Summary of the presentation of Dr. R.K. Sinha, Chairman, AEC, India, in the Panel Session 4 at the 'International Ministerial Conference on Nuclear Power in the 21st Century', St. Petersburg, June 29, 2013

The role of Thorium for facilitating large-scale deployment of Nuclear Energy

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(Title slide) I thank the organisers for giving me an opportunity to be a part of this Panel.

[Note: The text in italics may not be spoken. Energy is one of the main drivers for the growth of human civilisation. Considering the depletion of fossil fuels, their environmental impact, and the need for assured base load and security of energy supply, nuclear energy becomes an important component of the energy mix for the mankind. ^{235}U has remained the primary fissile component of the nuclear fuel being used to produce almost all the nuclear electricity currently being generated. Thorium, which has a natural abundance of three to four times that of Uranium, does not contain any fissile isotope, and requires to be deployed with a fissile material like ^{235}U or Plutonium or ^{233}U.]

This brief presentation will describe the potential of thorium for facilitating large-scale deployment of Nuclear Energy.

(Slide 2) *[Note: The text in italics may not be spoken. In order to set the tone for the case of Thorium utilisation, it is useful to look back over the time-line of growth in the number of countries commencing construction of the first nuclear power plant.]*

The slide shows the initial rapid growth in the number of countries commencing construction of the 1st NPP, and then a very long period of stagnation, nearly 27 years since 1985, until UAE in 2012 started construction of their 1st NPP near Abu Dhabi. The total number of countries stands at 34 now. We need to consider the factors that led to such stagnation. According to the IAEA, there are 29 countries actively considering launch of NPP, with a couple of them well advanced to announce their launch in the near future. We need to examine which technologies can lead to rapid expansion of nuclear power globally, in the near term and also in the long term.

(Slide 3) There are currently over 430 NPPs with an installed capacity of 370.5 GWe and another 69 are reported to be under construction. The IAEA - INPRO projection of the growth of nuclear energy cites an installed nuclear capacity of 1250 GWe (moderate growth) and 1875 GWe (high growth) by 2050. Growing global energy demand, environmental concerns including Green House Gas (GHG) emission and climate change, volatility of fossil fuel costs, need for assured base load and security of energy supply, etc. are the key drivers for the interest in and adoption of nuclear power, especially in countries with large unfulfilled demand for energy. The envisaged large-scale deployment of nuclear power would necessitate associated safeguards implementation (SGI) by the IAEA, and for adequately addressing proliferation concerns, the SGI costs could be substantial.

(Slide 4) In this context, the utilisation of thorium based technologies offers a distinctly attractive pathway to facilitate the enhancement of the global share of the nuclear energy, while at the same time addressing the proliferation concerns, and the attendant escalation of the costs of the IAEA safeguards implementation. The IAEA TECDOC-1575 Volume 5 describes the proliferation resistance requirements and also brings out a set of evaluation parameters for measuring the attractiveness (or otherwise) of the nuclear material and nuclear technology in innovative nuclear energy systems from the point of view of proliferation considerations. A caveat may be added, that 'no technology can be called proliferation-proof; however, intrinsic proliferation resistance could be considerably enhanced with appropriate technical measures'. Thorium based fuels, with their unique characteristics of difficult-to-dissolve and reprocess, easy to detect the hard gammas of ^{232}U daughter nuclides (which also aids deterrence), offer 'safeguards-friendly' technological options of fuel cycle.

(Slide 5) Among the two potential nuclear fuel options available in nature, Uranium alone contains a fissile material, while Thorium is entirely fertile and needs to be used along with another fissile material for generation of nuclear energy. Thorium can be deployed with a fissile isotope, ^{235}U or Plutonium or ^{233}U (to be produced by irradiating ^{232}Th in existing reactors and separated by reprocessing), as the driver for sustaining *in-situ* conversion of Thorium to ^{233}U and continued chain reactions to generate energy.

Thorium can be used in existing reactor types; for example, by using Th-LEU (Low Enriched Uranium) fuel in PHWR/PWR/BWR, that will result in reduced extent of production of Plutonium (due to the competition between ^{232}Th and ^{238}U for absorbing the neutrons). The use of Thorium with atomic number 90 in a nuclear reactor yields lower fraction of long-lived minor actinides in the spent fuel compared to that while using Uranium. Further, with the use of Thorium, one can not only avoid production of additional quantities of Plutonium, but also enable Plutonium disposition (i.e. incinerating the Plutonium), and in turn enhance global nuclear security.

In terms of fuel type, the well-known oxide fuels, particle fuels of TRISO type, as well as molten salts, are under investigation for the Thorium based nuclear fuel cycle. The ease of reprocessability, proliferation resistance and level of technology development, taken along with sustainability, are the aspects of high relevance for the inter-comparison of fuel types and reactor concepts to show the unique advantages and challenges of each option and the need and scope for further development work.

