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ADVANCED HEAVY WATER REACTOR: A NEW STEP TOWARDS SUSTAINABILITY

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India’s Nuclear Programme

- For over 50 years India has developed the “**Thorium Utilisation Programme for Sustainable Energy**”, through three stages.
- The programme envisages the definitive transition to a fuel cycle based on thorium, due to its abundant sources and shortage of uranium in India.
- The Advanced Heavy Water Reactor (AHWR) is the key component of the third stage, which is in the final stage of development [1].

Global Energy Needs

- The Human Development Report's per capita electricity consumption data indicates that the world may need 3,000 to 4,000 nuclear reactors to meet the global energy needs for the next decades [2].
- The nuclear power growth worldwide requires technology response to safety and security challenges, the ability to operate with the lowest level of technology infrastructure in many developing countries, a high degree of fuel efficiency and more advanced options for waste management.

First Stage

- The first stage is to build the Pressurised Heavy Water Reactor (PHWR) using natural UO_2 as fuel matrix, and heavy water as moderator and coolant.
- The first two plants were based on imported technology; subsequent plants are through indigenous research and development efforts. India has accomplished complete self-reliance in this technology, and this stage of the programme is in the industrial domain [3].

Second Stage

- Use of ^{239}Pu obtained from the first stage reactor operation as the fuel core in Fast Breeder Reactors (FBR). A blanket of ^{238}U surrounding the fuel core will produce fresh ^{239}Pu as more ^{239}Pu is consumed during the operation.
- In addition, a blanket of ^{232}Th around the FBR core also leads to the formation of ^{233}U, which serves as a fuel for the nuclear reactors of the third stage of India's Nuclear Power Programme.

Third Stage

- Breeder reactors using ^{233}U fuel. The ^{233}U FBRs will have a ^{232}Th blanket around the ^{233}U reactor core which will generate more ^{233}U.
- These $^{233}U/^{232}Th$ based breeder reactors are under development and would serve as the mainstay of the final thorium utilization stage of the Indian nuclear programme. Indian thorium reserves can meet the energy requirements during the next century and beyond [3].

Closed Cycle

- **Open cycle** → spent fuel is not reprocessed; disposal of the entire fuel. Huge underutilization of the potential energy of uranium.
- **Closed cycle** → spent fuel is reprocessed and partly used; chemical separation of ^{238}U and ^{239}Pu and further recycling. Other radioactive fission products are sorted out and appropriately disposed of.
- Indigenous technology for the reprocessing of the spent fuel, as well as the waste management programme have been developed by India.

Advanced Heavy Water Reactor (AHWR)

- **AHWR300-LEU** is a 300 MWe, vertical, pressure-tube type, boiling light water-cooled, and heavy water-moderated reactor.
- The reactor incorporates a number of passive safety features and is associated with a fuel cycle having reduced environmental impact [4].

The **AHWR300-LEU** fuel cluster (Figure 1) contains:

- 54 fuel pins arranged in three concentric circles surrounding a central displacer assembly.
- The Zircaloy-2 clad fuel pins in the three circles, starting from the innermost, contain 18%, 22% and 22.5% of $LEUO_2$ (with 19.75% enriched uranium) respectively, and the balance ThO_2.

