trol over nutritional input resulting in increased demand for wild fish for feed. Fish is a declining resource and there are serious environmental consequences related to the continued exploitation of fish stocks in order to meet the demands for an expanding market. Moreover, fish accumulates pollutants. The extracted oil often has an unpleasant odour and the proportion of specific fatty acids in its triacylglycerols is difficult to control. Considerable evidence has indicated that ω3 PUFA in fish oils is actually derived via the marine food chain from zooplankton consuming ω3 PUFA-synthesizing microalgae[9]. The importance of microalgae as source of PUFA has been recently reviewed[10]. The microalgae may have superior lipid stability compared to traditional PUFA because they are naturally rich in antioxidant carotenoids and vitamins and because lipids are bioencapsulated by the algae cell wall. Therefore, microalgae are some of the most important food/feed sources due to their nutritional value, and their ability to synthesize and accumulate great amounts of ω3-PUFA. Researchers and commercial producers developed several cultivation technologies that are in use today to produce microalgal biomass[10]. Martek Bioscience Corporation (http://www.martekbio.com), Columbia, USA, commercially produce DHA from fermentable strains of microalgae and this product is used in infant formulas.

The other solution to this problem is implementation of PUFA biosynthesis into oilseed crops which provide ALA and LA as suitable precursors for the production of large quantities of PUFA (C20- and C22-) for a growing human population. The past few years have witnessed the cloning and functional characterization of the genes involved in PUFA biosynthesis. The seed-specific biosynthesis of ARA, EPA and DHA has now been reported for various higher plants[11–13] including model plants (*Arabidopsis thaliana* and tobacco) and oilseed crops (soybean, linseed and mustard). Wu *et al.*[12] report that ARA reached the highest proportion of fatty acids in seeds and thus approach commercially relevant levels. The collective studies[11,12] represent a major step forward in the production of PUFA in transgenic plants and the significance of these advances has been recognized and discussed in a recent editorial[14] and review[15]. Successful accumulation of PUFA in all organs and particularly in leaves has been demonstrated[16]. This approach may result in green leafy vegetables rich in EPA and DHA along with mineral nutrients and vitamins as outlined by Bamji.

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Economics of nuclear power generation

B. P. Rastogi has conceded[1] that there are many good characteristics in the reactor concept ‘A Thorium Breeder Reactor’ (ATBR) proposed by us[2]. According to him, the single unacceptable feature of ATBR is the large fissile mass requirement in comparison to PHWR or PWR. He contends that ATBR would not be economical due to this exceedingly large Pu requirement both incore and out of core. He concludes with an ambiguous statement that *nuclear characteristics of Th cannot be wished away*.

It must be stated that the ATBR concept has been tailor-made essentially to exploit the very seemingly negative nuclear characteristics of thorium. Thorium does not have any intrinsic fissile content and is therefore ignored world over for nuclear power generation. As was brought out in our paper[2], there is a paradigm shift from the conventional nuclear power reactor designs while evolving the ATBR idea. We have suggested for the first time, to load the reactor with as much as 60% of the fuel by mass, by pure thoria rods with no externally fed fissile seed material in equilibrium core. These thoria rods, which are mere absorbers in fresh state, are prodded by the neighbouring Pu-bearing seed fuel rods, eventually to get converted into regular fuel rods. At least one batch size (120 fuel assemblies) of such pure thoria clusters are loaded in every fuel cycle. These thoria clusters after one fuel cycle irradiation occupy the third ring of every fresh seed fuel cluster and continue for three more fuel cycles. Seed in the form of reactor grade plutonium (PuO_2 in ThO_2) is considered in the inner two rings of seed fuel clusters. The Pu contents in fresh seed fuel rods are 200 g/kg and 140 g/kg in the inner and middle rings. The third ring contains thicker irradiated thoria rods with < 10 g/kg of

^{233}U bred *in situ* in the same reactor in previous cycle(s). The idea of loading seedless thoria rods is novel and is unique to ATBR. Through detailed fuel management calculations it is shown that the seedless thoria rods achieve nearly the same discharge burnup of 50,000 MWD/T in four fuel cycles or eight years as the inner two rings of seeded thoria rods which attain that discharge burnup in three fuel cycles of two years duration each.

