liberation,* that nuclear power stations in France functioned for an average of 5,000 hours per year. In its Annual Report for 1979 (Rapport d'Activite Compte de Gestion) the EDF admits that in 1979 its PWRs functioned with a load factor of 54.4 per cent (similar, according to Komanoff, for large PWRs in the US). Thus the EDF has assumed a load factor which is 20 per cent too high. The effect of that poorer performance is to raise the capital costs/KW installed of nuclear electricity by a corresponding amount.

Insurance against Accidents

In France, EDF pays nothing for insuring its nuclear power stations. The reason is that nationalised industries are supposed to insure themselves — auto-assurance — and the insurance companies are themselves nationalised. Thus losses incurred by nationalised companies, such as EDF, as a result of accidents, would be paid for by the same taxpayers, whether or not an insurance had been taken out against the risks involved.

In essence therefore the French taxpayer is landed with the entire risk of operating the nuclear power stations. That hidden subsidy is not revealed in the price of nuclear-generated electricity (see this issue p.288 for comment on accidents and insurance).

Hydroelectricity

On the EDF's own figures hydroelectricity provides by far the cheapest electricity (7.05 centimes/KWh 1979 value) in France; moreover as a renewable energy source it has no fuel costs whatsoever. Consequently hydroelectricity must take pride of place in the merit order, being operated exclusively on base load. Yet, apparently in France that situation no longer wholly prevails, the reason being the need to justify the enormous investment in nuclear plant by running it as hard as possible, and the technical difficulties of running it otherwise. Thus, some hydroelectric plants have been relegated further down the merit order to make way for the new nuclear plant coming on stream. But there is another reason for that relegation. Because of breakdowns in the nuclear plant and poorer than expected performance, the EDF must keep certain plant on hand that it can operate with great flexibility in case of sudden demand. Hydroelectricity fits the bill, as does gas turbine plant. The latter in fact is extremely costly to operate because of high fuel costs — hence a preference to use hydroelectricity.

Certain hydroelectric plants are therefore kept in a state of readiness, with the reservoirs behind the dams full. Consequently EDF is losing a certain proportion of power available to it through enhanced evaporation from the reservoirs. The holding in reserve of hydroelectricity, together with the loss of power from evaporation, both add to the cost of EDF's electricity, yet no account is taken of such an increase.

New Coal-fired Plant

Gas turbines and hydropower are in themselves insufficient insurance against nuclear inflexibility and unreliability. Furthermore the time — and cost — overruns on the nuclear programme have led to less generating capacity being available than expected. The need for extra fossil fuel fired stations has become apparent. Thus on May 18, 1977, Paul Delouvrier, then chairman of EDF, declared at Grenobles, that the EDF would ask the government's permission to build two 1,400 MW fossil fuel fired plants that had become necessary because of delays in the nuclear programme.

In the meantime existing thermal power stations are used to the maximum of their capacities. Indeed the load factor of those ageing plants actually went up from 69 per cent in 1978 to 72 per cent in 1979 (as against the 54 per cent of the PWRs). In its annual report for 1979, the EDF boasts of such high performances, which were achieved, "in spite of a greater use of the equipment, of the mediocrity of the fuel burnt, and of the age of the present population of coal-fired stations — more than 40 per cent of which have already more than 100,000 functioning hours to their credit."

That over-use of equipment must inevitably reduce the plants' lifespan, thus a further hidden cost of nuclear power that should be reflected in its generating costs.

Sale of Electricity at a Loss

In France new nuclear stations are coming on stream each year as a consequence of the construction programme. To keep nuclear stations operating solely on base load is clearly important if costs are to be kept down, and to achieve that EDF must boost sales. But sales are unlikely to grow if the product is dear, and EDF has therefore begun selling at a loss. Not that it admits freely to such a practice; on the contrary it employs a strategy to convince the public how cheap nuclear electricity is. Thus, in January 1980, when still President, Giscard informed Frenchmen that, because nuclear electricity was cheaper than other forms of electricity, those living within a 20 kilometre radius of nuclear stations would have their electricity bills slashed by 15 per cent. No such enticement was given to those in the vicinity of hydroelectric schemes.

That large sectors of industry are buying their electricity below cost is admitted by Paul Delouvrier. In an interview with Agence France Presse in 1976 he stated that "The reduction in industrial production has had the effect of reducing EDF's deficit predicted in 1975. Since each kilowatt sent-out is sold below its cost price, every kilowatt not sold actually reduced the deficit."

EDF will soon embark on a major sale loss to Eurodif which has established a massive uranium enrichment plant at Tricastin. The site is served by four 900 MW PWRs which will feed the enrichment plant with some 15,000 million kilowatt-hours per year. The electricity is at 11.97 centimes/KWh. Since EDF's annual report for 1979 indicates the delivered cost of electricity to be 18.82 centimes/KWh, the loss of revenue is 6.85 centimes/KWh leading to a total loss of 1,030 million francs per year.

Moreover the 106,000 employees of the EDF actually get their electricity almost free (they pay no more than 4 centimes/KWh — presumably in lieu of extra wages). At the same time the EDF is making great efforts to force French industry into staggering hours, and thus into returning to a three-shift system so as to even out electricity consumption during each 24 hour period.

Fuel Costs

Jean Bergougnoux, EDF's economist, expects the price of nuclear fuel to fall by more than 5 per cent while that of coal will increase by nearly 17 per cent.

In reality, nuclear fuel costs have turned out to be very much more expensive than predicted largely because of the unexpected high cost of uranium enrichment and the intransigent problems associated with reprocessing spent fuel. The extra cost of those processes was already admitted by the EDF in its Annual Report for 1979. Thus it indicated a 34.3 per cent increase in a single year in the costs of "contract work, equipment and external services".

The same report discloses that the provisions for losses "have been increased by 28.3 per cent in a single year, thus by 2,325 million francs". Hence the total mount put into those provisions in 1979 amounted to 8,215,547,700 francs — a truly stupendous sum. EDF acknowledges that the provisions are to pay for the cost of nuclear fuel and also for the decommissioning (declassement) of nuclear power stations. It has failed to make clear how it can be putting aside vast sums for meeting additional costs on the one hand, and on the other, can be enjoying falling nuclear costs.

La Hague Reprocessing Plant
Uranium Enrichment Plant

Breeder Reactors

Both the French nuclear industry and British are aware that the nuclear adventure must inevitably be short-lived unless there is a shift to fast reactors. In France Phenix 250 MW has been in operation for a number of years, and Super Phenix, a 1200 MW fast reactor, is currently under construction at Creys Malville. It should come on stream by 1983. According to Paul Quilles, the Socialist Party nuclear expert (*Liberation* 23.9.80) already 8 to 10 billion francs have been spent on it.

Marcel Boiteux, the present President of the EDF, is concerned that Super Phenix is turning out to be more expensive than foreseen. "Although it is premature to put Super Phenix in the same boat as Concorde" he states, "it is questionable whether it will be competitive since the price of the kilowatt-hour furnished by Super Phenix is likely to be closer to that furnished by heavy oil (33.52 centimes).

From the available material it is clear that the cheapness of France's nuclear electricity is a myth. To have any basis of reality, the costs of France's generated electricity would have to include the costs of research and development of both reactors and of other installations necessary for the operation of nuclear power; it should include cost overruns; the 20 per cent poorer performance than budgeted for; the need to keep hydropower as a back-up system; the need to build coal-fired plant for the same purpose, and to cater for delays in the commissioning of nuclear plants; it should include a rate of increase in construction costs to take account of the real fall in value of the franc as a result of inflation.

The inclusion of those costs alone will lead at least to a doubling of EDF's price of nuclear electricity and take it above the 25.80 centimes/KWh given for future coal-fired generation. That likely doubling of costs is still an underestimate, since the costs of dealing with the decommissioning of power plants and of coping with wastes generated in spent reactor fuel will undoubtedly be greater than the provisions made for them.

The Fast Reactor — A Pipe Dream

by
Peter Bunyard

Reprocessing was devised for extracting plutonium from spent fuel rods so as to make weapons. From then on the nuclear industry has been finding reasons to justify continuing with the technology. One of the more fashionable justifications is the environmental argument — that leaving the spent fuel intact leaves a greater, more hazardous bulk to be got rid of than if the spent fuel is dissolved and the fission products are then boiled down and re-solidified by integrating them into boro-silicate glass. The 'ecological argument' had been used equally by the British and French who are the only ones left in the western world with serious intent to reprocess on an industrial scale. Thus André Giraud, Giscard d'Estaing's Energy Minister told the magazine *Le Point:* "To reject reprocessing, is to choose to stock irradiated spent fuel in astronomical quantities. Without reprocessing the quantity of wastes is 30 times greater than after reprocessing . . . Reprocessing of spent fuel is an ecological necessity because it allows one to concentrate the radioactive wastes under a stockable form."

For a better perspective of the consequences of following the reprocessing pathway, it is well worthwhile taking a look at *La Gazette Nucleaire* (No 43) compiled by a French group of scientists — GSIEN. Those scientists dispel the myth that reprocessing leads to less environmental contamination than through leaving spent fuel intact.

Official French figures on the disposal of high activity waste are particularly relevant to Britain since BNFL is buying the French vitrification technology for itself. The continuous vitrification procedure — AVM — being tested since June 1979 at Marcoule, is supposedly able to produce 50 cubic metres of vitrified waste each year. So far it has dealt with waste of relatively low activity — of the order of 10 curies per cubic metre. In the future the procedure will have to cope with waste with an activity of between 80 and 300 curies per cubic metre.

With AVM, the aim is to reduce the volume of high activity waste by a factor of between 5 and 7, depending on the type of fuel, thermal oxide or Magnox. That reduction in volume might seem a laudable target, but as GSIEN points out, the vitrifiers take no account of the considerable volumes of low and medium activity wastes that are discharged into the environment. Table 1 shows that reprocessing followed by vitrification leads to the discharge into the environment of a much larger volume of radioactive waste — some hundredfold more — than keeping the spent fuel intact.

Of major concern to GSIEN is the loss of plutonium into the environment as a direct consequence of reprocessing. The nuclear industry has always been extremely guarded about such losses, since an admission that they ran into several per cent rather than tenths of a per cent, could expose the shaky foundation of nuclear power. Thus, as we have pointed out in The Grand Illusion (*The Ecologist* April/May 1980) plutonium losses of a few per cent incurred during reprocessing could eliminate all the plutonium gains made in a fast reactor. Aside from dangerous contamination of the environment, such losses would therefore limit nuclear power to providing a mere few per cent of the

Table 1 · The French Nuclear Programme and its Wastes

		Quantities accumulated until end 1979	Quantities produced per year PWRs 1980	1985	1990	2000	Quantities accumulated until 2000
Electricity production of nuclear origin (a)	TWh = 10^{12} Wh	59 (e)	53.6	195	330	580	≃ 7,000
Light Water Reactor installed capacity (a)	GWe = 1,000 MWe	5.7	13.3	37.9	66.2	119.0	
Spent Fuel discharged: tonnes	3.8 tonnes/TWh (b)	224	203	739	1,251	2,198	26,000
Plutonium discharged tonnes	37.6 kg/TWh (b)	2.22	2.02	7.33	12.41	21.81	263
Medium and low activity wastes beta, gamma	500 m^3/GWe per annum (c)	4,610	4,200	15,000	26,000	45,000	550,000
Solutions of high activity alpha, beta, gamma	15 m^3/GWe per annum (d)	138	126	460	773	1,360	16,400
Solution after vitrification	3 m^3/GWe per annum (c)	28					3,300
Cladding wastes high activity alpha, beta, gamma	15 m^3/GWe per annum (c)	138	126	460	773	1,360	16,400
Low & medium activity wastes alpha, beta, gamma	130 m^3/GWe per annum (c)	1,200	1,090	3,960	6,700	11,780	142,000

a) EDF forecasts made in the framework of the Government's 8th Plan, April 1980.

b) It was assumed that the PWRs would contribute significantly; with a thermal efficiency of 33 per cent and an average burn up of 33,000 MW days/t.

c) We assume that a reactor with a 1,000 MW electric capacity will produce 6.4 TWh/year.

d) Quoted from the Revu. Generale Nucleaire, February 1980 from a seminar given by Y. Sousselier at Laboratoire de l'Accelerateur lineaire d'Orsay (April 1975).

e) Until the 31.12.77 see M. Mentré (Annual Report of the Conseil d'Information sur L'Energie electronucleaire 1978) and for 1978-79 EDF memos (fiches d'information EDF) to the press on 25.11.79 and 25.1.80).

entire world's electricity requirements. Hence nuclear power would be irrelevant in the process of world development.

GSIEN confirms that the losses of plutonium are high in all stages of the extraction and manufacture of new fuel elements. Over a long period the accumulation of plutonium in the environment would be considerable and run into the tonnes rather than kilograms.

At the very least, GSIEN expects plutonium losses from reprocessing fast reactor fuel to amount to one or two per cent. Even that percentage — which is considerably lower than the losses presently experienced at the reprocessing plants of La Hague and of Windscale — would lead to large plutonium losses within a few generations, and it must be appreciated that the long 24,000 year half-life of plutonium means that any contamination is essentially forever. Equally important those plutonium losses make a complete nonsense of the strategy, proposed by Walter Marshall, Chairman of the UK Atomic Energy Authority, for getting rid of plutonium in the world through its incineration in fast reactors. Thus Marshall suggested that fast reactors could be made to operate without the blanket layers, so that instead of generating new plutonium — which anyway they do extremely slowly — they would gradually burn up their fuel.

GSIEN then reflects on the consequences of building a park of ten fast reactors of 1 GW each. Some 85 tonnes of plutonium would be needed as initial fuel for such a park. In fact, that initial plutonium would have to come from thermal reactors, and GSIEN calculates accordingly that 11,000 tonnes of spent fuel from light water reactors would have to be reprocessed. On the conservative basis that some 3 per cent of the plutonium on spent light water reactor fuel is lost, at least 2.6 tonnes of plutonium would get released with radioactive wastes into the environment.

Meanwhile, having gained the 85 tonnes of plutonium, the operation of the fast reactor park over 20 years, would lead to 414 tonnes of plutonium being in circulation. The plutonium losses, on a one or two per cent basis, would amount to between 4 and 8 tonnes. If then, after 20 years, the aim was to incinerate the remaining plutonium — 85 tonnes, the losses of plutonium would amount to between 6.8 and 13 tonnes.

Overall, of the original 85 tonnes of plutonium extracted from the light water reactor programme and then used in fast reactors, *some 16 to 26 tonnes would find their way into the environment, the precise amount depending on the efficiency of reprocessing and of fuel fabrication. Thus as much as one quarter of all the original plutonium could be lost — an appalling and wholly unacceptable amount.*

The alternative to reprocessing is to leave the spent fuel intact. GSIEN quotes various sources, including the Canadian and Swedish Atomic Energy Commissions, to show that spent ceramic thermal oxide fuel, encased in stainless steel or zirconium, is less likely to leak out than when it is vitrified. The spent fuel, being intact, also leads to smaller discharges into the environment.

Of course, as all nuclear power enthusiasts realise — to accept the notion that spent fuel should be kept intact is to deny the potential of the fast reactor to use up uranium-238. Not only will the empires built up in developing the fast reactor and in 'closing the fuel cycle' be condemned to wither away, but with them — once economic sources of fissile uranium have been consumed — the dream of nuclear power.

Nuclear Energy Costs — the US Experience

Capital costs of nuclear power stations in the US have escalated at a rate more double those of modern coal-fired plants, this despite new controls which have cut dramatically emissions from coal-fired plant. Nuclear is now lagging far behind coal and looks like dropping out of the race.

