THE PRESENT STATUS OF THE FAST BREEDER REACTOR INDUSTRIALIZATION IN WESTERN EUROPE

J.P. van DIEVOET, BELGONUCLEAIRE
25, rue du Champ de Mars
B - 1050 Brussels (Belgium)
32-2-513.96.90

ABSTRACT

The development of the liquid metal fast breeder reactor in Europe started in the mid-fifties, after the successful operation of EBR-1 at ARCO, Idaho, in 1951. A more and more integrated development among the countries of the European Community culminated in 1986 with the beginning to power of the 1200 MWe SUPERPHENIX plant at Creys-Malville, France. The road is now open towards the full industrialization of the liquid metal fast breeder reactor at the moment, in 2005, when the first European thermal neutron power reactor station will have to be decommissioned and replaced. The European programme aims at providing the utilities at that time with a clear choice between thermal neutron reactors and fast breeder reactors, both economical but very different in their use of the limited natural resource that uranium is.

THE ACHIEVEMENTS TO DATE

The industrial Fast Breeder Programme in Europe was launched in the mid-fifties in some of the present EEC countries and in collaboration with the USA. Let us recall briefly its successive achievements :

- Fast Source Reactors : HARMONIE, SUAK, TAPIRO
- Critical Power Reactor Core Mock-ups : ZEBRA, MASURCA, SNEAK
- Feasibility and Research Reactors : DFR, RAPSODIE, KNK-II
- Demonstration power plants : PHENIX, PFR, SNR-300
- Commercial size power reactors : SUPERPHENIX.

Regional agreements were successively signed between :
DEUTSCHLAND + BELGIUM + NETHERLANDS (DeBeNe): 1968
FRANCE + ITALY: 1974
DeBeNe + FRANCE + ITALY: 1976
DeBeNe + FRANCE + ITALY + UNITED KINGDOM (UK): 1984

The present industrial programme draws from the research, development, design, construction work and operation of facilities provided during the past 30 years. The main fields of development have been concerned with

- the physics of large cores and their means of control,
- the fuel and cladding resistance to high burn-up and long residence time,
- safety in general, including resistance to sodium fires,
- plant long-life materials and resistance to thermal shocks,
- heat transfer components,
- remote inspection of the plant and its equipments during operation,
- decay heat removal, including natural circulation,
- protection from outside events,
- on-site construction,
- operation simulation,
- fuel fabrication,
- reprocessing of irradiated fuel.

The latest opportunity to embody these developments in a single design has been offered by SUPERPHENIX (Fig. 1), a major combined effort of the five nations presently active in the field in Europe, drawing on experience gained from PHENIX, PFR and SNR-300 (Fig. 2)*.

The result is a 1200 MWe plant, the construction of which started in 1974. It reached criticality in September 1985 and its full nominal power in December 1986.
It is thus a major achievement and a technological success which can be ascribed to the following factors :

- slow but extensive build-up of comprehensive competence over a period of 30 years,
- early exchange of information, opinions and conclusions with the other programmes, namely : USA, USSR and JAPAN,
- progressive setting-up throughout the concerned industries of comprehensive quality control and quality assurance programmes,
- continuity of funding from the States and from the utilities,
- continuity of political aim in the individual countries or groups of countries.

