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The Future Role of Water Cooled Reactors- An Indian Perspective

D. Saha and R.K.Sinha

Reactor Design and Development Group
Bhabha Atomic Research Centre
Trombay, Mumbai-400085, India

Introduction

Though nuclear energy has been part of world's energy mix for more than fifty years, it currently produces only about 16% of total world electricity. Over the past two decades increased public concern about the safety of nuclear plants had resulted in socio-political constrains on its use.

However, a world-wide renewed interest in nuclear energy is now evident which is caused mainly by the following factors: a) progressively dwindling world reserve of fossil fuel, b) a deep rooted concern about global warming, c) fluctuating oil price and d) good performance of current nuclear plants. In the opinion of many it is the era of Nuclear Renaissance.

Introduction

For the sustenance of this renewed interest, besides effective utilization of nuclear fuel resources, a number of important issues are being addressed leading to the development of advanced reactor designs as well as fuel cycle technology. The major issues, which these advanced reactors and fuel cycle technologies are addressing include

- economic competitiveness,
- safety,
- waste disposal,
- proliferation resistance.

The role, a particular type of reactor and its associated fuel cycle will play in the 21st century depends on how it addresses the above issues.

A number of International programmes have been initiated to provide guidance and methodology for evaluation for the sustainable development of Nuclear Energy. Prominent among them are, INPRO and GIF

Water Cooled Reactor (WCR)

About 96% of installed nuclear power plants in the world use water as coolant. PWR and BWR using light water coolant accounts for about 87% and PHWR with heavy water coolant and moderator accounts for about 6%. It is expected that the water cooled reactors will continue to play an important role because of following:

- Technology is well matured,
- Large operating experience exists,
- Innovative features are incorporated in many a new design of LWRs specially in Gen III reactors to address various issues mentioned,
- Adequate R&D, fabrication and installation infrastructures exist.

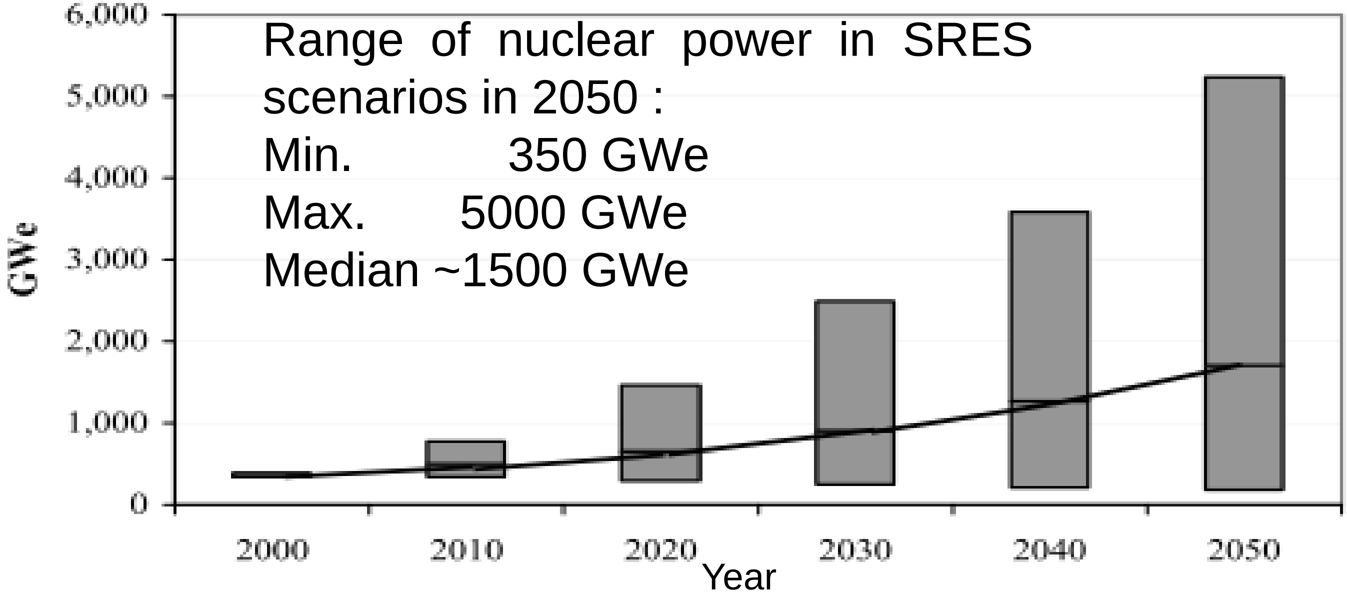
However, future role of LWRs will depend to a great extent on how effectively it addresses the issues of

- fuel resource utilisation in the backdrop of steeply rising energy demand
- Concern for Proliferation
- radio toxicity of waste

All the above issues are closely related to the choice of fuel and fuel cycle.

Nuclear Energy Demand

Special Report on Emission Scenarios (SRES), prepared during 1996-2000, by Inter-governmental Panel on Climate Change (IPCC) presents 40 reference scenarios



- None of the 40 scenarios considers policies designed to avoid or mitigate climate change.
- Non-electricity uses of nuclear power (i.e. in desalination and the production of chemical fuels) has not been considered.
- Electricity demand grows almost 8-fold in the high economic growth scenarios

Fuel Resources

Uranium and Thorium, the two heavy elements occuring in nature are the basic raw materials for nuclear fuel

Uranium Resources

– Identified resources*: 5.469 million tonnes
– Total resources (Identified + Undiscovered): 15.969 million tonnes

Ref: Uranium 2007: Resources, Production and Demand-The joint report by OECD Nuclear Energy Agency and the International Atomic Energy Agency

** : Recoverable @130 US$/kg of Uranium or less*

Thorium

– The occurrence of thorium on the earth's crust is nearly three times as that of uranium. Thorium in its natural form consists almost all of ^{232}Th with some trace amounts of ^{230}Th. Its half-life is 1.4×10^{10} years, which is more than that of ^{238}U.
– Near surface deposition (Monazite sand)- easy to mine.