Nuclear power costs are dominated by fixed costs on capital investment. In turn, these are determined by capital costs (construction costs) and capacity factors (utilization rates). Together, then, reactor capital costs and capacity factors will largely dictate the costs of nuclear power generation. My 1976 book *Power Plant Performance** and my 1981 book *Power Plant Cost Escalation*** were the first empirical studies of the capacity factors and capital costs of U.S. reactors. Indeed, I undertook them precisely because economic forecasts by the U.S. electric power industry consistently ignored the true performance and cost of nuclear plants. Throughout the mid-1970s, U.S. industry spokespersons merely asserted, without any attempt at proof, that design improvements and plant "maturity" would enable new reactors to operate at 70-80 per cent of capacity. Similarly, when concern mounted in the late 1970s about rising construction costs for reactors, the industry simply insisted, without demonstration, that capital costs were increasing no faster for nuclear than for coal-fired plants. Needless to say, these assertions have proven incorrect in the United States. No active orders for new reactors have been placed since 1974, a dozen plants with construction permits have been scrapped (along with some 60 on order), and a grudging admission is spreading within the power industry that nuclear plants have taken on too many economic liabilities to be cost-effective.

Capacity Factors

U.S. light-water reactors averaged 60 per cent capacity factor through 1980. This average subsumes all PWRs and BWRs over 400 megawatts capacity (electric) — 62 plants operating for 393 reactor-years. The average would be about 1 per cent higher if "load-following" were eliminated, but it would be 1-2 per cent lower if calculated on a capacity-weighted (sector-aggregate) basis.

* Published by the Council on Economic Priorities.

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Disaggregation of the data indicates: (1) virtually no difference (1 per cent or less) between the PWR and BWR averages; (2) modest maturation, i.e., small but statistically significant increases in capacity factors after the initial few years; (3) a weak "learning" effect, *i.e.,* only slightly stronger performance by newer units; and (4) a marked decline in capacity factors for larger plants, with reactors over 800 MW averaging only 54 per cent capacity factor, *versus* 66 per cent for plants under 800 MW.

The last point — the influence of plant size — is especially striking for reactors designed by Westinghouse — the progenitor of the Framatome design. Through 1980, the 8 Westinghouse plants of the 500-MW class (450-575 MW) in the United States averaged 72 per cent capacity factor — a very respectable figure, and easily the highest for any U.S. reactor grouping. Three other Westinghouse reactors in the 700-750 MW class averaged 63 per cent. But the 13 largest Westinghouse plants, those over 800 MW (823-1130 MW) averaged only 52 per cent capacity factor for their 63 reactor-years (almost 5 per plant). Moreover, the average has not improved with time, age, or generation. Other vendors' reactors show a similar tendency, although far less marked, toward lower capacity factors at larger sizes. Overall, U.S. reactor capacity factors appear to drop by 1.5 — 2 per cent, on average, per 100-MW increase in capacity (controlling for age and generation differences). This parallels the performance decline for larger fossil units in the United States. However, the decline is far more apparent up to 800 or 850 MW than beyond. Moreover, a portion of the nuclear decline with larger sizes is linked to accidents, such as Three Mile Island and the Browns Ferry fire, in which plant size may not have been a major contributory factor. Although I have not seen any official performance data for the French nuclear program, I understand that the current generation of PWRs has averaged approximately 70 per cent capacity factor. This far surpasses U.S. performance, especially that for the large Westinghouse plants which presumably most closely resemble the French design. The causes of the performance difference — both technical and institutional — are of interest to both countries. The large Westinghouse plants in the U.S. have suffered particularly from:

□ Steam generator corrosion and denting requiring inspection, tube plugging, and even replacement in several cases;

□ Cracked welds in feedwater piping;

□ Cracked disc assemblies in low-pressure turbines;

□ Deficiencies in mechanical systems, including inadequate construction of pipe supports, seismic design deficiencies, and faulty reactor coolant pumps.

It is of interest whether such problems have materialized for the French PWRs, and, if so, how the operators and safety authorities have responded. Some of the problems clearly dictated that plants be shut for operational considerations, but other shutdowns, such as for feedwater cracks and inadequate pipe supports, were discretionary and primarily "safety-related."

The 'start-up' of several French reactors with cracks in the cladding of pressure vessel nozzles in 1979-1980 exemplifies a potential safety issue that might have been treated more cautiously in the United States. Accordingly, there is a perception in America that the superior performance to date of French PWRs is the result not only of more efficient design and construction practices but also of lesser sensitivity to safety.

Capital Costs

Power Plant Cost Escalation provides the first measurement of increases in the cost to construct nuclear and coal-fired plants in the United States. The book examined the capital costs of all 116 coal plants and all 46 reactors completed from the end of 1971 to the end of 1977 (coal) and 1978 (nuclear), adjusted for inflation in construction inputs and interest rates. It found that:

□ Nuclear capital costs increased from an average of \$366/kW for plants completed in 1971, to \$887 kW for 1978 plants (both figures in 1979 dollars, with interest during construction calculated in real terms and accounting for only approximately 10 per cent of costs) — a 142 per cent increase *in addition to construction-sector inflation*, equivalent to an average real increase of 13.5 per cent per year. Virtually all of the increase is attributable to design changes and plant modifications which were intended to correct design faults and improve safety, and which increased the quantity of labour, materials, and equipment needed to build reactors while complicating design engineering and construction logistics;

□ Coal capital costs increased from an average of \$346/kW for 1971 plants to \$583/kW for 1978 plants with scrubbers — a 68 per cent real increase, or 7.7 per cent per year; almost all of the increase resulted from new pollution controls that have reduced emissions of particulate matter, sulphur dioxide, and oxides of nitrogen by two-thirds from 1971 plant levels;

□ Capital costs of U.S. nuclear plants declined only slightly with increasing reactor size, by 10 per cent per size doubling (over the 514-1130 MW sample) — not enough to offset the larger reactors' lower capacity factors; coal plant capital costs were unaffected by plant size over their 114-1300 MW range;

□ 'Duplicate' unit construction reduced both nuclear and coal capital costs by about 10 per cent compared to single-unit stations;

□ Increased builder familiarity with nuclear construction led to reduced costs, but the savings — 7 per cent per doubling in the number of reactors built — were far offset by the 50 per cent cost increase per doubling of installed reactor capacity attributable to increased efforts to reduce per-reactor risks as the nuclear sector expanded.

□ 'Licensing time' — the interval between construction permit application and award — had no discernible effect on real nuclear capital costs.

These findings put to rest the notion that nuclear and coal capital costs increased at approximately equal rates in the United States in the 1970s, or that any differences resulted from anti-nuclear protests and delaying tactics. Rather the difference in the rates of increase was sufficient to widen the excess of nuclear over coal capital costs from an average of 6 per cent in 1971 to 52 per cent in 1978 (91 per cent omitting the coal plant scrubbers).

Pressure to reduce 'societal costs' — accident risks, air pollution, radioactive emissions — was the primary cause of real capital cost increases in the United States in the 1970s. But the question arises: Why did nuclear capital costs increase so much more than coal plant costs? Although the answer is complex, the following explanatory factors stand out:

(1) The nuclear sector expanded far more rapidly (in percentage terms) than the coal sector in the 1970s and thus it required greater remedial measures to prevent its total societal costs from increasing rapidly;

(2) Coal pollution controls generally involved well-defined emission-reduction targets and thus could be planned *in advance of* construction, whereas reactor modifications frequently were imposed *during* construction (in response to discovery of new safety concerns) — a disruptive and expensive process;

(3) Coal pollution controls, even major new equipment such as scrubbers, could essentially be grafted onto the basic power plant without modifying it extensively, whereas nuclear design alterations to protect against earthquakes, fire, pipe breaks, electrical failure, etc., often necessitated pervasive engineering changes that impinged upon many plant systems and structures.

The differences were compounded: not only were mid-course design changes far more common at nuclear plants, but each change was more difficult, time-consuming, debilitating — and expensive.

The recent (1978) 52 per cent excess over coal capital costs is likely to be too great a handicap for nuclear plants to overcome through later fuel cost savings vis-à-vis coal plants in the United States. Yet the capital cost difference is almost certain to increase during the foreseeable future. Coal plants are presently following an advantageous learning curve. By investing an additional \$200 to \$240 per kilowatt (1979 dollars) — about a 35 per cent real cost increase — new coal plants could purchase improved pollution controls that would reduce their emissions of oxides and particulate matter by three-quarters compared to typical 1978 coal plants. The new coal plants would emit less than one-tenth as much pollution as the average U.S. coal-fired plant, and even less than California and New York plants burning very low-sulphur oil (0.2-0.3 per cent sulphur). Moreover, they would actually cost less (in constant dollars) than typical 1978 reactors (\$800/kW vs. \$900/kW, both in 1979 dollars).

But of course, reactors under construction in the United States will cost considerably more in real terms than the \$900/kW average for 1978 plants (1979 dollars). Nuclear capital costs are already rising to comply with known requirements such as: 'environmental qualification' of electrical equipment to withstand accident conditions of high radiation, temperature, humidity, pressure and caustic spray; more rigorous quality assurance programs to reduce design and construction defects such as seismic deficiencies; and layout modifications to increase the distance between primary safety-related equipment and its back-up. Nuclear costs will rise still further to meet future Nuclear Regulatory Commission requirements arising out of the Three Mile Island accident, including design features to accommodate melted cores safely. Moreover, the growing body of officially recognized 'Unresolved Safety Issues' such as systems interaction and steam generator support fracture toughness (fed by the burgeoning number of safety-problem incidents from reactor operating experience) portends still other costly design changes and equipment modifications.

There is no hard and fast way to project the resulting increase in reactor costs. Nuclear plant 'engineering estimates', by which utilities calculate the amounts and costs of labour, materials and equipment required to build power plants, are invariably overrun by changing, hard-to-predict design criteria that disrupt construction sequences and 'ripple through' interconnected plant systems. Indeed, the failure of engineering estimates to anticipate safety-related costs is evidenced by the huge (100 per cent or more in real terms) cost overruns experienced at virtually all U.S. reactors since the mid-1970s.

Future Reactor Costs

To estimate future reactor costs, I have relied upon the remarkably close link between increases in nuclear capital costs and expansion of the nuclear sector in the 1970s. This link, in conjunction with explanatory variables such as unit size, duplicate construction and builder experience, explains 92 per cent of the variance among U.S. reactor costs in the 1970s — a higher fit than is obtained when the passage of time is employed to explain increases in cost. The use of sector size as a proxy for cumulative risk-reducing efforts adding to costs is further suggested by the fact that the underlying factors contributing to regulatory stringency are all stimulated by increases in the amount of nuclear capacity. The growing reactor population has necessitated that per-reactor accident risks be reduced to maintain a high probability that no serious accident occurs; the expanding body of licensing reviews and operating experience has demonstrated that desired safety margins were not being achieved; increasing public concern, prompted largely by reactor expansion, has added to pressure to reduce risks and has aided in unearthing new safety problems; and the expanded regulatory effort required to oversee a growing nuclear sector has caused safety criteria to be applied uniformly to all plants, generally at a higher level.

The foregoing considerations support a projection of future U.S. nuclear capital costs through extrapolation of the relationship between costs and sector size, as measured from 1970s data. The result is a projected cost of approximately \$1400/kW (1979 dollars) for the next ordered and licensed U.S. reactor, assuming that all preceding reactors with construction permits are completed. Although current reactor cancellations would reduce the anticipated sector size (and thus the calculated cost), the projected cost is considerably less than is yielded by statistical projections employing calendar year — or, for that matter, than the observed costs of many plants under construction. Moreover, since the data used for extrapolation predate the Three Mile Island accident, they include no allowance for the apparent subsequent increase in the regulators' willingness to impose more stringent requirements in the interests of safety. The \$1400/kW projected cost of new U.S. reactors (1979 dollars) is thus far more likely to be exceeded than undercut.

Costs in France and the U.S.: A Comparison

The projected 75 per cent gap between future U.S. nuclear and coal capital costs (and indeed the actual 52 per cent gap between average costs for 1978 plants) contrasts markedly with the 17 per cent gap embodied in Electricite de France's 1980 cost projections (F3440/kW for PWRs, F2930kW for coal, both in 1-1-80 prices). The difference between costs in the two countries is even greater than these figures suggest, since the pollution controls stipulated in the 'reference' U.S. coal plant are far more comprehensive than in EDF's coal plant. Were the future United States coal plant's controls fixed at the 1978 level — which still probably exceeds the controls assumed by EDF — the projected U.S. nuclear-coal capital cost gap would be 130-135 per cent, versus EDF's 17 per cent.

The difference between U.S. and French rates of change in capital costs is also striking. As noted above, *actual* U.S. capital costs increased in real terms by 13.5 per cent per year for nuclear plants and 7.7 per cent for coal plants during 1971-1978. (The true U.S. real increase rates were actually slightly higher since the construction-price deflator used to adjust for inflation was 1-2 per cent per year steeper than the U.S. inflation rate.) In contrast, *projections* of real French capital costs increased during 1972-1980 by only 5 per cent per year for nuclear but by 7½ per cent per year for coal (10 per cent per year for coal during 1975-1980).[1] The moderate rate of increase in EDF's past cost projections for reactors may be plausible as well as enviable (although nuclear cost projections traditionally count for little — empirical data are what matter, and EDF should make these available). But the high rates of increase in the cost projections for French coal plants strain credulity.

Indeed, EDF's 1980 projection of future coal plant capital costs (F2930/kW in 1-1-80 price conditions) is roughly 20 per cent higher than the actual cost of a typical 1978 U.S. coal plant ($583/kW in 7-1-79 price conditions). Yet the emission controls for the U.S. plant — 99.5 per cent removal of particulate matter, 75 per cent capture of SO_2, and 35 per cent reduction in NO_x (cleaner than burning 1 per cent sulphur oil) — probably surpass the controls assumed in EDF's reference plant. The implication that a French coal plant could cost considerably more to build than a more stringently designed American plant should be of great interest to the French.

Total Generating Costs

In *Power Plant Cost Escalation*, I calculated that new nuclear plants with a 75 per cent excess capital cost over coal facilities in the United States would have approximately 25 per cent higher lifetime generating costs. Key contributing assumptions were:

(1) Capacity factors of 60 per cent for large reactors and 70 per cent for small coal plants;

(2) Continuing real increases of 2.3 per cent/yr in coal prices from a 1979 base of $1.20/MMBtu;

(3) Nuclear fuel costs pegged to 1979 prices of $35/lb for uranium yellow-cake and $94/SWU for enrichment, with real increases of 2 per cent and 1.5 per cent, respectively, per year;

(4) Equal nuclear and coal O&M costs, notwithstanding the far more rapid increase in nuclear O&M costs in the 1970s;

(5) Slightly higher real fixed charge rates for nuclear (10.3 per cent) than for coal (9.8 per cent) because of nuclear's 'risk premium' and its higher backfitting costs during plant life;

(6) Decommissioning and spent fuel disposal priced conservatively to account for only 8 per cent of total nuclear generating cost.

Different assumptions are required to project French generating costs, and it is beyond my scope to seek to stipulate them. I do note, however, that the higher cost of coal in France would be offset at least partially by the presumably lower degree and cost of pollution controls for French coal plants compared to those I assumed for future U.S. plants.

Finally, I wish to emphasize that my comparison of nuclear costs to coal costs does not imply that coal plants are the most efficacious alternative to nuclear plants. I have framed the issue of nuclear costs in relation to coal costs partly because coal plants present a real alternative to reactors. Equally important, the comparison is conceptually simple, and coal plant cost trends provide a convenient benchmark for nuclear cost trends.

The real energy issue facing France, the United States, and other countries is the replacement of oil with secure energy that is low in monetary and societal cost. In the United States, nuclear power contributes only marginally to oil displacement; roughly half of reactor output displaces coal, and the one-third drop in the consumption of oil for U.S. power generation from 1978 to 1980 was accomplished despite a concurrent decline in nuclear generation. Increased use of coal (primarily at previously under-utilized power stations) has contributed significantly to America's reduction in oil. But increased efficiency in energy use (not only in the utility sector but also in transportation, industry and domestic uses) has played a far larger role.

New U.S. nuclear plants coming on line in mid-1981 are producing end-use energy at the approximate cost of $85 per barrel of oil equivalent for industrial customers and $125 for residential users (mid-1981 price levels).[2] French nuclear power costs may be significantly less, and electricity does displace direct fossil-fuel use on a better than one to one basis (measured at the point of use). Still, it is an open question whether, even in France, electrification of industry and heating to replace non-utility oil with reactors does not merely trade one expensive form of energy for another. Full disclosure of empirical cost data for the French nuclear program would help settle this question.

