Super-Phenix: Ashes To Ashes?:

Problems and prospects of fast breeder reactors

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Introduction

The mythical Phoenix was believed to rise again reborn from the ashes of its own funeral pyre. The myth of the Super-Phenix is equally improbable - and much more alarming. The Super-Phenix is a nuclear power station that can - in a manner of speaking - create fresh fuel from fuel it has already burned: hence the evocative metaphor of its name. The Super-Phenix can also, however, produce the essential material for the most modern nuclear weapons. Although it is an international facility, and officially "civil" in nature, France is intending to use it to produce high-grade plutonium for nuclear weapons. The nuclear "ashes" associated with the Super-Phenix may thus in due course be far from metaphorical.

The diplomatic implications alone raise questions about Super-Phenix, and the type of nuclear plant it represents, that are long overdue for public discussion. Nor are the diplomatic questions the only ones requiring answers. Others include:

- the dubious technical status of this type of plant, and of its accompanying fuel-supply and waste-management technologies;

- its economic potential - or rather its lack thereof;

- and the concomitant, continuiing financial burden on taxpayers and ratepayers;

- its distorting effect on the energy policies of the countries involved;

- the safety hazards it presents - which will be aggravated by attempts to reduce its cost; and

- its drastic consequences for worldwide efforts to control the spread of nuclear weapons.

The Super-Phenix was to have been the first of a new generation of nuclear power plants, using a type of reactor called a "fast breeder". It is due to start up in 1984. But five of the participating countries - Belgium, France, Federal Germany, Italy and the United Kingdom - acknowledged at the beginning of this year that earlier long-term plans for fast breeders had to be dramatically revised. On 10 January 1984 they signed an agreement to set up a cooperative international programme of fast-breeder development. True to form in nuclear matters, the agreement was drafted and signed with no reference to elected representatives or their electors in the countries concerned.

It is therefore time - indeed long past time - that the fast breeder was called to the bar of public opinion. Too many worrying questions have been left unanswered for far too long. Before the

Super-Phenix starts up, or any multinational fast breeder programme is launched, the questions must be asked, and answers demanded. This dossier is an attempt to define the questions. The answers must come from governments, and from those behind the scenes who shape official nuclear policy.

What is a "fast breeder" and why?

To understand why the "fast breeder" gives rise to such acute controversy, it is important to understand what makes it unique - and in some ways uniquely worrying. The concept of the fast breeder originated in the 1940s, in the very early days of nuclear science and engineering. At the time, it was only one of many different possible designs of "nuclear reactor" being suggested and studied. A nuclear reactor was a device in which a controlled "chain reaction" could take place, splitting the innermost cores or "nuclei" of certain kinds of atom, and releasing "nuclear energy". The process was called "nuclear fission"; atoms that could undergo nuclear fission were called "fissile". Only one kind of fissile atom existed in nature: a rare form of the metal uranium, designated "uranium-235". Only 7 out of every 1000 atoms of uranium found in nature are of this fissile kind. The other 99.3 per cent are uranium-238, which cannot sustain a chain reaction.

In the 1940s and early 1950s uranium was a rare and costly metal, whose supply was also strategically acutely sensitive. Nuclear planners were convinced that the anticipated shortage of uranium would severely limit the future usefulness of nuclear energy. There was, however, a way to overcome this constraint on fuel supply. When uranium undergoes a chain reaction, some of its fissile uranium-235 nuclei are split and used up. But at the same time the chain reaction process also converts some of the non-fissile, common uranium-238 into another substance, called plutonium. The form of plutonium produced, designated plutonium-239, is fissile; it can support a chain reaction, just like the rare uranium-235.

In most nuclear reactors, the amount of plutonium produced in a given time is less than the amount of uranium-235 used up. The total amount of fissile material inside the reactor slowly dwindles; as common sense might make you expect, the reactor slowly burns up the fuel inside it. In one kind of reactor, however, the amount of plutonium produced can be slightly more than the amount of uranium-235 that is burned. The total amount of fissile material inside the reactor actually increases. The reactor converts the useless uranium-238 into fissile fuel material - plutonium - faster than the other fissile material is used. The type of reactor that can bring about this strange process uses "fast" nuclear particles to "breed" new fuel: the reactor is therefore called a "fast breeder".

