Fuel cycle strategies for growth of nuclear power in India

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Abstract. Nuclear power has been identified as an essential component to meet the growing energy demand of India. The three stage fuel cycle strategy to achieve this with the available resources envisages the use of natural uranium in PHWRs in the first stage, the plutonium-uranium/plutonium-thorium cycles in Fast reactors/Advanced HWRs in the second stage, followed by exploitation of essentially U233 in the third stage. The technologies necessary for this programme, mainly through the back-end of the fuel cycle including reprocessing, waste management and recycle of Pu have been developed accordingly, as a direct result of the closed fuel cycle policy followed by us from the very beginning. This paper addresses the considerations involved in several activities taken up in our programme, their current status and plans for the future.

1. INTRODUCTION

It is expected that bulk of the world nuclear growth in the coming decades will be in Asia, of which India is no exception, due to the projected population growth and consequent energy demand. At present our total installed electricity generation capacity is 90 000 MWe, of which the nuclear contribution is 1 840 MWe. By the year 2020, these capacities are planned to be 450 GWe and 20 GWe respectively[1].

This nuclear component is expected to be met by a mix of Pressurised Heavy Water Reactors (PHWRs), Light Water Reactors (LWRs), VVERS, Fast Breeder Reactors (FBRS) and Advanced Heavy Water Reactors (AHWRs). This structure of our plan has evolved due to our limited natural uranium (nat.u) reserves and need to exploit the abundant thorium resource.

The resource base of U is about 60 000 tons of assured resources with about 30 000 tons of estimated additional reserves[2]. The thorium resources are estimated at about 590 000 tons. The closed fuel cycle philosophy has hence been our natural choice from the very inception of our programme. A comprehensive back-end fuel cycle has been an essential component of our work plans. The related strategies worked out and studies being undertaken to realise that objectives are outlined hereunder:

2. THE THREE-PHASE POWER PROGRAMME

The nuclear power programme in India envisages the setting up of nat.U fuelled PHWRs in the first phase. Utilisation of Pu obtained by the reprocessing of the spent fuel from the PHWRs is the second phase in which FBRs using mixed oxide fuel will be set up, in parallel with the construction of AHWRS, which would use Th and a small feed of Pu. The third phase involves exploiting the Th-U^{233} Cycle in breeders, which could sustain a generation of 200 000 GWe using our large Th reserves.

At present, we have, a couple of BWRs and 9 PHWRs in operation, generating a total of 1 740 MWe . Construction is in progress on 5 PHWRs for a capacity augmentation of 1 660 MWe, with 3 of them nearing completion shortly. The projected growth for plant construction is shown in Table-1. These perspectives are in line with the projected international vision that FBRs will become available, driven by increased uranium prices, and reprocessing will be accepted, although it should economically compete with interim storage of spent fuel, and Pu would become a scarce commodity [3].

TABLE I. Projected Growth of Nuclear Generation Capacity up to 2020s

	Installed Capacity /No. of Reactors in operation											
Year	BWR		PHWR		FBR		VVER		LWR		Total	
2000	320	2	2.400	12	-	-	-	-	-	-	2.720	14
2005	320	2	3.400	14	-	-	-	-	-	-	3.720	16
2010	320	2	4.280	18	500	1	2.000	2	-	-	7.100	23
2015	320	2	7.780	25	500	1	5.600	6	220	1	14.420	35
2020			9.280	28	2.500	5	8.300	9	440	2	20.840	46

3. BACK-END CONSIDERATIONS

The need for effective utilization of limited resources, while ensuring meeting the environmental obligations, has been the driving force for adopting the Reprocessing and Recycle option. Exercising this option for a closed fuel cycle enables the resource base to be exploited for large scale nuclear power generation. Efficient utilisation of Pu is the key for the success of the closed cycle philosophy. Also, the Reprocessing and Recycle option will, while ensuring the sustainability of nuclear power, result in the reduction of actinide/minor actinide inventories and lead to safe management of rad. waste. The Th/U fuel, while necessitating a new reactor type, has benefits in this area-, and FBRs, in the burner mode, also facilitate this objective [4]. The long-term radiological risk is reduced very significantly as a result of the extraction of U and Pu from the spent fuel.

