similar size. Yet the goal of a commercial fast reactor system is to produce cheaper electricity than other systems such as thermal reactors. Fuel costs play a minor role in the total cost of nuclear electricity, so that fast reactors will only be competitive with thermal reactors if their capital costs are comparable (unless the price of uranium were to increase dramatically). The special safety requirements of fast reactors and the difficulties of using sodium in LMFBRs both suggest that the capital cost of a LMFBR will be much higher than a comparable thermal reactor. Furthermore, as has been indicated, the safety problems get worse for large fast reactors. It may be thought that my comments are overly pessimistic or overly theoretical — I am after all a theoretical physicist. But the one case study available on the capital costs of fast reactors does indeed bear out my conclusions.

The prototype German fast reactor SNR-300 has increased in cost (at constant 1972 prices) from the initial estimate of DM300 million at the time the reactor was authorised to the most recent estimated cost DM1223 million in October 1975 (O.Keck, University of Sussex Doctoral Thesis, 1977). These are not the final figures and the cost escalation is therefore by at least a factor of four in real terms. Keck also demonstrates that the initial cost estimate of the SNR-300 was in no way based on any evidence about the likely capital costs of fast reactor systems. The estimate was simply a number which the fast reactor proponents thought to be reasonable in view of the likely cost of a thermal reactor system of comparable size — I suspect that the figures we have heard from the AEA about the likely cost of CFR 1 have been arrived at in a similar way. Keck now estimates that the capital cost of the SNR-300 is five times that of a comparable LWR system ordered at the same time.

The importance of this case study is that the SNR 300 is the first and so far the only prototype fast reactor which has been built as if it were a commercial reactor; that is to say it has been built specifically with the goal of satisfying both the utilities and the licensing authorities. Therefore the utilities and the licensing authorities have been consulted from the early design stage in 1969. Keck says "After the designs were submitted drastic alterations became necessary as a result of the safety and environmental provisions demanded by the licensing authorities and substantially increased the costs of the plant... The most severe licensing requirement related to hypothetical accidents. The safety philosophy of the original design placed the emphasis on measures to prevent a core meltdown and a subsequent hypothetical nuclear excursion, and it was thought that this accident could be made sufficiently unlikely to avoid measures accommodating its consequences. The licensing authorities, however, not only required more stringent measures for prevention of this accident, but also stipulated that the impact of a nuclear excursion should be safely accommodated by the reactor vessel and the containment. . . .

"The demands of the licensing authorities not only increased the costs of the prototype plant, but also necessitated a lot of additional research and development in industry and government laboratories, which added considerably to the costs of the fast breeder project. For some items, the licensing requirements even went to the limits of technical feasibility, and imposed heavy tasks on scientists and engineers in industry and government laboratories."

So on the basis of this case study, there is every reason to believe that the licensing requirements for the fast reactor, arising specifically from the physics problems I have outlined, will cause an appreciable increase in capital costs relative to thermal reactor systems. Furthermore, the situation will get worse for larger fast reactors such as CFR 1 and Superphenix.

The relative higher capital costs of fast reactors compared with thermal reactors must be weighed against the prospective future price of uranium. In the words of The Times Mining Correspondent (*The Times*, 30 October 1978) "colossal new discoveries of uranium" have been made in the past three years in Australia and Canada. Therefore "prices are unlikely to go up faster from their current $42 a pound than inflation warrants". So there can be no urgency about developing a commercial fast reactor for economic reasons; it would be more cost effective to spend money on improving the present designs of thermal reactors. Although the AEA talk about a commercial fast reactor, there is no reason at present to use the term commercial. There still remains an enormous amount of basic work to be done on these systems before they can be regarded as a safe, sure and reasonably-priced source of electricity.

My final point is that fast reactors are too hard for us in Britain working alone, since we have neither the resources in money nor in people to do the job by ourselves. The greatest part of the UKAEA's budget and most of its qualified scientists and engineers since the mid-1960s have been committed to the fast reactor but, nevertheless, we cannot match the spending and manpower committed in the United States on fast reactor systems.

The UK is favourably placed for energy until the end of the century, while fast reactors cannot hope to be commercial until next century. A modest programme of research and development is indicated which does not strain the UK's resources, so that it is in a position to benefit from any future exploitation of fast reactors next century. The problem is similar to that in the field of fusion power and the solution is similar: there should be a common European programme of research and development, similar to JET and to the programme of research in elementary particle physics based at CERN in Geneva. If it is too late for the UK to join in the Superphenix project, it should indicate its willingness to join the next reactor after that. With its continuing experience of PFR at Dounreay and its large and assured stock of plutonium it can expect to be welcomed as a partner. I agree with Lord Flowers (*Nature* **264**, 496; 1976) that 'fast reactor developments is likely to be beyond our resources. It seems to me essential that if we propose it at all we should do so on a European basis'.

So it does not make sense for the UK to build CFR 1. On the other hand there is scope for being involved in planning the reactor to be built as a European collaboration (perhaps even the US and Japan would also be interested in participating) after Superphenix. The considerations I have outlined here would suggest that a sensible size for a LMFBR which avoids the problems connected with a large positive sodium void coefficient and which may have commercial potential next century would be about 500 or 600 MWe. PFR, Phenix and SNR-300 provide a sensible basis for the design of a reactor of this size.

France minimises risk of 'worst accident'

WHEN construction was authorised in May 1977 of Superphenix — the fast breeder reactor now being built in south-east France — the licensing authority stipulated that it should be built to meet certain safety specifications. One was that the double-walled reactor vessel, the lid and the dome housing the reactor, should be able to withstand the accidental release of 800 megajoules of mechanical energy. This was the energy which way believed might be released in the 'worse possible accident', that of criticality followed by a sodium explosion.

More recent studies by the French atomic energy authority and others (reported in *Le Monde*, 5 July) however, have concluded that the likelihood of such an accident happening is much lower than had previously been thought: 1 in 10^8 instead of 1 in 10^6. Three independent rod systems, the studies conclude, lower the probability of criticality. Even if the reactor did go critical, then it is highly unlikely that the energy released would be 800 MJ.

The recent studies have also shown, however, that the reactor buildings would be unlikely to withstand 800 megajoule explosions. (It is not ever clear precisely what maximum energy they could withstand.) The question therefore remains whether, given the reduced probability of an 800 megajoule explosion, the licensing authority will still insist that the reactor housing be built to withstand such energies — which would mean a substantial increase in cost. □