1. Rates of change of French cost projections were calculated by the author from unidentified EDF document, "Cout du kilowatt installe et du kilowattheure," pp. 22-24, provided by Dominique Finon. Cost estimates for oil-fired plants were used for 1972-1975, increased by 16%, the approximate difference between cost estimates for oil- and coal-fired plants. All estimates, nuclear and coal, were converted to January 1980 francs by multiplying by the inflation rates for all years up to 1980. Inflation rates were taken from "Evolution des Taux D'Accroissement Annuels des Prix Di Produit Interieur Brut Marchand (Apres 1970) de la Production Interieure Brute (Avant), " Table 1, from "Methodes Generales de Calcul, Evolution des Prix, Conversation P.1 B." The author wrote to the EDF Directeur General on 7 July and 27 July seeking information on the costs and performance of French PWRs, but received no reply.

2. Calculation modelled after Table A-6 in Vince Taylor, *Energy: The Easy Path,* Union of Concerned Scientists, Cambridge, MA, 1979. It assumes 1979 costs from author's *Power Plant Cost Escalation* ($887/kW, 60% capacity factor, 10.3% real fixed charge rate, 8.02 mills/kWh fuel cycle (as per Table 11.5) plus 10% to bring to 1981, and capital and O&M costs also increased by 8% twice for real escalation to 1981. Result, with 10% transmission losses, is 48.1 mills/kWh. Adding 12% and 60%, respectively, for industrial and residential transmission and distribution costs, and converting to 5.5 MM Btu average heat content of refined petroleum products (both as per Taylor) gives $86 and $123, rounded in text.

Energy: What's the Problem?

by
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Traditionally energy planners have seen energy like a currency, where one source can be exchanged freely for another. The 'Energy Crisis' does not stem from a lack of energy but from a failure to match forms of energy to the real requirements of the consumer.

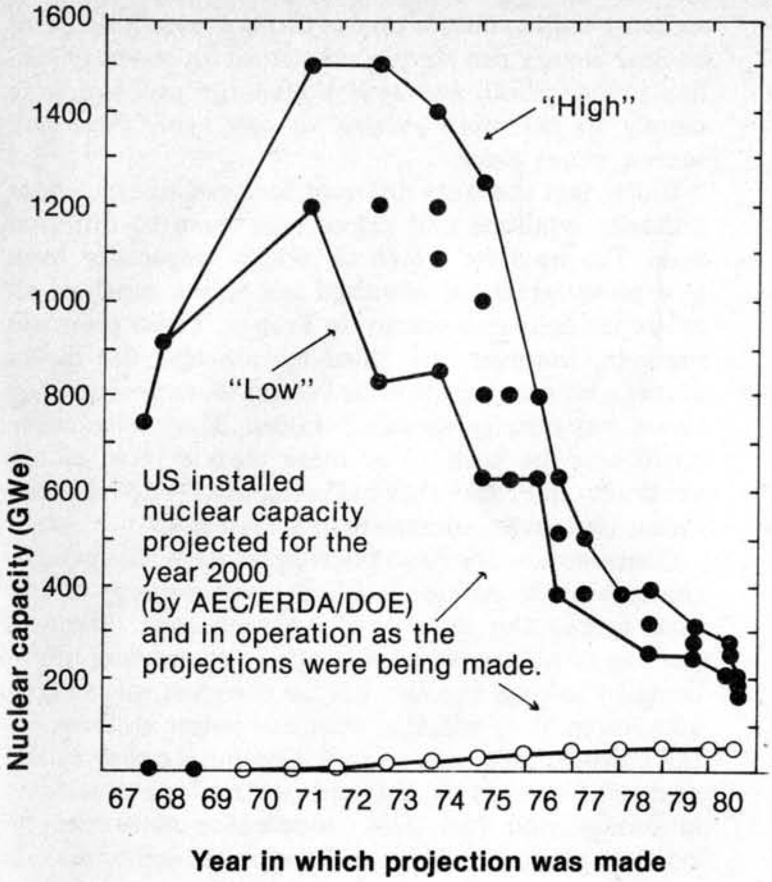
France has the most ambitious, comprehensive, and (until recent months) consistently pursued nuclear power program in the world. The 65 GWe of nuclear capacity planned[1] for 1990 (Carle, 1981) — averaging an extra 5.6 GWe/y throughout the 1980s — would produce twice as much electricity as all France used in 1975. France would, on this plan, use four-fifths more electricity in 1990 than in 1980 — a faster demand growth than during 1965-75 — and would get 73% of it from nuclear power.

The rest of the world is on a different course. Since 1973, official forecasts of nuclear capacity for the year 2000 have fallen by about eightfold for both the world and the United States (which had minus 46 net orders in 1975-80 (Brody, 1981)). That this collapse cannot be attributed to American political peculiarities is shown (Fig. 1) by the virtually identical pattern of collapse in countries where there are no regulatory impediments to building reactors (such as Canada) or to raising the price of electricity (such as the Federal Republic of Germany). Indeed, the same pattern occurs throughout the world's market economies, suggesting that its cause is fundamentally *economic.* As a result, despite three decades of devoted effort, nuclear power today is a minor energy source. It delivers to Japan half as much energy as renewables; to the U.S., half as much as wood alone (Lovins & Lovins 1980:66). Once hoped to fuel global development, nuclear power has proved far too complex and costly to replace such fuels as dung — which now supplies probably more energy. Further, no reactor vendor in the world has made a net profit, and many analysts now doubt that nuclear power will ever become a sustainable, profitable commercial enterprise.

Amidst this pattern of disillusion — the greatest collapse of any undertaking in industrial history — only in the Soviet Union and in France have nuclear forecasts held fairly steady; and only in France, with probably over $40 billion sunk, are those forecasts on the way to fulfillment[2]. A generation hence, will other nations wish, as Alvin Weinberg predicts, that they had pursued nuclear power with the singular tenacity France did — or will they be glad that they did not? The evidence suggests that official French determination to achieve an electronuclear economy has reflected both a misperception of the nature of the energy problem and an erroneous assessment of the technical and economic attractiveness of competitors to nuclear power. The latter error led to the canonical view that nuclear "was the only source capable of reducing the nation's dependence on foreign energy supplies" (Carle, 1981) — a view, we shall suggest, that is even less defensible today than it was in 1973. But the former error is more subtle, more fundamental, and less often discussed, so we shall consider it first.

Technology is the Answer! (But what was the Question?)

The flows of commercial energy in a society can be represented in stylized form by a "spaghetti chart" (Fig. 2). Primary sources such as fossil fuels, hydroelectricity, and nuclear power begin on the left-hand side of the chart, flow towards the right through various conversion processes such as power stations and refineries, and deliver to the right-hand side various final forms of energy to meet various end-use needs. In France, approximately 61% of those end-use needs require *heat* (consisting of about 36% heat below 100°C, 14% 100-600°C, and 11% over 600°C (Lovins 1978; more recent and exact assessments are broadly similar)). About 29% of all delivered energy is required as a portable *liquid fuel* for vehicles. And at most 10% does all of the special tasks which require energy in the



Note: Forecasts since 1978 were prepared by the Energy Information Administration, US Department of Energy, on different basis than pre-1978 forcasts. For nuclear capacity to be installed through 1995, EIA uses a ten-region input-output model to project electricity demand from GNP and population growth, then assesses nuclear capacity reactor-by-reactor, taking account of licensing and construction lead times and financial constraints. Post-1995 installed capacity, however, is constrained only by 1980 domestic manufacturing capabilities, not by siting, financing or demand. Since pre-1978 forcasts supposedly consider how many plants are likely to be installed, not just how many could be, the 1978-80 data exaggerate nuclear potential relative to earlier forecasts. The form and earlier data of this graph are due to C.F. Zimmerman & R.O. Pohl, *Energy 2;* 465-471 (Pergamon, U.K., 1977). Year-end operable capacity data (open circles), from EIA, declined from a high of 49.4. GWE at the end of 1978 to 49.1 at the end of 1979 and to 49.0 in mid-1980.

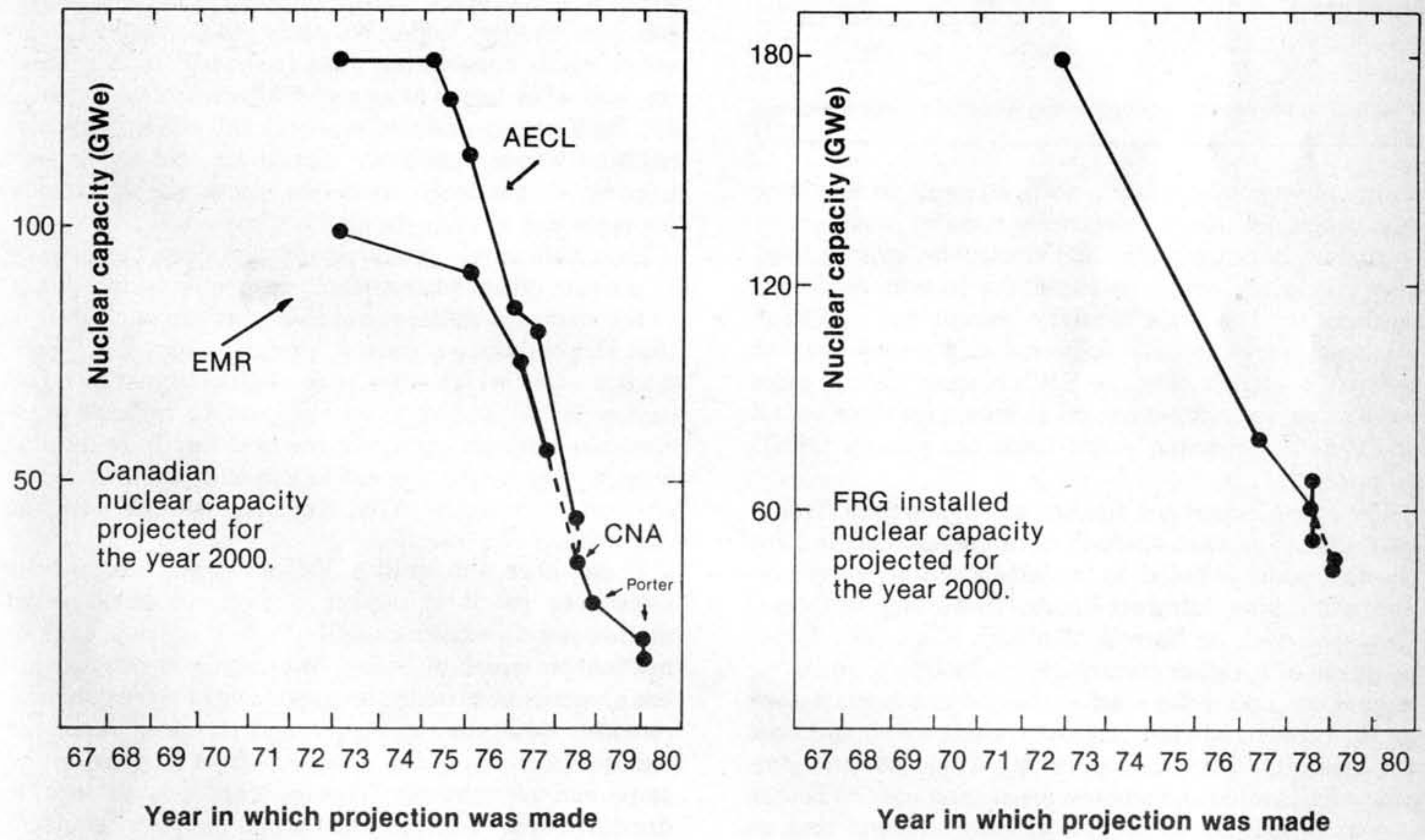


Fig. 1. A comparison of the pattern of decline of official forecasts of nuclear power capacity installed by the year 2000, for the United States (top), Canada (lower left), and FR Germany (lower right), all normalized in vertical scale. (No comparable German data are available after 1978; the 1979 datum is from USEIA, informally corroborated by German sources.)

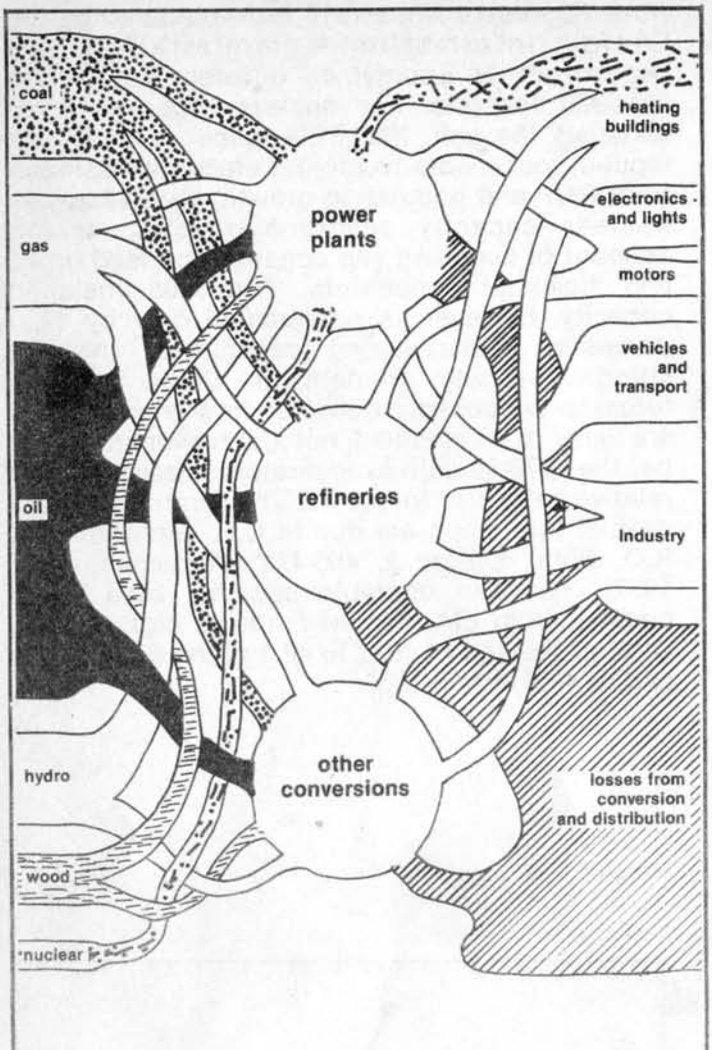


Figure 2: A schematic, stylized "spaghetti chart" (not to scale).

premium form of *electricity* and can use it to economic advantage. This last, "electricity-specific" category is so limited because additional electricity, even if used very efficiently, is far too expensive to compete in the markets for heat and mobility (except rail vehicles). For example, electricity delivered at a pretax price of US$0.074, or FFr0.44[3], per KWh is equivalent in price per unit of heat content to oil at about $120 per barrel or FFr5125 per tonne — 3½ times the present OPEC oil price.

The most important feature of our stylized "spaghetti chart" is that there is no economic demand for the commodities listed on the left-hand side. People do not want raw kilowatt-hours, fissioning uranium, lumps of coal, or barrels of sticky black goo. What people need is rather comfort, light, mobility, ability to bake bread and make steel — the end-use needs shown on the right-hand side. Logically, then, we should seek *the amount, type, and source of energy that will provide each desired end-use service at least cost.* Whether "cost" is defined to be only private internal cost or total social cost is a political decision that need not concern us here. The crucial point is that our goal should be to minimize the cost of providing energy services, not to maximize the amount of primary energy supplies. Traditionally, however, energy planners throughout the world have started on the left-hand side of the chart and treated energy demand as homogeneous — as if all forms of energy are alike, as if so many million metric tons of oil equivalent (Mtep)[4] of nuclear energy can simply substitute for so many million tonnes of oil, and as if the energy problem were merely to get *more energy, of any type, from any source, at any price.*

But in fact there are different forms of energy whose different qualities and prices suit them to different uses. The uses for which electricity (especially from new power stations) is suited are only a tenth of all needs for delivered energy in France. These premium markets, however, are filled up already: the power stations now in operation far exceed those needed to do those "electricity-specific" tasks. More electricity could *only* be used — as more than a third of the electricity in France today is being used — for heating: rather like cutting butter with a chainsaw.

