Overview of Indian position - Passive and Active Safety features of LMFBRs - Presentation at the IWGFR Specialist Meeting at Oarai - Nov. 5-7, 1991.

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I. INTRODUCTION

1.1 Because of the fact that Pressurised Water Reactors and Boiling Water Reactors constitute the bulk of the installed capacity in Western Europe and North America; and these reactors can be considered to have acceptable level of safety; one often comes across a statement that LMFBRs can be designed to be "atleast as safe" as the Pressurised Water Reactors and the Boiling Water Reactors. Perhaps there are non-technical reasons for describing the safety features and the resultant safety potential of LMFBRs in such non-positive manner. At least in this meeting of the specialists we need not consider the non-technical aspects and therefore, talk more positively about the safety of LMFBRs. Atleast in India, we the scientists and the engineers working in the field of LMFBRs are fully convinced that in terms of safety, LMFBR as a type is second to no other reactor type when full advantage is taken of the intrinsic features and is combined with good engineering. This conclusion is based on the detailed design studies carried out in the context of the proposed 500 MW Prototype Fast Breeder Reactor (PFBR).

1.2 Although India has an ambitious programme for deployment of LMFBRs, resources available for the perfection of the technology are quite modest in comparison to the resources deployed by other IWGFR member countries. Consequently, the cognisance of all available informations arising from R & D programmes of other IWGFR member countries becomes one of the most important considerations. Our own detailed design studies also contribute to the decisions taken. The actual experience of construction and operation is expected to lead to certain modifications in the design approach and it is hoped that these modifications will be more in the nature of removal of the degree of conservatism provided in the present design rather than increasing the complexity and cost of engineered safety features. With these general remarks, one can turn to the core of the "over view" presented in the following :

2. NUCLEAR SAFETY ISSUES

2.1 The safety of the reactor can be divided into nuclear and non-nuclear considerations. In the present over view, non-nuclear considerations have been touched upon only to the extent they have a bearing on the nuclear considerations.

2.2 Nuclear safety can be considered under the following headings:-

a) Flexibility and ease of operation over the entire power range from zero percent to beyond the limit determined by the safety settings. Indeed to allow for the uncertainty in the design analysis, it is necessary to investigate the operability of the reactor from zero power to atleast 150% of the nominal power.

b) Effectiveness of steps to ensure the safety as well as good plant availability under foreseeable incident conditions.

c) Guaranteed safe shut down of the reactor in the event of any conceivable disturbance.

d) Ability to remove safely and reliably the decay heat generated in the system while the reactor is held sufficiently sub-critical in the shut down state.

e) Containment capability including protection of the reactor from events external to the system.

3. BACKGROUND

3.1 It may be worthwhile to recall that the PFBR has a thermal output of 1200 MW and comes into the category of reactors of intermediate output-neither small like Prism nor large like Superphenix or EFR. The reactor has an overall non-significant positive sodium void coefficient. At the same time the reactor is not adequately large to give an internal conversion ratio of unity or slightly larger than unity to eliminate reactivity swings associated with the large burn up. For avoiding the problems of thermal striping radially heterogeneous concept stands positively rejected. There is some interest in the axially heaterogeneous concept, but the interest at present is more academic than real. To begin with, it has been decided to have a homogeneous core with fuel design optimised to give nearly minimum fuel cycle cost and a short doubling time.

3.2 As our own irradiation experience is limited, the initial cores have been designed to have refuelling at relatively short intervals while the possibility of extending the interval has been kept in mind. It may also be recalled that the reactor has been designed to accommodate any of the fuel options namely, mixed oxide, mixed carbide/nitride and a ternary metal alloy fuel (uranium + plutonium + zirconium alloy). The first few cores of PFBR would of course use mixed oxide fuel. But the growth potential of mixed oxide is totally unsatisfactory as India needs a very large contribution to nuclear energy programme from LMFBRs and the contribution has to arise from the limited amount of plutonium that is expected to be generated by the modest PHWR programme based on indigenously available natural uranium. An advanced fuel, therefore, appears absolutely necessary for the long term needs of Indian Nuclear Programme. At the time the decision for fuel for FBTR was taken, it was felt that the mixed carbide would be the preferred advanced fuel for Indian Nuclear Power Programme based on LMFBRs. But since then many things have happened. We have understood the problems to be faced in large scale fabrication of mixed carbide fuel arising from the pyrophorus nature of the material. Reprocessing of the fuel will also be significantly more expensive compared to reprocessing mixed oxide fuel. Resultant fuel cycle cost with mixed carbide is likely to be higher than the fuel cycle cost with mixed oxide and the extra revenue related to the larger breeding gain with mixed carbide fuel does not adequately compensate the increased fuel cycle cost. Had there been no other option, we would have perhaps continued to put our faith in the mixed carbide fuel. But the developments in the area of ternary metal alloy fuel reported from Argonne National Laboratory appears to provide a better alternative to the mixed oxide fuel. As of today, this assessment is still in the nature of a technology forecast. But increasing number of people feel that metal alloy fuel will be perhaps the best option in the long term, capable of providing minimum fuel cycle cost and a good growth potential without any compromise with safety. It is, therefore, felt that the reference fuel for the initial core of PFBR is mixed oxide while reference fuel for fast reactor programme beyond PFBR will be the metal alloy fuel.