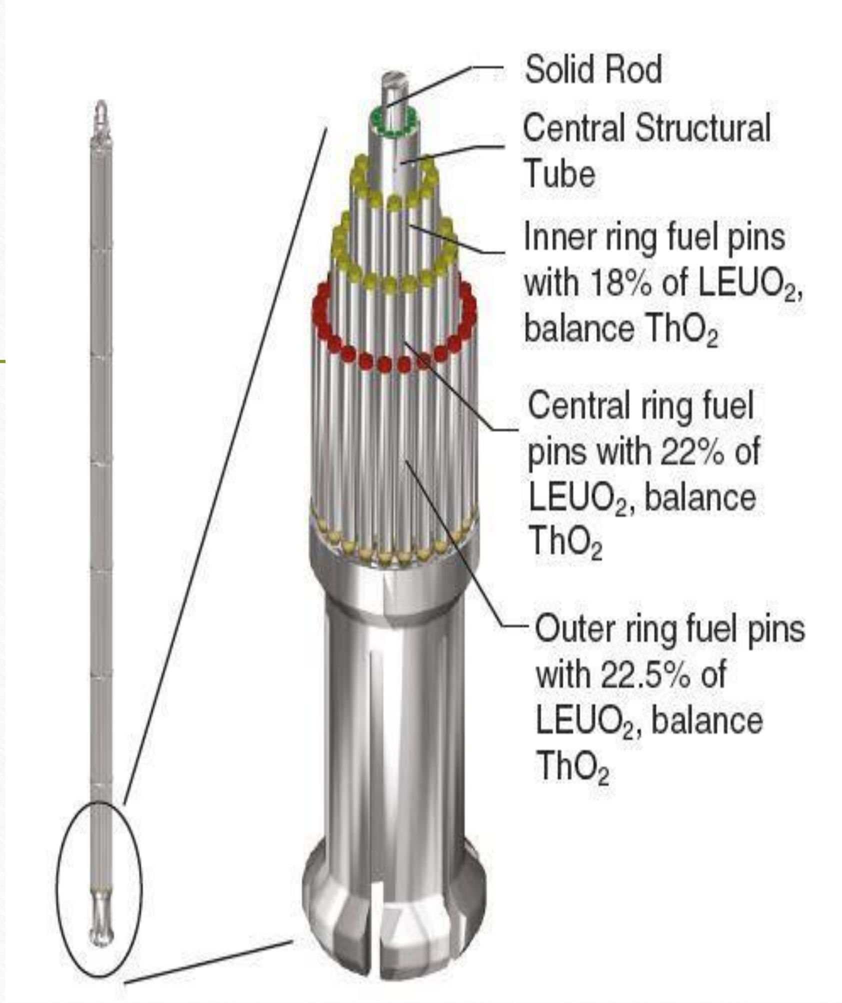

Figure 1: AHWR300-LEU fuel cluster (Source: [4]).

AHWR300-LEU Features

- Using heavy water at low pressure reduces potential for leakages.
- Elimination of major components and equipment, such as primary coolant pumps and drive motors, and corresponding saving of electrical power required to run these pumps.
- Hundred years design life of the reactor [4].

Proliferation Resistance

- As a result of its mixed fuel, the plant produces only 21% of the plutonium as compared to a modern LWR (Figure 2).
- Due to its significant percentage of thoria, conventional approaches for dissolution are highly inefficient, thus making reprocessing more difficult [5, 6].

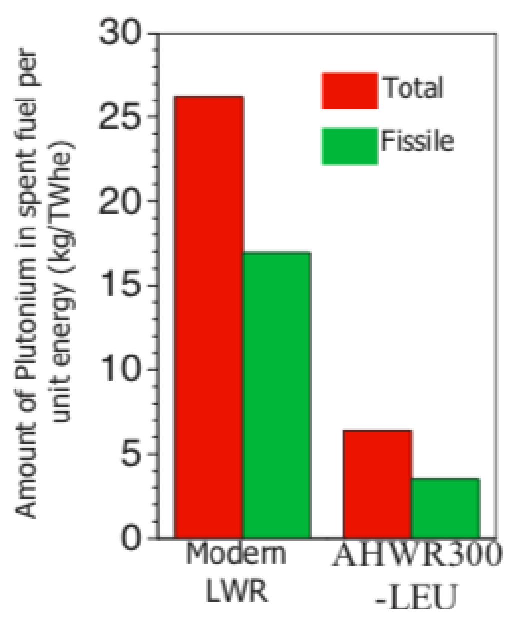

Figure 2: Reduced waste generation as compared to modern LWRs (Source: [2]).

Reduced Waste

- 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. As compared to the modern LWR, AHWR300-LEU results in 37% less minor actinides. This will lead to a reduced burden on waste disposal requirements.
- Thorium oxide is eminently suitable for long-term storage because of the inert matrix.

The Brazilian Experience (1)

- According to the 2018 NEA/IAEA report, Brazil has the second largest thorium reserve on the planet, after India [7]).
- In 1965 in the city of Belo Horizonte, the Thorium Group was created, a team of nuclear engineers that aimed to make Brazil autonomous in the design and construction of this type of reactor. The group's task was similar to that of India's Nuclear Programme.

The Brazilian Experience (2)

- Researchers were sent for training in France, and the first Brazilian research facilities applied to power reactors were created. Several studies of heavy water reactor physics were performed in these laboratories, with heavy water supplied by the United States.
- However, around 1968, the leaders of the country's electric sector started to defend the choice of reactor with light water and enriched uranium. The Thorium Group broke up shortly after this decision [8].

Conclusion

- Fifty years ago in Brazil the idea of building a thorium-powered power reactor was set aside. The thorium reserves remained idle.
- At some point in the future, the price of uranium will increase due to its decreasing availability, which may cause the cost-benefit variable to tip in favor of thorium reactors; it is worth starting to think about this as soon as possible.

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Thank you!