3.1 Reprocessing and Plutonium Fuel Fabrication

Reprocessing with plutonium recycle option has endowed the programme with several mid-course options in both U & Th fuel cycles with Pu forming the vital link between the two [5]. At present there are three reprocessing plants in operation one for research reactor spent fuel at Trombay (nat.U fuel) and for power reactor zircaloy-clad oxide spent fuel one each of 100T capacity at Tarapur (in operation since 1978) and Kalpakkam (recently commissioned). PUREX process is adopted in these plants. Further, provision has been made for augmentation of capacity at the recently commissioned plant at Kalpakkam. Also planned is a separate reprocessing facility for the mixed carbide spent fuel from the fast research reactor or FBTR and 2 additional plants for the PHWR spent fuel. Keeping in mind the need to reduce the toxicity potential of the waste to be disposed off, and to have better partitioning efficiencies, R&D activities are being pursued with these objectives. Alternative extractants, reduction of the actinide content of the wastes including minor actinides, etc. are under investigation. Simultaneously, work is on hand for the development of Co-conversion routes for mixed oxides, e.g. the sol-gel process, which would supply free flowing microsphere granules as feed for MOX fuel fabrication. This dust-free process goes a long way in enabling automated MOX fuel fabrication by omitting the hazardous powder handling steps of the process flow -sheet and will be amenable for thermal reactor or fast reactor fuel fabrication programmes. The sol-gel processing step can be integrated into the reprocessing plant, which will have operational advantages.

3.2 Fast Reactor Fuels and MOX Programme

For our fast test reactor FBTR at Kalpakkam, mixed carbide of 70% PuC-UC composition was chosen as the fuel for the first core, after detailed feasibility studies were conducted on this new fuel type. This fuel has performed satisfactorily, and the core comprising of 25 fuel assemblies of 61 pin design has accumulated a burn up of more than 50 000 MWd/Te, Recently, it has been relicensed for burnup extension to 65 000 MWd/Te. The post-irradiation examination of the maximum rated fuel to evaluate the expected life-limitation due to pellet-clad contact by fuel swelling has indicated potential burnup extension well beyond the licensed limits[6]. It is now planned to carry out experimental irradiation in the FBTR of compositions Of UO_2-PUO_2 typical of commercial fast reactors for the proposed Prototype Fast Breeder Reactor (PFBR) at Kalpakkam. Fabrication of the test pins is under way. Studies on mixed nitrides are also under consideration as doubling time could be an important consideration in the coming decades. Mixed nitride fabrication would be comparatively easier than mixed carbide, as also reprocessing.

As for thermal recycle, feasibility studies were carried out for enabling MOX use in our BWRs and PHWRS. Based on these, MOX fuel has been introduced in a small scale in the BWRs at Tarapur. This MOX fuel assembly design incorporates three Pu enrichments in the 6 X 6 fuel bundles. This fuel design replaces the standard LEU fuel rod design with similar performance and is planned for use up to 30% of core assembly. The lead assemblies, fabricated in a MOX fuel fabrication plant set up at Tarapur[7] have seen a burnup of more than 16 000 MWd/Te, and work is on hand to progressively enhance the number of MOX fuel assemblies in these reactors. Studies were also conducted for PHWR fuel bundles with MOX in the inner 7 rods of the 19-rod bundle design[8]. While a reference bundle design has been made, irradiation studies are planned to be taken up shortly. In this scheme, it is expected that there will be considerable savings in nat.uranium consumption, primarily due to the enhancement of the design average core burn-up from 6 800 MWd/Te to about 10 500 MWd/Te. The annual Pu requirement for this scheme is quite small for the 220 MWe reactor. There will be considerable savings in the back-end costs and the load on reprocessing and waste management will be significantly reduced, as also work load on the fueling machines for these on-load-refueling reactors.

3.3 Radioactive Waste Management

The programme on safe management of radioactive wastes envisages two distinct modes of final disposal-, near-surface engineered, extended storage for low and intermediate level active wastes and deep geological repository for high level and alpha bearing wastes. A waste Immobilization Plant for the treatment of high level waste has been in operation at Tarapur, wherein a semi-continuous pot glass process is applied for calcination and melting 'in process vessels as the means for vitrification. Two additional plants are under construction at Trombay and Kalpakkam. A comprehensive view on vitrification takes into account melt development, acceptable product characteristics and processing techniques. The melt developments are constantly reviewed and eformulated to accommodate changes in the inactive constituents associated with the high level liquid waste and the equipment and techniques to accomplish it. To enable high melting glass forming, joule heated ceramic melters and cold crucible practices are being introduced, changing from the current induction melting practice.

