Technology Considerations for Deployment of Thorium Power Reactors

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Presentation Outline

• What? (electrons from Thorium in WCRs)
• Why? (technical reasons, national needs and economic/safety benefits?)
• Who? (nuclear countries with a long-term vision, newcomers?)
• When? (10-20 years, if we start now)
• How? (existing WCRs, evolitional transition, complementary FC’s)
Some relevant global “Buzzwords”

- Sustainability
- Renewable Energy, Carbon Footprint
- Global Warming, Climate Change
- Inherent Safety, Proliferation, Security
- “Atoms for Peace and Development”
  Yukiya Amano, DG IAEA
IAEA’s Role

One of the IAEA’s statutory objectives is to “seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world”

- Nuclear Science and Applications
- Nuclear Safety and Security
- Nuclear Energy – Nuclear Power – NPTDS
- Technical Cooperation
- Safeguards
NPTDS is considering adding a new technology line – **MSR** – in 2016 with a planned Technical Meeting to assess the current status and needs.

Thorium FC may be relevant to ALL of these.
What is needed for Deployment?

- supportive government policy and acceptance by an educated public
- integration of “the right technology” into a national energy policy
- nuclear infrastructure
- design and safety concept maturity and/or design/concept validation
- co-operation between vendor/operator/regulator
- a sound economic/financing plan
Hypothesis

“Water-cooled reactors are capable of accommodating thorium-containing or even thorium-based fuel designs. Known technology challenges can be mastered and there are no “show-stoppers” in a gradual transition to a “complementary” thorium/uranium-based nuclear energy program, while there remain significant obstacles to full Th/\(^{233}\text{U}\) implementation.”

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Inherent Advantages

- Greater abundance and easier mining (no natural radioactivity), currently a “waste product” in various industrial mining activities
- Higher thermal conductivity and melting temperature, thus cooler fuel centerline temperature and larger margins to fuel melting in severe accidents. More suited as a “no-melt fuel” even at very high burnup
- Chemically stable (has only one oxidation state), thus would not oxidize during defected-fuel operation or during transients that may induce fuel cladding defects or in a waste repository
- Fission produces much less minor actinides (including Pu), significantly reducing waste radiotoxicity beyond ~100 years
- The slower natural decay of $^{233}$U allows longer delay (less fissile material loss over time) until reprocessing (i.e. a longer cooldown)
- In principle can achieve a fully self-sustainable breeding fuel cycle in thermal WCRs
Inherent Disadvantages

- *Fissionable material needed at the beginning (years) of the reactor operation*
- *A lower delayed neutron fraction requires faster reactor control and neutronic trip shutdown response due to reduced reactivity worth of control/shutdown devices. Reactivity coefficients are also negatively affected. However, these effects are comparable to MOX fuel.*
- *Chemically stable, making the dissolution process during reprocessing more difficult*
- *The high-energy gamma emitters in $^{232}$U decay chain necessitate more expensive, remotely operated, shielded reprocessing facilities; the presence of $^{220}$Rn also requires a more complicated ventilation system and the presence of $^{228}$Th in the “excess” thorium requires shielded secure storage for ~20 years.*
- *Beta decay produces long-lived radionuclides (including $^{231}$Pa) that contribute to waste radiotoxicity*
External Factors affecting Th “Interest”

- Government (national) policy and public opinion relating to nuclear energy, which, in combination, determine a country’s willingness to invest in technology, in valuation of CO$_2$ emissions reduction, and in setting national energy mix goals.

- Resource availability, fuel source security, both global and local, including for competing technologies such as fossil.

- Economics: Fuel cost (raw/recycling), relative magnitude of the fuel cycle cost components as a fraction of overall cost of nuclear power generation (including capital and financing costs).
  
  *E.g. for Thorium the increased reprocessing costs may be offset by benefits from higher fuel burnup and longer fuel cycle lengths.*
CRP on Near Term and Promising Long Term Options for Deployment of Thorium Based Nuclear Energy (2012-15)

CRP provides a platform for sharing of research results among participating Member States and the key focus is on the development of strategies for deployment of Thorium based nuclear energy in NEAR, MEDIUM and LONG TERM timeframes & the identification of gaps in achieving the same. Results will be published in the form of a Document at the end of the project.