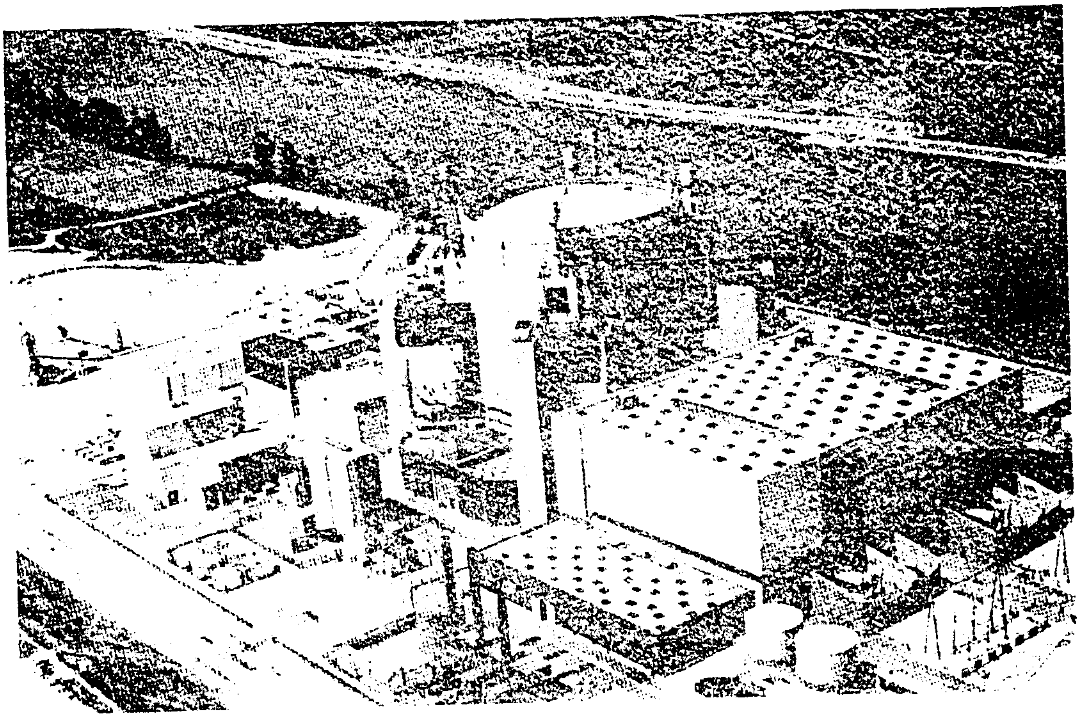

Fig. 1 - SUPERPHENIX

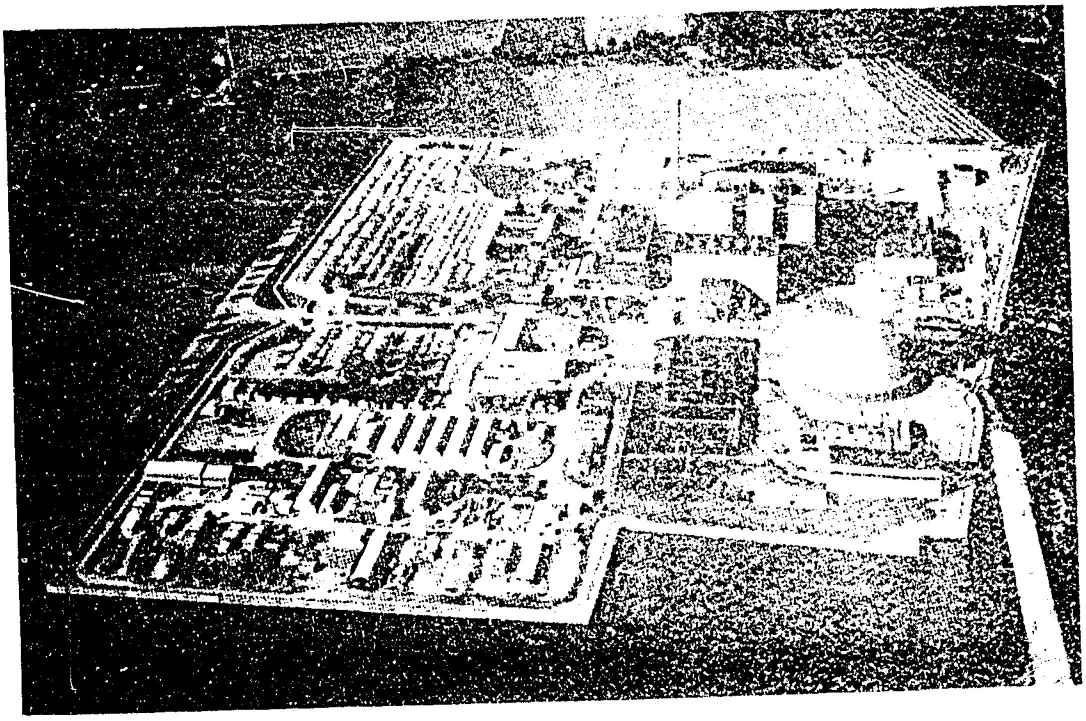

Fig. 2 - SNR-300 *

It is remarkable that, contrary to the LWR, the intermediate step of 600 MWe plants could be avoided with its corresponding expenses. That risk could be taken, with a successful end result, because the absence of high pressure in the primary system eases greatly the design and fabrication of the major components.

