the same as they were four or five hundred years ago. As a result of the changed Acts, semi-educated persons become elected as members of the University Executive Councils for indefinite tenures to pass judgement over university administration, standards and appointments, whereas university teachers get in by rotation for a limited term of one year instead of being elected by their colleagues. The Deans of Faculties are again appointed by rotation so that except two the remaining faculties remain unrepresented in the Council and the Deans too have a limited term of one year. Senior-most Lecturers and Readers who fail to secure the higher ranks, even by promotion become representatives of Readers and Lecturers, it is claimed to avoid electioneering. Above all, Vice-Chancellors are not elected but selected by a strange Committee which has one nominee of a political chancellor and only one of them elected by the Executive Council and the other nominated by the Chief Justice of the High Court and thereafter the Chancellor has a second and final choice of appointing the Vice-Chancellor. And mind you, a political Chancellor has supreme power over twenty or more universities. Unless we bring back our old Acts of Universities there is hardly any chance of improvement.

In spite of the extreme paucity of avenues of employment for graduates or postgraduates in science, our Universities are unable to control the mad rush for admissions in universities and colleges. No one even thinks of methods of controlling admissions in universities and colleges. Their numbers have been rising year after year without quality control. More universities and colleges are opened where quite a large number of students enter for training as 'netas' for later political life through student unions because this is the most easy course for a lucrative profession. Others join because there is nothing else they can do in the largely elusive hope of qualifying for some employment and also because the cost of graduate and postgraduate education is easily affordable, sometimes being cheaper than school education. I think it is late but not too late and we must plan our higher education particularly in science where the cost of education is relatively high. One of the methods of controlling the rush of students for higher education is to make it costly as they have done in Cambridge and Oxford. The fees in these universities are so high that only the best students who hold government scholarships for education or children of those who can afford such costly education can enroll there. Naturally when the toppers or the students whose parents pay such high amounts for their higher education enter the universities, they seldom waste their time and opportunity for learning. We must therefore make our primary education free and easily affordable but make our higher education particularly in science costly so that only our best and motivated students get in. Finally those students who choose scientific research must do so as an end in itself and not as a means to some other end.

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SCIENTIFIC CORRESPONDENCE

Who is afraid of breeders?

We present here our comments on the article by Tongia and Arunachalam[1].

Who is afraid of breeders? Many are. The main basis for the fear is the concern for nuclear proliferation as the fast breeder reactor (FBR) breeds or produces more fissile material than it consumes. The fear has manifested itself in many forms.

One of the earlier manifestations was the argument against the closed U-Pu cycle initiated during the International Fuel Cycle Evaluation (INFCE)[2]. Fortunately and correctly, the conclusion from the INFCE studies was that 'No fuel cycle is free from proliferation'. Nevertheless, we witnessed the abandoning of the FBR programme in the UK, Germany and USA; the joint European FBR programme also has been disbanded all due to the fear. Then came the campaign that as there are abundant resources of energy (coal, oil, gas, uranium and the highly enriched uranium and plutonium from the dismantled weapons), there is no need to breed, we should only burn fissile material. So France is converting its breeders to burners, with inert matrix fuels, etc.[3] The Russian Federation, Japan and India are the only three countries that have announced plans to continue with the FBR on a commercial scale. (While China is now building a 65 MW test fast reactor, and South Korea a 50 MW test fast reactor, we started construction of our 40 MW Fast Breeder Test Reactor [FBTR] way back in the seventies.)

Now come Tongia and Arunachalam with the advice to India that fast breeders do not breed fast enough and therefore 'India should consider entering into long-term agreements with other countries, with appropriate policy innovations for importing uranium'. Alas they have not told us which countries and what are the 'appropriate policy innovations'. It is interesting that in their paper under Methodology, in the subsection 'Plutonium from PHWRs' (p. 553), Tongia and Arunachalam state, 'The availability of uranium from other countries is not included in these calculations as there are restrictions imposed by the Nuclear Suppliers Group on the supply of nuclear materials to India'. So their advice is very