Consider now the contradiction between the two conceptions of the energy problem — more energy of any kind *versus* the right kind for each task. Planners seeking to minimize the cost of energy services might begin by asking, say, what is the cheapest way to heat a building. They will find that new power stations are the costliest way, and so seek a national policy of discouraging or even phasing out electric heat as a waste of money and fuel. But meanwhile, more supply-oriented planners will be starting on the left-hand side of the spaghetti chart, and musing: "We must replace the foreign oil coming into our country; oil is energy; we need some other source of energy; nuclear power provides energy; Voilà! We shall build reactors." By not carefully considering what the energy is to be used for, and what forms of energy will do each task cheapest, such supply-oriented planners will end up building reactors whose electricity cannot be sold *except* for heating — precisely what the more cost-conscious planners had already decided not to do.

From this purely economic point of view, the feature of nuclear power plants which makes them irrelevant to the energy problem is not that they are nuclear; it is that they produce a form of energy — expensive electricity[5] — for which there is no additional market[6]. Debating what kind of power station to build is thus somewhat like shopping for the best buy in brandy to burn in your car, or the best buy in antique furniture to burn in your stove. It is, from the end-use point of view, the *wrong question.*

If one does not build a nuclear power station, the substitute for it is neither a new coal-fired power station nor an existing oil-fired power station. It does not matter which of these power stations can provide the cheapest electricity, because *none* of them can even remotely compete[7], in either cost or speed, with the *real* competitors — the cheapest ways to provide the same end-use services. Those cheapest ways include draftproofing, thermal insulation, window shutters and shades and coatings, greenhouses, heat exchangers, and the like. Indeed, because such measures, properly done, cost only about two centimes (0.4c) per kW-h (SERI 1981), or less than the *running costs alone* for a new nuclear power plant, a nation that has just finished building such a plant would probably save money by writing it off and never operating it (Lovins 1981a; Lovins & Lovins 1980:48-49).

Economic Priorities

Economists will recognize this approach as the familiar process of listing successive points on a "supply curve" — ways of providing increasing amounts of a particular energy service at increasing incremental cost — and pursuing the cheapest measures first. For providing warmth in a building, for example, stopping up holes in the walls is usually cheaper than thermal insulation, which is often cheaper than passive solar measures, which are generally cheaper than active solar collectors, which are generally cheaper (if intelligently designed) than electric heating, even with a heat pump (Lovins 1981; Sant 1980, 1981; SERI 1981).

The same logic applies also to substituting for existing oil-fired power plants. If one wants more electricity, whether for such substitution *or* to provide more electricity-specific energy services, then the available sources of that extra electricity, in approximate order of increasing price, are:

1. Eliminate pure waste of electricity, such as lighting empty offices at headache level. Each kW-h saved — at essentially zero cost — can be resold.
2. Replace with architecture — better thermal efficiency and cost-effective solar systems — the electricity now used for space-conditioning and water-heating. Electric utilities with over 40% of U.S. generating capacity now give low-or zero-interest loans for such measures because the electricity thus saved for resale costs them far less than building a new power station.
3. Make electricity-specific uses as efficient as is worthwhile compared to building a new power station. This means, for example, at least doubling the average practical efficiency of industrial electric motors and their drive trains[8] (Murgatroyd & Wilkins, 1976), trebling that of lights, and quadrupling that of household appliances (Nørgård, 1979, 1979a). The costliest such measures pay back, at present French electricity prices, in five years (Lovins and others, 1981).

By these means alone, France could operate an economy larger than today's, with no changes in lifestyle, using no thermal power stations of any kind — old or new, fuelled with oil, gas, coal, or uranium. Just the present hydroelectric capacity would provide a surplus of electricity — if France used electricity in a way that saves money. But if still more electricity were desired, the next cheapest sources would include (Lovins & Lovins 1981; Sant, 1980, 1981; SERI, 1981):

4. Industrial cogeneration, combined-heat-and-power stations, low-temperature heat engines run by industrial waste heat ("bottoming cycles") or by solar ponds, modern wind machines and small-scale hydro in good sites, filling empty turbine bays in existing large dams, and within a few years — if not already[9] — solar cells (photovoltaics).

It is only after these cheaper measures had been exhausted that one would consider

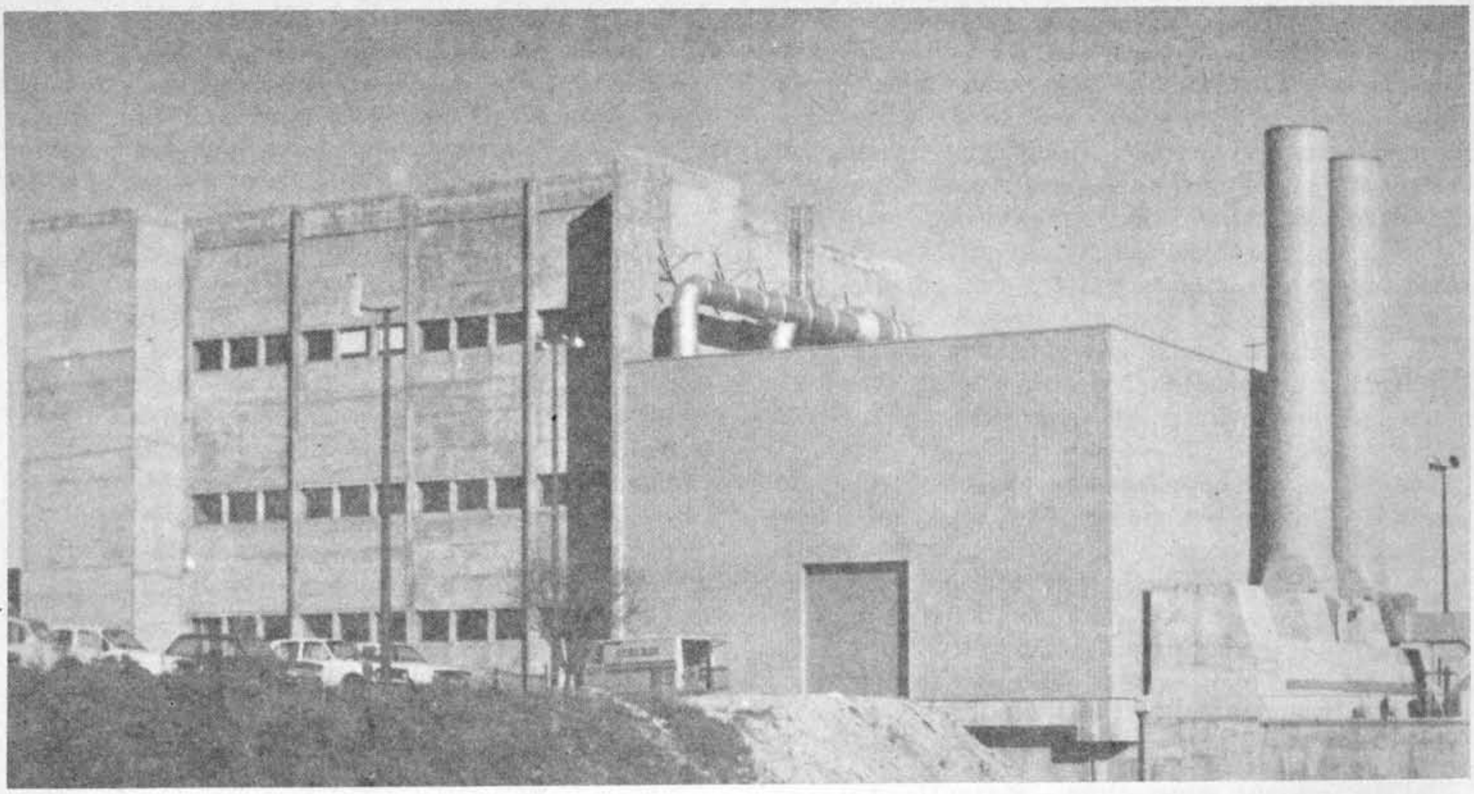
5. Building a new central power station —

because that is the costliest and slowest known way to get more electricity, or to save oil.

Saving oil is rightly a high priority for Europe and for France. Traditional emphasis on replacing oil with electricity, however — France plans a direct uranium-for-oil swap (Carle, 1981) — ignores both the high relative price of electricity and the very limited scope for direct replacement, since only about a tenth of all oil used (a rapidly decreasing fraction) is burned in power stations. The other nine-tenths of the oil provides heat and mobility — markets in which new power stations are certainly uncompetitive (Sant, 1980, 1981) if not altogether impractical[10]. Even in 1975, when the burning of oil in power stations was more common than now, the instant replacement of all OECD countries' oil-fired power stations by nuclear reactors would have decreased OECD oil imports by only 12% and the imported fraction of oil used by about 5% (Taylor, 1979). In France, where a third of the electricity was hydraulically generated, the overnight substitution would have decreased oil imports by about 10% and the imported fraction of oil used by only about 0.5% (ibid.). Worse, the substitution would not have been instantaneous, and would have replaced oil imports with broadly comparable uranium (and capital) imports, even assuming successful deployment of fast breeder reactors[11]. The type of nuclear reactor assumed — thermal or fast, burner or breeder — has no significant effect on the basic economic argument outlined above (though breeders probably worsen such problems as safety, waste management, and proliferation, and look uncompetitive even with today's thermal reactors until at least the mid-twenty-first century (Lovins & Lovins, 1980)).

Because most oil provides heat and mobility, any serious program to save oil must focus on these uses. In the United States, simple programs to weatherize buildings and replace inefficient with efficient cars — or, in brief, to stop living in sieves and stop driving Petropigs — could eliminate oil imports within this decade, before a power station ordered now could deliver any energy whatever, and at a tenth of its cost (Schneider, 1981). In France, the priorities would be more weighted towards buildings than cars[12]. But data below suggest that French efficiency goals fall far short of what is now technically feasible and economically worthwhile. If cheaper and faster measures to save oil are not exhausted first, then every franc spent to build power plants will actually *slow down* oil replacement because that franc is no longer available to be spent on more effective measures.

To summarize the argument so far: comparing nuclear power with other kinds of central power stations is assuming the wrong competitor. It does not matter whether uranium is cheaper than oil, since neither is cheaper than mineral wool. The issue is not nuclear *versus* coal-fired power stations[13] *versus* unemployment and freezing in the dark; rather, nuclear power *versus* the full range of cheaper ways to meet each of our energy service needs. All these investment opportunities must be compared fairly and symmetrically with each other in costs, rates, risks, and difficulties, to determine the best package of measures. Instead, however, French energy policy, like that of most other countries, has been dominated by a left-to-



Marcoule Vitrification plant in France. Nuclear power depends on such plants working properly if it is to have any future.

right reading of the spaghetti chart — by a supposed need for a profound transformation of *how energy is used* in order to use *the form of energy supplied* by the technology chosen.

Economic Risks

This transformation has included stimulation of demand for electricity, especially for heating. (Over 40% of new housing starts in France in recent years have been heated by electric resistance.) But if people who heat with electricity are not to face ruinous incremental costs, their heating must be cross-subsidized by other classes of users, or the new supply investments must be subsidized by the Treasury, or both, in perpetuity. The economic burden is apparently being shifted in both these ways (for example, in the Treasury's forgiveness of five milliard francs in EdF debt in early 1980); but from the point of view of the whole nation, the extra cost can only be shuffled around, not avoided.

Furthermore, investment in electrical supply beyond the true economic demand for this form of energy poses grave financial risks for the solvency of any electrical generating enterprise — even a large, publically owned one such as Electricité de France. Demand for electricity may be so sensitive to price that higher prices may actually reduce long-run revenues; and even if the response is smaller than that, it can occur so much faster than plant construction that EdF overbuilds beyond its ability to amortize the new plants from revenues (Lovins, 1979, 1981). The same unstable cash-flow, large price response, and saturated market that have already brought many public and private electric utilities, in many countries, to the brink of insolvency also threaten EdF. In this respect there is nothing unique in French conditions which could protect EdF from the fiscal consequences of overinvestment. EdF's big problem in the 1990s may be, not keeping up with growth in electrical demand, but writing off more than a hundred milliard francs' worth of uncompetitive thermal generating plants.

Such a massive misallocation of resources also has broader macroeconomic effects. In the U.S., for example, every 1-GWe power station built *loses* the economy about four thousand net jobs, directly and indirectly, by starving other sectors for capital (Hannon, 1976). Likewise, in an era of floating exchange rates seeking equilibrium, subsidized exports of nuclear equipment produce no net economic benefit for France. This is because, in consequence of an economic principle known as Lerner's Symmetry Theorem, any balance-of-trade gain is offset by a corresponding "import rebound." The only net effect is therefore to transfer income, capital, and jobs from non-nuclear to nuclear industries *within France* (OMB, 1975).

The Least-Cost Alternative

As all these economic risks have become more widely appreciated in recent years, a safer and cheaper alternative has emerged. Technological progress has been extraordinarily rapid, and information once available only to a few has become more widely known, in two broad technical areas not seriously considered in the original French nuclear decisions: energy efficiency and renewable energy sources. Despite the gratifying increase in French efforts in these directions, recent international developments suggest that France, like other countries, is still not devoting to them nearly the attention they merit — simply because the nuclear program has already pre-empted such a large share of national resources.

The state of the art in efficient energy use and appropriate[14] renewable sources has been reviewed elsewhere

(Lovins, 1978; Lovins & Lovins, 1981; Lovins and others 1981; SERI, 1981; *Soft Energy Notes*) in far greater and more technical detail than is possible here. A useful indication can be gained, however, from a few salient examples.

Nearly a third of the end-use energy in France is used to heat buildings. Compared to the Western European housing stock (Schipper & Ketoff, 1980), the best present art in new houses needs only 0-5% as much space-heating energy to maintain greater levels of comfort (Rosenfield and others, 1980; USDOE, 1981). The extra capital cost of such "superinsulated" buildings is recovered through energy savings in at most a few years (ibid.; Lovins and others, 1981). Detailed analyses and practical experience in several European countries have likewise shown that it is cheaper to save at least 80% of the heat used in most existing buildings than to build a power station to heat them, even via a heat pump (Krause, 1980; Lovins and others, 1981; Nørgård, 1979; Olivier and others, 1981; Romig & Leach, 1977). Upwards of half the heat can be saved by straightforward measures that were cost-effective against the oil and gas prices of several years ago (ibid.). Savings in the commercial sector are typically even larger and cheaper (Lovins and others, 1981; Rosenfeld and others, 1980; SERI, 1981). Equally simple hardware now available can cost-effectively save more than half the energy used to heat domestic water (ibid.). In sum, higher energy productivity in European buildings can reduce their energy needs to only 10-20% of the present level, at a fairly steady rate over the next fifty years or so, with considerable gains in comfort and convenience (Lovins and others, 1981).

Equally remarkable progress has been made in transportation (ibid.; Gray & von Hippel, 1981). A typical European car consumes of the order of 10 litres of fuel per 100 km driven (24 miles per U.S. gallon). A cost-effective combination — paying back in a few years at present fuel prices — of proven technical measures can improve this by about 80%, i.e. to 2.1 *l*/100 km (110 mpg) (ibid.). With a 30% share of 2-passenger models in the fleet, this would drop to 1.9 *l*/100 km (125 mpg). By early 1981, Volkswagen had already made an advanced diesel Golf (Rabbit) prototype with tested USEPA efficiencies of 3.0 and 2.4 *l*/100 km (80 and 100 mpg) for city and highway driving respectively; even these figures could be considerably improved, e.g. by an infinitely variable transmission or series hybrid drive. Such cars are comfortable, can perform about the same as today's models, and can resist crashes much better (via energy-absorbing but very lightweight materials). Available, cost-effective technical measures can likewise improve the typical European efficiencies, per passenger-km or per tonne-km, of buses and trucks by 50-60%, of railways and ships by 25-50%, and of civil aircraft by about 50% (Lovins and others, 1981). If such measures had been thoroughly used in FR Germany in 1973, they would have provided exactly the same transportation services at lower financial cost, using 64% less fuel (ibid.), without requiring any further technical progress or change in lifestyle.