Sand containing Monazite in Kerala Sea Beach, India

Fuel resources and fuel cycle

The important question now is whether the available fuel resources can meet the energy requirement ?

The answer lies in the fuel and fuel cycle option adopted. The two fuel cycle options being followed are

a) Closed Fuel cycle and

b) Once-through Fuel cycle

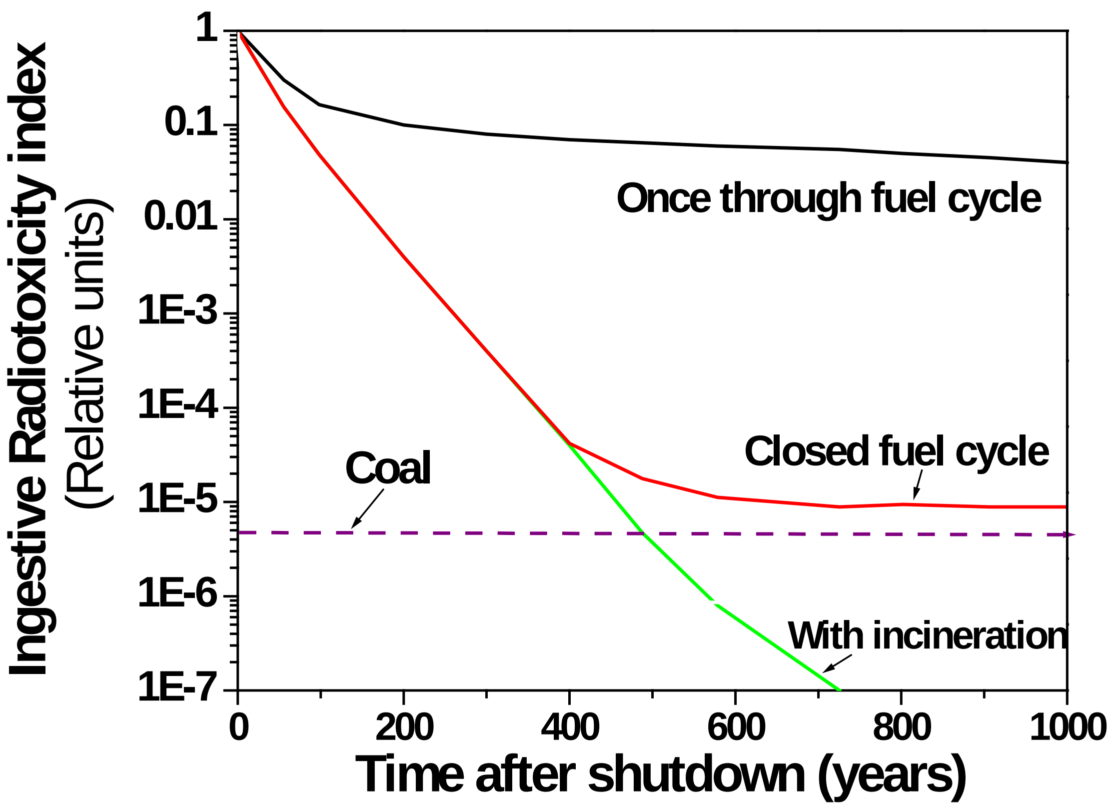
Approximately only 15% of discharged fuel is being reprocessed. Once-through cycle is adopted for majority of discharged fuel from the consideration of proliferation and economics among other issues.

Since the fissile material in spent fuel is a fuel resource, sooner or later, it is necessary to recuperate this material to attain sustainability in terms of fuel resource.

Fuel Cycle

In once-through cycle, the energy content of plutonium in storage remains unused and it degrades. The rapidly increasing volume of Plutonium in spent fuel and its radiotoxicity are also matters of concern.

The effect of the choice of fuel cycle on meeting the energy requirement can be explained with reference to three stage Indian nuclear power programme.



Indian Nuclear Power Programme

A blue print of a phased nuclear power programme with closed fuel cycle considering fuel resource position in India was prepared as early as in 1954 and pursued consistently

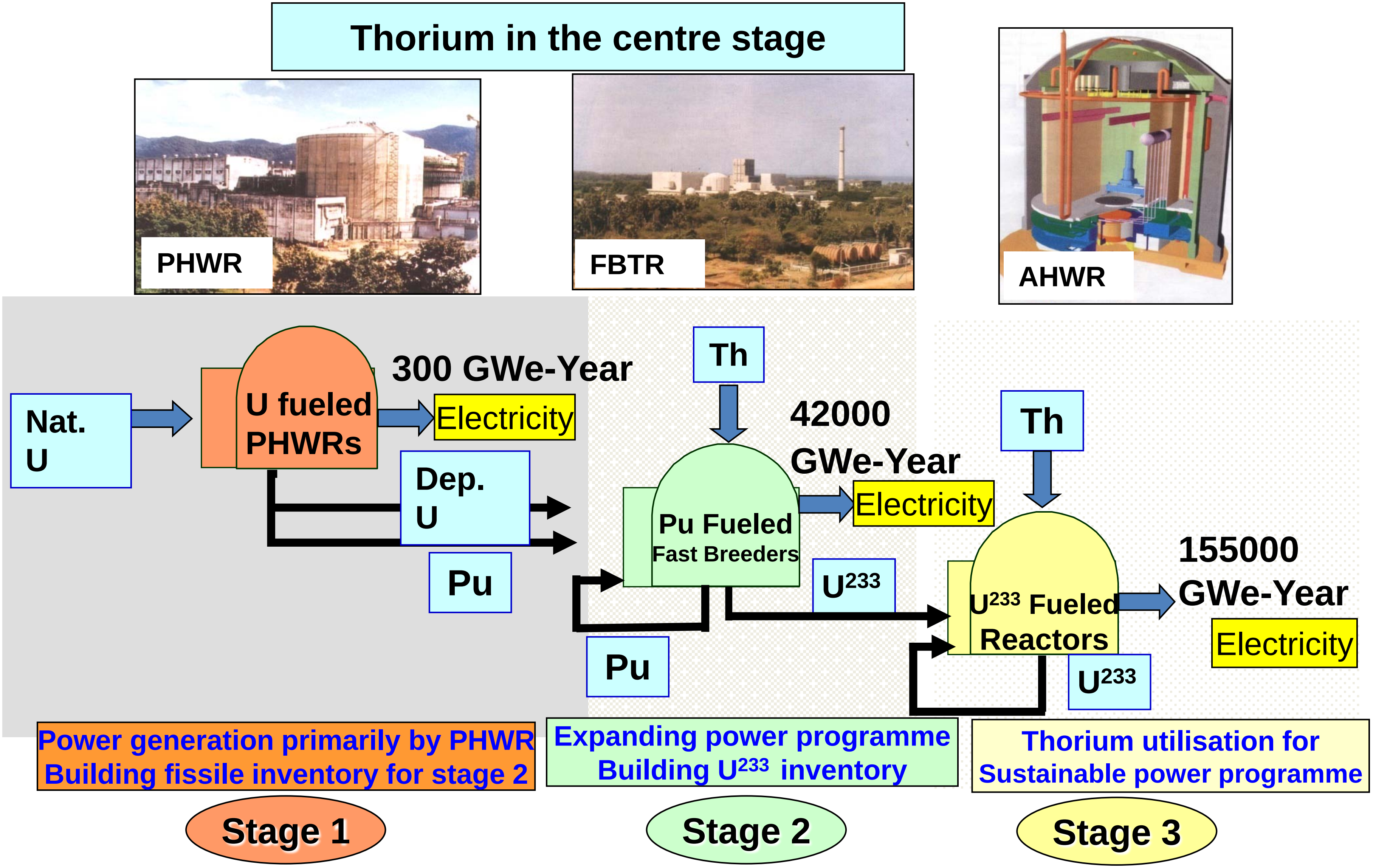
The three stage Indian nuclear power programme is focused on the Utilization of modest amount of Uranium and vast amount of Thorium available in the country.