The body of knowledge resulting from the programme which was executed is presently distributed among the following entities :

- The system know-how pooling companies : SERENA (France + Italy + DeBeNe) and FASTEC (UK) which are bound by an agreement. The know-how pool has been fed both by the State research organizations and the system design companies, i.e. NOVATOME, ANSALDO-NIRA, INB, NNC. The latter then became licensees of the System know-how pooling companies, the license fee depending on the level of former contributions.

- The component manufacturers : Some of the essential components are manufactured by the design organizations themselves. The others have been fabricated by independent, specialized suppliers who are not working only for the Fast Breeder. In that case, the knowledge can evaporate quickly if not sustained by a regular flow of orders. To remedy partially this situation, the depth of detailing the design work performed by the design organization goes as deep as the manufacturing companies allow when negotiating their contracts, in order to preserve as much knowledge as practicable within the permanent Fast Breeder design organizations. The low design pressure of the Fast Breeder primary and secondary systems, and therefore the reasonable thickness of its shells, make it quite feasible to complete manufacturing and assembling of components and systems in on-site temporary workshops which can serve the successive reactors built on the same site. For SUPERPHENIX a first rate quality was obtained, drawing on the personnel of the contracting manufacturers and also from the site neighbouring communities and industries. Thus, much of the total money spent was spread over a large part of Europe, the site area included.

- The fuel manufacturers : The specific problems of plutonium handling tend to limit the number of fabrication plants. Although plutonium laboratories have been operating in France, the UK, Belgium, Italy, Germany and Switzerland, the progressive structuring of the programme organization has led to a concentration of production plants in France at Cadarache, in Belgium at Dessel, and in Germany at Wolfgang - Hanau.

- The utilities and their architect engineer offices : The share of work and of construction know-how varies from country to country between the utilities and the design and engineering companies. Either the utility takes care of the balance of plant and overall architect engineering of the plant (typical case : France), or it is the system design and supply company which performs these tasks and responsibilities (typical case : Germany), with possibilies for intermediate situations. In general, the utilities began to gather appreciable know-how at the time they participated financially to the construction of the 3 European prototype powerplants, because these plants were to generate a large amount of electricity which had to be sold on the utilities network. The actual operation of the 2 plants to be commissioned brought much operating know-how. The sodium systems have proven to be both reliable and repairable. Because of the design precautions taken in view of the short-life but high-level induced radioactivity of the primary sodium, and in view of the flammability of sodium, handling and maintenance activities occur mainly by remote operation resulting in a very low radiation exposure of the personnel, measurably lower than in corresponding size LWR's. In other words, the extra capital costs involved has been beneficial in terms of the operator safety.

- The reprocessors : A Fast Breeder programme does not make sense without prior construction and operation of uranium fueled power stations, and then reprocessing their fuel to recover plutonium. In France and in the UK the technology for reprocessing uranium fuel was initially derived from the reprocessing of natural or very low enrichment uranium military fuel. The reprocessing for civilian purposes gained much experience through the design, construction and operation of the OECD plant of EUROCHEMIC, located in Belgium at Dessel, which operated with great success and is now closed and partly decommissioned. It was based in part on US reprocessing know-how. Today, the reprocessing industry is commercially active only in France, at Marcoule and La Hague, in the UK, at Dounreay and Sellafield, and in Germany, at Karlsruhe and Wackersdorf. Although there are prototype facilities in Dounreay and Marcoule dedicated to the reprocessing of fast reactor fuel, most of the industrial reprocessing activity is concerned with LWR fuel. Fast reactor fuel has been reprocessed both in the dedicated facilities and in normal LWR fuel reprocessing plants using dilution with depleted or low enriched uranium fuel. Both schemes are demonstrated to be workable. Plutonium recovery has been so complete that the actual burn-up could be measured from the overall material balance in the plants.