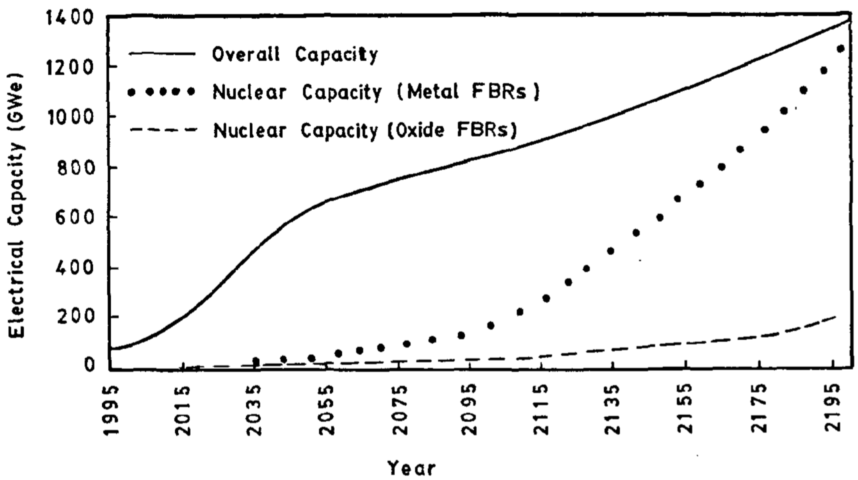

Figure 1. Installed electrical capacity in India and possible contributions from oxide FBRs (0.6 PLF, 2% cycle losses) and metallic FBRs (0.6 PLF, 1% cycle losses).

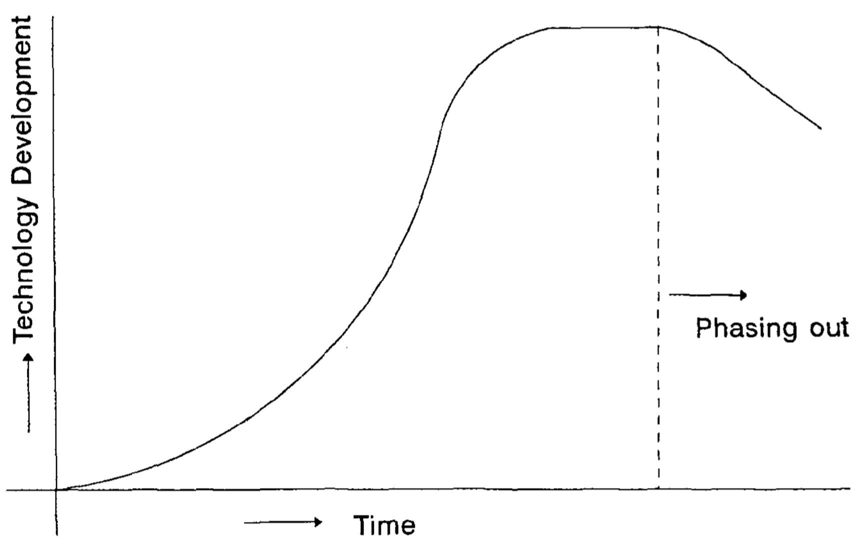

Figure 2. The learning curve for technology development.

clear. The appropriate policy innovations should be those that satisfy the Nuclear Suppliers Group to remove the restrictions!!

Fast breeders do not breed fast

The main conclusion in their paper is that it appears difficult to have FBRs with short doubling times and hence the contribution of FBRs to the country's total electric capacity requirement could remain low till the latter half of the 21st century (figures 5 and 6 of their paper).

It is a common misconception that the adjective fast in fast breeder qualifies the word 'breeder'. It does not and indeed fast breeders do not breed fast. Walter Marshall[4], in the context of ~ 30 years doubling time for the oxide fuel, commented in 1980, 'In short, fast breeders do not breed fast, they simply use fast neutrons and breed rather slowly'. But as the fissile atom density in the fuel increases, i.e. as we go from oxide → carbide → nitride → metal, the doubling time decreases and fissile material growth rate increases (as indeed are the results of Tongia and Arunachalam in their tables 4 and 7 respectively). They have also demonstrated the effect of better breeding of advanced fuels (metal/carbide) in their figures 5 and 6. It is surprising that in their Figure 4*a* they plot the possible nuclear capacity for *oxide FBRs only*. In Figure 1 we depict their Figure 4*a* including the possible FBR nuclear capacity with metallic fuel, using data given by them. Even with their questionable assumptions; the growth rate is good!