- The first stage of the programme comprises setting up of Pressurised Heavy Water Reactors (PHWR) with Natural Uranium fuel and heavy water moderator.

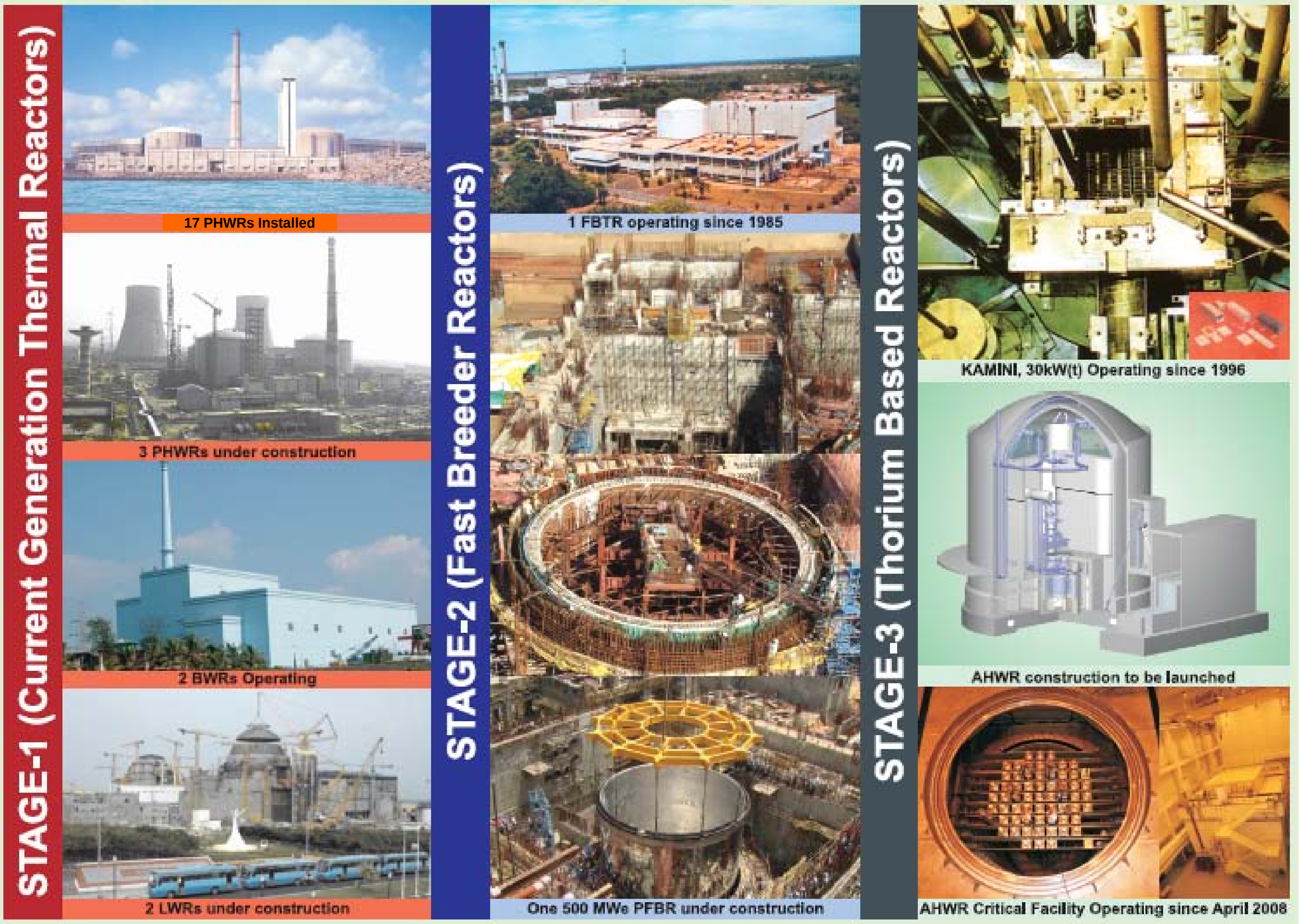
- The second stage envisages development of fast breeder reactors using depleted Uranium and Plutonium obtained from the first stage. Thorium will be irradiated in these reactors to obtain U^{233}

- The third stage aims at the development of reactors based on U^{233} fuel obtained by irradiating Thorium in second stage.

