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Evolution of LMFBR Plant Design for Reliability and Availability

R. A. LANGLEY, JR.

Bechtel Corp.,
San Francisco, Calif.

In order to provide competitive power, the LMFBR of the future must have a degree of reliability and availability not shown by those plants currently operating. This paper reviews the lessons of our experience to date and from them defines trends in plant design which will lead to commercial realization of the LMFBR.

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Evolution of LMFBF Plant Design for Reliability and Availability

R. A. LANGLEY, JR.

INTRODUCTION

The liquid metal-cooled fast breeder reactor must gain acceptance by the utility industry as a source of central station power on the basis of its ability to compete economically with alternatives. Not only must the capital and nuclear fuel costs be competitive, but the plant must achieve the high availability required of a base-loaded station in order to yield acceptable operating and maintenance costs and unit power costs.

High availability is achieved through reliability and maintainability. Reliability and maintainability are built into a plant from the start of the design work to the completion of preoperational testing. Availability is then achieved from this base through thorough training of operating and maintenance personnel, institution of a well-considered preventive maintenance program, and meticulous attention to maintenance procedures.

The early liquid metal-cooled reactors have not been designed for commercial competitiveness. They reflect the uncertainties associated with the pioneering effort they represent. The approach to design of future plants must be quite different if they are to take their place as competitive power producers.

By applying our experience in design, construction, and operation of the early reactors and considering all factors involved in the development of preliminary design of the demonstration FBR plants, we can develop criteria for the design, construction, start-up, and operation of the large commercial FBR plants which will follow from this criteria.

TRENDS IN DESIGN

There are basic and significant differences in the designs being developed, and the plants being constructed in the prototype or demonstration plant size range both within the United States and throughout the world. Certainly, foremost among these differences is the primary system concept of either a large vessel, container, or

"pot" in which system components are submerged and a piped system in which individual components are joined by piping systems similar to the PWR. The approach to the refueling system is also an area of major difference among the nuclear system design organizations. There are about as many combinations of under reactor vessel head, through head, and opened head refueling systems each coupled with its own method for storage during cooldown as there are nuclear systems designers. Numerous other basic system design philosophy differences exist.

There will be no clear-cut optimum resolution of these current design philosophy differences for the commercial FBR, just as there is no clear-cut commercial superiority to be found between the present BWR and PWR reactor systems. Some FBR design concepts may drop by the wayside, as has happened in the thermal reactor field, but others will evolve as their proponents strive for improvement.

It is not the purpose here to discuss evolution of the different individual FBR design concepts. The overall facility design must, in each case, be built around the criteria, concepts, requirements, and design of the particular reactor system. Principles and criteria applicable to the overall plant engineering, erection, and construction for all concepts can, however, be set forth. These general criteria, based on our experience to date, define a trend in FBR plant design which the writer believes both necessary and desirable for commercial realization of the LMFBF.

EXPERIENCE BASIS

What has been learned from our experience with liquid metal-cooled reactors and test rigs? What lessons should we apply in our development of plants of the future? Let us take a brief look at the problems and successes of the past to see what they may yield in plant design criteria.

Consider first the problems. Almost every

liquid metal-cooled reactor to date has had at least one serious problem at some time in its operating history. These problems have included sodium spills, sodium leaks, sodium fires, pump failures, fuel meltdowns, steam generator leaks, and refueling system failures or breakdowns. While these incidents have all been well within the facility safety design and have, in fact, developed great confidence in the ability to design, construct, and operate LMFBR's safely, almost without exception they have resulted in loss of availability which would be completely unacceptable in a commercial plant.

What, then, are the successes? Probably the most significant success is that we have suffered and overcome the failures. We have learned that the sodium environment is not so hostile that maintenance cannot be performed and repairs cannot be made, regardless of the difficulties involved in locating, identifying, and working on the fault. The recent return of Enrico Fermi I to power and the repair of the pipe leak at Dounreay Fast Reactor in 1967 are certainly prime examples of this.

A considered examination of the problems which have occurred in the past shows that greater attention to design detail and to quality assurance during design would have either minimized them or avoided them completely. In a great many cases, the problems were very significantly aggravated by inaccessibility of the area where the fault occurred. For the plants of the future, such faults must, to the utmost extent possible, be eliminated. In addition, the plant must be designed with the recognition that should a fault occur, it must be repairable with a minimum of plant unavailability. A philosophy of plant design, which is a basic requirement for all nuclear power plants, immediately develops from this examination. The plant must be reliable and maintainable.