Dangers in projecting from the past and present to the future

As scientists and engineers, all of us know the dangers in extrapolating to the future using data from the past/present. The slope in the future of the learning curve of any new technology (Figure 2) is difficult to predict and the pitfalls in making long-range predictions are obvious. In the analysis by Tongia and Arunachalam plant load factor (PLF) is the most important parameter and they vary it between 40 and 70%. True, these were the PLFs for Indian PHWRs before 1995. But TAPS-I had PLF of 84%, MAPS-II of 78% and Narora of 90% in 1997–98 (ref. 5). The average PLF for all the plants in the last three years is greater than 70%. Indeed with these PLFs even with the many other erroneous assumptions in their paper, nuclear growth through FBRs becomes feasible particularly with advanced fuels. It is wrong to project the low PLF of the earliest years as valid for the growth of FBRs for over a century in the future.

Resource utilization

FBRs have many advantages. In the context of the paper under discussion, two are relevant and important: growth capability and resource utilization capability. The authors have failed to note that the growth capability of FBRs is secondary to their resource utilization capability. By the use of FBRs the utilization of uranium can reach 60–80% as compared to less than 1% with LWRs and PHWRs on once through cycle or a few percent with Pu recycle[6] (Figure 3). As noted in table 1 of the paper by Tongia and Arunachalam, this translates to atleast 50 times more energy

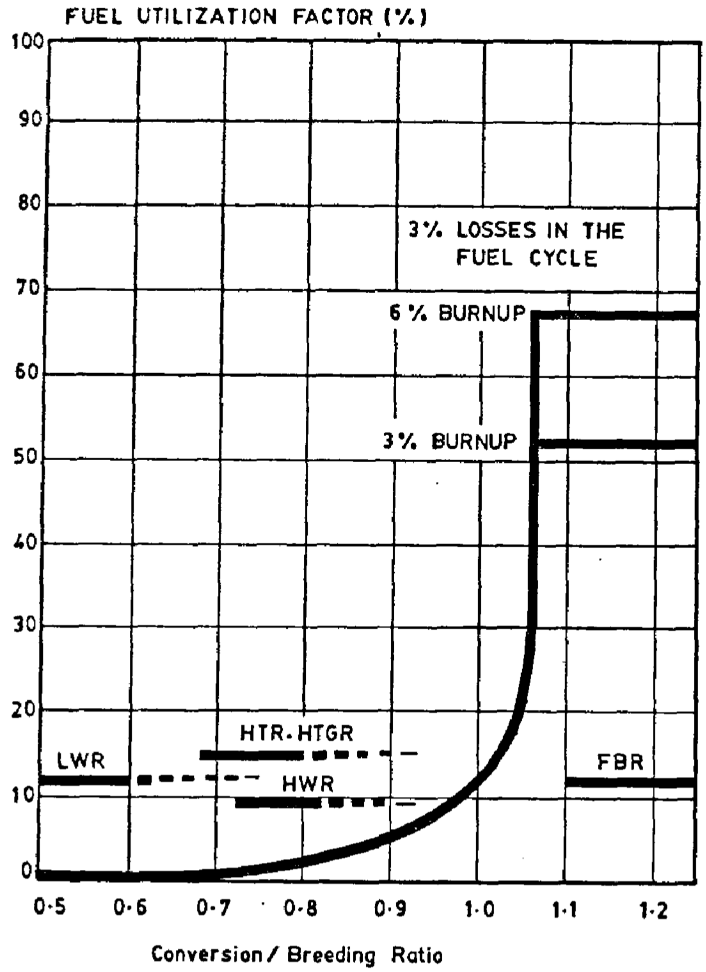

Figure 3. Utilization of uranium as a function of conversion/breeding ratio.

extracted from indigeneous uranium or 50 times less uranium to be imported for the same amount of electricity produced.