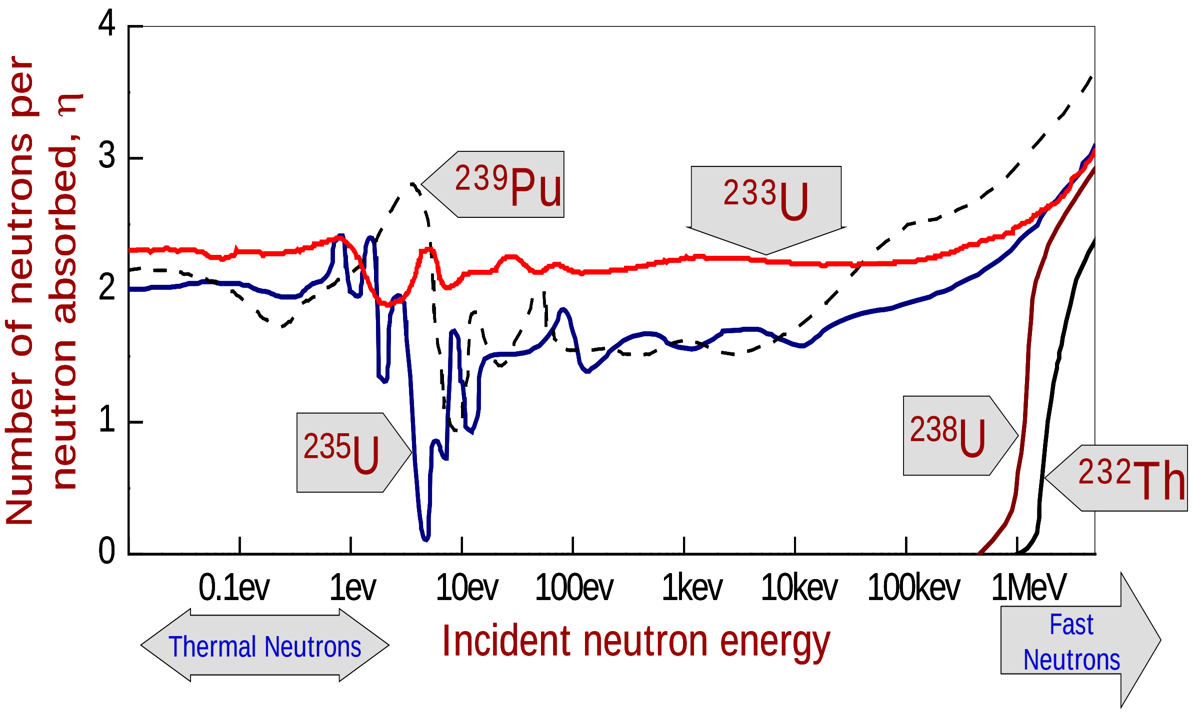
Three Stage Indian Nuclear Programme



Present Status of the Indian Nuclear Power Programme



Advantages of using thorium

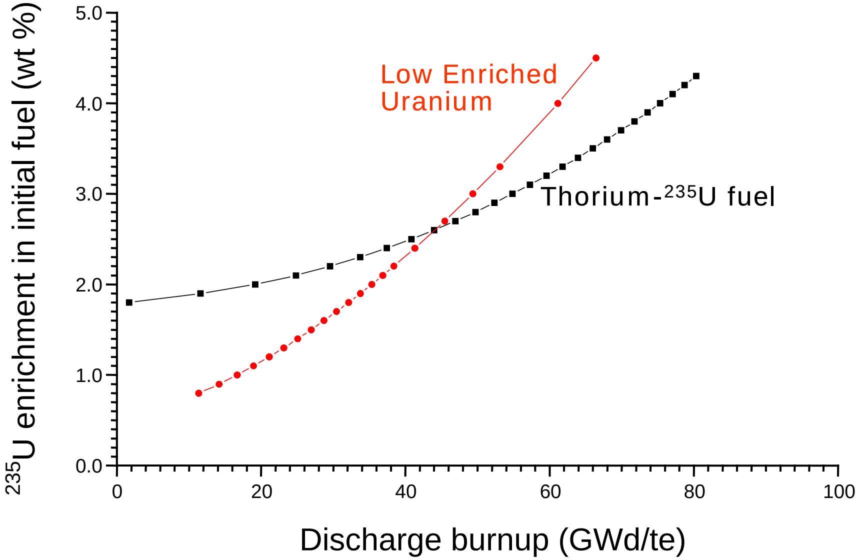


•^{233}U has an η value (greater than 2.0) that remains nearly constant over a wide energy range, in thermal as well as epithermal regions, unlike ^{235}U and ^{239}Pu. This facilitates achievement of high conversion ratios with thorium utilisation in reactors operating in the thermal/epithermal spectrum.

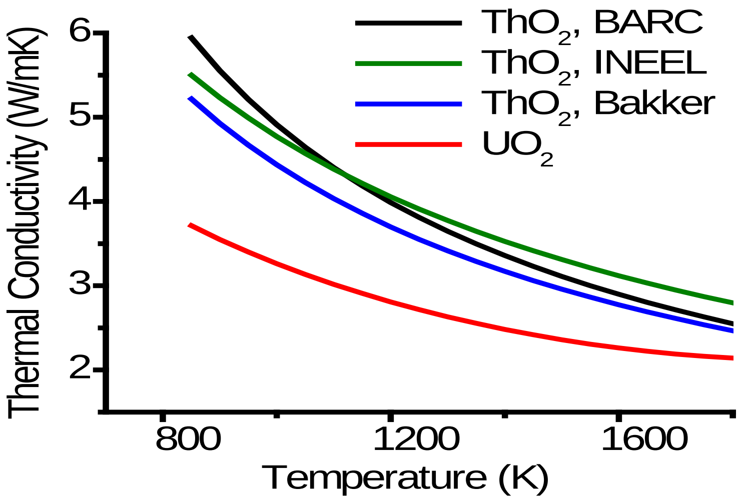
(η: Number of neutrons released per thermal neutron absorbed)

