LWRs over FBRs, so that one would be far removed from an overall breeding situation and the total uranium demand could be significantly higher than for a programme based only upon high-conversion thorium fuel cycle reactors.

This approach is unnecessary, however, it being much more logical to start fast reactors with U-235 and produce the eventual Pu-239 inventory *in situ*. In this way all of the plutonium would be produced and consumed in its most favourable environment. The time to produce a full plutonium inventory and, therefore, a true breeding situation would be much shorter and the uranium input very much reduced, possibly by a factor of four, compared with the LWR approach.

A further advantage of this course is that it would make the fast reactor independent of any thermal system, and it would relieve the latter of the requirement to work on the uranium fuel cycle in order to provide plutonium for fast systems.

While thermal reactors are not appropriate sources of plutonium for fast reactors, it is worth stressing that the converse is not true, insofar as U-233 could be generated efficiently in thorium introduced into the blanket of a fast breeder reactor. In this way a fast reactor with a good breeding ratio could support high conversion thermal reactors with a combined energy output several times greater than its own.

This is an important possibility leading to a symbiosis of a small number of fast breeders with a larger number of high conversion helium-cooled high temperature reactors, which would be preferred to the fast reactor on all counts other than neutron economy.

Conclusion

In the foregoing a world viewpoint has been taken deliberately, because no individual nation can hope to proceed in an isolated manner in resolving problems of such significance as those presented by the energy situation.

Unless some viable major alternative energy source (such as nuclear fusion) comes along, there will be a minimum cumulative requirement of 10^{19} kilojoules of thermal energy from nuclear fission over the next 50 years, and at the end of that time the annual energy contribution will need to be 10^{18} kilojoules a year. The requirement is far beyond the capabilities of light water reactors working on their present uranium fuel cycles, but it would not be beyond the capacity of thorium fuel cycle thermal reactors, notably the high temperature reactor, provided that they were being followed up with a well established programme of fast reactors.

However, the strategy of using thermal reactors (predominantly LWRs) to produce the plutonium inventories needed for breeding does not appear to be viable. The rapid exploitation of the breeding capabilities of fast reactors requires that they should generate their own plutonium from the initially available U-235. On this basis the evolution of fast reactor exploitation would proceed independently of the programme of thermal reactors. Eventually, the two would come together in a symbiosis, in which an overall breeding situation would be maintained with a minimum of fast reactors. □

FRANCE

Debating nuclear power

Alexander Dorozynski reports from France on the nuclear power debate there

THIS year may be decisive for the ambitious French programme of rapid development of nuclear energy. Well before the debate triggered by the "all nuclear" decision of the Pierre Messmer government in March 1974 physicists and ecologists started voicing worries about the programme's safety and reliability, and the doubters appear still to be growing in numbers and in political weight.

The controversy has spread beyond the potential dangers of a technology that has not been entirely mastered. Those arguments find a focus in the huge nuclear waste treatment plant in La Hague, at the tip of the Cotentin directly south of Bournemouth, and in the Superphénix fast breeder reactor, to be located just 44 km from Lyon. The debate now extends to many of the economic and political arguments advanced by the powerful Electricité de France (EDF), the state monopoly employing some 100,000 persons and one of France's largest and most powerful enterprises.

The Ministry of Industry and Research has been only marginally effective in dealing with the 'dissidents', and in the face of mounting public awareness, a public relation campaign is being mounted by EDF. Embarrassingly, some of the approaches to be taken have been revealed by an ecological weekly, *La Gueule Ouverte*, which has published a confidential EDF document giving recommendations about how to deal with different categories of opponents, such as the public at large, members of the parliament, physicians, teachers, journalists, and so on.

Now another publication, *Science et Vie*, France's largest science magazine, is publishing the results of a debate it has organised about the economic soundness of the programme. The debate put face to face economists from the EDF and members of the Institut Economique et Juridique de l'Energie (IEJE), a small group formed at the University of Social Sciences of Grenoble. A guest participant was Professor Irvin C. Bupp, Jr, a Harvard University economist who has taken part in a MIT study of the evolution of the price of water reactors in the US—PWRs are being installed in France under a patent agreement with Westinghouse.

The initial nuclear programme has already been toned down under Valery Giscard d'Estaing's presidency: annual plant construction will be decreased from a 6,000 MW capacity in 1976 and 1977 to 5,000 MW in 1978, and the goal of producing by 1985 nuclear energy equivalent to 60 million tons of oil has been adjusted downward to 55 million. But until now, few had challenged the figures authoritatively produced by EDF concerning the price of the nuclear kilowatt, and the cost of nuclear plants.

"The only economists who have ventured to challenge official figures are those of the IEJE," points out one participant, Jean Marie Chevalier, professor of economics at the University of Paris-Dauphine. "In fact, the nuclear programme has been imposed upon the country by EDF and the Commissariat a l'Energie Atomique (CEA). Never has there been the slightest counter-expertise. The government let it go without compromising itself. Thus, if need be, it will be able to reject upon EDF the responsibility of the aberrant situation we might end up with." The figures are now likely to be subjected to close scrutiny.