It is easy to appreciate why such a possibility excited nuclear engineers from the outset. If fast breeders could be successfully developed, they would forthwith eliminate any problems about scarcity and cost of uranium. Instead of burning up only the fissile fraction of the uranium - less than one per cent of it - nuclear power plants could burn up nearly all of it, simply by converting it into plutonium in fast breeders. The fuel would still have to be removed from the fast breeders, because of the buildup of fragments of split nuclei that interfered with the chain reaction. But the plutonium in this "spent" fuel could be recovered chemically and made into new fuel - more of it than there had been originally.

It was an extraordinarily seductive idea - and to influential nuclear planners in the 1980s it still is. However, the ideal concept of the fast breeder pouring out an endless cornucopia of nuclear electricity has at last come up against some hard-edged technical, economic and political realities. The glorious promise of the fast breeder has faded almost out of sight.

Fast breeder beginnings

The earliest omen for the fast breeder was propitious. The first electricity generated by nuclear energy was produced by the Experimental Breeder Reactor (EBR-1) at Idaho Falls, in the US, on 20 December 1951. The next omen was, however, less so. On 29 November 1955, as a result of a technician's error, the EBR-1 suffered the first-ever core meltdown accident. The responsible nuclear authorities at once covered up the accident. Even the chairman of the US Atomic Energy Commission did not find out about it until April 1956, when the *Wall Street Journal* asked him for a statement.

The cover-up might have been prompted by knowledge that a consortium of utilities led by Detroit Edison were already planning to build what was at the time a full-scale commercial fast breeder power station. It was to have an output of 60 megawatts, and to be sited near the city of Detroit. In honour of the Italian physicist who had built the first nuclear reactor, the new station was to be called the Enrico Fermi Power Plant. In the event it did him little honour. It met with bitter local opposition, led by the United Auto Workers, one of the most powerful trades unions in the country. The dispute went all the way to the Supreme Court. It gave the project the go-ahead by 7 votes to 2; but the dissenting justices wrote an angry minority opinion against it, which proved to be amply justified.

The Fermi plant started up in 1963, but ran into technical problems of every kind. The heat output from a fast breeder reactor is so intense that designers have chosen to carry the heat out not with water or gas but with molten sodium metal. Sodium reacts violently with water; keeping the two apart while using molten sodium to boil water in so-called "steam generators" has proved to be an engineering challenge that remains unsolved even in the 1980s. Steam generator problems have dogged every fast breeder from the Fermi plant onwards.

The Fermi plant also had problems with pumps, valves, and other hardware. It operated intermittently, usually at low power, until autumn 1966. Then, on 5 October, a piece of metal came adrift in the heart of the reactor. It blocked the flow of cooling liquid, and two fuel elements melted, releasing radioactivity all through the reactor. That at once posed an unpleasant problem; but there was a worse one in prospect. The fuel in a fast breeder, unlike that in a conventional reactor, is made of concentrated fissile material. Its normal arrangement in the reactor is less than optimum for supporting a chain reaction. If the fuel is damaged, the possibility arises that it might collapse into a more favourable arrangement. The outcome might be a runaway chain reaction - in effect a small nuclear explosion. The resulting energy release would, to be sure, blow the collapsed fuel rapidly apart and stop the reaction. But even a runaway of a fraction of a second might release enough energy to blow apart not only the collapsed fuel but the reactor containment itself. The consequent release of radioactivity would devastate the surroundings over an area of thousands of square kilometers around the plant.

Concern about this alarming possibility was one of the reasons why the clean-up at the Fermi plant took several years. The plant started up again in mid-1970, but operated only sporadically. By late 1971 its owners had had enough. It was shut down and mothballed, and is now being slowly decommissioned.

In the United Kingdom, the first fast breeder power station was the Dounreay Fast Reactor. For safety reasons it was built at Dounreay, an isolated site on the north coast of Scotland, and surrounded by a steel containment dome. It started up in 1959, but persistent technical troubles kept it from reaching full power until 1963. It operated thereafter as a test facility, until it was finally shut down in 1977. Other small fast breeders included the Soviet BR-5 and BOR-60, eventually of 10 and 12 megawatts output respectively, and the Experimental Breeder Reactor-2 (EBR-2) in the US, with an output of 18.5 megawatts, all still in operation as test facilities.

The 40-megawatt Rapsodie, in France, started up in 1966, and operated until 1983, when a sodium leak led to final shutdown. But the Southwest Experimental Fast Oxide Reactor (SEFOR) in the US, with a nominal output of 20 megawatts, operated only intermittently, from 1969 to the beginning of 1972, before being permanently shut down.