•Separated ^{233}U contains ^{232}U. The half life of ^{232}U is about 69 years. The daughter products of ^{232}U (^{212}Bi & ^{208}Ti) are high energy gamma emitting isotopes that makes separated U233 proliferation resistant

Advantages of using thorium



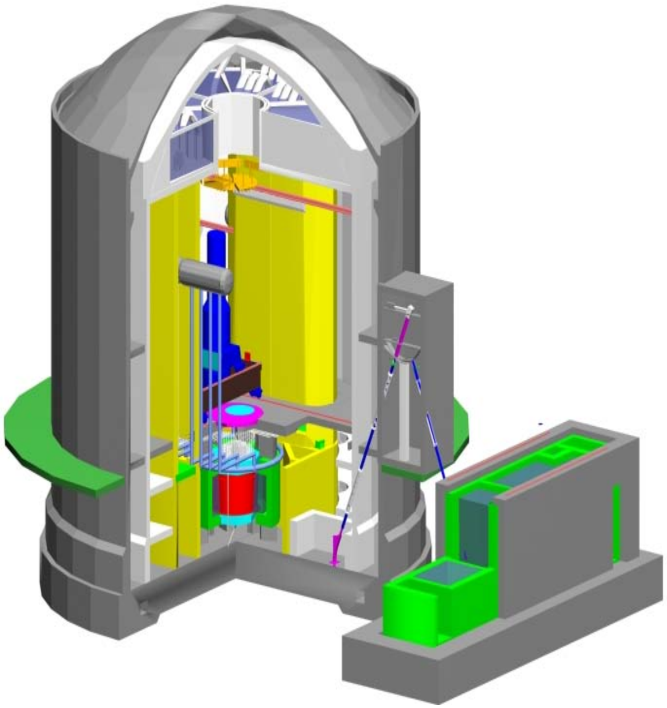
Enrichment requirement for Th-^{235}U fuel and LEU



Thermal conductivity of ThO_2 vs UO_2

- For Burn-up exceeding 40 GWd/T the required enrichment level to get a reactor critical is less for Th-^{235}U fuel compared to LEU. Now burn-up more than 40 GWd/T is achievable in many LWRs. Hence it is now possible to introduce Th in current generation LWRs.
- By virtue of being lower in the periodic table than uranium, the long-lived minor actinides resulting from burnup are in much lower quantity with the thorium cycle.
- The thermal conductivity of ThO_2 is higher than that of UO_2 and thermal expansion coefficient of ThO_2 is less that that of UO_2, resulting in lower fuel temperature and lesser strain on clad.

Advanced Heavy Water Reactor (AHWR)



Present Status : Pre-licensing appraisal by regulatory body is completed and site evaluation is in progress.

Critical facility commissioned.

AHWR is developed for technology demonstration as transition to 3rd stage with two main objectives of meeting sustainability criteria and Thorium utilization.

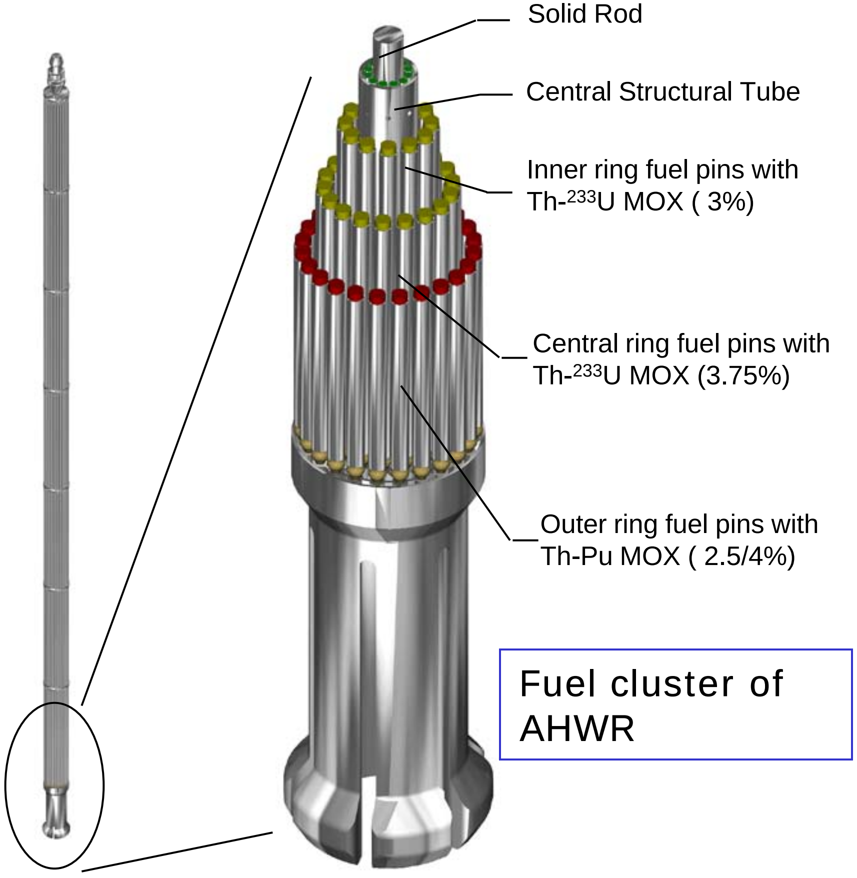
The AHWR is a 300MWe boiling light water cooled, heavy water moderated, vertical pressure tube type reactor designed to produce most of its power from thorium. The core consists of $(Th\text{-}^{233}U)O_2$ and $(Th\text{-}Pu)O_2$ fuel.