On fast reactor fuel, the experience has been extensive enough to allow for the detailed design of a facility capable of reprocessing 60 t of fast reactor fuel per year. However, the need for such a facility will arise only after a substantial programme of Fast Breeder construction and operation does materialize, i.e. after 2005, corresponding to the replacement of the nuclear power stations in operation to-day. (Fig. 3)
LWR spent uranium fuel is currently reprocessed. The recovered plutonium is recycled in MOX fuel bundles. Later on, once-recycled plutonium fuel can be reprocessed and the separated plutonium can be used to fuel the next Fast Breeders.

A NEW PROGRAMME IS WARRANTED

It took 30 years to develop a 1200 MWe sodium cooled Fast Breeder. During that period of time, nuclear energy has been used more and more extensively to generate electricity in a number of countries, some of them relying on it for much more than 50 % of their yearly production. The LWR has been by far the major tool used for that production. At present, very few new nuclear power stations are called for. If after the successful operation of SUPERPHENIX, sodium cooled Fast Breeders built one at a time were cheaper to build and operate than recent standard LWR's, some utilities in Western Europe would without any doubt order a few of them during the coming 20 years, i.e. until such time that the existing LWR's need to be replaced hence and bringing about a steady market of a maximum of 4 plants a year or even more if the electricity demand and/or the nuclear share in electricity production increases (see Fig. 3).
Three questions arising today are :

- did the sodium cooled Fast Breeder miss its golden opportunity ?
- can it find a new opportunity and a new market in 20 years time ?
- if such is the case, how can this turn of events be brought about ?

The sodium cooled fast breeder certainly missed its first golden opportunity for the reasons that :

- Electricity production whether nuclear or not is a high responsibility industrial operation, because it affects the life of everyone. A new and revolutionary product requiring plutonium, sodium and delicate chemical irradiated fuel reprocessing must be scrutinized for a long period of time before it can be relied upon for production at a large scale.

- Because of potential sodium water reaction an intermediate cooling system must be built, and because of sodium opacity and induced radioactivity, a shielded, mechanized and automated fuel handling system must be incorporated in the design. These additional investments are not yet entirely offset in SUPERPHENIX neither by the benefits derived from a stable, low-pressure primary system, nor by a cheaper fuel cycle. Thus, capital costs are presently higher than those of a corresponding single LWR.

- The Fast Breeder fuel cycle does not rely on uranium easy to handle because of its low radioactivity, but on a mixture of uranium and plutonium resulting from the reprocessing of irradiated fuels containing highly radioactive plutonium and uranium isotopes. The costs induced by this high radioactivity must be offset by a much higher achievable average burn-up in each fuel bundle which reduces the number of fuelling cycles over the plant lifetime. The Fast Breeder fuel should be able to sustain at least three times the average burn-up presently achieved or to be achieved in LWR's (35,000 and 45,000 MWd/t respectively). Otherwise the total costs of the Fast Breeder fuel cycle cannot compete with that of the LWR fuel cycle using plutonium recycle. The present SUPERPHENIX fuel cycle does not yet reach that objective.

The new market opportunity provided after 2005 by the replacement of existing plants can be met because :

- The operation of SUPERPHENIX can demonstrate timely to the utilities that, after 2005, they can safely rely on such a machine and on its fuel cycle to produce reliable, cheap electricity. The level of conceptual design know-how reached today with the construction and operation of SUPERPHENIX, is such that progress cannot be achieved by new conceptual studies only. It is mandatory to confront directly the questions raised by the utilities and by the authorities to shape the improvements suggested into workable and demonstrated solutions. This can only be achieved through actual construction.

- The analysis of the total construction costs of SUPERPHENIX, as analysed in a study sponsored by the EEC and UNIPEDE, will show first that one is not so far today from the costs objective, and second on which construction items costs reductions should focus. Improved designs in these fields have already been established. They are being analysed and their adequacy can be demonstrated in the 2 next plants.

- The equivalent of an average burn-up in excess of 100,000 MWd/t has already been recently demonstrated on fuel rods in Western Europe. New materials presently under large scale testing such as ferritic steels, coupled with improved core designs minimizing peak neutron flux, will yield the burn-up required to reach the economic threshold well in time before decisions have to be made in 2005.