The unfortunate experience with the Fermi plant in the US left the further development of fast breeders to the US Atomic Energy Commission. In 1968 it ordered a larger experimental plant, the Fast Flux Test Facility (FFTF), with a planned output of 400 megawatts of heat but no electricity-generating stage, to be built at Hanford. By the time the unit at length reached full power, in 1980, its costs had exceeded the initial estimate by about a factor of ten.

Fast breeder prototypes

The other original fast breeder countries meanwhile moved on to prototype plants intended as the forerunners of fully commercial units. The first to start up, in November 1972, was the Soviet BN-350, at Shevchenko on the Caspian Sea. It was intended to deliver 150 megawatts of electricity plus the equivalent of another 200 megawatts in the form of heat for desalination (production of fresh water from salt water). A year later, however, a US surveillance satellite photographed what appeared to be fire or explosion at the plant. After long silence the Soviet authorities eventually conceded that there had been three sodium leaks, one at least serious enough to have produced a hydrogen-fire. The plant continued to operate, but details about its status were - and remained - difficult to come by.

The next prototype to start up, in mid-1973, was the 250-megawatt Phenix, at Marcoule in France. It reached full power in 1974, but thereafter suffered a series of problems with sodium leaks. It was shut down from autumn 1976 to mid-1977, to deal with leaks in the sodium pipework; and in April 1982 further leaks led to a fire and another prolonged shutdown. The cumulative electricity output from the plant from 1974 to late 1983 was only 55.8 per cent of its design capacity.

In the United Kingdom, the Atomic Energy Authority in 1966 ordered the 250-megawatt Prototype Fast Reactor, to be built at the Dounreay site. Difficulties with design and construction meant that it did not start up until 1974; and it was soon apparent that the steam generators were unsatisfactory. They had been intended to serve as full-scale prototypes of steam generators for the so-called "Commercial Fast Reactor" then being planned. But they developed so many leaks that they have had to be completely rebuilt, with two-thirds of their interiors completely replaced, at a cost of over £20 million. Work is still in progress; whether the new steam generators will perform adequately remains to be seen. Experience with other steam-generator modifications, including those on Westinghouse pressurized-water reactors in recent years, indicates that judgement must be reserved until the new units prove themselves. In the meantime, partly as a result of the steam-generator problem, the cumulative electricity output from the Prototype Fast Reactor to late 1983 was only 10.6 per cent of its design capacity.

In Federal Germany the Federal Ministry for Research and Technology built a "compact sodiumed-cooled reactor" - German acronym KNK - at its Karlsruhe nuclear research centre. In 1977 a new fast-particle core was inserted, and the reactor was relabelled KNK-2. But the main

German effort was devoted to a multinational prototype, designated SNR-300, to be built near the village of Kalkar in Federal Germany, not far from the Dutch border. The plan originated in 1968, with the signing of agreements between the governments of Federal Germany, Belgium and the Netherlands. The agreements made it possible for the nuclear research centres of the three countries to cooperate on fast breeder development, and encouraged electrical utilities and manufacturers to combine their efforts in a fast breeder programme.

In 1972, utilities from the three countries joined forces to form a company labelled SBK, to build and operate first a prototype fast breeder and then a commercial "demonstration plant". RWE of Federal Germany held 68 per cent of the shares, and Synatom of Belgium and SEP of the Netherlands 14.5 per cent each. The CEGB of the UK subsequently took a 3 per cent share. At the same time the manufacturers joined forces to create a fast-breeder construction company labelled INB; Interatom of Federal Germany held 70 per cent, and Belgonucleaire of Belgium and Neratoom of the Netherlands 15 per cent each.

The capital cost of the prototype plant, the SNR-300, was estimated in 1972 to be DM 1535 million, including DM 200 million for escalation. It was, to say the least, an underestimate. From the outset the large majority of funds for the SNR-300 came from the governments of the participating countries. The contributions from the utilities were modest to begin with, and grew progressively more so as the costs climbed. By March 1982 the estimated cost of completing the plant had reached DM 5000 million. Both the Dutch and the Belgian governments had let it be known that they were deeply unhappy at the thought of putting yet more money into what was now looking like an open-ended commitment with no apparent upper limit.

The Bonn government, for its part, was acutely conscious that it was paying for the cost-increases virtually in toto. Although the electrical utilities were the nominal beneficiaries of the project, they were proving acutely reluctant to increase their contributions to its skyrocketing cost. One stumbling-block was the legal status of the project, which gave the Bonn Parliament the right to refuse a final operating licence to the reactor. While a Parliamentary "Enquete Kommission" considered the issue, the Bonn government agreed to provide six months' interim funding in an effort to resolve the question of contributions from the utilities. By October 1982 a formula had been found by which the utilities undertook to boost their contributions. Then it emerged that the latest estimates put the cost of completion a further 25 per cent higher, to over DM 6000 million.