Important Features :

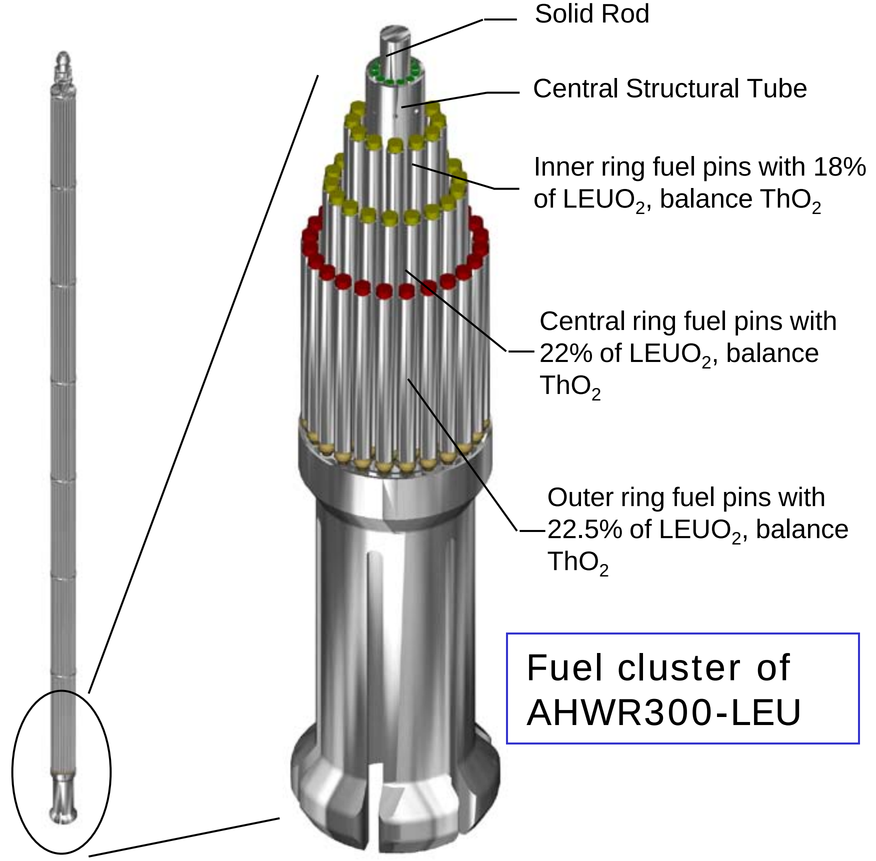
- Natural circulation heat removal under normal operating and shutdown conditions
- Low core power density
- Slightly negative void coefficient of reactivity
- Direct injection of ECCS water into fuel pins during Loss Of Coolant Accident (LOCA)
- Large inventory of water inside containment
- Passive containment cooling and isolation
- Utilization of moderator heat
- Utilization of low grade heat for desalination

AHWR300-LEU: Advanced Heavy Water Reactor with LEU-Th MOX Fuel

In AHWR 300-LEU, LEU-Th MOX fuel is used in place of Th- ^{233}U and Th-Pu Mox used in AHWR



Fuel cluster of AHWR



Fuel cluster of AHWR300-LEU

AHWR300-LEU: Advanced Heavy Water Reactor with LEU-Th MOX Fuel

Issues addressed

- Proliferation resistance
  - Use of LEU and thorium leads to reduced generation of Plutonium in spent fuel with lower fissile fraction and a high (~10%) fraction of ^{238}Pu
  - Fissile uranium in the spent fuel contains about 200 ppm of ^{232}U, whose daughter products produce high-energy gamma radiation
- Waste management
  - The AHWR300-LEU fuel contains a significant fraction of thorium as a fertile host. Thorium being lower in the periodic table, the quantity of minor actinides is significantly reduced.

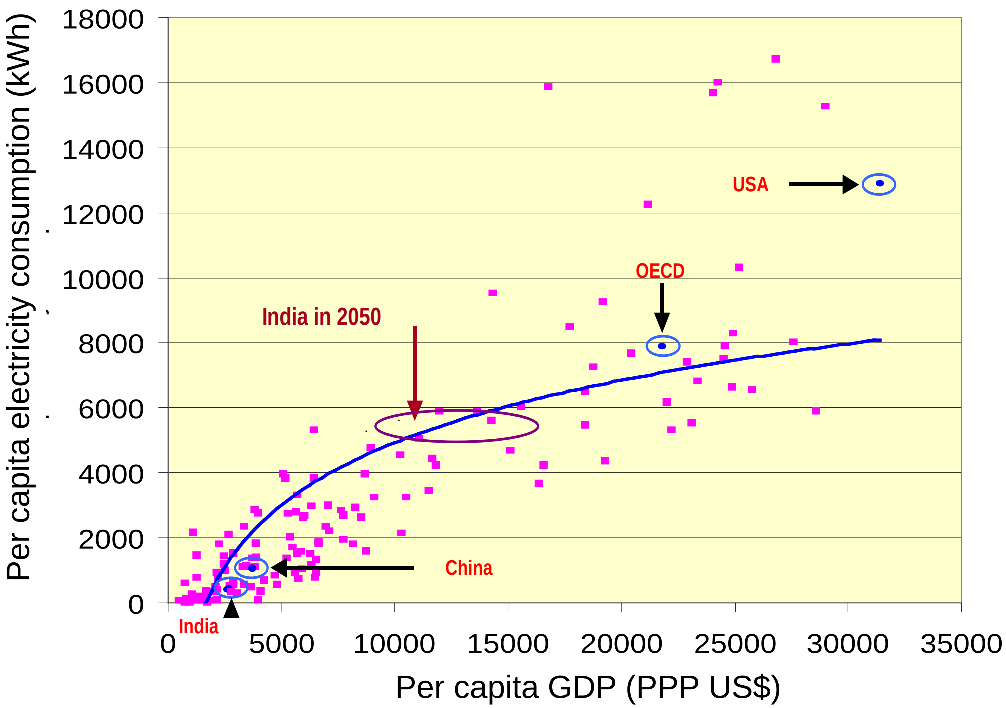
Requirement of High Energy Growth rate

What is not mentioned in earlier slides is the rate of energy growth, the time factor.