A nine-sector analysis of the 1973 FR German industrial sector (ibid.) shows, conservatively, that cost-effective and well-documented technical improvements would have raised sectoral energy productivity by at least 45% — or by 57% if a more energy-conscious materials policy were also adopted. This does not include the parallel effect of change in the composition of industrial output, which has in fact been the largest contributor to French energy savings in industry during 1960-78 (CGP, 1981: 21). The full technical efficiency improvement alone may take the best part of a half-century to achieve, but has already begun. It is broadly consistent with this expectation that the 8th Plan projects, conservatively, about a 29% improvement in energy per unit value added in French industry during 1978-2000 (ibid.:63).

Adding up the Savings

Detailed, disaggregated national analyses of how much energy efficiency is worth buying cannot be precisely transferred to a different country. Nonetheless, it is instructive, and sufficiently accurate for present purposes, to illustrate the potential by applying to the entire economy of France the aggregate efficiency gain derived from an up-to-date 14-sector analysis of the 1973 FR German economy (Lovins and others, 1981). (Models with hundreds of sectors, such as that of Olivier and others (1981), tend to identify larger total savings.) On this basis, one could envisage in the year 2030 a France as urbanized as today, with a real Gross Domestic Product (GDP) 2.8 times today's (assuming this to be possible and desirable on other grounds), but with energy use totalling about 53% *less* than today's.

For the European Economic Community as a whole, if Europe's largest energy resource — the inefficiencies in using energy today — were mined systematically, though not exhaustively, economic activity could increase 2.4-fold while energy use simultaneously *fell* by 57% — just about the EEC's present energy import dependence. Thus the EEC would be energy-independent if new sources merely balanced any decline in the present rate of extraction of domestic fuels. Similar arguments suggest (Lovins and others, 1981) that even with massive industrialization of all developing countries and with a doubling of global population, economically efficient use of energy would decrease total world energy needs, by about 2030, to about a third less than their present level. In the longer term, even with further economic growth in the developing countries, total energy needs would be lower still (about 3½ TW, compared with 8-9 TW today), and the use of both fossil and nuclear fuels would be about zero.

Such results must seem astonishing to anyone not acquainted in detail with the latest technical achievements in wringing more work from our energy. The technologies are moving so fast, and so many of the most important developments are not reported in the ordinary literature, that despite a few specialized international publications such as *Soft Energy Notes*, it is extremely difficult to keep up. But "energy shrinkage scenarios" are rapidly becoming commonplace as the logic of what Roger Sant (1980) calls the "least-cost energy strategy" penetrates official thinking. In the U.S., for example, a very detailed government study has shown (SERI, 1981) that least-cost investments just to the year 2000, assuming two-thirds growth in real GDP and large increases in personal comfort and mobility, could simultaneously decrease total energy needs to about a quarter below the present level, and reduce the use of non-renewable fuels by nearly half. The demand for central-station electricity, too, would probably decline — so far that if by 2000 the U.S. had retired all old, oil-fired, gas-fired, and nuclear power stations, there would still be capacity to spare. Similar results have recently emerged from careful, highly disaggregated analysis of European economies (Krause, 1980; Leach and others, 1981; Lovins and others, 1981; Nørgård, 1979; Olivier and others, 1981; Sørensen, 1981).

How Quickly?

In the 1970s it was widely assumed that efficiency improvement, even if economically worthwhile, would be very slow to achieve. But even the most sanguine students of energy savings have been astonished by their actual speed. In the EEC during 1973-78, for example, the ratio of primary energy use to GDP decreased by about 8% while primary energy used increased only 0.42% (St. Geours, 1979) — a ratio of about 19:1, implying that about 95% of all EEC economic growth was fuelled by energy savings and only about 5% by all net supply expansions combined. The average energy/GDP elasticity for that period was negative in the United Kingdom, The Netherlands, Belgium, and Luxembourg; the highest elasticities were only 0.4 (Denmark) and 0.3 (FR Germany). Later figures were better as real price increases started to bite. In the U.S., even more strikingly, the ratio of energy savings to net new supplies was 2.5:1 in 1973-78, over 50:1 in 1979, and nearly infinite in 1980 — when real GDP was flat (within about 0.1%, well inside the statistical noise level) while primary energy use fell by 3.7%. Moreover, nearly all these impressive savings have been "good-housekeeping" or "low-cost/no-cost" measures. They have barely scratched the surface of achievable savings that are cheaper than new supply (Lovins and others, 1981). It is true that the savings will gradually become harder and costlier to achieve. But at the same time, with or without help from governments, the many market imperfections that now inhibit efficient choices — such as lack of fair access to information and to capital — can be removed, and the real prices of fuels are bound to rise towards replacement cost. If these effects cancelled out the diminishing returns to efficiency investments, producing a more or less linear rate of long-term implementation, then the 1973-78 EEC record (8% saving) would imply an 80% (5-fold) saving over fifty years without anyone's really noticing.

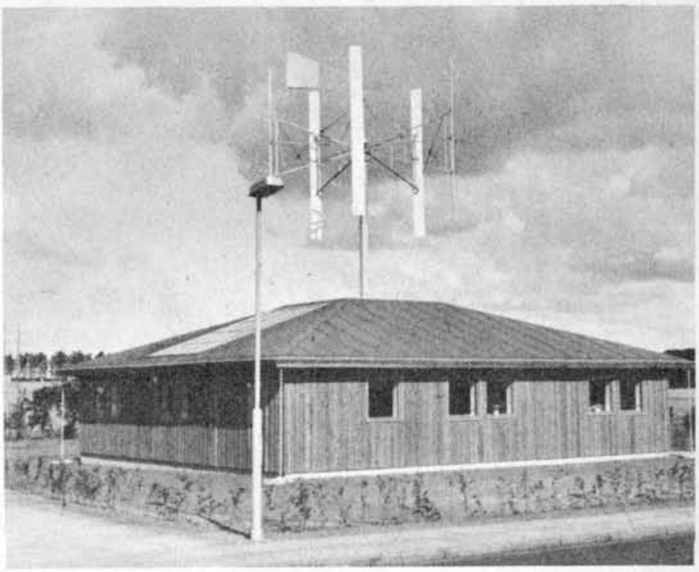
To put it another way: the EEC's 8% primary energy saving during 1973-78 amounted to some 3.1 EJ/y (about 64 Mtep, or 70% of the entire 1979 oil consumption of France). That primary energy was equivalent to about 2.36 EJ/y (49 Mtep) of delivered energy. But that much delivered energy would have been supplied, at the actual 1979 EEC capacity factor and grid loss, by *145 GWe* of additional installed nuclear capacity, which is *10.9 times as much* as the nuclear capacity which the EEC countries actually installed in the same period, at considerable economic and political cost. A relatively spontaneous efficiency "program" with scant resources outpaced a vigorous, lavishly funded nuclear program by better than ten to one. Even in France during 1973-79, the reduction in energy used per unit of GNP came approximately 10% from coal, 13% nuclear power, 14% hydro, 20% natural gas, and 41% from greater efficiency (calculated from Ministère de l'Industrie data (Sweet, 1981): a modest efficiency program outran the world's most aggressive nuclear program by 3.2:1.

Some local examples are even more striking. Heat losses in oil-fired FR German single-family dwellings fell by 20% during 1973-79. Nova Scotians weatherized half their houses in a year; some New England towns did over 15% in two months. Such savings add up on a national scale. Mainly by insulating buildings and switching to combined-heat-and-power stations, Denmark cut its total use of direct fuels by 20% during 1979-80. Japan has had seven years of essentially zero growth in energy use (better than France) with an average GDP growth rate of about 4%/y — at least a point faster than France. Millions of individual actions — people seeking to save energy to save money — are together outpacing the giant supply programs by tens or hundreds to one, despite an investment ratio of five or ten to one in the opposite direction. Though supply planners are often reluctant to pin their confidence on these decentralized, uncontrolled, individual actions, precisely the same mechanisms are at work here which have always been invoked as the rationale for forecasting *growth* in demand. The countless small choices which in the past have added up to national demand are simply responding to different signals of price, scarcity, and insecurity.

There are indeed good reasons to suppose that efficiency improvements will continue far to outpace complex, centralized, long-lead-time supply technologies. The former investments take days, weeks, or months to install, not a decade. They can diffuse rapidly into a vast consumer market, like digital watches or pocket calculators, rather than requiring a tedious "technology delivery" process to enter their narrow, specialized market, like huge power plants. Smaller, simpler, more understandable technologies can be designed, built, installed, and used by a wide range and a large number of people, so they can better adapt to local conditions and harness the ingenuity latent in any diverse society. Furthermore, big, complex technologies are slowed down by the same problems everywhere at once — finding a site, marshalling the capital, assembling and training the workers, building the infrastructure, inducing the local population to accept something they may not want. In contrast, smaller, simpler technologies are slowed down by diverse, temporary problems, which are *largely independent of each other* — problems of retraining in one case, building codes in another, marketing in another. Because of this independence of constraints, dozens of individually slowly-growing soft-path investments can add up, by strength of numbers, to very rapid total growth. This immense *diversity* of efficiency technologies is both an intrinsic source of their speed and an insurance policy against unforeseen technical or social obstacles.

Renewable Energy: An Awakening Giant

In one large, diverse country with which we are familiar — the United States — these same characteristics have already made renewable energy sources the second-fastest-growing source of additional energy supply (in terms of total energy added in recent years). Renewables came second only to efficiency improvements, and well ahead of all the vast expansion of U.S. coal-mining (RTM, 1981). The U.S., like Japan, already gets more than 7% of all its primary energy from renewable sources. It has about half a million solar buildings — half of them passive, and half of those made by adding greenhouses and Trombe glazing to existing buildings — and the number is doubling annually. In the most solar-conscious areas, about 6-7% of all space heating was already solar by 1980, and 25-100% of new housing starts were passive solar. In 1980, 15% of all U.S. house-builders and virtually all prefabricated housing companies offered passive solar designs. In New England, more than 150 factories switched from oil to wood, as have more than half of the rural households. Private woodburning has increased more than sixfold, and a few stove foundries grown to over 400, in a few years. The forest products industry now gets more than half its energy from its own wastes. There are over 40 principal wind-machine makers. Commercial "windfarms" are now successfully competing on utility grids in several states; larger ones are being built by some of the largest industrial firms; and Hawaii plans to get 9% of its electricity from wind by 1985[15]. Some 10-20 GWe of new, small-scale hydroelectric capacity will come onto the grid during 1981-83, and permits were sought during 1979-81 (mainly for commissioning by 1983) for a further 20+ GWe — twice as much as all U.S. nuclear orders (gross, not net of cancellations) since 1975. Under a 1978 law which helps to create a competitive market in electrical generation, entrepreneurs are springing up to collect surplus electricity — often from renewable sources or industrial cogeneration — and sell it back to the grid at a handsome profit. There are over a thousand retail outlets for fuel alcohol. Most states have biomass fuel programs, and many farmers' organizations are praising the improved economics and independence that integrated biomass systems can bring to previously marginal farms. Several geothermal industrial parks are under construction. An Israeli industrialist will offer in the U.S. in 1982 his successful 1981 scheme of contracting to supply solar steam to factories at 10% less cost than they now pay: he simply pockets the difference. Municipal governments are starting to profit from the energy and resource yields of solid wastes, from local small-hydro resources, and from selling energy savings to utilities for the money it saves them. Industrialists are eyeing emerging designs for low-cost, high-temperature collectors. Japanese industry, having sold at home in

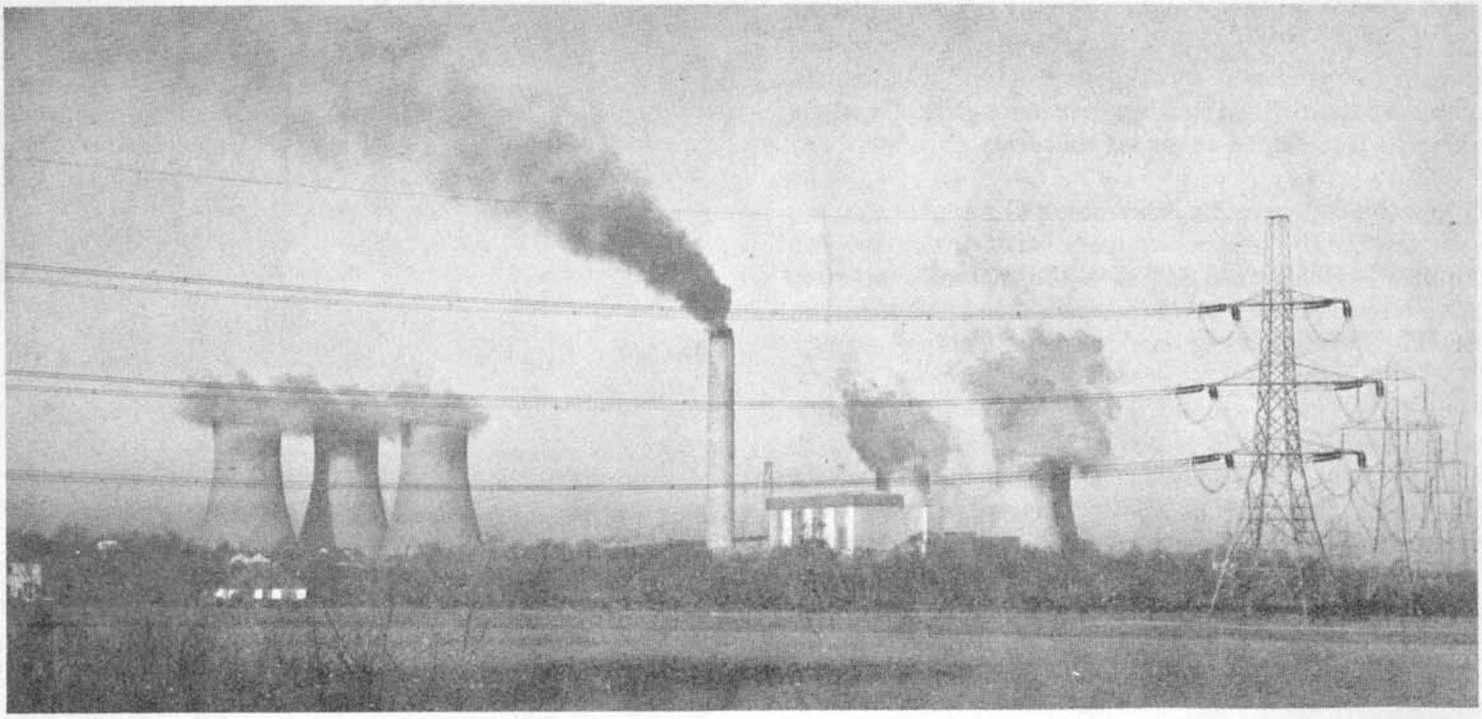


A rather ugly, but effective, 'zero energy' experimental house in Denmark (top) contrasted with a modern solar-energy house in West Germany. In Britain, the Department of Energy has been severely criticised by the 1980 House of Commons Select Committee on Energy for not devoting more resources towards research on energy conservation. "We were dismayed" comments the Committee, "that seven years after the first major oil price increases the Department of Energy has no clear idea whether investing around £1300 million in a single nuclear plant . . . is as cost effective as spending a similar sum to promote energy conservation."

1980 alone more than $500 million worth of solar collectors (750,000 for hot water and 13,000 for industrial process heat), is entering the U.S. market. Southern California Edison Company, one of America's largest private utilities, has switched its top investment priorities from central stations to efficiency and renewables, because they are now the best buy. In short, diverse, localized initiatives in thousands of communities and millions of factories, offices, and homes — actions taken from the bottom up, not from the top down — are adding up to a quiet energy revolution that is reshaping the American energy system with unprecedented speed. A similar process is at work in Japan, Sweden, Denmark, and elsewhere.