Research Topics:
1. Reactor Systems: Concepts and designs that can effectively use thorium as a fuel.
2. Thorium based fuel fabrication / processing technologies
3. Thorium fuel performance
4. Spent thorium fuel reprocessing technologies
5. Economics of thorium fuel cycles
6. Identification of gaps that may affect commercial deployment
7. Strategies for deploying thorium fuel cycles in different time frames

Participating Member States
Canada, China, Czech Republic, Germany, Italy, Israel, India, Russian Federation and USA
Ensure sufficient R&D, Analysis, testing and (ideally) prototyping

- R&D: Minor knowledge gaps, e.g. mixed-fuel properties
- Analysis: Current codes are capable, but require validation and uncertainty assessments
- Testing: In-reactor irradiations and PIE have shown promising, even superior performance, but more data is needed
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Proposed Path Forward - Options

Heterogeneous core ("mixed core")
- fissile and breeding fuel regions (pins, bundles, or assemblies) are physically separated and only neutronically coupled (also referred to as seed/blanket configuration)
- Reprocessing of Th portion requires shielding and new contamination monitoring processes (no $^{239}$Pu)

Homogeneous core
- fuel meat itself consists of a fissile/fertile material mix
- could have regions of various enrichments
- manufacturing challenges (density, homogeneity without "hot-spots") and reprocessing of Th/U/Pu MOX

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Share good practices of planning, implementing and licensing mixed cores used in different Member States.

- Usually some operational limits must be changed and possibly some hardware changes (control system, I/C) may be required.
- Mixed core analysis has primarily considered (unwanted) T/H effects (flow imbalance) on DNB/CHF limits, however, for Th introduction flow imbalance may be necessary to maintain these safety limits or desired to maximize power (minimize de-rating). Must consider NOC and accident conditions.
- It is necessary to confirm that a core is operating in the manner that it is expected and predicted to do, including peaking factors, which are a key parameter for nuclear safety. To ensure this, in-core measurements of neutron flux are made to determine the local power. The necessary hardware and software are usually initially supplied by the reactor vendor, but it may be necessary to upgrade either to support a new fuel design or vendor.

There is significant experience in the operation of mixed cores throughout the world and there have been no significant problems seen which have resulted from such operation.
Examples of Heterogeneous Cores

Lightbridge’s thorium-based seed and blanket assembly mockup for Russian-type VVER reactors used in thermal-hydraulic testing.
Opportunities for Collaboration

• Detailed physics/thermalhydraulics and safety analysis, both steady and transient, of heterogeneous fuel assemblies to determine to what degree local power/coolant flow matching is required in order to achieve the target burnup, breeding ratio, and %-energy from Th, while maintaining all safety/trip margins and regulatory/operational limits.

• Determination of fuel material, fuel/cladding interaction, and fission gas release relevant to the fresh-to-high-burnup region of homogeneous-core (mixed Th/U/Pu) fuel, including any microstructure effects. This is needed to verify/validate predictive models and assumptions.

• An objective, unbiased investigation into which currently-deployed reactor type is most suitable (CANDU, PWR, BWR) for near-term introduction of thorium fuel, based on technical, economical, and regulatory factors.

• There are probably a few more…
Recent IAEA Publications

Role of Thorium to Supplement Fuel Cycles of Future Nuclear Energy Systems

Experiences and Trends of Manufacturing Technology of Advanced Nuclear Fuels

Chapter 3: Thoria

Thorium fuel cycle — Potential benefits and challenges

“Improving the efficiency of utilization of mineral resources (whether it is uranium or thorium) while reducing ultimate waste streams are among the major challenges that the nuclear energy industry must address if nuclear energy is to develop significantly and become a sustainable source of energy for the long term.”

and

“The thorium option has never been fully discarded and “the thorium fuel cycle” has, albeit with fluctuating intensity, continuously been studied worldwide.”

… so let’s pick up the momentum and keep going …
CONCLUSIONS

Large scale implementation/deployment of thorium fuel is unlikely to happen based on current or foreseeable economic, technological, waste management, or safety/security/safeguards drivers alone. Therefore, the significant licensing work, which would need to be undertaken for the implementation of thorium fuels and the R&D required for closing remaining technology gaps, require a long-term vision and steady effort, including international collaborations on thorium issues (technological, economical and socio-political) to make a gradual transition possible that could eventually be called “Renewable Nuclear Energy”.

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THANK YOU - NAMASTE

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