As has been elaborated in our paper, in ATBR, nearly all the conventional neutron absorbers like burnable poison, soluble boron and even mechanical control rods are practically eliminated during the operation at rated power of 600 MWe. The burnup reactivity load due to depletion of Pu is almost entirely compensated by breeding of U in thoria rods. In thermal power reactors like PWR or BWR, either soluble boron is diluted or mechanical control absorber rods are retracted to provide the reactivity compensation with burnup. In PHWR the reactivity is maintained by refuelling one or two channels per day in equilibrium core. The important physics characteristics unique to ATBR are that there are no significant control manoeuvres and there is no need for refuelling for two years of incessant operation at rated power of 1875 MWt. The core excess reactivity is intrinsically maintained within a small band by a delicate balance of fissile loss in seed fuel rods and fissile gain in fertile thoria rods. The core reactivity increases slightly by 8 mk during the first year up to middle of fuel cycle (indicative of net fissile material growth) and then decreases to the starting value at the end of fuel cycle. The cycle duration is as much as 720 days. The thoria rods must be present inside the reactor throughout the fuel cycle so as to enable continuous and maximum breeding of fissile material. *They are by design not withdrawn like control rods of LWRs in order to gain reactivity when the Pu depletes*. It is for this reason that there is a large amount of unburnt Pu content as high as 140 and 65 g/kg respectively in the inner and middle seed fuel rings at the time of discharge. The total uranium accumulated in the initially seedless thoria rods at the time of discharge is nearly ~ 19 g/kg (85% fissile) while the conversion of at least 43 g/kg of thorium into uranium is used to achieve the above-mentioned high discharge burnup. The large unburnt fraction of Pu is a welcome feature in closed fuel cycles since it can serve as the base for topping the differential Pu needed for the next fuel cycle. In fast breeder reactors (FBRs) using Pu seed, such high residual Pu fraction is quite common.

Thus the large Pu loading in ATBR is deliberate so as to generate the surplus neutrons needed for high fertile to fissile conversion rates at all times till the time of discharge. The Pu seed has several roles to play unlike the ^{235}U of conventional power reactors. When fresh, the Pu-bearing rods take the major share of reactor power. In addition, they serve as matchstick to ignite the large fertile thoria mass which are mere absorbers in their fresh state. A high thermal neutron flux ambience is created in the uniformly placed seedless thoria cluster regions, which are termed as flux trap or fissile breeding zones. After the fertile thoria rods accumulate the asymptotic fissile content of ~ 15 g/kg, their share of reactor power steadily improves. Close to the discharge burnup the power share of these thoria rods becomes comparable to or better than those of seed fuel rods.

As for the economics of a fuel cycle, there are several aspects which need to be discussed in depth. In the first place it is not fair to judge the economics of ATBR against the present day power reactors adopting once-through or open fuel cycles. The PHWR and LWR mentioned by Rastogi consider the naturally available ^{235}U as fuel and are used in 'use and throw' or better 'use and store' mode. The future reactors that would use the man-made Pu or ^{233}U as fuel should aim for higher and higher fissile conversion and they must invent means of 'use and grow' mode so as to make the maximum multi-use of the recycled fuel. The ATBR proposal is a first step in such direction.

Use of seedless thoria rods in 60% of the core is suggested in ATBR. This has resulted in relatively large Pu requirement of 2.2 Te per cycle. The physics design attempts to conserve this Pu as long as possible while prodding the seedless thoria rods to become regular fuel rods and eventually take over the major power share at the time of discharge. Due to this design aspect, as much as 60% of Pu remains unspent. The thoria rods reside in the core for one additional fuel cycle and reach the same discharge burnup of 50,000 MWD/T. Reactivity swing with burnup is very low. Reactivity initiated transients are less probable in ATBR since soluble boron and control rods are eliminated for rated power operation and the reactivity coefficients are negative and small in magnitude. High Pu content in discharged fuel decreases the differential Pu requirement to less than one Te for each fuel cycle. The quantum of fuel passing through the refuelling route is less due to high Pu seed content as well as due to loading of 60% of core mass with seedless thoria rods. In future reactors using the reprocessed fuel the above characteristics of ATBR would prove to be advantageous. The present ATBR design with Pu seed can generate the uranium from thorium at the rate of 400 kg in two years and can provide the means of smooth transition to ^{233}U seeded ATBR cores eventually.

As was stated above, the fuel cycle cost of reactors using ^{235}U or once through fuel cannot be compared with those of the future reactors that would consider the back-end or man-made fuel like Pu or ^{233}U. If and when the back-end of fuel cycle becomes common at least in some countries willing to invest in the heavy infrastructural requirements, the advantages highlighted for ATBR such as 50–60% of the core being loaded with non-reprocessing route fuel and the high specific seed content resulting in low volume of such fuel would make the ATBR idea acceptable. In fact, in view of the superior operational characteristics it would be gaining the attention of proponents of other proven reactor systems as well.