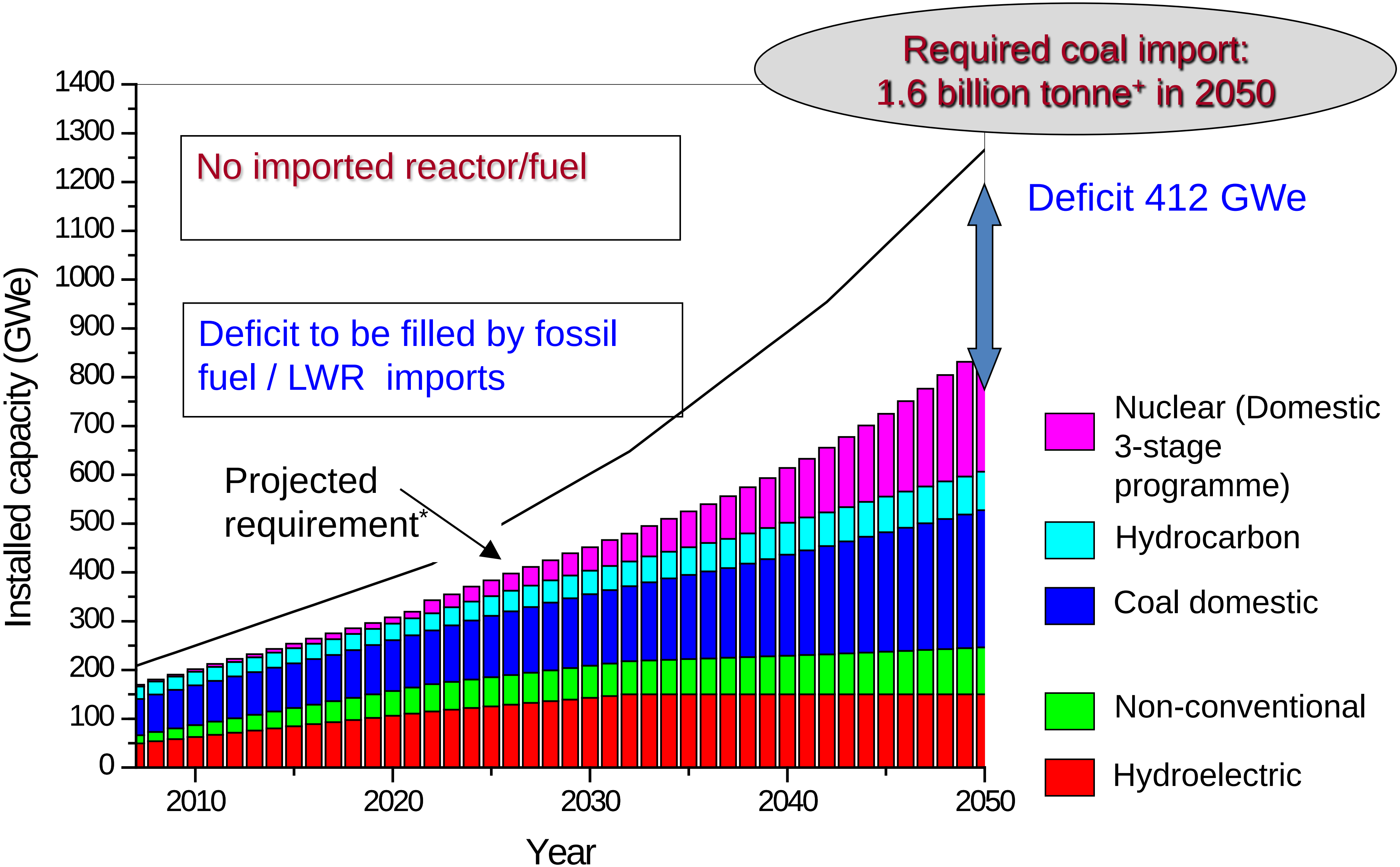
India is on a rapid economic growth path. To match this growth rate we need high rate of increase in installed capacity .To meet this target the following two options are considered:

- Importing Light Water reactor
- Fast Breeder reactors with shorter doubling time

The next slide shows the extent to which imported light water reactors are helping in achieving the energy growth rate target



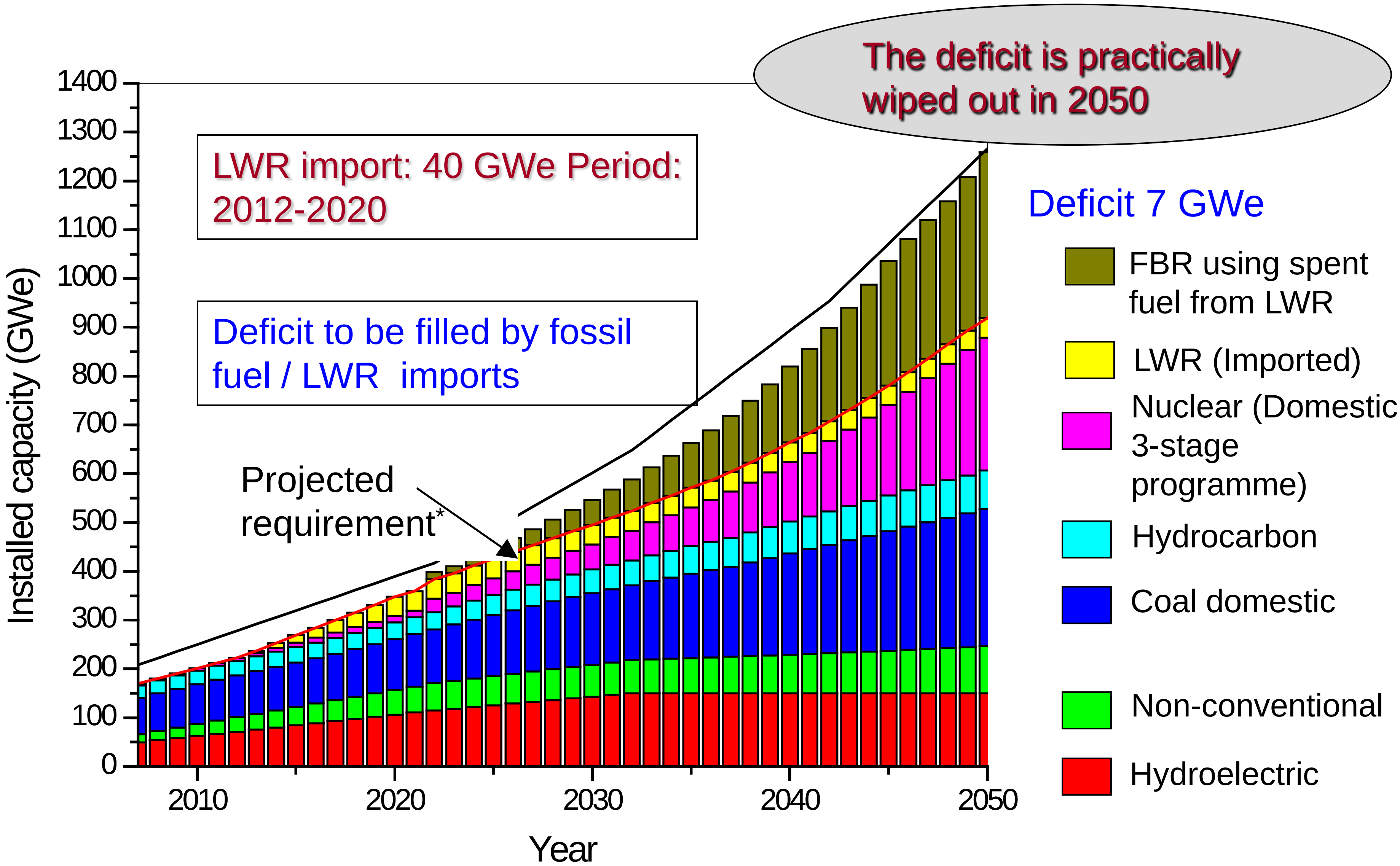
Strategies for long-term energy security



