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lutonium and thorium in the Indian nuclear programme

e paper by R. Chidambaram and C. nguly (*Curr. Sci.*, 1996, **10**, 21–35) cusses many aspects of plutonium d thorium utilization in the Indian clear Programme. However, use of rium is not viable due to some imrtant physics aspects of thorium ich were overlooked in the above per.

It is well known that thorium is found in nature without any fissionable isotope. What is not emphasized is that its thermal absorption cross-section is three times that of ^{238}U. This implies that replacing uranium fuel by thorium fuel, in an uranium-fuelled reactor, would require three times enrichment of thorium (^{235}U, Pu or ^{233}U) compared to that of uranium, if nuclear characteristics of the reactor (e.g. burn-up in MWD/Te) are to be maintained. For example, a natural uranium heavy water reactor (PHWR) which uses 0.7% ^{235}U enrichment, would require 2.1% enrichment if thorium is used. Similarly, light water reactors (LWRs) which use about 3–4% enriched uranium would require 9–12% fissile material enrichment when thorium is used. Let us further quantify this statement. A 500 MWe PHWR, now being built at Tarapur site, uses 80 Te of incore inventory of natural uranium which contains 560 kg of ^{235}U. However, if it is fuelled by thorium, it would require about 1.7 Te of pure fissile material in the form of ^{235}U, Pu or ^{233}U. Not only that, a thorium fuelled reactor will also require equivalent out of core inventory of fissile material which would be always locked up in the reprocessing and fuel fabrication plants. Hence a thorium fuelled 500 MWe PHWR would require about 3.4 Te of pure fissile material to have the same fuelling characteristics as those of a natural uranium fuelled reactor.

India has 78,000 Te of natural uranium according to the paper mentioned above. To burn even fifty percent of it, centuries would be required. If fissile material becomes available as freely as the paper mentions, then natural and depleted uranium would also be available without restriction. In that case there would be no incentive to utilize thorium. Hence, so long as uranium (natural or depleted) is available, thorium would never be used, even if fissile material becomes available without any restriction.

2. Apart from the above nuclear characteristics, two other nuclear properties require attention.

   a) Resonance absorption cross-section of thorium is much less than that of ^{238}U. It is because of resonance absorption of ^{238}U, natural uranium heavy water reactors use fuel channels separated from one another with large quantities of heavy water to slow down fission neutrons past resonances. As thorium would always require enrichment and does not suffer from resonance absorption like ^{238}U, pressure tube type heavy water reactors (with on-load fuelling) do not give any advantage to thorium utilization. If ever thorium is used, it would be used in light water reactors, where clustering of fuel rods and on-load fuelling is not done.

   b) ^{233}U is formed from absorption of neutron in thorium by an intermediate step which involves ^{233}Pa with half-life of 27.4 days. This necessitates removal of ^{233}Pa outside the reactor core for decay or to have a reactor of very low neutron flux (low specific power), as absorption of a neutron in ^{233}Pa is a double loss, loss of a ^{233}U atom as well as that of a neutron. If maximum possible production of ^{233}U is a requirement, then lowering flux in the reactor increases the capital cost of a project. Removal of ^{233}Pa actually means that fuel be removed continuously from the core for ^{233}Pa to decay. Such a possibility exists only with fluid fuelled reactors where the fuel is either in aqueous solution or in form of a molten salt. Several experiments on these concepts were done at the ORNL, USA without much success.

3. The paper mentions that thorium could be utilized in India through PHWRs using natural uranium, Pu–Th and finally ^{233}U–Th route. What does it mean? A 500 MWe PHWR uses 2200 Te of natural uranium in its 30-year life and produces 5.5 Te of fissile plutonium (70% load factor). Extending this fuel cycle to

10,000 MWe programme means utilization of 44,000 Te of uranium, which may be the maximum available for economic exploitation. One also ends up with only 110 Te of fissile plutonium.

