The role of Thorium for facilitating large scale deployment of nuclear energy

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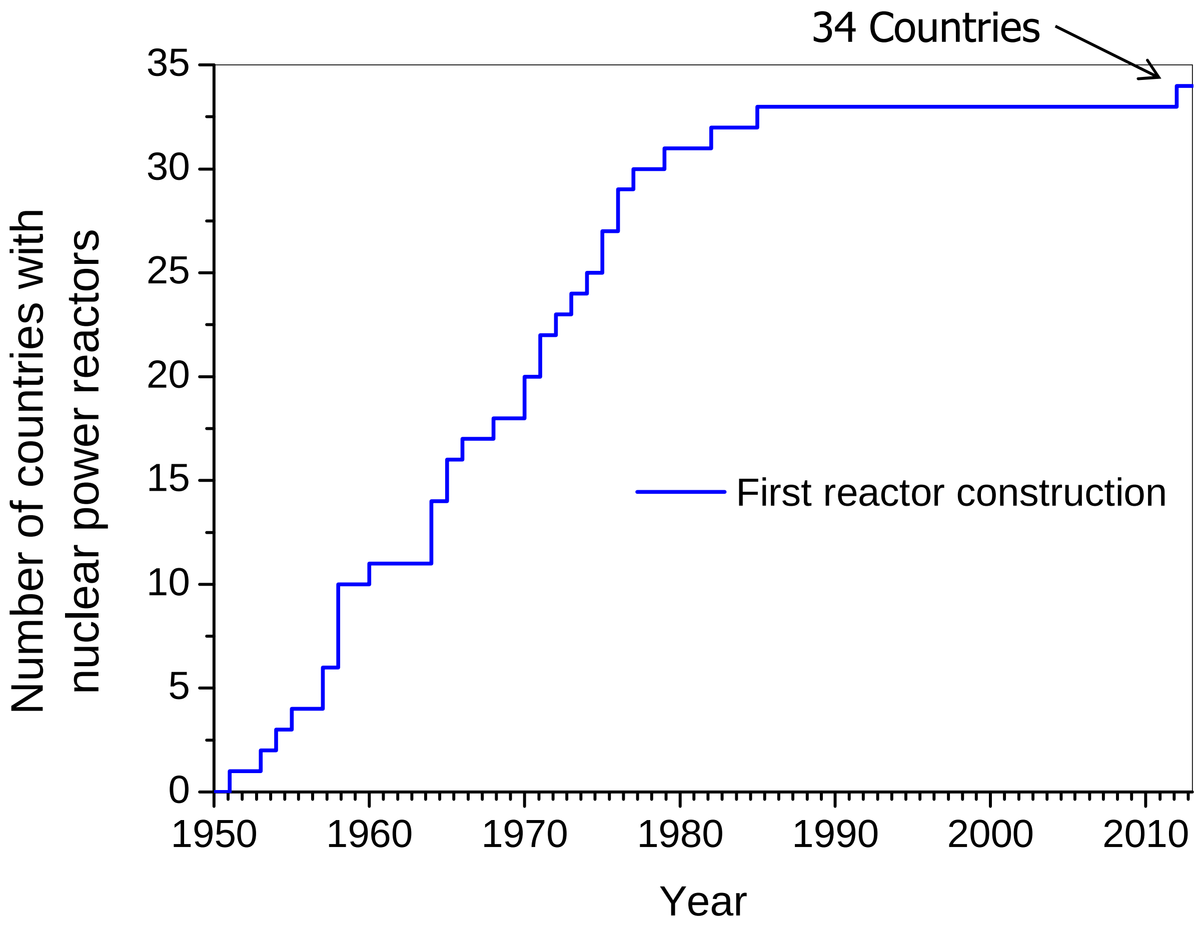
Profile of growth in the number of countries that have ever initiated construction of nuclear power plant