For a time the SNR-300, although some 80 per cent complete, hovered on the brink of cancellation. A Federal German election, however, intervened, and returned a new government to Bonn. It was led by the Christian Democrats, who had long been more sympathetic to the nuclear industry than had the Social Democrats. By a split decision, the Enquete Kommission recommended that Parliament abandon its veto over licensing of the SNR-300; and Parliament concurred. In early 1983 the new Minister for Research and Technology announced that funds would be made available to complete the plant. Its cost was by now expected to exceed DM 6500 million. Only 28 per cent of this would come from the electrical utilities; almost all the remainder would come from the taxpayers of the participating countries.

The plan had always been to follow the SNR-300 with a second plant in Federal Germany, a full-scale so-called "commercial demonstration" plant. The status of this long-term plan in 1984 will be discussed below.

In Japan, the Power Reactor and Nuclear Fuel Development Corporation, a government-backed agency, in 1966 announced plans to build a fast breeder test facility. Called "Joyo", it eventually started up in 1977, with an output of 100 megawatts of heat (but no electricity generating stage); it did not in fact reach this full power until 1981. Japanese nuclear planners in government, electrical utilities and manufacturing industry had been looking since 1968 toward a larger prototype fast breeder, to be called Monju. But they wrangled incessantly as to who should put up the money for it, each faction insisting that the others ought to contribute more. Official go-ahead for Monju was announced on a number of occasions, but nothing much happened beyond design work until 1983. Site work has now commenced; but the financial in-fighting persists, and may well intensify if Monju's estimated cost continues to spiral upward.

In the US, although the Atomic Energy Commission was building its Fast Flux Test Facility, it wanted to move on at once to greater things. In 1972, as the Fermi plant was being laid to rest, the AEC joined forces with nuclear manufacturers and electrical utilities to build "the nation's first fast breeder demonstration plant", a 380 megawatt unit to be sited at Clinch River, near Oak Ridge in Tennessee. Westinghouse was to be the lead contractor, and a consortium of 340 utilities was to put up $250 million towards the cost of the plant.

At the time this cost was estimated at $400 million. Even compared to other nuclear cost-estimates, this proved to be wishful thinking on a heroic scale. By 1982 the most optimistic estimates put the probable cost at $3500 million; critics produced analyses suggesting that a more realistic estimate was $7000 million, and some went as high as $10 000 million. The electrical utilities refused to boost their contribution; essentially the whole of the cost-increase was to be borne by the US Department of Energy - that is, by taxpayers. Many of these taxpayers had grown thoroughly disenchanted with the project; and in Congress their elected representatives were getting the message.

The Clinch River plant was still not so much as a hole in the ground; and a coalition of nuclear critics - mostly political "liberals" - and fiscal conservatives joined forces to press for the cancellation of the project. It was in the home state of the Senate Majority Leader, and he defended it stubbornly; but at last, in October 1983, both Houses of Congress voted definitively to cut off any further federal finances. Clinch River was dead. The US fast breeder programme, however, still rolled on, as will be described below.

In Italy, the Comitato Nazionale per l'Energia Nucleare (CNEN), the government nuclear agency, began a fast breeder programme in 1962-63. In 1966 it announced plans to build a unit called the Prova Elementi di Combustibile (PEC), a fast breeder with an output of 116 megawatts of heat (but no electricity generating stage). A site at Brasimone, between Bologna and Firenze, was at last approved in 1973. Thereafter the anticipated completion date of the plant slid inexorably into the future, as the costs mounted.

In 1973 the estimated cost of PEC completion - back up researches included - was, according to CNEN, of 132 billion liras. The start up was due in 1979 but that year the plant was only 30 per cent completed, at a cost of about 450 Billion liras.

Between 1980 and 1982 the Interministerial Committee on Economic Planning (CIPE) appointed two Commissions to verify and precisely outline cost, schedule and operating conditions of PEC, and to consider also the cancellation of the project. In January 1983 the second Commission concluded that the project could go on at certain conditions, one of which was that Italian electrical utility ENEL - until then not interested in PEC - took part in it. The Commission also urged the technical and financial commitment of Italian industry and foreign partners.