This fissile plutonium could possibly be used to enrich thorium to produce ^{233}U. However, it should be noted that yield of ^{233}U is less than half the quantity of plutonium by weight, due to lower neutron production capacity of plutonium defined by its 'eta' in thermal energy range. It would take about 30 years for conversion of plutonium to ^{233}U by successive recycling. The end result would be maximum 55 Te of ^{233}U. As we have seen that a thorium–^{233}U PHWR of 500 MWe capacity would require 3.4 Te of ^{233}U, one would then be able to install about 8000 MWe under this fuel cycle scheme. Canadian studies have shown that it is not possible to design a self-sustaining thorium – ^{233}U based PHWR. Moreover, even for the sake of argument, if one assumes it is possible to design such a system, the end result of all these efforts would be 8000 MWe installed capacity, about half a century from now, provided 10,000 MWe PHWR programme based on natural uranium succeeds with very expensive fuel cycle costs due to low burn up of fuel and other properties of ^{232}U which is produced with ^{233}U and gives strong radioactivity. Are our efforts worth spending in that direction?

In case fast breeder programme already taken up in India succeeds, then there would be no incentive to use thorium as it brings down its very property, which is breeding. Fast reactors are Pu–U systems and would never be used for thorium utilization, till uranium is available.

In case unlimited availability of fissile material becomes possible due to success of accelerator breeding or dismantling of nuclear weapons, as the paper hopes, thorium may be utilized to use its good metallurgical property. In this case one would use once-through fuel cycle. Highly enriched thorium fuel would be irradiated to very large burn-ups of the order of 100,000 MWD/Te, and then disposed off without reprocessing. This could be done only in LWR reactors.

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Balakrishnan and Kakodkar reply:

1. It is precisely because thorium appears in nature without any fissile isotope that the first generation of nuclear reactors are all uranium-based, and not thorium-based. The thermal absorption cross-section of thorium is indeed higher than that of ^{238}U, but it does not mean that the initial fissile content that is needed with thorium is proportionately higher. Two facets of thorium fuel cycle that Rastogi has not touched are: a) the much higher reactivity worth of ^{233}U in thermal reactors, compared to that of ^{235}U, owing to the higher number of fission neutrons released per neutron absorbed by ^{233}U; and b) the substantially slower fall in reactivity as fuel burns in a reactor which contains thorium in place of ^{238}U. The initial fissile content in a reactor is not just to make the reactor critical but also to sustain a certain high level of discharge burnup of the fuel. Due to the much slower fall in reactivity with fuel burnup in a thorium-fuelled reactor, the initial enrichment needed in a thorium-fuelled reactor is not three times that needed with ^{238}U but lower. A much better basis of comparison would be life time fissile material requirements. Thorium-fuelled reactors permit much larger use of *in situ* bred fissile material. It has been shown by calculations that at high burnups, life time fissile natural requirements are in fact lower with thorium than with ^{238}U.

   What we should not lose sight of is the fact that we are endowed with a large thorium resource. In energy terms this resource is several times larger than any other indigenously available energy resource that is suitable for bulk electricity production. Several studies showing superior performance of thorium in a number of reactor systems are available and there is no doubt on this score. What is really needed is to develop the specific technologies suitable for thorium exploitation. This is where India will have to take initiative as no other country capable in nuclear technology has any urgency to do so because they have access to large uranium resources.

   It should also be clear that breeders (based on fission or non-fission route) are necessary for growth in nuclear power capacity in our country regardless of whether we are talking of use of uranium or thorium. (In fact we are talking of making use of both.) There is no clash between breeder development and developments in the area of thorium utilization. The sooner we do both, the better off we would be, in view of our large electricity needs.

2. a) While heterogeneity by way of making the fuel in the form of rods as used in both PHWRs and LWRs does give advantage in light of the resonance absorption phenomenon, having the bulk of the heavy water separated as moderator from the coolant heavy water in a PHWR when there is no such separation in a Light Water Reactor is due to the difference in the neutron moderation characteristics of light water and heavy water. It has nothing to do with resonance absorption or with the differences in the nuclear properties of ^{232}Th and those of ^{238}U. Thorium is known to work well in a number of reactor systems and calculations have shown several advantages with heavy water lattice arising out of better neutron economy.

   b) It is well recognized that removing the intermediate product ^{233}Pa from the active reactor core in order to increase its chance of decaying to ^{233}U rather than getting converted to ^{234}U is desirable and that realization is what led to the development of Molten Salt Breeder Reactor in the US and to the fluid fuelled heavy water reactor under the KEMA project in the Netherlands. In the present situation where these technologies did not mature due to other technological hurdles, the PHWR, the heavy water reactor system is much better suited to thorium fuel than the Light Water Reactor with its poor neutron economy and without any capability for on-load fuel reshuffling.