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Reply:

No special response is needed on the comments of Jagannathan, as he has admitted that the fuel cycle cost of ATBR cannot be compared with present day PHWRs or LWRs. However, in view of my long association with nuclear power, I would like to make a few general comments.

Economics of nuclear power is a very complicated subject because it depends on many factors such as interest rate, duration of construction, lifetime of plant, decommissioning and fuel cycle costs. For the last 32 years, India was isolated from the world's development of this industry. During this period nuclear technology has passed two generations. At present, third generation power plants are being built in Europe and Asia and research and development is being carried out on generation IV plants.

If the Indo-US nuclear agreement materializes, India would be in a position to take benefit from the developments in other countries. It is high time India makes a comprehensive study of the developments which have taken place in heavy water reactors as well as in light water reactors. It may be even worthwhile that for this study, apart from the DAE, IITs, other institutions and industry may be involved.

Economics of power is fundamental for development, whether nuclear, coal, gas, oil, hydro, wind or solar. It is also a function of space and time. One hopes some of our institutions would take up such studies, which would help in decision-making.

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NEWS

MEETING REPORT

Nematology and plant parasitic nematodes*

Delegates from 16 centres representing 15 states of the country participated in the workshop and group meeting of the All-India Coordinated Research Project (AICRP) on plant parasitic nematodes, to cater to overall development of science of Nematology in the country. The mission of the programme is to enhance crop production in the country through nematode management. The mandate of the project is to conduct coordinated trials for reducing crop losses caused by nematode pests and to demonstrate the nematode management technologies through on-farm trials.

Mathew C. Kunnungal (Agricultural Production Commissioner, Government of Kerala) inaugurated the workshop and group meeting. In the inaugural address, he highlighted the need for location-specific research, including organic farming in addition to coordinated trials of national importance. He also emphasized that major thrust is to be given to export-oriented crops like pepper, cardamom and other spices for Kerala and also pesticide-free vegetables, legumes and fodder production. He released a compilation of nematological investigations in Kerala, *Nematode Pests of Crops in Kerala – An Overview*, and also its Malayalam version.

The keynote address was delivered by T. P. Rajendran (Assistant Director General of Plant Protection, Indian Council of Agricultural Research, New Delhi). He explained the objectives of AICRP in research, training and extension. The prime research objectives are to develop state-wise distribution maps of important plant parasitic nematodes, to validate and document crop losses and nematode management technology in irrigated and rain-fed cropping systems, to conduct multi-location on-farm testing of nematode management options for major nematodes, to select out suitable cropping systems for nematode management, to identify sources of resistance and develop nematode-resistant cultivars and pest risk analysis for major nematode pests in Indian agriculture. He also emphasized the need to update the knowledge of scientists through specialized short-term training programmes. He highlighted that in extension activities, priority should be given to the demonstration of nematode management technology in rice, vegetables, pulses and oil seeds and video demonstration of nematode damage symptoms, biology and management technology.

R. K. Jain (Project Co-ordinator AICRP on Plant Parasitic Nematodes, Indian Institute of Agricultural Research) delivered an exploratory talk, explaining the current research programme and also the future thrusts. In current research he explained the needs to include identification of hot-spots and agro-ecologically conducive areas for key nematode pests, documentation of the state-wise distribution maps of agriculturally important nematode fauna of India, identification of sources of nematode resistance in different agricultural and horticultural crops and their testing under nematode-infested conditions, dynamics of community structure of nematodes for their management in need-based cropping systems (vegetables, pulses and horticultural crops) in different agro-climatic ecosystems, impact of nutrient supply system on major nematodes in cereals, pulses and vegetable-based cropping systems in different zones, pest risk analysis for major nematode pests in Indian agriculture, development and demonstration through on-farm testing of cost-effective, eco-friendly integrated nematode management technologies against key nematode pests, organization of short-term training programmes in nematology and demonstration of latest nematode management technologies and finally the organization of national campaign and country-wide public awareness drive against key nematode problems.

Jain also dealt with several future thrust areas for projects: farmer participatory on-farm research trials on nematode management technologies, strengthening nematode taxonomy and providing identification

*A report on the fourteenth National Nematology Workshop and Biennial Group Meeting of AICRP on Plant Parasitic Nematodes held at College of Agriculture, Vellayani, Kerala Agricultural University between 7 and 9 November 2005.