In February 1983 the CIPE authorized the prosecution of the project, with an added estimated cost of 850 billion liras (1982), corresponding to 1125 billion of current liras. The PEC completion is now foreseen in 1988, while no forecast for the actual operating phase exists.

Enter Super-Phenix

In 1968, electrical utilities in member countries of the European Communities began discussions about coordinating development of fast breeders. In May 1971 major utilities in France, Federal Germany and Italy - Electricite de France (EdF), Rheinische-Westfaelische Elektrizitatswerke (RWE), and Ente Nazionale per 1'Energia Elettrica (ENEL), respectively agreed to commercialize the French design of fast breeder based on Phenix. In December 1973, after some legal obstacles had been surmounted, the three utilities signed an agreement to collaborate on construction of two full-scale fast breeder power stations. One was to be sited in France, the other in Federal Germany.

The French station was to be called Super-Phenix, and was to have an output of 1200 megawatts of electricity. It was to be built by a joint-venture company known as Nersa (for Centrale Nucleaire Europeenne a Neutrons Rapides S.A.). At the outset 51 per cent of the shares in Nersa were held by EdF, 33 per cent by ENEL, and 16 per cent by RWE. In 1974 RWE transferred its share to a company known as SBK (for Schnell-Brueter-Kernkraftwerkgesellshaft). SBK was already building the SNR-300 fast breeder prototype at Kalkar. SBK, as mentioned earlier, was a joint-venture company also part-owned by Electro-Nucleaire of Belgium, SEP of the Netherlands, and the British Central Electricity Generating Board. The full-scale station in Federal Germany - known as SNR-2, to follow the SNR-300 - was intended to be a replica of Super-Phenix. it was to be built by a joint-venture company known as Esk, with the same three corporate partners but with the holdings of SBK and EdF reversed. The subsequent status of Esk will be discussed below.

EdF had decided as far back as 1971 to build the new French fast breeder at a site called Creys-Malville, near the German and Italian borders, about 30 km east of Lyon. The site application, for a so-called "declaration of public utility", was made by EdF in July 1973, and granted at length in November 1976. In this connection it is curious to note a recent comment by M. Remy Carle, a senior executive of EdF. In *Nuclear Europe*, January 1983, writing on "Super-Phenix and Beyond", M. Carle declared that "The decision to build a fast reactor plant at Creys-Malville, in France, was taken by the Board of Nersa on December 20, 1976". If this is not a simple misprint it can only be an attempt to suggest that the project has been brought to its present stage much more quickly than is in fact the case. It was in fact first announced in 1972, and its construction was then scheduled to commence in 1975. Site work actually began in 1976.

The almost complete lack of provision for public consideration or democratic discussion of the project has been well-documented (notably in *Energy In France,* a careful and dispassionate study written by Dr N. J. D. Lucas, then on the staff of Imperial College, University of London, and published by Europa Publications, London, in 1979). The absence of avenues for rational public participation led to a series of increasingly violent confrontations, accompanied by uncompromising use of the French CRS. A frenzied battle in July 1977 led to the death of one protestor and hundreds of injuries, some serious.

The protests were ignored, and construction of Super-Phenix continued. At the time it was anticipated that the plant would start up in 1982; but the seemingly inevitable slippages occurred. It was also anticipated that Super-Phenix would be followed immediately not only by SNR-2 in Federal Germany but also by six further replicas in France. In 1978, with construction already well underway, the cost of Super-Phenix was estimated at FFr 6000 million. However, by mid-1982 the cost of completion was being estimated at FFr 12 000 million; and October 1983 Nersa approved an estimate of FFr 19 000 million.

Even in mid-1982 it was admitted that the electricity from Super-Phenix would cost about twice as much as that from conventional French nuclear power plants. In July 1982 EdF revealed that it was in what it called its worst financial crisis for 30 years. It was facing an annual loss of FFr 8000 million, as a result of low electricity demand and the high cost of foreign borrowing to finance its ambitious nuclear power plant programme. In 1983 the position grew worse, with electricity demand falling well short of earlier forecasts. Even official French projections showed that the existing nuclear plant programme would lead to a substantial and embarrassing excess of generating capacity by the end of the decade.

The long-term plans for a further six replicas of Super-Phenix were looking more doubtful by the month. The advent of the Mitterrand government had not, to be sure, changed official French nuclear policy as much as many Mitterrand supporters had expected and desired. But the possibility of persuading EdF to order six - or even four or two - replicas of Super-Phenix seemed remote. Why order stations to produce electricity that was not needed, at a price twice as high as that already available? The government let it be known that it would not decide about furter fast breeders in France until there had been a year or more of operating experience with Super-Phenix. By 1984 the plant is not expected to start up until late this year, nor supply electricity to the grid until 1985. That means no formal decision about a follow-up plant until 1986 at the earliest.