3.3 Consequently PFBR design is progressing in such a manner that the reactor can be fuelled initially with a mixed oxide fuel while it should be possible to load some metal alloy sub-assemblies in the oxide core before changing the full core to the metal alloy. To be able to achieve this, it has been decided that the power density will be kept constant irrespective of choice of the fuel. The total flow of primary sodium arising through the core and the head developed by the primary sodium pumps will be the same for any of the fuel option. The size of each fuel sub-assembly will also be the same and external features (head, foot and the body would also be the same). The pin diameteres would of course differ. Inlet and outlet sodium temperatures for the metal alloy option may have to be little lower than the inlet and outlet temperature for the initial mixed oxide option. Therefore, there will be an economic penalty as the electrical output of the reactor with a metal alloy fuel will be less than that of the mixed oxide core. This economic penalty is considered acceptable in view of the valuable operational experience to be gained for the whole core irradiation of a metal alloy. Main considerations (a) to (e) listed above are, therefore, examined for different fuel options.

3.4 The analysis is not complete in all respects for all the different fuel options but all important aspects have been examined for the three options. Behaviour of mixed nitride fuel is expected to be very similar to the behaviour of mixed carbide fuel and consequently completion of the analysis of mixed nitride fuel is a low priority effort.

4.0 SUMMARY OF RESULTS

4.1 Flexibility and Ease of Operation: The studies carried out have not revealed any difficulty in operating the reactor over the entire power range, in spite of the fact that all reactivity coefficients are not negative. The sodium void coefficient is positive while the Doppler coefficient is negative. The sodium void effect is smaller than the Doppler coefficient as long as sodium does not reach the boiling point and hence overall power coefficient remains negative. The magnitude ofcourse varies for the different options. Moreover the coefficients in general are small as is expected for LMFBRs and therefore, contribute to the ease of operations.

4.2 Safety in respect of incidents : Single events like loss of a primary pump, loss of a secondary sodium pump, accidental withdrawal of a control rod at the design speed and other similar incidents have been analysed in detail for the three options. With the design of the reactor protection system planned for PFBR as detailed in a separate presentation at this meeting, atleast two and many times three independent outputs from reactor protection system are available for taking the necessary safety action. In most cases, lowering of the rods to adjust the power to a lower level is considered adequate and reactors scram is not required.

Indeed even without safety action the plant is expected to be stabilised under conditions which can be considered as acceptable taking into account the fact that failure of the reactor protection logic to take corrective action will be a phenomena of much lower frequency than the initiating incident itself. For example if tripping of one primary sodium pump may have a frequency of two per year, in the life of the plant, we may expect 50 to 60 incidents. Out of the 60 incidents safety action not taking place due to the failure of reactor protection logic is likely to be less than one in the life time and for the one incident the conditions would be acceptable.

4.3 Ability to shut down the reactor safely in the event of major disturbances :

Loss of heat-sink and loss of primary flow are considered as representatives of major incidents. Detailed analysis has shown that the reactor protection logic provides sufficient number of diverse output to safely shut down the reactor. Here it is worthnoting that it is contemplated to provide adequate number of "Gem" Sub-assemblies (Gas Equipped Modules) conceived by designers in USA. If credit is taken for the negative reactivity contributed by these Gem modules, mere tripping of the primary sodium pumps can shut down the reactor safely without any assistance from the reactivity control system. The safety margin is highest in the case of metal alloy fuel and the safety margin decreases progressively and becomes minimum for the mixed

oxide fuel. Indeed it is possible that the safety authorities may not consider this safety margin without the credit for "GEM" sub-assemblies as adequate to prevent boiling of sodium in the "hot" sub-assemblies to obtain full credit of the inherent safety features. It is ofcourse necessary to provide for a slow coast down of the primary flow. The fly wheel with a time constant of 12 seconds is planned for the primary sodium pumps. The fly wheel is mounted directly on the shaft of the pump so that certain amount of stored kinetic energy is always available without dependance on any other equipment or system.