Countries without Oil

Despite such new empirical evidence, it is commonly said that renewable energy sources will take a long time to develop and deploy — or, in Remy Carle's



Didcot, a modern coal-fired plant in the UK. Can we continue to accept such pollution when the technology exists for controlling it?

words (1981), that "several decades will pass before 'les energies nouvelles' . . . make an impact in quantitative terms"; that energy savings are also slow and costly and are at best a partial answer; and that only large increments of conventional supply technologies, therefore, can be relied on in the near term. But failure to assess *comparative* rates of oil displacement runs the risk that, having dismissed renewables as slow, efficiency improvements as costly, and both as inadequate, one may choose an investment stategy that is simultaneously slow, costly, *and* inadequate.

If speed is of the essence, speed must be assessed: per franc invested, what will save the most oil soonest? Hardly nuclear power — the most complex, demanding, and specialized energy technology available. The very short lead times for getting efficiency improvements and soft technologies in place enable them to start displacing oil (and saving energy and money) right away, not in 1988. They come in affordable, flexible increments, not a billion dollars at a time. They can be ordered and installed before there is time for them to incur escalation and interest charges. And they provide more jobs — better distributed by locality and occupation — than power stations, further aiding their rapid acceptance, rather than largely monopolizing the scarce technical skills needed at the cutting edge of the economy.

Decisions to buy efficiency or renewable technologies *need not depend* on whether, which, or how much indigenous fossil fuel a country has available. It is sometimes argued that an ultimately solar-based economy, though perhaps attractive for a country which (like the United States) has abundant transitional fuels, is out of the question for countries (like France) dependent from day to day on massive oil imports. But this argument asymmetrically begs the question of what fuels such fuel-short countries will use as a bridge to their proposed dependence on uranium and/or coal instead — for that shift, too, will take much time: by our arguments, even a longer time. In other words, whether a country has its own fossil fuels, or which ones, or how much of them, has *nothing to do* with whether conventional or soft-path investments can displace the country's oil use faster and cheaper. That is a quite separate question of logistics and (mainly) of institutional inertias. It is the key question to examine, starting now, for all alternative investments at the margin — including continuing the construction of power plants already begun. Many U.S. private utilities, following similar logic simply to ensure their economic survival, are now abandoning nuclear plants in which they have already invested up to a milliard francs or more. It would have been better, of course, not to invest that money in reactors at all; but even having done so, the utilities are better off cutting their losses than throwing good money after bad. The lower capital intensity and the short lead time and fast payback of efficiency/ renewables investments mean that every dollar, or franc, diverted from nuclear to soft-path investments is effectively multiplied, increasing its present value by at least severalfold (Kahn and others, 1980).

Doctrinaire assumptions about which investments will save oil (or provide energy services) fastest and cheapest are no substitute for sound analysis taking account of recent international progress. We are persuaded by the foregoing arguments and practical examples, as was the Harvard Business School's energy study (Stobaugh & Yergin, 1980), that the best such investment is improved energy efficiency, and that next come the appropriate and proven renewable sources. Next in priority of cost, speed, and difficulty are synthetic fuels; and last — costliest and slowest of all — are power stations. By never making that ranking, either through socialist planning or through a competitive marketplace, the principal nations of the world have, like France, taken those choices in reverse order, worst buys first. The new Government of France faces the challenge of adapting a nuclear program, begun in very different circumstances and amidst prevalent misconceptions about available alternatives to the world of today: a world where new power stations are simply uncompetitive with other measures by which end-users can obtain the same energy services more quickly, easily, and safely (Sant, 1980, 1981).

One of these new circumstances is the growing realization that many nations which are poor in fuels, such as France, are rich not only in ideas but also in energy — renewable energy. Perhaps the most impressive example is Japan, which has the widest range of renewable options of any industrial country (except possibly Norway and New Zealand) — enough, using present technology, to meet virtually all long-term energy needs quite comfortably (Tsuchiya, 1980). The same sufficiency of proven renewable sources applies to every country so far studied: about fifteen, including e.g. Britain (Olivier and others, 1981), FR Germany (Krause, 1980), Denmark (Meyer and others, 1977-80), Sweden (Johansson & Steen, 1978, 1981), the whole Nordic region (Sørensen, 1981) and of course the U.S. (Sørensen, 1980) and Canada (Brooks, 1981). France is particularly blessed with renewable energy flows that can be economically harnessed: not cheaply, but considerably more cheaply than nuclear power. The sun, whether direct or diffused through cloud, is sufficient to maintain comfort in efficient buildings throughout France and throughout the year, based on the foregoing analyses for less favourable climates. The French sun is also sufficient to provide high-temperature industrial heat using modern collector designs, some of which can provide 500-600°C under load on a cloudy winter day (Lovins & Lovins, 1981). France has abundant agricultural wastes — probably enough to run an efficient vehicle fleet without growing special fuel crops or endangering soil fertility. (Just the straw burned in the fields of France is equivalent to about a tenth of the entire primary energy use of France (Lewis, 1980).) French hydroelectric capacity, as mentioned earlier, would today provide a surplus of exportable electricity if efficiently used. It can also provide free storage for the grid integration of small hydro and of wind-power where sites are suitable; also of solar cells later in this decade (Lovins & Lovins, 1980; Sørensen, 1979). Rather detailed consideration of the technical and economic status of these technologies in European conditions (Caputo, 1981; Krause, 1980; Olivier and others, 1981; Lovins & Lovins, 1981; Lovins and others, 1981; Sørensen, 1979) suggests that if French energy investments were determined solely by lowest direct economic cost, France would within a few decades be a sizeable net exporter of renewable electricity and liquid fuels to the rest of Europe.

Energy Security

To grasp the full significance of a least-cost energy strategy for France, however, it is important to examine more closely the nature of energy security — allegedly the central motive of the French electronuclear program. In 1973, it was easy to imagine that energy meant oil, and that energy security meant ability either to keep the oil coming or to substitute for it those sources of energy that could not be cut off by other countries. But in France as elsewhere, most of the actions springing from this narrow conception of energy security have actually served to make energy supplies *more* vulnerable to disruption by accident or malice. In particular, as France learned on 19 December 1978, central-electric grids are among the most brittle energy systems known. Since they depend on dozens of large and precise machines rotating in exact synchrony, and strung together by a frail network of aerial arteries, they can be easily turned off — by sabotage, technical failure, or natural disaster — with instantaneous and calamitous social consequences.

Some results of the French emphasis on nuclear power are particularly worrisome: the lack of technical diversity in new French reactors (so that the same problem can be common to all of them); the prospect that a major release, perhaps by sabotage, of the inventory at La Hague or at a reactor could make an area larger than all France uninhabitable (Beyea, 1980; Fetter & Tsipis, 1980, 1981; Ramberg, 1980); and the prospect of a national breeder-reactor economy entirely dependent on the smooth functioning of a single reprocessing plant costing tens of milliards of francs. But even leaving these nuclear insecurities aside, the nature of a synchronized electric grid is such that a handful of people, perhaps even one person, could, using low technology, black out a city, a region, even much of Europe for a period of at least days and possibly a year or more (Lovins & Lovins, 1981). This risk, and the shift it implies in the balance of power between large and small groups in society, is causing much concern in certain military circles in France, as it is in the United States and the Soviet Union. In an age when trained terrorists are regularly attacking centralized energy systems from Angola to Chile and from Italy to Rhodesia, to balance the life of the nation on such a vulnerable system seems the height of imprudence. Detailed government reports in Sweden (FOA, 1981) and the U.S. (Lovins & Lovins, 1981) have lately shown that a more dispersed, diverse, renewable, and above all efficient energy system would be far more resilient in the face of all kinds of disruptions and surprises, deliberate or inadvertant. This is not the usual design philosophy of power engineers. The engineers of EdF are to be congratulated on their technical achievement in making French electrical supplies relatively reliable in the face of normal, predictable, calculable kinds of technical failure. But such reliability cannot achieve resilience against surprises — against the unexpected or unforeseeable (of which the 1978 blackout was an example) — and may even reduce it. What is needed is rather an energy system whose basic design makes catastrophic failures structurally *impossible.* The keystone of such a resilient system is high energy efficiency: this displaces the most insecure supplies (such as foreign oil and nuclear power), trims peak loads, limits extremes of system behaviour (such as the temperature swings in unheated buildings), and greatly increases the time and scope available for improvising new supplies to replace failed ones. In a least-cost combination with efficiency, relatively decentralized renewable sources can provide profound benefits for individual and national security.

Policy Implications

A least-cost, resilient energy strategy would avoid not only energy insecurity, but also many other political costs of a more centralized, electrified, nuclearized future: greater concentration of political and economic power, more subservience of local autonomy to central-government dictate, more inflation and unemployment, inequitable allocation of more energy (to rich urban people) and of its social costs (to poor rural people), more bureaucratization, more erosion of civil liberties. The soft energy path also averts the chilling prospect that in a few decades we shall have tens of thousands of bombs' worth of plutonium per year circulating as an item of commerce within the same international community that has never been able to stop the heroin traffic.

In contrast, the soft path is available equally to rich and poor, rural and urban. It is implemented largely by local and individual choice. It preserves competition and rewards enterprise. It gives the energy and the side-effects to the same people at the same time so that they can decide for themselves how much is enough. It enhances national security, yet is nonviolent. And it offers, by example and by the potential for direct help, the opportunity for developing countries to replace oil with those renewable sources which they too possess in such abundance. It is this convergence of political with economic logic that is already leading people and communities in many countries to begin to implement a soft energy path with surprising speed.

This approach implies a strategic sense—a concern for the unknowable long term—which has long distinguished French planning. But its implementation does not necessarily require, and may indeed be inimical to, the Napoleonic tradition of highly centralized planning. The kind of energy leadership which, by international experience, seems to work best is not a mandate of one massive but arcane technical project, but rather diverse efforts, at all levels of government, to ensure that everyone—from individuals to communities, from unions to banks—has the *incentive and opportunity* to address those parts of the energy problem which are nearest them. As Lao-tse said of this style of leadership some two and a half millenia ago:

> Leaders are best when people scarcely know
> they exist,
> not so good when people obey and acclaim
> them,
> worst when people despise them.
> Fail to honor people, they fail to honor you.
> But of good leaders who talk little,
> when their work is done, their task fulfilled,
> the people will all say: "We did this ourselves."

Notes:

1. We assume this figure even though the U.S. Energy Information Administration's detailed 1980 plant-by-plant analysis considered only 38.5-44.2 GWe feasible by 1990 (50.1-56.5 GWe by 1995) (EIA, 1980).
2. The USSR achieved only a third of its nuclear goal for the 1970s, half for the past five years; its first PWR is five years behind schedule.
3. The average end-1980 French domestic price. We assume (8/81) FFr5.9 = US$1.
4. Million metric tons (tonnes) of oil equivalent assumed equal to 48 x 10^{15}J.
5. If a source of extra electricity cheap enough to compete with direct fuels, i.e. around 1c/kW-h, should become available—as it may later in this decade via amorphous and other innovative photovoltaics—this limit might not apply.
6. The habit of accounting in primary energy terms exaggerates (by threefold) the need for and contribution of power stations. With electrification, over half the primary energy growth is lost in conversion and distribution, not delivered to users.
7. For detailed economic comparisons, see Lovins (1981) and Lovins & Lovins (1981).
8. Over 50 GWe of motors use 64% of French industrial electricity (CGP, 1981:30). A typical improvement in a 45-kW motor saves about 30% with an 18-month payback (:31). Better coupling and controls save still more (:32). A total saving of about 25% is conservatively expected for French industrial motors by 1990 alone (:34).
9. Conventional Czochralski-silicon-wafer arrays, now selling for $7-10/Wp, will sell for $2.80/Wp (1980 $) by late 1982 just by using proven production methods. The U.S. Department of Energy confidently expects $0.70/Wp—competitive on most utility grids in central-station applications—by *1986*, and many manufacturers (including Sanyo, which has built a $50 million commercial factory for amorphous-silicon cells) expect to beat this goal. Even $7/Wp arrays can compete on many U.S. grids today with cheap optical concentrators and waste-heat recovery on a single-building scale, and on a community scale, $15/Wp is economic to-day (Ross & Williams, 1981).
10. Nuclear district heating, even if practicable, is still uneconomic—about the same as nuclear-electric heat pumps. Nuclear process heat, e.g. in steelmaking, is at best very far off and probably impracticable. Pure-electric cars cannot, even in principle and assuming battery breakthroughs, compete with highly efficient fuelled cars, such as series hybrids, which offer all the same advantages without having to carry around a tonne of batteries.
11. This is because the plutonium fuel cycle, even with implausibly short breeder doubling times, takes over a century to come to equilibrium: each GWe of breeder capacity needs about 30 GWy of LWR operation first to make its startup inventory of plutonium. As a result, if, for example, France achieved her 1976 goal of 104 GWe of nuclear capacity by 2000, and if primary energy demand growth slowed from 5.3%/y (1963-73) to 3.8%/y (1976-2000: Workshop on Alternative Energy Strategies, Case C-2), then despite aggressive breeder use and domestic uranium mining, France in 2000 would be importing nearly half her uranium, and using 70% *more* oil and gas than in 1975. Imports would include about 130 Mtep of oil, 65 gas, 7 coal, and 70 uranium (or 127 without thermal plutonium recycle)—about 8,600 to 15,600 short tons of U_3O_8 per year (Taylor, 1979). Recently lowered demand forecasts do not change the principle of this example: nuclear power provides too little, too late.
12. Cars are still important, however. In FR Germany (Lovins and others, 1981), a shift of fleet efficiency from its 1973 level (10.6 *l*/100 km) to 4 *l*/100 km would have saved, at 1973 car and driving levels, over 14 milliard *l*/y of gasoline, worth at early-1981 prices some $9 milliard per year—an average of $530/car y. Such a cash flow in the hands of German consumers rather than of OPEC should have a large multiplier effect, and is produced by an inflation-proof investment. FRG buildings used over three times as much fuel in 1973 as cars, and thus offer even greater scope for rapid savings.
13. After years of this irrelevant debate in the U.S., it is turning out that nuclear expansion there has displaced mainly coal, not oil, and that the idled coal plants could more than displace all the oil plants (Brody, 1981; Lovins & Lovins, 1980). Moreover, nuclear plants commissioned in the U.S. have sent out costlier electricity than contemporaneous coal plants since about 1975 (Komanoff, 1981, 1981a). Publically available French marginal-cost comparisons are too opaque and unspecific to support any conclusion; but neither are they relevant in a least-cost strategy.
14. Appropriate, that is, in energy quality and in scale, in order to minimize the economic cost of providing a given energy service. We also call such renewables "soft ('douces') technologies". Not all renewable sources are soft.
15. The Netherlands is shortly expected to approve a windpower project yielding 12% of projected power demand, or 9 TW-h/y, in 2000 (3 by 1990): *Business Week* 42L, 7.IX.81.

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Books

The Unacceptable Face of the Nuclear Industry

NUCLEAR WITNESSES. INSIDERS SPEAK OUT. Leslie J. Freeman. W. W. Norton, $16.95.

"Back in 1947 they knew. The data had been gathered at Argonne National Laboratory. They knew that the newborn puppies, whose mothers had been fed small amounts of radioactive strontium-90, were dying of underdevelopment and serious birth defects. The government knew and decided to keep it secret. The government set up the study. The government knew the results. And the government kept those results from the American people. Why?"

These are the words of the physicist Ernest J. Sternglass, one of the sixteen men and women whose first-hand experiences of the United States' nuclear establishment have been gathered together in *Nuclear Witnesses.* Secrecy is one of the book's recurring themes: a secrecy that conceals, among much else, negligence, misjudgement, plain ignorance and corporate greed.