RELIABILITY

Reliability is built into a plant through careful, conservative design which includes an appropriate degree of redundancy, use of appropriate quality equipment and materials, and a thoughtfully conceived, diligently executed quality assurance program. Our experience to date has shown us that in all of these areas, greatly increased effort is needed to achieve the desired level of reliability. In view of the very extensive effort now being applied in design, materials selection, and quality assurance for all nuclear power plants and the extensive amount of material written about it, it is only necessary to

summarize the significant points here. They are:

- 1 The characteristics of liquid metal systems, including high-temperature operation, transient temperature effects, the effects of sodium outleakage, and the corrosive effects of even slightly contaminated sodium, to name a few, require that the Engineer-Constructor put more design effort into those parts of the plant, including reactor plant auxiliary systems, than is necessary to achieve the same degree of reliability for an LWR.

- 2 Quality assurance in fabrication and erection of sodium containing systems is far more critical in the LMFBR than in other reactor systems, due again to the properties of the coolant, the effects of impurities on the coolant, and the consequences of even a very small leak.

Reliability of the plant as a whole, as gained from redundancy of components and systems, must, in future commercial plants, be limited to those elements forming the safeguards systems, and those elements (such as some instrumentation and, perhaps, pipe heaters) which must be located in relatively inaccessible areas. Economic considerations will require such reliability that nothing further is justified.

Reliability is affected by design margins and operating conditions. Early in the development of the LMFBR, an objective was a primary sodium temperature of 1200 F and steam conditions of 1000 F at the throttle valve with reheat to 1000 F. It was always assumed that "modern steam conditions" would provide optimum plant economics. With the expected very low fuel cycle costs, efficiency is not the significant factor that it is in the fossil fueled plant which bred the "modern steam conditions." Extensive investigation has shown significant advantages in materials selection, particularly in the steam generators, and in reliability throughout the sodium systems, to the adaption of lower system design temperatures than those originally sought. The same approach is equally true in the turbine plant. Since efficiency is not as significant as reliability, in a relative sense, the turbine plant should be as simple in design as possible. This approach has a double benefit in that it simultaneously increases plant reliability while reducing capital cost. Future commercial LMFBR plants will show an increasing trend toward a steam cycle without reheat, and with perhaps four or five feedwater heater stages, rather than seven or eight as found, for example, on the UKAEA PFR plant.

MAINTAINABILITY

As with reliability, maintainability must be built into a plant from the start of preliminary design work. It must be considered in the establishment of plant design criteria, and attention must be paid to that criteria throughout the plant design effort.

What is the appropriate maintainability philosophy for the commercial LMFBR? Plants of the future will have a balance between minimization of capital investment and maintainability. Application of our experience provides a basis for establishing a maintainability philosophy which defines maintenance design criteria for the plant while minimizing capital investment.

Loss of availability on sodium-cooled nuclear plants to date has been almost totally due to the difficulties encountered in locating faults, identifying them and making in situ repairs. Regardless of the care taken in building reliability into plants of the future, some faults are possibly going to occur. We cannot now anticipate what those faults might be or where they might occur. Commercial FBR plants could not be justified if these faults were to cause a loss of availability for such plants, with their very large capital investments, as have occurred in today's plants. The commercial plants must be designed to overcome maintenance problems in minimum time consistent with plant capital cost.

Availability will be achieved through an approach to maintenance in which all potential faults can be located, isolated, corrected, or removed and replaced with a minimum of downtime. This defines the first basic maintenance design criterion, accessibility.

From the overall plant designer's standpoint, accessibility must be carefully built into LMFBR plants. The ability to quickly reach and inspect all piping, components, and out-of-vessel instrumentation is vital. This accessibility must be achieved with full recognition of the problems to be overcome. Some principles which will be employed to achieve accessibility include:

- 1 Fluid systems and subsystems must be capable of mechanical isolation. This isolation must be carried out down to the subsystem level required to drain the system and make the necessary inspection and repairs or replacements. Rapid inspection and repair or replacement for vital systems will not permit the approach by which a system is allowed to slowly cool down, either from a thermal or radioactivity standpoint, if that system is required for continued plant operation. Isolation of the system is a problem

not only for the system designer, but also for the plant designer. An independent drain system and provision for filling each element of the sodium plant which can be isolated must also be provided.