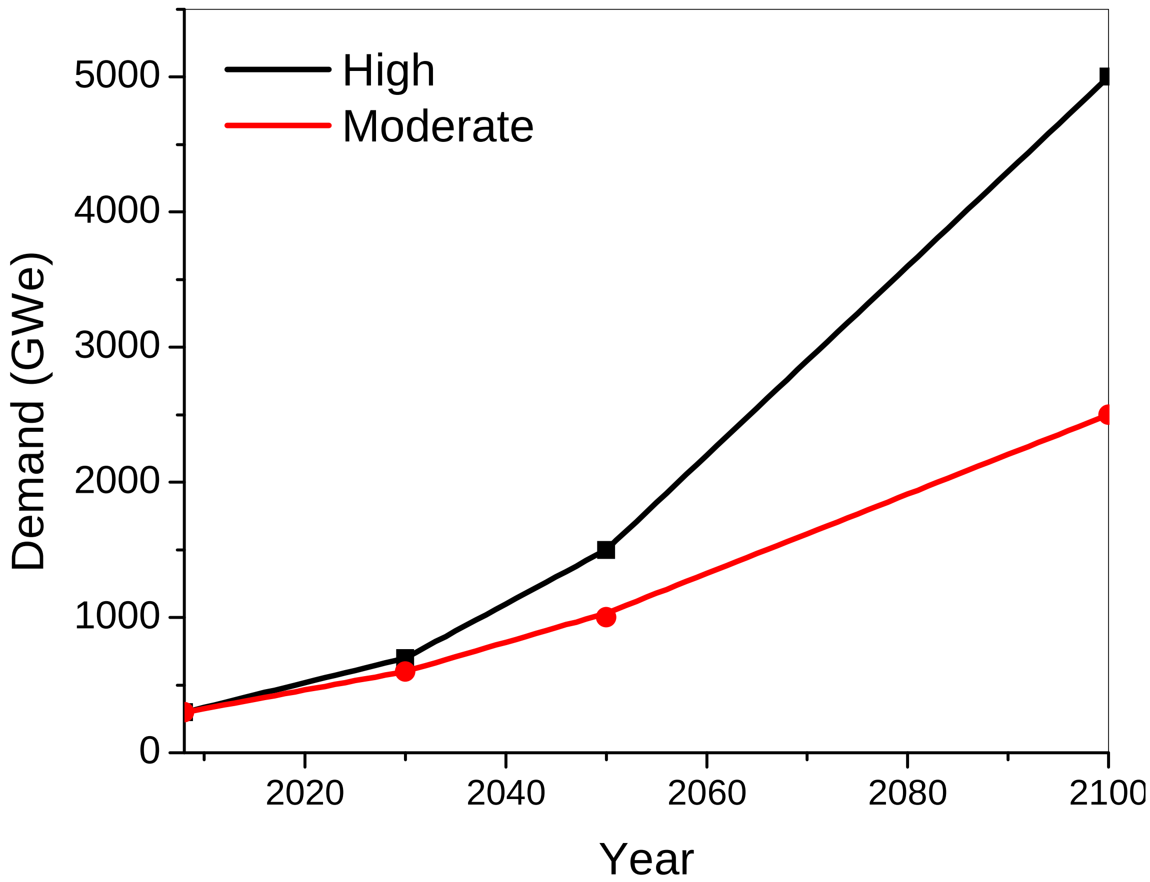


In spite of the existence of nuclear power in the world for the last six decades, the number of countries which have, at any time, launched construction of their first nuclear power plant remained stagnant at 33 from 1985 to 2012, until the UAE started construction of their first NPP.

Ref: IAEA PRIS June 2013

IAEA INPRO projection for the growth of nuclear power in the world – expected to be driven mostly by emerging economies and new entrants

- Present status of nuclear
  - 434 nuclear power reactors operational, 69 under construction (370.5 GWe net installed capacity)
- Projections by IAEA - INPRO
  - By 2050, required net installed nuclear power capacity will be about 1250 GWe (moderate) and 1875 GWe (high)
  - By 2100 about 3125 GWe (moderate) and 6250 GWe (high)



Cost of implementation of IAEA safeguards for the enhanced level of deployment could be substantial.