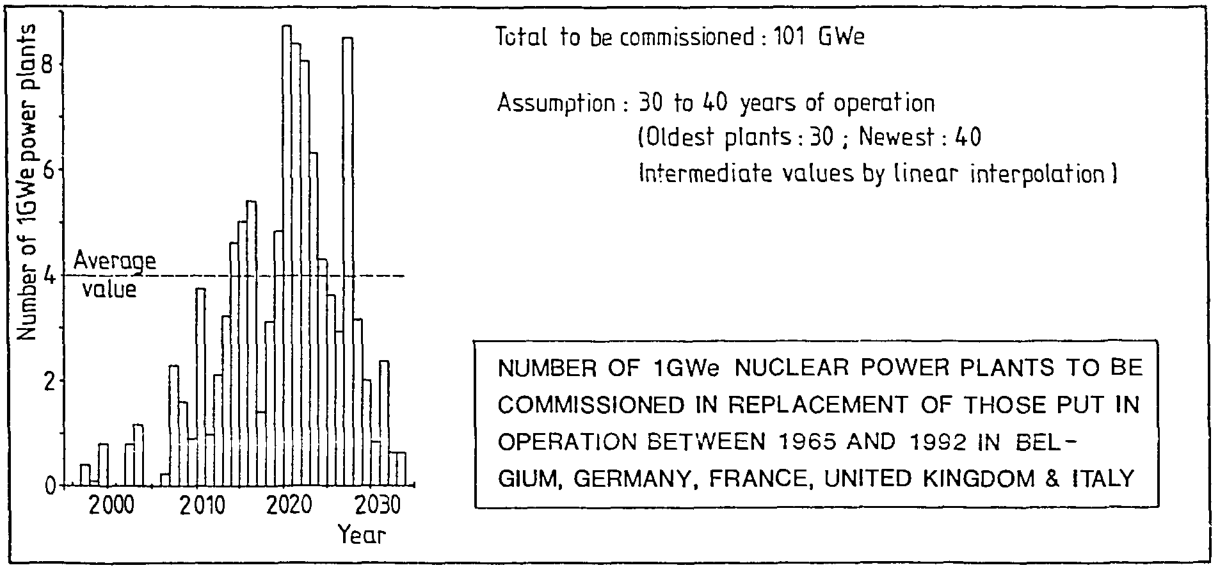

Fig. 3 - Nuclear power stations in operation

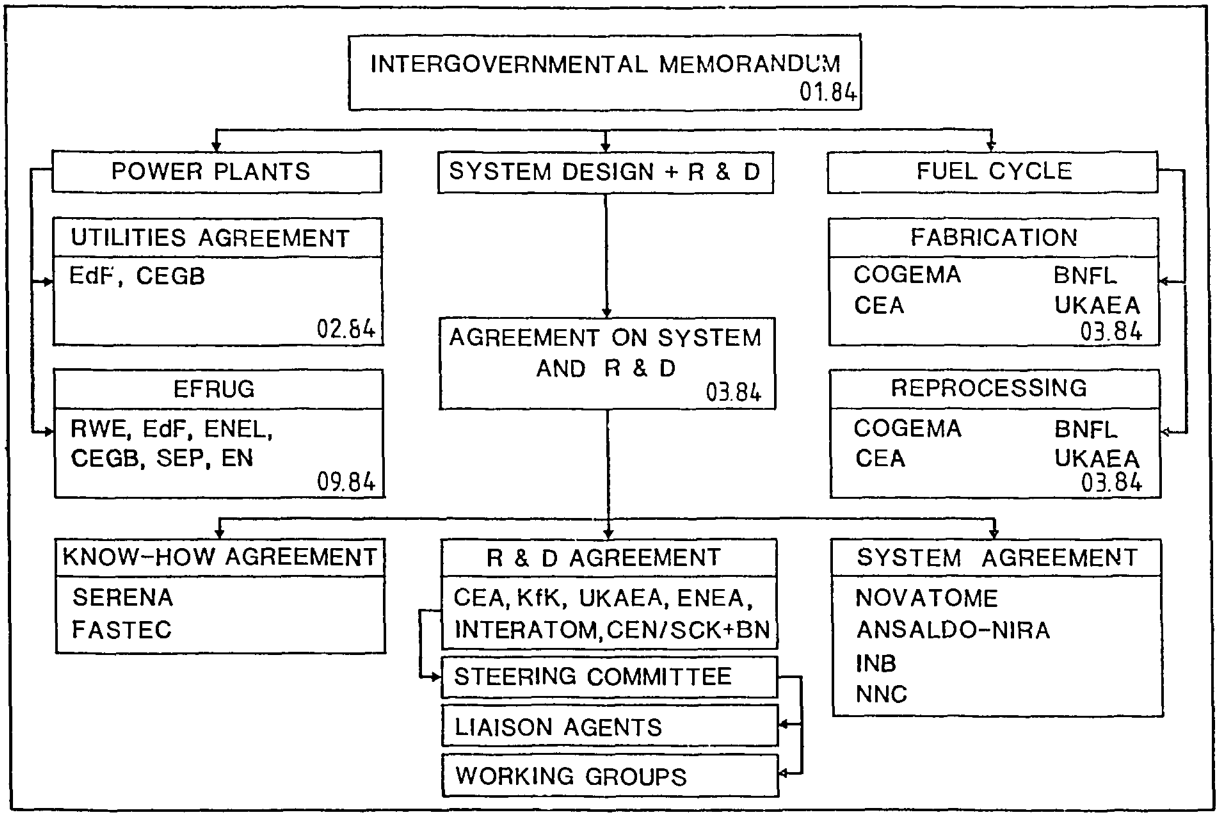

Fig. 4 - Intergovernmental agreements

For the fuel cycle, at that time plutonium fuel fabrication and Fast Breeder fuel reprocessing will both have been technically fully demonstrated.

The means to achieve the objective can be the construction of 2 improved large size Fast Breeders built sequentially before 2005, by the West European utilities which will have accumulated the adequate experience through the construction and operation of many LWR's, through reprocessing of part of their fuel as well as through the recycling of the extracted plutonium in these same LWR's. Such utilities will enjoy the advantageous position of being able to select among :

- fossil fuel power plants
- new LWR's
- sodium cooled Fast Breeders.

As Western Europe does not enjoy fossil fuel resources available locally at low costs, its real choice will lay between LWR's and LMFBR's provided the outlined programme is actually implemented. Otherwise, LWR's will be the only choice and, in such a situalion, LWR's construction price as well as natural uranium feed price over the forty years of operation of these new plants and other fuel cycle prices, are bound to rise, so that nuclear electricity production costs will be only marginally inferior to fossil fuel generating costs, without providing the appropriate assurance in supply, both in price and availability, as exemplified in 1973 by the oil crisis. The economical and therefore political risks for Western Europe of not having the Fast Breeder option reliably available in 2005, far outweigh the costs of a coherent Fast Breeder industrialization programme.