That does not mean, however, that French fast breeder proponents are sitting idle: on the contrary. Conscious of the pressing need to bring down capital costs, French fast breeder designers had already embarked in 1982 on a major programme of redesign. Super-Phenix was no longer to be the model for a succession of replicas. Instead the designers looked for ways to get not 1200 but 1500 megawatts from a reactor of the same physical size. This would mean increasing the heat output per unit volume by 25 per cent - a challenge not only because of the extremely difficult engineering but also because of the possible safety implications of such an intense heat-output in the event of a malfunction.

Unfortunately, such safety implications run directly counter to the other main cost-cutting measure being considered. The designers also undertook an analysis of possible accident sequences in an effort to convince themselves that they could dispense with the containment dome above the reactor - originally incorporated to confine radioactivity in the event of an accident in the reactor. Such analysis, however, depends on computer models of malfunctions. The data available about what might happen within a malfunctioning core of a 1500 megawatt fast breeder relies entirely on extrapolation from much smaller plant. Whether it can be used to justify dispensing with a containment dome seems open to doubt.

It should be added that the only other country thus far to contemplate a 1500 megawatt fast breeder - the Soviet Union - appears to have shelved the idea for the time being. The 600-megawatt BN-600, at Beloyarsk, started up in 1980, several years behind its original schedule. In the mid-1970s the Soviet plan had been to move on directly to a so-called BN-1500. By 1980, however, the plan had been scaled down to an 800-megawatt unit. In 1984 even this less ambitious plan seems to have achieved little progress. Earlier Soviet pronouncements about series construction of fast breeders appear to have met the same fate as the equivalent French plan - probably for many of the same reasons.

Fast breeders versus reality

In the 1940's, nuclear planners viewed the fast breeder as the key to long-term use of nuclear energy. At the time, uranium was scarce and costly, and subject also to the constraints arising because of its strategic significance for bomb-making. The fast breeder's ability to convert the common uranium-238 into plutonium, and to use the plutonium as fuel, appeared then to be of central importance in nuclear technology. Such is no longer the case. In the 1980's the strategic significance of uranium is much reduced, and the economic context dramatically altered. Uranium is now available in abundance, from many different suppliers. Indeed it is so plentiful that its price has fallen embarrassingly low, and appears unlikely to rise substantially in the foreseeable future.

Even political constraints on supplies, in the interests of controlling weapons-proliferation, have come up against the almost desperate desire of suppliers in countries like Canada and Australia to see some return on investment in mines already operating. Exploration activities have once again subsided, because so many potentially exploitable deposits have already been found. Market prospects have receded drastically, as a corollary to the reduction in nuclear plant programmes everywhere in the world. Spot prices for uranium are hovering around US $25 per pound. The latest edition of the OECD "Red Book", *Uranium: Resources, Production and Demand*, published in January 1984, foresees no shortage of low-cost uranium until well into the next century.

The future growth of electricity demand also appears unlikely to come close to the levels anticipated as recently as the mid-1970s. Future prospects for nuclear power plants of any kind are less promising than they have ever been, both because of this limited electricity demand and because of the escalation of the actual cost of nuclear electricity, even from conventional nuclear plants. Only a major programme of conventional plants could provide a basis on which to add a programme of fast breeders. The conventional plants would be necessary to produce the plutonium to fuel the first tranche of fast breeders. Only after fast breeders had been operating in substantial numbers for many decades could their plutonium-production become self-supporting.

This consideration leads inevitably to another. Before the plutonium produced in conventional nuclear plants can be used to fuel fast breeders, it must be recovered from the conventional spent fuel. The technology involved is called "reprocessing". Reprocessing originated as an essential stage in weapons-manufacture. Uranium was made to undergo a chain reaction specifically in order to change some of it into plutonium. The plutonium - fissile material - could then be separated out from the uranium and used in warheads. With the advent of civil nuclear technology in the 1950's, nuclear planners assumed that it would still be necessary to reprocess civil spent fuel, to recover plutonium and unburnt uranium for re-use and to put the radioactive waste into a form suitable for eventual disposal.