In Figure 4, we give the potential of different energy resources in India. For *energy independence*, the long range planning should base a major share of electricity generation of a country on indigenous resources. The importance of FBRs, in this context, for India is obvious, given the kind of growth in energy demand expected in the coming decades and later into the second half of the next century and even for a lower growth rate than that assumed by Tongia and Arunachalam.

The question is not where will the uranium come from but where is the uranium?

While the paper has recommended the construction of a large number of thermal reactors using imported uranium to rapidly increase the nuclear power base, it has not studied the implications of the suggested strategy and the kind of electrical capacity growth that could be achieved (as in their figures 5 and 6). Without such an analysis the recommendation of the paper cannot be accepted. In their figure 4 it is seen that by 2055 a target electric capacity of 600 GWe is projected, and if as advocated in the paper, a substantial fraction (say 50%) of this is to be from thermal nuclear power plants, then it implies that about 300 GWe should be fed by imported uranium. On once through fuel cycle basis this requires mined uranium of 20 *times* the U resource available in the country, i.e. 1.2 million tonnes of natural uranium, which is more than the reasonably assured uranium reserves in USA and Canada together. Not only is such import unfeasible in the context of world uranium availability but such an import requirement will grossly compromise the energy independence and energy security of India. In addition, the strategy for reprocessing or other disposition of the spent imported fuel requires considerable study and is not touched upon in the paper. It is also to be noted that the use of Pu–Th cycle in thermal reactors cannot increase the installed thermal nuclear power capacity but can at most maintain it at the same level.

A recent OECD study[7] has examined three scenarios for the change in the present nuclear share in the world energy production in the next hundred years (Table 1 and Figure 5). The most optimistic scenario (I) projects a total nuclear installed capacity of 1120 GWe in 2050 for the whole world, which means a production of about 1 TWy per year. We cite these only to show that a total nuclear generation of 1 TWy per year can be sustained by the open LWR cycle for only 44 years by the world's uranium resources[8] (Figure 6). In the absence of any other new technology, FBRs will ultimately become relevant and necessary for the whole world.

FBR initiation does not depend on doubling time

Starting from the fact of long doubling times of present day FBRs, Tongia and Arunachalam conclude that the Indian FBR programme will take a very long time to make a significant contribution to the growing national electricity base. This conclusion come from incorrect or unjustified assumptions as explained below. The natural uranium available in India can be used to set up about 10–15 GWe of PHWRs. The Pu available from the spent fuel of this initial PHWR base is enough to set up over 25 GWe of FBR capacity, i.e. atleast 50 FBRs of 500 MWe capacity each. The growth rate upto this initial FBR capacity is governed by the rate of setting up of PHWR plants and the rate at which the PHWR spent fuel is reprocessed. In this period the fissile growth from the FBR breeding process is only a bonus and certainly not a limiting factor, i.e. in this phase it is the Resource Utilization Capability of the FBRs which is important and not the growth capability.