THE DEVELOPING STRATEGY

For the next 20 years, the strategy which is developing can be expressed in a condensed form as follows :

- operating LWR's using the uranium fuel cycle,
- reprocessing all or part of the irradiated uranium fuel to safely isolate and condition the fission products for ultimate storage,
- recycling the separated and purified plutonium once as MOX fuel bundles in LWR's, saving uranium for the future and making plutonium pay for its own storage,
- storing the irradiated MOX fuel bundles, and reprocessing them only at the time their plutonium can be used for Fast Breeders,
- around 2005, having the breeder option available to influence the uranium cycle market price through a proper balance between the number of fast breeders and LWR's to be ordered.

This strategy is leading to the restructuring of the nuclear industry in Europe and, translated in industrial terms, its consequences are that :

- LWR's construction programmes are put on "low burner" for a few decades,
- LWR's in operation offer servicing opportunities for a variety of industrial activities such as uranium fuel reloading, MOX fuel loading, fuel reprocessing and storage, equipment maintenance, plant decommissioning, replacements, conditioning and disposal of radioactive materials, storage, etc.
- Fast Breeder construction can only be contemplated as an "insurance policy" that must be effective and obtained at low costs. This can be achieved only through the setting up of a cooperative common sequential programme by the interested utilities. Such a programme started with the SUPERPHENIX and SNR-2 decisions of 1973.