Civil reprocessing, however, has proved to be far more technically difficult than military reprocessing. Civil spent fuel is some ten times as radioactive as military material, posing severe handling problems. Every reprocessing plant thus far built to handle modern ceramic fuel has been a partial or complete failure, economically or technically or both. Even the French reprocessing plant at Cap La Hague, the only plant currently operating commercially, has had a cumulative throughput of less than half its design capacity. Plans to expand reprocessing in France have been cut back drastically; similar plans elsewhere have slowed almost to a standstill. The Thermal Oxide Reprocessing Plant planned for the Windscale site of British Nuclear Fuels was given the go-ahead in 1978. In early 1984 ground has still not even been broken for its construction.

A corollary of this technical difficulty is sharply increased cost. The cost of reprocessing modern civil fuel is now so high that electrical utilities everywhere have begun to seek alternative ways to deal with their spent fuel. Long-term storage is now recognized as technically feasible and economically preferable, and utilities in the US, the UK, Federal Germany, Sweden and elsewhere are now making provisions for such storage. This in turn means that plutonium will only become available for fast breeder fuel if the cost of recovering it is charged to the fast breeders.

An incisive analysis by French economist Dominique Finon, entitled "Fast breeders: the end of a myth?", was published in the British journal *Energy Policy* in December 1982. Using official French figures Finon demonstrated that the cost of reprocessing to recover plutonium would make it impossible for fast breeders ever to compete economically with conventional nuclear plant - to say nothing of other ways of providing energy services.

Breeding bombs

This array of problems would of itself spell the end for any technology not so assiduously fostered by governments and their hapless taxpayers. There is, however, a further and yet more ominous problem. The fresh fuel for a fast breeder contains plutonium, in a form that is readily separable by simple chemistry. Anyone in possession of fresh fast breeder fuel is ipso facto within weeks, if not days, of having nuclear weapons material. A country desirous of retaining the option of nuclear weapons, without meeting diplomatic objections, may equip itself with all the necessary bomb-components, ready to insert plutonium at short notice. If it has a fast breeder, it will have such plutonium ready to hand - with a wholly plausible civil excuse for its possession. In such circumstances international "safeguards" cannot provide adequate "timely warning", in the customary phrase, that a non-weapons state may have "diverted" civil material for use in a bomb.

To make matters worse, the stated policy of French nuclear authorities is to use both Phenix and Super-Phenix to produce weapons-plutonium for the French "Force de Frappe". Statements to this effect have appeared over the names of senior French spokespeople, and in French official publications like *Energies*, the EdF bulletin. A critical commentary on the proposal by independent French critics Yves Lenoir and Michel Genestout was published in *Science et Vie* in October 1982. They pointed out that the fast breeder, in operation, burns plutonium of fairly low quality, but produces in its so-called "blanket" region very high-quality plutonium, suitable for the most compact and sophisticated nuclear weapons. In technical terms Super-Phenix will be an excellent military facility. It is not, however, supposed to be. It is a multinational facility; 33 per cent is owned by the Italian utility ENEL; and 16 per cent is owned by the international company SBK, with shareholders in Federal Germany, the Netherlands, Belgium and the UK. If French military intentions are carried out, electricity users in all of these countries will be helping to buy French nuclear weapons.

The implications have already evoked a major dispute in the Bundestag in Bonn, and in the Dutch Parliament. The assurances given by the governments in each case fall considerably short of answering the central question. The Dutch government has declared, for instance, that material "used in" Super-Phenix will be subject to safeguards and confined to civilian uses. This leaves open the crucial possibility that the blanket plutonium - produced in Super-Phenix but not "used" in it - will be available to the French military authorities, precisely as they have asserted.

Such blatant and explicit use of a civil facility - indeed not merely a civil facility but a multinational civil facility - for weapons-purposes will deliver a death-blow to any lingering pretence that civil nuclear activities can be kept separate from military. The Non-Proliferation Treaty comes up for its five-year review in 1985, with every possibility that this time it faces complete collapse. The weapons-states have made not the slightest attempt to comply with Article VI, calling for "negotiations in good faith on effective measures relating to cessation of the nuclear arm race at an early date and to nuclear disarmament". Nuclear exporters offer more generous terms to clients in non-NPT states than to those in member-states, in direct and blatant contravention of Article III,2. If now the nations of Europe turn a blind eye to a gross diplomatic affront like the use of Super-Phenix as a weapons-plutonium plant for France, the dwindling good faith underlying the NPT will be summarily wiped out, once and for all. Furthermore those countries outside the NPT who are keen to separate plutonium for what they call "civil" uses - countries like Argentina, Brazil, India and Pakistan - will be able to do so with diplomatic impunity, by pointing to the example of France and its acceptance by NPT parties like Belgium, Federal Germany, Italy, the Netherlands and the UK. In such circumstances the rapid and uncontrolled proliferation of nuclear weapons would seem inevitable. So, too, would the ultimate horror of their use.