From these accounts it's clear that the working practices of the nuclear industry leave ample room for improvement. A carpenter employed in reactor construction reports that concrete supports, cracked as a result of careless pouring, were simply patched over to conceal them from site inspectors; that unqualified workers were employed to weld the reactor vessel; and that the site foreman routinely issued incorrect instructions because he didn't understand how to read a blueprint. A pipefitter recounts that levels of reactivity inside a plant which had been operating for some time became so high that maintenance staff reached the federally permitted dose for a three-month period in a week and a half, and were hired on a half-daily basis for the dirtiest jobs, and used up their and were then laid off until the next quarter; at a fuel-reprocessing plant, transfers were hired on a half-day basis for the dirtiest jobs, and used up their three months' allowance in a matter of minutes. Day-to-day problems of plant operation are solved by improvisation and fagding: "What keeps a nuclear plant running," an engineer remarks, "is lots of Kotex, lots of masking tape, and lots of plastic bags."

One of the reasons for the secrecy surrounding the civilian nuclear power programme is that it has been run in close harness with the military weapons programme; around 40 per cent of the Department of Energy's budget is spent on weapons production. Not only do civilian reactors provide a useful source of plutonium for bombs, but they also play an important propaganda role, in promoting the idea of "atoms for peace". *Nuclear Witnesses* includes recollections of the first phase of this campaign, Project Plowshare, which envisaged using nuclear explosions for civil-engineering purposes. One scheme was to excavate gigantic underground cavities for storing natural gas. Tests were made, but the gas was found to be too radioactive to use; in one case, as a result of miscalculation, the explosion broke through the surface, releasing radioactivity into the atmosphere. Far worse fallout would have resulted from another scheme: the creation of a new Panama Canal by exploding a chain of bombs. There was also a proposal for a nuclear-powered aeroplane but, after millions of dollars had been spent, the project foundered on an insoluble design problem: the larger the reactor, the more lead shielding required; and the more lead on board, the larger the reactor had to be.

Some design problems are discovered too late: in one nuclear installation described in *Nuclear Witnesses,* a duct carrying radioactive waste gases was laid under the floor of a laboratory where a dozen people worked. In the course of time, the duct became highly contaminated, and radiation in the lab above reached dangerous levels. Rather than having the duct cleaned, which would mean shutting down the plant, an expensive operation, the management insisted that lead sheet be laid on the lab floor instead; as the radioactivity increased, further layers were laid down, to a depth approaching an inch.

Most of those whose testimony Leslie Freeman quotes have paid a price for speaking out: construction and maintenance workers find that they're out of a job and, as likely as not, out of the union too, which makes it difficult to find other work; engineers are subjected to "the closest I've ever come to experiencing a witchhunt" and accused of political motives; scientists face harassment and assaults on their scientific competence and, if they persist, lose their research funds. One reports an attempt on his life. As head of a health and safety team at Lawrence Livermore Laboratory, John Gofman quickly discovered the Atomic Energy Commission's attitude towards scientific papers that imply health risks of radiation: "We must stop that publication," he was told on one occasion. "If we don't stop that publication, the credibility of the AEC will just disappear, because it will be stated that we've been lying." In time, the credibility of the AEC did disappear; it was re-organised and renamed, but not re-staffed.

Nuclear Witnesses is an excellent book. Through his choice of informants and in his explanatory notes and interpolations, Leslie Freeman gives a comprehensive view of the nuclear business, both historically, starting with its Cold War origins, and across the fuel cycle, beginning with cancer-ridden uranium miners. The effect is invigorating: when confronted with the clean self-image of technological excellence and scientific rigour that the industry would like to present, it's good to be reminded of the messy realm of patch-and-hope engineering, the profit motive and the bomb programme that it actually occupies. The last word can go to John Gofman: "the whole thing about nuclear power is this simple: can you or can't you keep it all contained? . . . The answer is they're not going to accomplish it. It's outside the realms of human prospects."

Bernard Gilbert

Morality Suspended

NUCLEAR BRITAIN, Peter Bunyard, New English Library, £1.50.

'Nuclear Britain' is a first-rate survey of the short but explosive history of the atom. It takes us from Rutherford to Hiroshima to Windscale to Three Mile Island and a little beyond. It provides all the basic facts for an obituary of nuclear power.

It might seem a little premature to suggest the demise of the nuclear industry, but Peter Bunyard's book contains enough information to allow the reader to diagnose that the industry is suffering from a terminal disease. It is perhaps significant that the book's preface has already been superceded by events. In it, the author tells us of the angry story of Plogoff in Brittany. Police, gendarmes and parachutists were called in by the French authorities when thousands of protesters decided to obstruct the siting of a nuclear power station planned for the area.

Significantly perhaps, between the time Peter Bunyard submitted his manuscript and the time the book was published, the new French President cancelled the project.

There are other clues to be had that the nuclear industry's previous zeal had been somewhat dampened. Why has the decision on the building of Britain's commercial fast reactor been so long in coming? Why have plans to mine Orkney uranium been shelved? Why were the authorities so reluctant to flex their muscles at Luxulyan in Cornwall where protesters held up drilling operations on a possible power station site for so long? Could it be that public opinion, once enthusiastic has now become indifferent or even sceptical towards nuclear power?

It is, of course, far, far too early for the anti-nukes to start dancing in the streets to celebrate the demise of the atomic goliath. There are however grounds for optimism. In the western world at least, if the experts fail to fool all of the people all of the time, there are limits to which they can go to enforce unpopular policies. It is true that important information can be withheld and the propaganda machine manipulated to prevent the people from knowing the full implications of all the facts, but once even some of these implications are realised, there is a limit to the amount of legal and physical power the authorities can use to get their own way.

In much of Europe, America and even Britain, governments acknowledge that the anti-nuclear lobby is a significant force and one which has to be allowed for in any future planning. To commit Britain to a full nuclear economy would involve committing the authorities to a long, drawn out struggle which they might not win and which would offend every British sense of decency and fair-mindedness. To give one example, if any attempt was made to mine uranium in Orkney, the lack of cooperation and even outright hostility from the island people would hamper the operation and make it virtually impossible. Mining could only take place with a massive use of troops which would outrage the rest of Britain and make the exercise politically impossible.

For many years now the nuclear debate in Britain has been carried out between two sets of people who have not been speaking the same language. It is no wonder the debate has been a series of confrontations. The classic example was the Windscale inquiry. The anti-nuclear group knew that they had the best of the argument and yet, in Peter Bunyard's words, the report by Mr. Justice Parker was 'a total sell-out to the establishment, every single point being conceded to the pro-nuclear lobby. His conclusions and recommendations were seen as an enormous insult to the objectors.'

While superficially the two sides were heard to be talking the same language, in reality they were not. The nuclear debate is a political debate and the two sides held such totally different political assumptions there was no room for consensus. What makes it harder for the ordinary political commentator when trying to interpret the debate is that the political division has nothing to do with the traditional left wing-right wing spectrum of debate.

One of the values of Peter Bunyard's book is that it deals with the nuclear issue as a political issue. Despite the high-powered physics involved in the atomic industry, most of which is not too difficult to follow provided one understands the language of mathematics, the basic issues raised are not hard to comprehend. Indeed the basic scientific facts are not in dispute. Neither are the areas of ignorance. It is known, for instance, that radioactivity is harmful. It is not known however what the long-term effects of small doses might be. The political division comes about when risk has to be evaluated in social terms. The pro-nuclear group says that to maintain industrial society we will need nuclear energy despite the small, but in the circumstances acceptable, risk. We don't want to go back to the stone age do we? The anti-nuclear group looks at the same facts and agreed risks and says, it is better to look for an alternative to the industrial society we have today, because the risks involved in going nuclear, as small as they might be in terms of probability, are too great and dangerous in effect if anything should go wrong.

As Peter Bunyard's chronicle of the nuclear saga shows, once an individual, or an institution gets locked into one or other mode of thought, little can be done to bring about a change in outlook. Indeed any tactics, however underhand or illegal, can be justified in pursuit of one's goal. As in war, morality is suspended. It is only by one side or another winning the hearts of the uncommitted that victory can be achieved.

In the western democracies there is evidence that the battle for the hearts of the uncommitted is being won by the anti-nuclear lobby. Few inroads are being made however in areas where the nuclear issue is not open to public debate. The totalitarian states, particularly those where civil and military nuclear programmes are intertwined, pursue atomic research unbothered by protesters and public inquiries.

The danger is that if it should be that one of the totalitarian states brings about the death of the nuclear industry, there will be no one left on the planet to write about the obituary.

The book's strong point is that it provides a clear and readable history of nuclear power in Britain, particularly the history of the first generation of reactors and the political decisions involved.

The book's weakness is that it lacks an index.

Ted Harrison

The Finest Products of the Human Species

THE PHYSICISTS: A Generation that changed the world. C.P. Snow. Macmillan, £8.95.

C.P. Snow's account of the development of 20th century physics, and of the personalities involved, is, as might be expected from a lifelong apologist of science, unflinchingly orthodox. Written largely from his own memory, the main value of *The Physicists* seems to me to lie in the character sketches of the chief protagonists of this "generation that changed the world", many of whom Snow knew personally. The descriptions of Rutherford and Bohr, for example, are particularly evocative. The book is also copiously illustrated with photographs of the physicists whom Snow talks about, as well as of some of the instruments and machinery used in research.

Written in what is sometimes a rather laconic, abbreviated style, *The Physicists* is in fact a first draft which Snow had intended to expand, but which he was prevented from doing by his death in July, 1980. As William Cooper, who was a lifelong friend of Snow, explains in the introduction, Snow wrote the book "straight off and at great speed", which may account for the occasional innacuracy and also for the imbalance of the book in favour of atomic and nuclear physics. The brief sections on radio astronomy, molecular biology and the silicon chip together take up less than a tenth of the book, and solid-state physics is not mentioned at all. Clearly, Snow's main interest was in the spectacular story of the unveiling of the mysterious micro-world in the "golden age" of physics before the 1930s, a process which culminated in the fission of the atomic nucleus and the production of the atomic bomb in 1945.

Throughout the book, the feeling that Snow seems to want to excite in the reader is that here were the greatest men doing the greatest things: it is not for us mere mortals, who do not belong to the scientific elite, to question what they were doing, but rather to lower our heads in awe at their superhuman achievements. In the professional scientist, who is epitomized in the nuclear physicist, we find the highest product of the human species; likewise, in the professional life of the scientist we have a model of the most desirable life, which ordinary people can but aspire towards, but presumably never attain without themselves becoming scientists. It is constantly reiterated that, while sharing in the imperfections and frailties of common humanity, nuclear physicists have tended to embody supreme human virtues such as wisdom, benevolence and magnanimity. In a moment of extravagance, Snow describes Niels Bohr as "the quintessence of Scandinavian virtue and the personification of Nordic manhood". A more serious consequence of Snow's tendency towards unreserved eulogy is his quite uncritical acceptance of the rightness of the decision of scientists during World War II to work on the atom bomb. "There was no scientist or anyone else involved who didn't believe that the work was necessary. That included Einstein and Bohr, who were among the loftiest and the most benign spirits of our species. They don't need to receive moral instruction from persons who did not live inside the situation." Despite the appallingly destructive forces that nuclear physics has placed in human hands, Snow is broadly optimistic about the future. Not only are nuclear weapons relatively beneficial as peacekeepers, but we may look forward to a future in which infinite sources of energy may be supplied from nuclear fusion — a prospect which Snow thinks is wholly advantageous. Nuclear energy generated by fission is, oddly enough, not mentioned.

It seems to me that no really serious questions are raised in this book and, as if in recognition of this defect, William Cooper has seen fit to add as an appendix the text of a lecture delivered by Snow in 1960 entitled "The Moral Un-neutrality of Science". In it Snow argues that while it would be too much to ask of scientists that they refuse to work on projects which may lead to the development of technologies which have morally questionable consequences, scientists do have an obligation to publicise the knowledge they have, so that members of the public are made aware of the implications of what they are doing. Here the important question of the ethical responsibilities of scientists is at least brought up, though we may baulk at Snow's answer to this question, which amounts to a moral passing of the buck. For physicists must surely bear some moral responsibility simply for putting into human hands vastly increased powers to do inhuman things (I am thinking here not simply of war technologies, but of peacetime ones like genetic engineering). A question that is scarcely touched on in the book, but which I find myself left with after reading it, is: what is it that motivates Snow's physicists in their drive to lay bare the secrets of the sub-atomic world? Is it a desire to understand the foundations of existence (in which case it must in part be a religious urge), or is it a desire to control and manipulate nature for the benefit of humanity, or is it merely an incessant and unbridled curiosity, the satisfaction of which is somehow seen as a justifiable end in itself?

Jeremy Naydler

Organic Experiments

EFFECTS OF ORGANIC AND INORGANIC FERTILISERS ON SOILS AND CROPS. Results of a long term field experiment in Sweden. B.D. Patterson and E.V. Wistinghausen. Nordisk Forskningsring, Meddelande.

We live in a rational age when hunches are no longer enough to convince anyone but those who feel them. Scientific proof is what we need, whether it be to demonstrate the validity of the Turin Shroud, of Darwinian evolution or of Einstein's theories of relativity. It's all very well therefore to munch away at our organically grown food and then proclaim to all who care to listen that not only is it healthier for having been grown that way but it tastes better. Such enthusiasm has a tendency to invoke cynicism if not downright disbelief, although it is fair to say that attitudes are changing; people are becoming more receptive to the notion that it *does* matter how food is produced.

To date research comparing organically grown crops with those conventionally grown using soluble fertilisers has been sparse. Instead farmers and horticulturalists have been inundated with advertisements persuasively selling the barrage of chemicals needed to push production up to present-day expectations. Yet when such comparative studies are carried out, the hard data accruing from them must surely send a twinge of apprehension running through the agrochemical industry. Undoubtedly, the comparative economics of the two systems — the organic and conventional — are bound to have most impact on farmers who would rather not spend more than they have to. Thus the findings of Professor Barry Commoner's group at the Centre for Biology of Natural Systems must seriously challenge conventional thinking that chemical farming is the best bet. The Centre's study over two years of comparable farms in the mid west, growing similar crops on similar soils indicated in the mid 1970s that the marginally higher yields from conventional farms were offset by higher costs. Today, more than half a decade later, as a consequence of inflation and real price increases, organic farms, if properly managed, must be taking the lead, at least in economic terms.

But costs are not everything, and it is therefore extremely encouraging to find research being carried out on what happens to crops and soil when different growing techniques are applied. B.D. Patterson and E.V. Wistinghausen have been on their field experiment at Jarna in Sweden for some twenty years, and at last they have published their results, and in English too. Both researchers were brought up on farms, in their respective countries, Sweden and Germany, and both got degrees in agriculture at conventional universities and then became interested in biodynamic farming. The field experiment was straightfoward enough and has since been repeated by the department of agriculture at the University of Upsala, with similar results. Eight different fertiliser regimes were carried out over a four-fold crop rotation including summer wheat undersown with a clover/grass mixture, a year of clover/grass, followed by potatoes and then beets. The fertiliser regime consisted of six-month old composted manure with the addition of biodynamic compost preparations and one per cent levels of meat and bone meal; similar composted manure but without the biodynamic preparation; raw manure with the additions of horn and bone meal; raw manure plus NPK fertilisers, the levels of each being half those used in separate applications; unfertilised control, and then three inorganic NPK regimes plus trace minerals, but with the levels of fertiliser used doubling and quadrupling in the last test systems.

The importance of the experiment, especially to those of us dedicated to the ideals of organic farming and gardening, is that it has been devised by trained agronomists, is scientifically carried out and scrupulously controlled, so that the results written up in this book are given in terms of practical facts and figures. It does not claim that organic farming will give us the earth, only the earth nature gave to us, and the ecological controls they devised are unarguably the best for us and for the future well being of our agricultural land.

Peter Bunyard

Bending the System

STRESS EFFECTS ON NATURAL ECOSYSTEMS, edited by G.W. Barrett and R. Rosenberg. John Wiley & Sons Ltd. £19.50.

Now that governments, supported by public opinion, require developers and industrialists to minimise the adverse environmental effects of their activities, it becomes rather important to devise techniques for predicting the ecological outcome of projects. The task is far from simple. Ecology is a young discipline and while it is acquiring predictive tools at an impressive rate, it is subjected to political pressures to run before it can walk, and to attain impossibly high levels of predictive accuracy. Its subject material is almost infinitey variable, after all, the resources that can be devoted to field work are limited, and effects which follow causes in one place and time may not do so invariably. Thus regulations often are made on the basis of knowledge that is inadequate, or amounts to no more than a guess on the result of a computer simulation compiled, as often as not, from data obtained from textbooks and passed from programmer to programmer.