THE PRESENT STATUS OF THE FAST BREEDER INDUSTRIALIZATION

Industrialization of the Fast Breeder will be a reality only when a number of large units can be offered at economic conditions, and when a steady flow of orders can be counted on for an appreciable amount of time. That status can be reached only in 2005. In the meantime, the "insurance policy programme" must be implemented, i.e. 2 large Fast Breeders should be built sequentially, each being simpler, more effective and more economical than the former. These views have been expressed by the European Commission in their Indicative Nuclear Program. On what present achievement can one count to reach that aim ?

A. Status of safety Criteria

Although the Fast Breeder industrialized in Europe utilizes sodium at low pressure, as soon as large power units were built near populated areas, and this is especially true for SNR-300 and SUPERPHENIX, the safety criteria to be applied were derived from those defined for LWR's, because they were already in legal practice and because they were comprehensive and applicable to the same power range. However, for the specific use of the 2 cited reactors, an envelope accident was considered, the hypothetical core disruptive accident (the so-called Bethe-Tait accident), and a system of core catcher was introduced to take care of the core cooling after a hypothetical meltdown. This situation reflected the lower degree of knowledge of the Fast Breeder safety features when compared to the knowledge accumulated over more than 30 years in operating LWR's in military as well as civilian power plants. Today, it is possible in France and in Germany to build a Fast Breeder according to established criteria and rules. In the UK, a public inquiry is first required as it is the case for the extension of reprocessing plants or for the introduction of the LWR's. In the other EEC countries, in which LWR's have been built, the knowledge exists to incorporate the changes required by the specific features of the Fast Breeder. Since many years a working group on Fast Reactor Safety exists within the EEC in which experts regularly meet to harmonize methods for the evaluation of Fast Breeder safety.

B. Intergovernmental collaboration agreement

The Governments of 5 EEC countries have expressed their will of collaboration by signing an agreement in Paris in January 1984. This agreement is the key to a set of detailed agreements summarized in the diagram of figure 4 which shows the participants in the implementation of the Fast Breeder industrialization strategy and it will be detailed hereunder.
For the reactor design and Research and Development (R & D), an agreement was signed in March 1984 between the system companies and the R & D organization of the countries having signed the intergovernmental collaboration agreement.

C. Status of the R & D

Industrialization requires further R & D because :

- average burn-up per fuel bundle must exceed 135,000 MWd/t for the fuel cycle to become economical,
- the fast breeder design must be simplified and more intensive use should be made of the remarkable and presently demonstrated cooling capabilities of sodium as a large power reactor coolant.

Today, the integrated R & D structure is written down in the R & D agreement refered to in Fig. 4. This agreement contains the following aims and organizational means :
The aim of all R & D actions is to support the design of the next improved plants as defined by the engineers of the System companies. Liaison Agents from the R & D national organizations establish a permanent link with their respective System design organizations. A Steering Committee is the highest decision body of the agreement. It decides upon "work packages" and their means of implementation. The Liaison Agents and the coordinators of permanent technical working groups all report to this Committee. The working groups are responsible for the implementation and coordination among all countries, of the tasks approved by the Steering Committee and defined as "work packages".

D. Status of the utilities

The SUPERPHENIX and SNR-2 agreement were signed in 1973, approximately a year before the first oil crisis, the consequences of which could not have been anticipated. The present situation is being examined by the utilities of the 6 countries concerned with the Fast Breeder option in the frame of the "European Fast Reactor Utility Group", with a permanent secretariat located in Paris. The remarkable consensus and cohesion demonstrated through the last 10 tumultuous years by the utilities which participated in the SNR-300 and SUPERPHENIX projects, i.e. SBK and NERSA respectively, are the best warranties for the success of the next joint venture. The future will tell if links will develop between the European utilities and their counterparts of other continents, in order to further minimize the total costs of the "insurance policy" that is the Fast Breeder option.

E. Status of the system suppliers

The companies which supplied the Fast Breeder systems up to now are :
NOVATOME in France,
ANSALDO-Nira in Italy,
INB (INTERATOM, BELGONUCLEAIRE, NERATOOM) in the DeBeNe countries,
NNC in the United Kingdom.