Reference: IAEA PRIS, June 2013 and INPRO GAINS, 2011

Thorium based fuel cycles could offer opportunities for substantial reduction in the cost of implementation of IAEA safeguards

- IAEA TECDOC 1575 (*INPRO Manual*)
  - "Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for innovative nuclear energy systems (INS) to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons program."
  - This document also brings out a set of evaluation parameters for measuring the attractiveness of nuclear material and nuclear technology in INS from proliferation considerations.
- Unique characteristics of thorium based fuels - difficult to reprocess, easy detectability and deterrence due to high radiation field of daughter products of ^{232}U.

No technology is proliferation proof, however intrinsic proliferation resistance could be enhanced with technical measures.

Ref: IAEA TECDOC 1575 Vol. 5

Some important characteristics of thorium based fuels for nuclear power generation

- Thorium does not have fissile isotopes, hence, thorium needs to be utilised as a fertile host along with added fissile material
  - The three options: ^{235}U, Plutonium and ^{233}U
- Thorium can be used in current reactor types (LWRs, PHWRs)
  - **With LEU** - Reduced generation of Pu, Pu isotopic composition less attractive for diversion, reduced minor actinides, more efficient use of mined uranium.
  - **With Pu** - Plutonium disposition, less efficient use of Pu
- Thorium (+ fissile) can be used in various fuel forms in existing and future reactors
  - **Mixed oxide pellet type fuel**- well established technology; difficult, though feasible, to recycle
  - **Particle type fuel**, in the form of TRISO particles - large thermal margin enables taking advantage of negative fuel temperature coefficient, strong barrier to release of fission products, reprocessing and high level waste disposition a major challenge.
  - **Molten salt type fuel** - design options provide for long term sustainability, technological challenges in reprocessing.

Three stages may be conceived for enhancing the global reach and volume of deployment of nuclear power using thorium

- Stage A – Immediate growth
  - Use in existing reactor types, with enriched uranium based fuels, to enhance the global reach of nuclear power while aiming for reduction in the cost of implementation of IAEA safeguards.
- Stage B – Transition phase
  - Use in breeder concepts to augment ^{233}U resource for further utilisation in ^{233}U/Th fuelled reactors, either currently established or emerging new designs.
- Stage C – Long term sustainability
  - Use in advanced nuclear energy systems, taking full advantage of the unique characteristics of ^{233}U-Th based closed fuel cycle, such as molten salt breeder reactors and accelerator driven sub-critical systems.

Several aspects of thorium use, with various fissile options relevant for the three stages, have been investigated worldwide