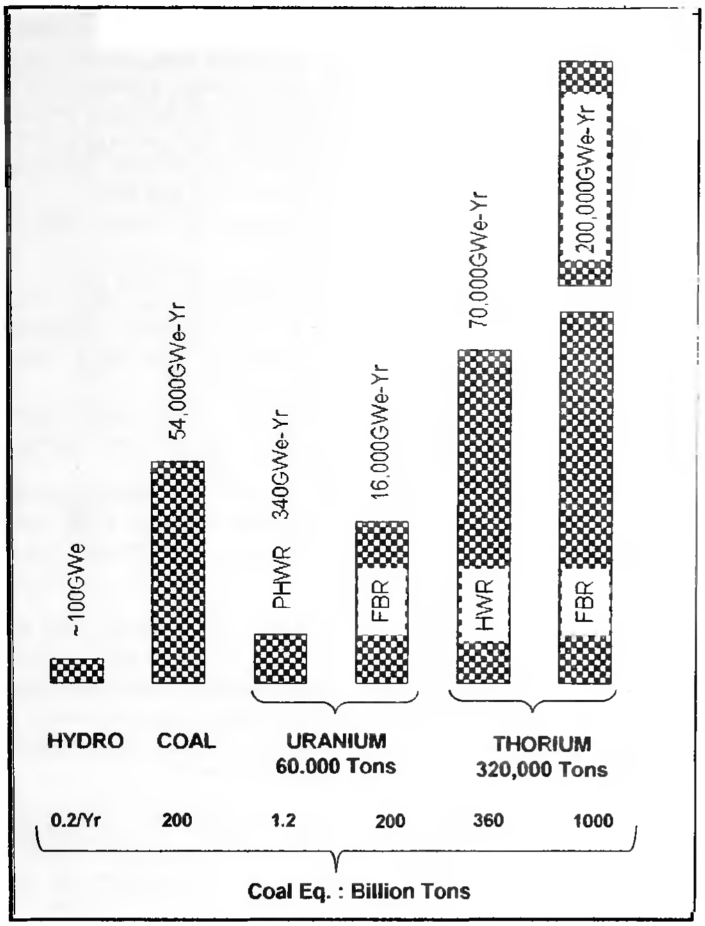

Figure 4. Comparison of different energy resources for electricity generation in India.

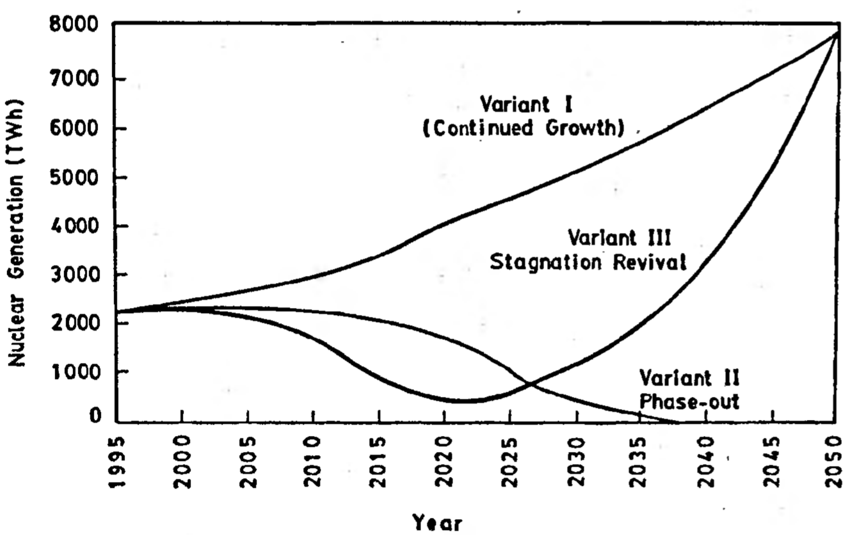

Figure 5. World nuclear electricity generation projections.

Table 1. Three variants of world nuclear power capacity (GWe) up to 2050

Nuclear variant	2000	2010	2020	2030	2040	2050
Continued-nuclear growth	367	453	569	720	905	1120
Phase-out	360	354	257	54	2	0
Stagnation followed by revival	355	259	54	163	466	1120

The need for short doubling time arises only after a substantial base of FBRs (25 GWe) is set up and hence only compound system doubling time (CSDT) applies and the simple doubling times (SDT) used in the paper are not applicable.

We are working on advanced fuels for the future

Once the initial FBR capacity based on PHWR Pu has been successfully established, it will be necessary to have FBRs of short doubling time (12–15 years) to be able to further grow the FBR capacity in tune with the growth of the national electricity base. Many studies exist defining the technological developments needed in order to enable FBRs to have short doubling times. In particular, Tongia and Arunachalam have referred to studies by Lee who has identified several required developments to current FBR technology in order to have adequately short doubling times in the Indian context. In fact, we are very much aware of the need to develop advanced FBR fuel (advanced oxide, nitride, carbide or metal alloy) in order to have FBRs with good growth capability. R&D for advanced FBR fuels is one of the important objectives of the Indira Gandhi Centre for Atomic Research (IGCAR). Starting from the base provided by the mixed carbide fuel experience in FBTR, studies on advanced fuels including their fuel cycle are a part of the IGCAR R&D programme. The extreme sensitivity of the doubling time to factors such as fuel material, fuel design (e.g. pin diameter), plant load factor, out of pile cycle time, discharge burnup, cycle fissile losses and breeding gain is also well known. Studies[2] have shown that with a large pin diameter optimized for breeding, even the oxide fuel can give doubling times as low as 15 years and this is still lower for carbide/nitride/metal.