(Slide 6) Three stages can be envisaged for enhancing the global reach and volume of deployment of nuclear power using Thorium. The first stage is applicable for the growth in near-term and meeting the needs of those countries with well-planned nuclear power aspirations. In this case, one can deploy an existing reactor type (PHWR, PWR, BWR). Thorium can be used in such a system, as for example, by using Th-LEU (Low Enriched Uranium) fuel. The reduced extent of production of Plutonium (due to the competition between ^{232}Th and ^{238}U for absorbing the neutrons), as well as the presence of hard gammas from ^{232}U (present at nearly 200 - 1000 ppm level of total Uranium in the spent fuel, depending on the reactor type), enhance the proliferation-resistant feature of this approach. Proliferation concerns and allied issues have often come in the way of more rapid and widespread deployment of nuclear energy option (particularly in some regions of the world). Further, the cost of the IAEA safeguards implementation can be substantial with the growth envisaged. Th-based nuclear technology could help more effectively address the twin aspects cited above.

The second stage is one of transition, involving the use of Thorium in breeder mode to augment ^{233}U resources for further deployment in ^{233}U/Th fuelled reactors, either currently established or emerging new designs. This would involve also addressing the challenges of reprocessing of Th-based fuels. On account of the possibility of achieving a conversion ratio exceeding one in ^{233}U-Thorium based thermal reactor, the potential of Thorium for providing a sustainable source of energy in the future, aided by availability of enough fissile material to begin with, is immense. This will lead us to the third stage.

The third stage emerges from the above concept, and is also driven by the continuously increasing worldwide energy demands and the role of nuclear power as a sustainable, low carbon, and reliable base load source of electricity. For long-term sustainability, it is envisaged to take full advantage of the unique characteristics of ^{233}U-Th based fuel cycle, through development and deployment of advanced nuclear energy systems, such as molten salt breeder reactors and accelerator-driven sub-critical systems.

(Slide 7) Thorium option has been investigated by different countries in the past, with various fissile options, relevant for the three stages cited above. For example, the breeding of ^{233}U has been demonstrated in the Shippingport Light Water Breeder Reactor; Thorium has also been used as a fertile host in many gas cooled and other reactor types. The IAEA has brought out a compilation on Thorium use (STI-PUB-1540, 2012) that serves as a reference volume. Currently, a large volume of developmental work is going on in different countries, including in Russian Federation and China, among others.

(Slide 8) Apart from the fuel cycle aspects, for large-scale growth of nuclear power worldwide, it is required to develop highly satisfactory technological solutions and meet the challenges in ensuring a very high level of safety and security, against external and internal threats, as well as extreme natural events, and commensurate with the enhanced number of NPPs and locations. Various scenarios of failures and/or nonavailability of safety systems need to be addressed in the design and construction, so that no unacceptable radiological impact would be there outside the NPP boundary.

(Slide 9) India has been steadfastly following the strategy of its 3-stage nuclear programme, making use of ^{235}U, Plutonium and ^{233}U sequentially in closed fuel cycles. Initial deployment of Th is planned to be done once the Indian fast breeder reactor programme is well under way, and will be followed by large scale Th-^{233}U use in advanced reactors. Substantial work on thorium based fuel cycle technologies has also been carried out. As a technology demonstrator, an Advanced Heavy Water Reactor (AHWR, 300 MWe) has been designed in India and a project is underway for commencing its construction. The Indian AHWR design has several innovative and advanced features (while yet using existing PHWR pressure tube technologies), including a number of passive safety systems addressing prolonged black-out situations (conceived and incorporated much before the Fukushima - Daiichi accident took place in Japan that led to global attention on such passive safety features), failure of all sources of power and control instrumentation etc. Furthermore, AHWR has a versatile design capable of accommodating different fuel configurations. For example, AHWR with LEU-Th core can be a choice for the first stage described earlier. Similarly, AHWR with Pu-Th MOX fuel core would be suitable for demonstrating closed thorium fuel cycle as well as Pu disposition option.

(Slide 10) Extensive experimental and computational work has been done for the validation of AHWR design, which includes setting up large testing facilities. Compared to a modern LWR (that is, advanced PWR of high burn-up 60GWd/t) of equal capacity, the AHWR will produce 30-35% less Pu (both total and fissile Pu). This aspect, taken along with the higher fraction of ^{238}Pu produced (~10%) and the presence of about 200 ppm of ^{233}U in the spent fuel, would render this approach to be more proliferation-resistant. Similarly, AHWR would have about 30% less production of minor actinides.

(Slide 11) The Indian studies have shown that, even in the Fukushima-type scenario, decay heat from AHWR can continue to be removed without any external electrical power or source of water, or operator action, for as long as 110 days, due to the gravity driven water pool (GDWP) included in the AHWR design. This assessment has been done based upon certain boundary conditions (as shown in the slide).

(Slide 12) In conclusion, it is reiterated that, for the sustainable growth of nuclear power worldwide, Thorium offers several attractive features, making it an ideal choice as a fertile host. It is left to the human innovation and technological endeavours to harness the benefits of Thorium for achieving sustained long term production of nuclear power.

In the near-term, interested countries can use Thorium in existing reactor types while duly addressing proliferation concerns and facilitating a reduction in the cost of implementation of the IAEA safeguards. In the long-term, sustainable large-scale deployment and expansion of global nuclear power could be achieved through development and adoption of advanced nuclear energy systems comprising appropriate reactor technologies and associated fuel cycle systems.

(Slide 13) Thanks for your kind attention.