+ Assuming 4200 kcal/kg

*Ref: "A Strategy for Growth of Electrical Energy in India", document 10, August 2004, DAE

Strategies for long-term energy security



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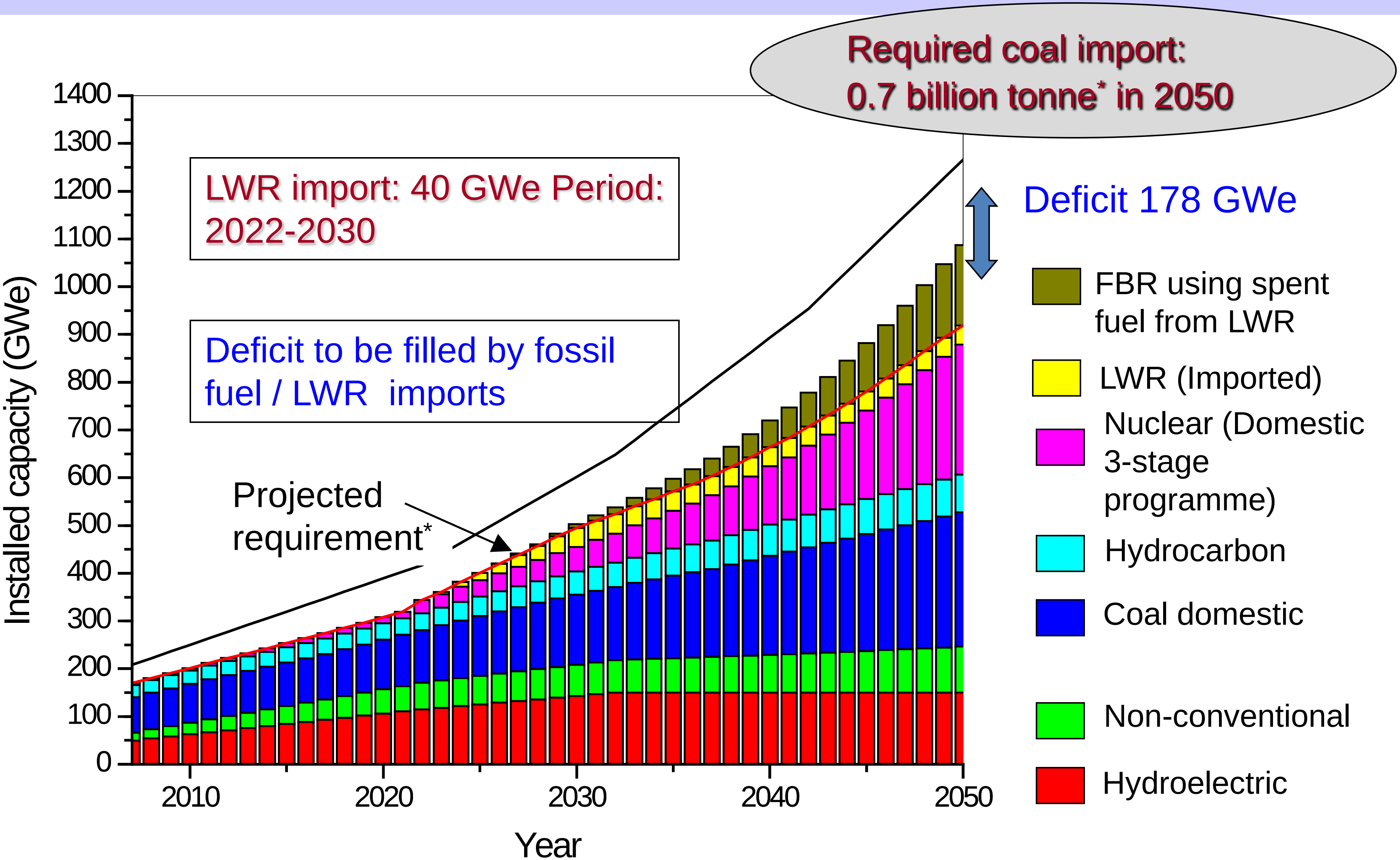
Strategies for long-term energy security



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Concluding Remarks

- Indian nuclear energy programme suggests that light water reactors are going to play a major role in achieving the required energy growth rate.

- However, the prerequisite, to achieve the required growth rate and to achieve sustainability in terms of fuel resource, is the adoption of closed fuel cycle.

- Introduction of thorium is necessary to achieve sustainability in terms of resource. Thorium can be used in current generation reactors where high burn up is achievable.