We note that Tongia and Arunachalam have made no attempt to calculate the values of FBOC and FG (in their eq. (1)) and take them from studies of others. On the other hand, pessimistic assumptions are made for EF, FL, PLF which are assumed to be applicable for over a hundred years in the future. In fact discharging fuel to out-of-pile storage and reprocessing of short cooled fuel are methods for reducing EF for

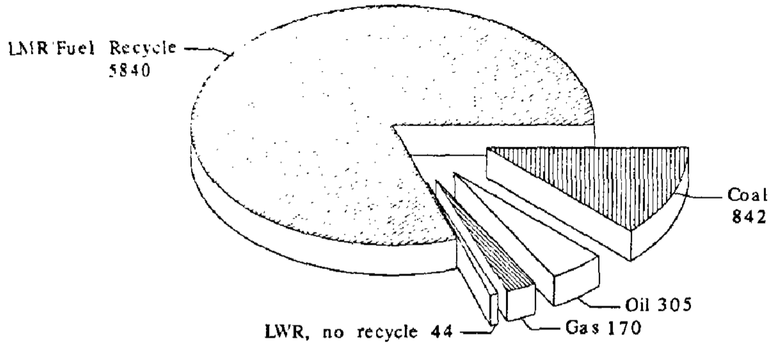

Figure 6. World fixed energy resources (TWy).

future reactors. Reduction of FL is also very important for future FBRs to have short doubling times and to reduce the actinide waste storage problems.

Further, the plant load factor cannot be taken at low values for growth studies (p. 552). When PLF is very low the reactor system cannot be sustained on economic grounds itself and any growth capability is irrelevant. Hence it is necessary to take the minimum PLF at the level needed for economic viability as the input for growth capability studies.

Conclusion

In conclusion the fast reactor system remains the only system for a complete and meaningful utilization of India's nuclear resources. Without this system it is not possible to have a sustainable nuclear power development in the country. As coal resources deplete and hydro resources saturate, the nuclear power fraction has to increase. The FBR option remains the only means of meeting the electrical energy requirements in the industrially developed India of the 21st century. Import of natural uranium along with light water reactors, can at best be a short-term measure of meeting immediate electrical energy demand but cannot be recommended on a large scale or as an option for sustainable development.

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Molecular chaperones

Molecular chaperones, of different classes, are now known to participate in a large variety of cellular functions. They assist in *de novo* protein folding, stabilize proteins under stress conditions and maintain polypeptide chain components in a loosely folded state for translocation across organeller membranes[1–3]. While the central dogma in protein folding from the sequence stands challenging, the involvement of cellular factors in the folding process show promising results. In view of the traditional domain of biophysicists and theoretical biologists, the protein folding problem will be interesting to see whether molecular chaperones will be able to influence the pathways of protein folding or even the final outcome of a folding reaction. Are there situations where the information specified in the linear sequence of amino acid residues is not sufficient for folding to the native state? Has the co-evolution of proteins and chaperones perhaps favoured certain folding pathways over others? To address these fundamental and very important questions, we analysed the amino acid composition, hydrophobic and charged patches, the residue–residue contacts in molecular chaperones and the monomeric globular protein sequences and compared the results.

The crystallographic data for a set of 4 chaperone proteins (GroEL, GroES, HSC70 and PapD) and the amino acid sequences of 92 chaperones and 74 monomeric globular proteins form the source of our study. The three-dimensional structures have been taken from the recent release of the Protein Data Bank (PDB) of the Brookhaven National Laboratory[4,5]. The sequence information for chaperones and globular proteins are taken from the SWISS-PROT[6] database. The PDB and SWISS-PROT codes used in this analysis are described in another article of ours[7]. We found a minimum deviation for most of the residues and the compositions for both chaperones and globular proteins are statistically significant. Also, a small deviation of 0.01 to 0.05 is observed for the amino acid composition of the 20 residues when one protein was omitted at a time, indicating the validity of the data set.