Each one of the system suppliers has potentially the know-how to design and build a complete system, while only one project at a time will be required in the next 20 years. Therefore, a restructuring process was started some years ago that should lead to :

- integration of efforts through the setting up of integrated system teams and, later on, project teams,
- specialization at each present site of system design activity,
- incorporation of the required manufacturing software know-how.

Formalization of the new structures awaits the definition by the utilities of a program outline for the future. A comprehensive set of adapted rules has now been written in France by NOVATOME after the successful SUPERPHENIX construction and commissioning, and is under review by the European partners. These rules will be used for the next plants and would be in current practice at the time Fast Breeders would have to be designed and built in series.

In the recent past, INB has been working on the conceptual study of SNR-2, while NOVATOME-NIRA has been working on the conceptual study of SUPERPHENIX-2. NNC has recently brought its own expertise to both studies. Both studies have been using the pool concept used for SUPERPHENIX, but with variations derived from the results of a jointly performed analysis of plant safety features as defined in France and Germany. Other variations result from the learning effect due to construction of the 4 previous Fast Breeders, and from a common desire to be innovative in simplifying the design of their components and which, in SNR-300 and SUPERPHENIX, were at the origin of a large fraction of the costs. The first results of both studies are now available in a comprehensive form and have been used over the past 2 years to lead the coordinated R & D efforts in the right directions. The target will be to become more economical than the most modern coal fired plants with full desulfurization of the flue gases, while nearing the economics of the then offered LWR's.

F. Status of the manufacturers

For those parts which are not manufactured by the system designers themselves, there exists obviously a number of potential experienced manufacturers in the 6 West European countries bound by the 1984 agreements. However, only part of them will be allowed to supply the components of the next 2 plants and the continuity of maintaining the specific manufacturing experience. It is therefore imperative for the System designers to detail their drawings, procedures and fabrication requirements to such an extent that even non-Fast Breeder experienced companies can, in the future, provide qualified bids and be selected for further supplies.

G. Status of the fuel manufacturers

Two groups of plutonium fuel manufacturers are forming progressively : ALKEM, within the SIEMENS group of companies on the one hand, and COGEMA + BELGONUCLEAIRE + BNFL, which are bound by agreements, on the other hand. These manufacturers have produced Fast Breeder fuel but will be supplying plutonium fuel mostly for recycling in the LWR's over the next 20 years. Their combined capacity for the production of Fast Breeder fuel is sufficient to fuel the present 4 Fast Breeders operating in Europe and possibly, with some adaptations, the next 2 plants.

Presently, R & D in manufacturing is more oriented towards producing correctly and cheaply the fuel specified by the System designers, and towards preparing, welding and inspecting the new materials specified for long fuel life. There is less intensive work to develop quickly a new fuel product, as mixed uranium-plutonium oxide is unsurpassable in accumulated evidence of excellent behaviour.

H. Status of the Reprocessors

The facilities at Dounreay and those at Marcoule, can handle part of the Fast Breeder fuel irradiated in Europe, about 6 to 7 t/year each. However, the reprocessing of Fast Breeder fuel is costly in such relatively small installations. As no pressing need exists to reprocess more Fast Breeder fuel at such high costs, temporary storage methods are being developed which are adapted to the heat generation and design of Fast Breeder fuel bundles. The TOR facility will be used to study the modification or substitution of process equipment, and will be used to refine the processes which will be used in the industrial facility of the next century.

CONCLUSIONS

The Fast Breeder development programme in Western Europe has achieved, with the operation of SUPERPHENIX at 1200 MWe in December 1986, the results which were expected and with an additional delay which was only minimal under the circumstances. A second period of progressive industrialization lays ahead for the next 20 years. The men who have succeeded in bringing about this remarkable team work, will all be retired in 20 years. A next generation will have to be trained and motivated during the design, construction and operation of the next 2 simpler and cheaper projects, to make around 2005 the Fast Breeder the main strategic and economic choice of utilities in Western Europe.

REFERENCES

1. Indicative Nuclear Program of the European Community, Doc. Nr COM(85)401 FINAL. (1984-1985)

2. Société Française pour l'Energie Nucléaire (SFEN) : Conference in Paris - Proceedings (December 1986)

* "Freigabstelle : Düsseldorf
Freigabe Nr : 18 S 605"