4.4 Fuel-melting and Core Catcher :

Progressive melting of the fuel pins due to propagation of the fault has also been studied for all the fuel options. It has been observed that in each case initially there is some addition of reactivity as fuel moves from a region of lower importance to the region of higher importance. But as the fuel movement continues under the influence of gravity, the fuel soon enters the region of lower importance and therefore, contributes negative reactivity to the system. Detailed analysis has shown that even simultaneous melting upto seven full sub-assemblies can be taken care of by the reactor protection system provided. Such large failures can be considered as beyond the design basis and therefore, the overall position can be considered as acceptable. Further, it has been shown that the molten fuel flowing downward will freeze before reaching the top surface of the grid-plate. Hence core-catcher is considered unnecessary by the designers. Safety authorities have yet to take a decision in this regard.

4.5 Decay Heat Removal :-

Normal approach to the removal of decay heat would be the operation of any one of the secondary sodium loops and its associated steam water circuit. It may be recalled that PFBR is a four loop reactor and therefore, there is abundant redundancy in the design for removal of the decay heat as long as power is available for operation of the pumps. But in the event there is a power failure decay heat will be removed by the decay heat removal system based on sodium to air heat exchangers. The system consists of sodium to sodium heat exchangers immersed in the main vessel in the hot pool and a sodium to air heat exchanger based on natural covection as the cold end of the decay heat removal loop. Four such loops have been provided to provide near normal temperature distribution within the hot pool while the cold pool temperature is limited to 500 °C. Consequently putting the decay heat removal system into operation does not involve any significant thermal stresses. Each DHR loop is designed to remove 8 MWth so that even in the extreme event of 2 of the 4 loops being not available, two loops remaining in service will be able to remove the decay heat without the temperatures in any part of the system exceeding the safety settings. Removal of the decay heat by natural covection from the main vessel walls as is the case for the Prism reactor is not favoured because of the relatively large size of the reactor and more importantly because of saline atmosphere as PFBR will be located in a coastal area. The stainless steel which is the material of construction for the main vessel is expected to get sensitised during the life of the plant and therefore, it is essential to avoid contact of the saline air with the sensitised stainless steel. Indeed for this very reason the material of construction for the decay heat removal system has also been chosen as ICr-IMO Ferritic steel to eliminate the possibility of sensitisation and inter granular corrosion failure.

4.6 Containment Capability:

With the design provisions, core melt down can be considered as an event of extremely low probability and can be classified as beyond the design basis. Yet it has been considered in determining the containment capability of the system. Detailed analysis has shown that for any of the fuel option, the mechanical energy releases during Hypothetical Core Disassembly Accident (HCDA) will be less than 200 Mega Joules. Energy release of this magnitude can be absorbed without failure of the main vessel or the roof slab. Indeed no sodium is expected to be released to the containment building yet as a design basis, it has been assumed that upto 500 Kgms of sodium can be ejected into containment building. This ejected sodium can catch fire and give rise to over pressure of 200 to 250 milli bars.

The containment building has been designed to withstand such pressure build up and limit the release to less than 0.1% of the building volume per hour. The resultant spread of contamination at the site will be modest and the dose at a distance of 1 Km. from the reactor building will be less than 9 REMs.

During the course of studies, it has been observed that integrity of the primary sodium system is most important for the safety of LMFBRs. This integrity can be breached by external events like an aircraft crashing on the reactor building or sabotage or persistant enemy action. The site selection ensures that the probability of an air craft crashing on the reactor containment building is less than 1×10^{-8} per year. Yet it is considered prudent to provide a containment building which is more of a barrier to stop the external objects reaching the primary sodium system to preserve its integrity. PFBR containment building, therefore, has been designed as an impact resistant structure.

CONCLUSION

In conclusion it is felt that LMFBR can be designed very easily to eliminate anxieties about their safety and no difficulties are expected in the licensing of these reactors.