- 2 All systems and subsystems which can be isolated mechanically must be isolated physically. If a system can be isolated mechanically, but there are pipes or components from other systems in the vicinity whose thermal or radioactive condition does not permit access, little has been gained. The systems and subsystems must be laid out and arranged in the plant so that there is sufficient shielding between systems and components to permit access to any one isolated element with adjacent parts of the plant in a hot and radioactive condition. If, in a particular design, any of the sodium containing systems normally operate in an inert atmosphere, atmospheric separation must also be provided between systems.

- 3 Components and instrumentation must be easily maintained. Instrumentation must be designed for simplicity in disconnection, removal, replacement, and reconnection. Following isolation of the system, it must be possible to quickly cut out, remove, and replace faulty components, such as pumps, valves, and heat-transfer surfaces. Only the simplest repairs should be made in situ, rather than in the repair shop. All components must be located where they can be reached with appropriate lifting devices. Vertical removal through equipment hatches using reactor building cranes appears to be the simplest, most direct and quickest way to get disabled components out and their replacements in. This requires very careful plant layout and dictates a horizontal, rather than vertical, arrangement of the systems. Fortunately, such an arrangement is completely compatible with system design to provide appropriate component elevations both to meet component sodium-free surface requirements and to provide the required sodium drain capability.

- 4 Insulation must be easily removable and replaceable. It must be designed so that sodium leaks can be detected quickly. Small leaks, which occur behind insulation and are not quickly found, will soon result in major problems. Rapid location of leaks, as well as periodic system inspection, can have a significant effect on plant availability.

- 5 The systems must be designed to minimize contamination during component removal and replacement and to permit independent cleaning and purging of each unit which can be isolated. Use of either a part of the cover gas system or a portable gas system may be possible. In either case, connections must be provided at the time of system

design.

The second basic maintenance criterion for commercial LMFBR plants is that no special maintenance facilities for the repair of sodium components should be provided. Whether they be single purpose or multipurpose, such facilities are expensive and add significantly to the capital cost of the plants.

The early plants, those now operating and those in the prototype or demonstration plant category, have extensive facilities for equipment decontamination and repair. This is quite reasonable, since the plants are developmental in nature. The possibility for extensive component repair and modification has been recognized, as has the industrial capability to conveniently make such repairs. The approach described here for component removal and replacement in commercial FBR's would not have been possible for these early plants unless each were to stock a complete set of spares, since their components are not, in general, standard products. Such an approach would have been prohibitively expensive.

One feature of the maintenance experience with these early plants should be noted here. The special maintenance facilities designed into the plants have not been helpful in correcting the faults which have occurred. The major problems have not, for the most part, been component problems requiring the use of repair stands, component decontamination facilities, and equipment casks. Some principles, which will be employed in design for component maintenance, include:

- 1 Commercial FBR's must use components of such sufficiently demonstrated reliability that only very infrequent repair should be anticipated. Components should be sufficiently standardized, at least for any one reactor supplier's designs, so that replacement with another unit is possible.

- 2 Repairs should be made at the manufacturer's shop where the expertise, material, and equipment necessary to make the repairs are available.

- 3 Components should be shipped from the plant to the shop with a minimum of sodium decontamination prior to shipment and the major decontamination and cleaning effort performed at

the manufacturer's shop. This will be accomplished through proper component environment control.

This approach will result in minimization of the effect of component maintenance and repair itself on both plant capital cost and availability.

One other aspect of maintenance that should be mentioned is preventive maintenance. Preventive maintenance will increase plant reliability and reduce plant downtime for unscheduled repairs. The plant design features described in the foregoing will facilitate implementation of a good preventive maintenance program. Isolatability, accessibility, including accessibility of every external weld in the sodium and cover gas systems, and easily removed insulation will all permit rapid inspection and correction of minor faults before they develop into serious problems.

SUMMARY

Evolution of the LMFBR as it progresses toward commercial maturity will include the following trends:

- 1 Availability of designs based on significantly differing design philosophies and principles with no clear commercial optimum.
- 2 A high percentage of plant capital cost attributable to engineering and quality assurance.
- 3 Plants designed for maintainability through accessibility and interchangeability with a minimum of on-site special repair facilities.
- 4 Steam conditions of temperature and pressure somewhat below those of modern fossil-fired power plants with the primary system sodium temperature somewhat below the once sought objectives of 1200 F.
- 5 Planned preventive maintenance programs which overcome the apparent obstacles of sodium radioactivity and atmospheric control.

If we are to benefit from our experience, it is through development in the directions outlined here that the LMFBR will achieve the reliability and availability to gain acceptance as a commercial power source at a cost competitive with alternate energy sources.