This book represents the attempt by ecologists to deal with the problem. It is a thoroughly professional work that will do much to advance the "state of the art". The book consists of twenty papers presented at a symposium, called "Stress Ecology", held in the autumn of 1978 in Jerusalem. If I have a criticism it is of the time it has taken to bring this useful information before a wider audience.

The central part of the book deals with the effects of stress on terrestrial and aquatic ecosystems, and the dedicated preservationist may find surprises in it. John H. Ollenshaw and Read H. Baker, of the University of Newcastle-upon-Tyne, for example, explain that white clover *(Trifolium repens)* is an almost ideal plant for contributing nitrogen to poor upland pastures in Britain, but that the variety used is poorly adapted to the harsh climate in which it is used. They are seeking an improved strain that will combine the winter hardiness of the British variety with the longer growing season of a Mediterranean variety. Their aim, in a word, is to improve the natural ecosystem in which upland farmers try to make a living. Other papers deal with prairie grasses, with forests, and with side effects of Fenitrothion, the insecticide that has replaced DDT in the forests of Canada.

The papers describing marine and freshwater aquatic systems deal, inevitably, with the effects of oil spills, including those which pollute coastal mangrove forests in the southern USA, where Ariel E. Lugo, Gilberto Cintrón and Carlos Goenaga find the effect is more severe inland, away from the tidal flushing by which the outer regions of the forest are cleaned. In general, the students of coastal systems find that where the environment is inherently unstable, as in estuary mouths for example, recovery from environmentai stress is quicker and more complete than it is in more stable ecosystems, whose populations normally do not need to tolerate wide ranges of temperature, salinity, or nutrient availability.

The scientific questions may have answers. The political or moral questions may not. Since natural ecosystems are subject to constant change, since those of us who live in high latitudes should remember that every few tens of thousands of years advancing ice sheets cause ecological devastation — though not extinctions — on a scale that far exceeds our puny industrial efforts, and since even the hallowed tropical rainforests change their character and composition over the years, we need to define the word "stress". Several papers early in the book attempt to do so. Having decided what it is that we should measure, a second question arises. Like all species, humans alter the environments in which they live, but how are we to tell whether a change is "for the better" or "for the worst"? Such qualities are tricky to assess. To take an extreme example, what appears as industrial dereliction to one person may be an important archaeological find to another.

It is encouraging to see that so important a branch of life sciences is receiving the attention it deserves. If the progress indicated by these papers is maintained, the time may not be far distant when the protection of non-humans by humans is informed by something more substantial than pious rhetoric.

OTHER BOOKS RECEIVED

The God that Limps. Science and Technology in the Eighties. Colin Norman. W.W. Norton (no price given)

"If the experience of the postwar years have taught us anything it is that there are no simple technological fixes for complex social problems." So writes Colin Norman and this is a belief that our readers will have met time and again in this journal. Nevertheless Norman goes on to state that technological innovation can succeed, and indeed, must be introduced for the eventual benefit of man. His thesis is that it's not the microchip and it successors that cause the damage, but rather the manner of their introduction. This is a thoughtful and serious book, but one in which the solutions offered do not seem convincing.

Save the Dolphins. Horace Dobbs, Souvenir Press, £7.95.

Perhaps you thought the real carnage stopped with the great whales, but in Horace Dobb's new book we learn that dolphins are being slaughtered by American tuna fish trawlers and are hunted and massacred in their thousands by the Japanese. As if this were not enough *all of us* are polluting the seas and relentlessly creating an environment in which dolphins simply cannot survive. Indeed Dobbs concludes that this most magical and friendly creature must now be counted an endangered species. His book makes one despair of the human species.

Resettling America. Energy, Ecology and Community. Gary Coates (Ed) Brick House Publishing Co., Andover, Mass., USA. $14.95.

In his enthusiastic foreword to this book, Amory Lovins tells us that advances in the use of "soft" or "appropriate" technology in the USA have far outstripped what he would have predicted three years ago. Indeed a note of optimism runs right through its 550 pages ranging over politics, people, food, energy, land use and so on. Part 1 is titled *Vision*, Part 2 *Expression*, Part 3 *Reflection* and its all there for those who want a handbook to that Utopian Community which sounds so much more attainable than it ever really is. Copiously illustrated and good value.

LETTERS

Contraceptives and the Population Explosion

Dear Sir,

I cannot leave unanswered the article by Pierre-Marie Brunetti in your issue volume 11 for July and August, entitled "A new look at contraception". Space does not permit a detailed analysis of the paper. I entirely agree with the author that all our methods of contraception are very far from ideal, but as I point out in my book ("The Pill", Oxford University Press; paperback £1.95; page 206), while we can hope for a successful outcome to research "we have to lead our sex lives now, with the methods actually available now". As far as the IUCD and the Pill are concerned, while they do have risks, these can be convincingly shown to be outweighed by the benefits for many women. Not for those who can manage to abstain, or use the condom or diaphragm, as favoured by Dr Brunetti — but the remainder who happen to comprise a pretty large number in the real world. The methods Dr Brunetti favours, although as he rightly says more "gentle" prove in practice to have their own kind of side-effects, namely nuisance value — couples find that they interfere with love-making and in practice therefore they tend to have a high user-failure rate. This is particularly true of all the safe period methods, unless reliance is placed solely on the second (post-ovulatory) phase, identified by taking the basal body temperature, or by one of the newer techniques which we among others are researching here at the Margaret Pyke Centre.

We do have an environmental crisis on our hands. Over-population is an important factor in that crisis. So it is unrealistic to demand, as Dr Brunetti does, that the methods that we use, such as the Pill, are harmless. Taking risks is inevitable in life. What matters is whether the benefits outweigh them. Many couples have reason to bless the admittedly flawed medical methods which we must continue to rely on until something better is discovered. Has Dr Brunetti forgotten that every ten seconds there are about 38 new births and 15 deaths on this planet, leaving 23 extra mouths to be fed?

Yours faithfully,
John Guillebaud MA FRCSE MRCOG
Medical Director,
Margaret Pyke Centre,
15 Bateman's Buildings,
Soho Square,
London W1 5TW

Gravity! Gravity! Gravity!

Dear Sir,

Efforts have been made recently to champion one dominant physical law which can be claimed to explain the problems of our time. Thus both Heisenberg's principle of uncertainty and the law of entropy, of increasing disorder (discussed in recent articles in their journal) have been set forth as fundamental to recent developments in politics, economics and the environment. Thus according to Rifkin, "entropy is the supreme law of nature and governs everything we do."

As Goldsmith so clearly showed, this law fails to pass the basic test of applicability to both organic and inorganic systems. At first it would seem that Archimedes Principle, that wherever there is something, it has displaced something else — so applicable for example to the New International Economic Order — could fulfil this role of a universal, all-encompassing law so sought after by our modern savants, carrying with it many central strategic implications. The mode of discovery of the law, by the insertion and then removal of an organic entity (Archimedes) into an inorganic medium (water) surely illustrates the organic-inorganic interaction required by any universal law.

Yet there is one other law that has a greater claim to our considered attention, and this is the law of gravity, which also involved the action of organic matter (an apple) in its discovery. Not only must the apparent success of both organic systems (birds, bats) and of inorganic systems (aeroplanes, rockets) in countering this law give us the opportunity of considering to what extent natural laws can be overcome in the brave new technocratic world of the future, but from the earliest times the force of gravity has combined with political and cultural forces. Thus the trumpets at Jerico forced a musical-political-religious-physical interaction which reduced the massive walls to rubble. Note too the contribution of mathematics in helping to define the number of circuits required (some quantification is always useful). This must surely be one of the greatest examples of interdisciplinary, holistic action known to man.

Of course, the relevance to the trickle-down (or weak bladder) theory of economics is quite obvious. Indeed this new interpretation of the primacy of the law of gravity in all spheres will provide a great boost to laissez-faire economics, which is under attack today on the basis of experimental fact. Since the law of gravity is well established and not to be questioned, the data is in need of urgent reinterpretation.

The collapse of our civilisation is not after all due to uncertainty or disorder, but to the perfectly simple fact that everything must ultimately fall over under the action of gravity, be it E. Goldsmith after a night on the town or J. Rifkin similarly moving into a state of greater confusion.

Yours faithfully,
John Robinson.

Entropy and the Biosphere

Dear Sir,

I gather from Professor Scorer's letter in the Sept/Oct issue of *The Ecologist* that he is unable to appreciate the biologist's difficulties over the Second Law of Thermodynamics — a law on which I may say, as a very humble biologist, I was brought up.

Professor Scorer describes the closed system as notional — useful in the calibration of observed events. Such events may occur within living systems or outside. In the latter case they may, or may not, be artefactual.

Once a non-living system occurs or (in the case of artefacts and engines) is set up, entropy applies and wear and eventual breakdown result. In living systems events are otherwise; energy climbs uphill and the molecule gives way to macromolecule. For a time the architecture, instead of breaking down, builds up. It is true that there is a term to this so that the Second Law weighs against the integration of biology and, since we die, eventually wins. But living systems reproduce and again bring the Second Law in question. What the Second Law fails to explain is how the integrative processes, and the astonishing architecture which results, have been able to appear on the scene.

Professor Scorer writes of weather and geological turmoil continuously making new minerals available to life forms and of salts in the rain feeding the tropical forests. But how, in a world of entropy, does the biosphere appear on the scene and how do life forms have the ability to use what the wind (which bloweth where it listeth) and the turmoil of geology make available?

Yours faithfully,
Dr. Kenneth Barlow, F.R.C.R.,
Shouler's End,
Thornborough,
Buckingham.

Planners: Not to Blame?

Dear Sir,

The article by Mr. Hildyard on the causes of this summer's riots displayed a gross ignorance of the forces which have been operating for many years to bring about the present conditions in inner cities. It is entirely unrealistic to put the major blame on physical planning and utterly naive to believe that professional planners played leading roles in such activity.

The decline of inner cities has occurred on a vast scale even where there has been little public intervention. Recent research at LSE suggests that this is due to fundamental changes in the location labour and other requirements of industry and commerce. These are beyond the capacity of even national governments to change. They reflect aspirations of large numbers of people and even although their many undesirable consequences are now readily apparent they are not reversible.

That decentralisation policies continued too long may be the case, but they merely reflected a recognition of basic trends. Physical Planning which does not do so fails to work. That many public planning decisions were ill conceived is true. Political expediency, pressures by developers and others, myopia on the part of national and local politicians and civil servants have all been evident. However it is only fair to recognise much was well meant and that in a rapidly changing situation few people even professionals could have been expected to know what was best. Moreover this activity took place in a near absence of any coherent social policy (partly due to paucity of theory). Without this and given the newness of physical planning as a profession it would have been impossible to have planned properly. One might add that many professional planners did express their reservations but politicians, municipal and Ministry of Transport engineers, and others overruled them.

It is moreover quite false to assume that all redevelopments are unsuccessful. On the contrary several redeveloped areas are much sought after as living areas with keen demand by residents of outer suburbs to move into them. Vast areas were beyond saving and it was quite impossible to redevelop them to retain their original social and economic characteristics.

Yours faithfully,
John Munro,
(City and Regional Planner),
Glasgow.

Science, Animals and Evolution

Dear Sir,

In expressing my appreciation for Stephen Clark's thoughtful review of *Science, Animals, and Evolution* in the last issue of *The Ecologist* (Vol. 11, No. 4, 1981), I have at the same time two comments: 1) Dr. Clark states that I profess to be a Christian, but this is not so, and 2) Dr. Clark's discussion of Jacques Monod's views on scientific objectivity would, I believe, have been more pertinent had he related them more explicitly to the discussion of *Chance and Necessity* that appears in my book.

Yours faithfully,
Cathering Roberts,
Berkeley,
California.

Nuclear Survey

Dear Sir,

Last year, the government announced its intention to carry out test drillings in rural England and Wales as part of the research programme into methods of disposing of high-level nuclear waste. One of the areas for study was the Vale of Evesham, and in order to gauge the feelings of the local population we carried out an "opinion poll" in Evesham and Pershore. We would emphasize that this was intended as a thorough and statistically valid survey, not merely as a publicity stunt (although it had obvious propaganda value if the results differed from local councillors' prejudices).

We found that an overwhelming majority were opposed to nuclear waste disposal in their area and that a clear majority wanted their local council to oppose the test drilling. Out of curiosity, we also asked a further question: "Are you in favour of, or opposed to, Britain having any more nuclear power stations?" We expected, among the solid Conservative local population, that at least 50% would favour nuclear expansion. In fact, "antis" (42%) outnumbered "pros" (36%).

Since then, we have been invited to carry out or assist with similar surveys in other areas; in particular the other English nuclear waste research sites (Tewkesbury, Bridgwater, Loughborough and Rushcliffe, near Nottingham) and more recently (in connection with the proposed new reactor at Sizewell), Ipswich and the Suffolk coast. The results are summarised in Table 1.

Of course our individual surveys are open to criticism: the samples are relatively small and the precision of most of the figures in Table 1 is only about ± 5%. Nevertheless we have tried to sample and interview in as professional a manner as possible and have checked for sample bias in terms of age, sex and class. We are encouraged by the consistency of the results we have obtained.

Perhaps the most interesting observation (apart from the general opposition to nuclear expansion) is the negligible effect of political allegiance. For example, Loughborough and nearby Rushcliffe gave similar results despite the fact that the former is Socialist-controlled and the latter strongly Conservative. In the same way, in connection with the Sizewell PWR survey we found that attitudes among the rural Conservatives in Suffolk Coastal district were much the same as those of the urban population of Labour-controlled Ipswich. Both showed a higher percentage in favour of nuclear expansion and a lower proportion of "don't knows" than elsewhere in the country. This we attribute to the increased awareness and security associated with the long and safe operation of the existing Sizewell reactor — though strenuous propaganda efforts in the area by Sizewell's "information officer" had clearly made their mark.

The main message of these results is that about half of the population do not want any more nuclear power stations. Only a few years ago this would have been unimaginable and there has clearly been a massive swing against nuclear power as the public has become better informed of its implications. It would be very interesting to know whether our results, confined as they are to southern England, are typical of Britain as a whole. If so, it is difficult to see how the government can justify its persistent promotion of nuclear power. One thing is certain: if the swing against nuclear power continues at its present rate, the writing will be on the wall for the nuclear industry, no matter what government is in office.

A report summarising the results of surveys mentioned is available from the Food and Energy Research Centre, Cleeve Prior, Evesham, Worcs., price £1.

Yours faithfully,
D. S. Warren & P. J. Riley,
Food and Energy Research Centre,
Cleeve Prior,
Evesham,
Worcs.

Table 1: Attitudes to Nuclear Power

Area	Survey date	Sample size	% in favour	% opposed	% don't know
1. Vale of Evesham	July 1980	250	36	42	21
2. Tewkesbury	Sep 1980	349	30	47	23
3. Loughborough	Nov 1980	260	30	54	17
4. N. Somerset	Dec 1980	345	34	47	19
5. W. Somerset	Dec 1980	247	21	55	24
6. E. Somerset	Dec 1980	253	29	51	20
7. Rushcliffe	Dec 1980	249	29	57	14
8. Suffolk Coast	June 1981	633	39	47	14
9. Ipswich	June 1981	326	38	51	12
10. Visitors to Suffolk	June 1981	124	39	51	10

Asbestos: A Correction

Dear Sir,

The photographs appearing on page 114 of the May/June 1981 issue were incorrectly identified as scenes in the environs of Hindustan Ferodo of Bombay. Actually, these shots depict conditions outside of another asbestos company in India, Shree Digvijay Cement Company in Ahmedabad. Shree Digvijay is an affiliate of Johns-Manville, the largest American asbestos company. Further discussion and photography of both Shree Digvijay and Turner and Newall's affiliate Hindustan Ferodo may be found in *New Scientist,* February 26th, 1981.

Yours faithfully,
Barry Castleman,
Knoxville,
Maryland, USA.

Classified