For instance, EDF economists have tagged the nuclear KWh with a cost of 7.5 centimes, while that of the 'classical', oil-fired KWh varies between 11.5 and 12.5 centimes. IEJE economists ask if this price is realistic. Just across the border, in West Germany, the nuclear KWh is priced at 6 pfennig (12 centimes), and Patrice Romain of the IEJE maintains

that if engineering costs, insurance, cost of processing waste and of dismantling reactors are included, the EDF price goes up steeply. Then there is the cost of uranium, which has gone up from $5 a pound in 1973 to $40 a pound. Nuclear fuel cost, once estimated at 20% of total costs, has now reached 30% and is still growing. If waste treatment is included, notes Jean-Marie Chevalier, it may reach 60%.

Similarly, the cost of constructing nuclear power plants is challenged. Is it closer to the FF2,150 per installed KWh, as quoted by EDF, or to FF6,700, the price France would like to charge for similar installations in Iran? Does this difference mean that a cost in constant francs must be upped by 50–100% for a foreign country, that more safety factors are included for export, or that EDF discounts some hidden costs that appear elsewhere in its budget? In the United States, Bupp notes, this cost was $130 per installed KWh in 1965, $300 in 1972, and is estimated today at some $700 (about FF3,500).

Another major argument frequently advanced for the intensive development of nuclear power is also being challenged: that of energy independence. According to a report to the National Assembly, French requirements in uranium from now to 1985 are estimated at 85,000 tonnes, and by 1990 at between 115,000 and 125,000 tonnes. "If France had to count on its own resources, these would be exhausted between these two dates," states the report. France may have interests in mining operations in Niger, Gabon and Canada, but it is wondered if there is a guarantee that these interests will be preserved.

There are questions, too, about France's real independence with regards to enrichment. France's uranium enrichment plant at Pierrelatte, designed for military purposes, has insufficient production capacities. The Tricastin plant nearby should only be operative in 1980—if all goes well.

None of the 'dissidents', whether physicists or economists, argue against nuclear power as such. Their major objection is that the EDF plans for producing energy from the atom and using electricity as a vector have closed the door to alternatives. In 1977, only FF30 million will be devoted to research in new energy sources, as against FF2,474 million budgeted for CEA projects.

"We are making a mistake by not playing the card of natural gas," adds Chevalier. "Gas is found everywhere—in North Africa, the Middle East, the Soviet Union, Holland, under the North Sea. It is energy which, unlike oil, is not dominated by multinational firms... Contracts between state and state could be made to preserve equitably the interests of both parties. And gas is a decentralising energy, unlike nuclear power, which leads to the development of maxi-sites and of national distribution networks. With gas turbines, we can produce locally and on a small scale electricity and heat, thereby reducing social costs."

Chevalier believes that no other form of energy can be made available as rapidly as gas, and that within four years, a flow could be created that would represent a saving of FF25–35,000 million. Meanwhile France, which imports three-quarters of the energy she consumes, could explore alternatives before the nuclear 'solution' becomes irreversible. □

Nuclear Engineering International

Reprocessing plant at La Hague

● **Azim Kidwai writes from Karachi:** Although nuclear cooperation between Canada and Pakistan has ended (see *Nature*, January 6, page 9, and also January 13, page 95), the deal with France for the supply of a nuclear reprocessing plant still stands. The plant was one of the main bones of contention in the dispute with Canada. Considerable pressure on Pakistan to cancel the French deal also came from the USA. Pakistan defended the right of two sovereign states to enter into such agreements, but to allay the fears of those who thought that the plant would be used for other than peaceful purposes, it showed its willingness to negotiate further safeguards even though the agreement had been cleared by the International Atomic Energy Agency.

The ending of Canadian assistance will have its effects. The only nuclear power plant running in Pakistan, the 137 MW Karachi nuclear power plant (KANUPP), was supplied by Canada. Its fuel, essential spare parts and the technical assistance for its maintenance were from Canada. A policy of self-reliance may now be the order of the day, and the Chinese experience when Russian technical assistance was withdrawn in the early 1960s is being cited.

The supply of fuel to KANUPP may pose no problems, as fuel fabrication is likely to be arranged from sources other than Canada. Eventually fuel is to be fabricated in Pakistan itself, and had Canada not, two years ago, stopped the shipment of equipment for fuel fabrication from Canada to Pakistan, the fuel for KANUPP would now be locally available. Considerable uranium bearing sandstones have been discovered in the northern areas of Pakistan in the Dera Ghazi Khan district and a survey of uranium bearing ores has been completed with the assistance of the International Atomic Energy Agency. Plans are in hand for their exploitation.

KANUPP feeds into the Karachi grid only 85 MW on average, and although its closure for long periods could be a source of irritation a 125 MW steam-powered generating unit is under installation, to be commissioned by July next. Another five gas-turbines each of 25 MW have also been urgently ordered for Karachi as a further reserve to be commissioned by July 1978.

The Pakistan government called the Canadian action arbitrary, adding that it violated three bilateral agreements on cooperation with Pakistan in peaceful uses of atomic energy. She found unreasonable the new conditions for which Canada was asking. One was that Canadian safeguards "will cover Pakistan's entire nuclear programme, not merely the nuclear facilities provided by Canada". Pakistan also found unacceptable the demand that even if "Canada should terminate all nuclear cooperation with Pakistan under the bilateral agreements, Pakistan shall nonetheless remain bound by its commitments under those agreements for the rest of the operating life of KANUPP". □