The fast breeder: what now?

The doubtful prospects for the fast breeder were acknowledged, obliquely, in an official statement by the UK Secretary for Energy in November 1982. After the customary obeisance to the long-term potential of the technology the statement conceded that there were nevertheless unlikely to be commercial orders for fast breeders until well into the next century. It should be noted that the UK has been spending more than £100 million of taxpayers' money per year on the fast breeder, in Parliamentary grants to the UK Atomic Energy Authority. The position in other fast-breeder countries follows a similar pattern, with the fast breeder taking much the largest share of government expenditure on energy research and development. How could such lavish expenditure, on a technology whose relevance to society's energy requirements is currently nil and seems likely to remain so indefinitely, be justified?

Rather than trying to rebut the technical, economic and diplomatic charges levelled at the fast breeder, the governments of Belgium, Federal Germany, France, Italy and the UK ignored them. Instead they announced, on 10 January 1984, that they had signed an agreement to pool their efforts on fast breeders, in a collaborative international programme. In February 1984 Electricite de France and the Central Electricity Generating Board signed a further agreement, to cooperate in the construction of fast breeder power stations, beginning with the eventual successor to Super-Phenix. The CEGB agreed to contribute a substantial fraction of the capital investment for the new plant, and to accept electricity from it via the cross-Channel link. At this stage there appears to be no information about the timing or technical status of this arrangement; but it has also been reported that the January agreement will expedite not only the plans for a French successor to Super-Phenix, but also the long-delayed plans for an SNR-2 in Federal Germany. At the time of signing the January agreement the UK Secretary of State for Energy let it be known that the Netherlands was likely to add its signature soon, and that in the longer term both Japan and the US might join in the international collaborative effort.

In this connection, it should be noted that despite the cancellation of Clinch River the US fast breeder programme is still one of the largest in the world, as regards technical activity and finance. The US Department of Energy and the Electric Power Research Institute are already at work on a design study for the next fast breeder after Clinch River. The DOE was reported in December 1983 as planning to ask Congress for funds to build a fast breeder fuel fabrication facility, a reprocessing plant for fast breeder fuel and a waste-solidification unit at Hanford, adjoining the Fast Flux Test Facility. Erstwhile US plans for a so-called "Large Demonstration Plant" - Super-Phenix-size fast breeder - appear for the moment to be in abeyance; but earlier discussions about international collaboration on such a plant indicate that the US will be watching the European grouping with interest. The US has already carried out joint experiments with the UK Atomic Energy Authority, using the Dounreay reactors; precedents for trans-Atlantic tie-ups are thus ready to hand.

So, to be sure, are precedents for technological cooperation between European countries. The first name that springs to mind is Concorde. The agreement between the UK and France to collaborate on a supersonic airliner has cost the taxpayers of both countries stupefying sums of money, in pursuit of a development long since stamped as commercially futile, and a disastrous misdirection of aerospace policy in both countries. Yet the agreement is still in effect; each country is waiting for the other to be the first to cancel, and thereby incur the consequent financial penalties. What price pan-European involvement in developing fast breeders that make Concorde look like a bargain? Will the long-suffering taxpayers once again pay up?

Just as Concorde distorted aerospace planning in the UK and France for many years, a fixation on the fast breeder has grievously distorted energy policy in the countries mentioned above. It has also elicited some extraordinary energy-strategy position papers from the European Commission since 1974. As a result, the much more immediate and relevant research and demonstration for improved efficiency and conservation have struggled for institutional and financial support, while official planning has been preoccupied with electricity, nuclear power and the fast breeder.

Concorde, for all its futility, had no tacit military implications. An international fast breeder programme - especially one involving France and Super-Phenix, with its dual-purpose role - will give the green light for fast-breeder and plutonium-fuel development anywhere in the world. Ostensibly civil activities of this kind provide the ideal diplomatic cover for weapons-development. Certain countries may already be engaged in such activities. If Western industrial countries continue their headlong pursuit of the plutonium-fueled fast breeder, we shall in due course find ourselves, and our children, in a world where nuclear weapons material is an everyday article of commerce, bought and sold by the tonne. The prospect of such a future is chilling. Before we go any farther in this ominous direction we must surely pause and look where we are going.