The solid storage surveillance facility (SSSF) has recently been commissioned at Tarapur for the interim storage of high level wastes. For the purpose of final disposal, the choice is focused on igneous rock formation and some selected sedimentary deposits. Investigations are in progress for the evaluation of candidate sites for a repository.

3.4 The future options in Waste Management

The partitioning and transmutation options are also under study in India. For the present, these studies are limited to the partitioning of the long-lived actinides from the high level wastes. At an appropriate time, a long-term policy on the final utilization/transmutation of the recovered actinides would be evolved, based on the technologies that would be available in future.

CMPO based solvent extraction and extraction chromatographic studies with high level wastes are in progress. It is intended to develop flow sheets for partitioning of relevant actinides from the wastes to reduce their alpha burden. KSM-17(equivalent to PC-88 A) based extraction chromatography has given viable results for trivalent actinides separation from trivalent rare-earths, which appear together in the CMPO process[9]. Electro oxidation of Ce followed by its removal by TBP or KSM-17 extraction is possible for the separation and reduction of Ce content in Am.

4. Th AND U^{233} CYCLE

Thorium bundles are being irradiated in the PHWRs for the purpose of initial flux flattening at reactor startup. It is planned to recover U^{233} by reprocessing using the thorex process which has been under use for research reactor irradiated Th/ThO_2 rods and studies are planned for the fabrication of U^{233} based fuel. The Advanced Heavy Water Reactor currently under design envisages obtaining almost 80% of the energy generated using Th and the balance through Pu[10] and the fuel assembly design is being appropriately made. It is expected that we would be taking up fabrication of this type of fuel in the near future. Thoria is also the chosen blanket element in the FBTR, wherefrom quantities of U^{233} could be separated. Development work on fabrication of U^{233} based fuels is hence an essential task. Remote refabrication is envisaged for this purpose and a pilot plant scale facility is planned to be set up in the coming years. For the present, a low energy neutron radiography facility, KAMINI, has been in operation at Kalpakkam using U^{232}-Al plate type fuel elements fabricated at Trombay[l 1]. Steps are also planned for clean up of U^{233} to keep U^{222} levels low enabling the fuel cycle to manageable limits. This would be a major solution to our near near-term and long-term plans for thorium utilization.

5. KEY FACTORS FOR THE BACK-END STRATEGY

The key factors for the long-term back-end strategy in order to implement the 3-phase nuclear power programme efficiently flow from the directions of work programme outlined in the previous sections. It is essential that the reprocessing and waste management operations which make available the Pu and U^{233} for the second and third phases, are carried out efficiently with minimum burden to the environment . Further, for ensuring economic viability, the reprocessing capacity would be planned and added to make Pu available for use on Just-in-Time (JIT) basis. Such a scheme would also alleviate the problems posed by presence of AM^{241} in stored Pu. Some capacity of Away-From-Reactor (AFR) storage has to be built up for the interim storage of spent fuels. Recycled uranium (depleted) would be ploughed back into the fast breeder fuel cycle. Schemes for the burning of minor actinides in fast reactors or by transmutation techniques are to be evolved and implemented. In order to execute the second phase of the programme effectively, MOX and fast reactor fueling schemes would be organized on a larger scale. For efficient implementation, higher burnup fuel designs have to be evolved and tested after establishing that the fabrication procedures are simplified to enable automated fabrication. The PFBR and the AHWR are vital links for the 2nd and 3rd phase, and their success needs to be ensured. As such, for the two reactor types, considerable design effort is under way and several component fabrication/performance studies are also being proceeded with. Aspects of the advanced fuel cycle, e.g. the $Th-U^{233}$ cycle for the long-run are being addressed and there is optimism that the issues are quite resolvable, although there is no underestimation of the magnitude of the task.

6. CONCLUSION

The present status of the Indian nuclear power programme is addressing the essential elements of the three phase power programme, based on the resource constraints on uranium and abundant availability of thorium. The near term strategy is crucial and would demonstrate the adaptability of the plans for the long-term growth anticipated to meet the bulk energy demand foreseen. The back-end area has, as such, many possibilities and challenges, and will have to be addressed taking into account the progressive demonstration of the key technologies.

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