The concept of a PHWR started with natural uranium, gradually leading to a self-sustaining ^{233}U + thorium cycle by passing through a plutonium–thorium intermediate stage is nothing new. Our studies have shown that such a self-sustaining fuel cycle started with no external supply of fissile material will increase the PHWR-based nuclear capacity by about 50% compared to what can be achieved with the same quantity of natural uranium used in the once-through mode. What is more important to recognize is that the energy that one can extract by going into Th–^{233}U mode in PHWR is many times larger than without it. One should not confuse the question of growth with energy potential. For growth we need to breed fissile material fast. For realizing the energy potential of nuclear resources, we need to develop thorium utilization capability. We need to do both. When talking about thorium we are concerned with the latter.

4. It is clear that early generation fast reactors should use ^{239}Pu–^{238}U fuel system to enable faster growth of fissile material. That does not preclude beginning with thorium utilization which is equally well done in thermal reactors with perhaps much lower cost.
5. With the hypothetical situation of unlimited availability of fissile material, the question of whether one should opt for reprocessing the discharged fuel or go for a high burnup once-through cycle depends on many considerations. However, as far as comparison between PHWR and LWR is concerned, what can be said with absolutely no uncertainty is that a thorium fuel cycle is far more beneficial in a PHWR than in a LWR for the simple reason that all the neutrons that are absorbed by hydrogen and by the various reactivity regulating materials in a Light Water Reactor with its shut down refuelling will be profitably absorbed by ^{232}Th to produce ^{233}U in a PHWR where the deuterium that is present, instead of its lighter isotope hydrogen, does not absorb neutrons. Besides, in a PHWR with its on-load fuelling there is hardly any excess reactivity that is nullified by neutron absorbing poisons.

Further, from a long term perspective, the recycle option which we are adopting is environmentally far more benign as compared to the option of permanent disposal of fuel.

Thus, in summary, we have to reiterate that thorium has a very important role to play in the Indian nuclear power programme, and as far as its use in thermal reactors is concerned, there is no doubt that thorium is better used in heavy water reactors than in the light water reactors. Even if the high pressure coolant heavy water is replaced by light water due to other considerations, heavy water is certainly the better moderator that can give higher mileage out of thorium – not light water.

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SRO spy scandal – An unending witchhunt

s individuals associated with the untry's space programme over the last enty years and more, we are deeply ncerned about what has happened and continuing to happen to one of our llow scientists S. Nambinarayanan. e are choosing this route to express r concern because of our inability to tervene meaningfully in the compli-ted chessboard of moves and counter-oves that seem to make inevitable the ntinued persecution and traumatiza-on of a valued colleague.

Many of us have known 'Nambi' for er twenty years. He was the leader of e team of engineers sent to France for quisition of liquid rocket technology. e led with great ability, ISRO teams sted with the responsibility of deliver-g the second and fourth stages of the PSLV project. He was also for a while the leader of the cryogenic engine project. Like all of us, 'Nambi' may have his share of virtues and faults, but we have always appreciated his deep commitment to technology development in the interests of ISRO and the nation. The arrest and interrogation of Nambi in the so-called ISRO espionage case and the attendant newspaper publicity have done immense damage to his morale and even more damage to his innocent family.

The CBI investigation completely absolving S. Nambinarayanan of any wrong doing and the verdict of the Chief Judicial Magistrate, Ernakulam discharging all the accused in the ISRO 'espionage case' are now on record. However the clearance recently accorded by the Kerala High Court to further investigate the case will drag Nambinarayanan and his family through another period of misery. From the record and the evidence behind the 'espionage case', there appears to be no basis for the continued harassment of a person whose innocence has been proven. The reasons for our statement are summarized below.

The major allegation against Nambinarayanan was that drawings and documents relating to the Viking engine and cryogenic technology were handed over to foreign/enemy countries in exchange for large amounts of money in US dollars, and that these took place at three different locations (Madras, Bangalore, Trivandrum) in January, June and September 1994 on specified dates and times.