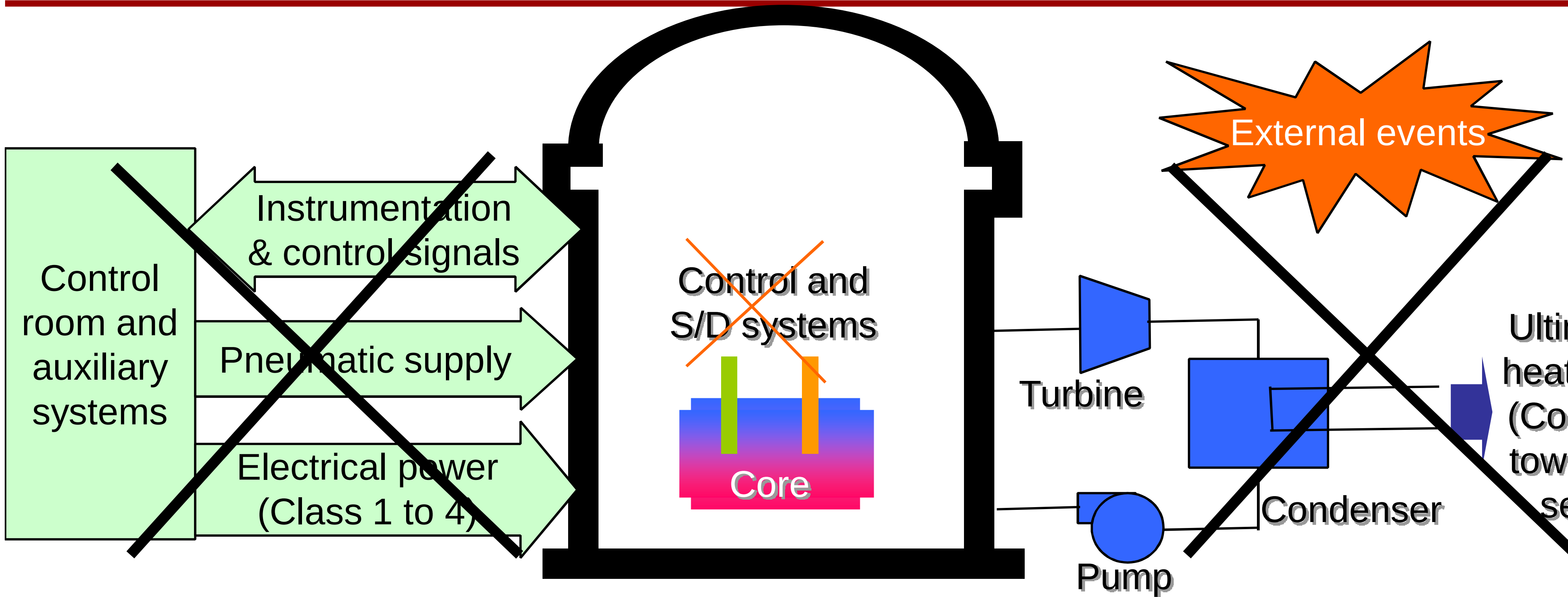
Chemical and/or physical form	Fissile options for use with thorium		
	^{235}U	*Plutonium*	^{233}U
Oxide	**Indian Point, USA** **PHWRs, India** **BORAX-IV, USA** **SUSPOP, Netherlands** **AHWR-LEU, India**	**Lingen, Germany** **AHWR, India**	**Shippingport USA**
Particle	**THTR,Germany** **Fort St. Vrain, USA** **Peach Bottom, USA** **AVR, Germany** **Dragon, UK**		
Molten Salt			**MSRE, USA** **MSBR, USA**

Currently, a large volume of developmental work, towards thorium utilisation, is also being carried out in different countries (including Russian Federation and China).

Colour codes: Blue: Operated reactors (>100 MWe or >100 MWt); Green: Operated reactors (<100 MWe, or <100MWt); Red (Designed, but not operated / to be operated)

Ref: IAEA TECDOC 1450, IAEA-TECDOC-1155, INEEL/EXT-98-00799

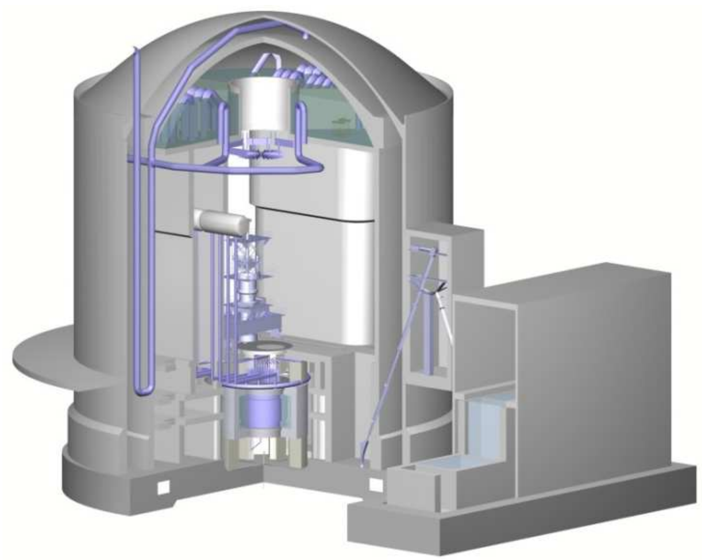
Apart from the fuel cycle aspects, large scale nuclear deployment will call for a higher level of safety and security, against internal and external threats, commensurate with the enhanced number of NPPs



- No unacceptable radiological impact outside the plant boundary with
  - Failure of all active systems, and
  - Failure of external infrastructure to provide coolant, power and other services, and
  - Failure of shutdown actions, initiated by instrumentation signals and
  - Inability of plant operators to manage the events and their consequences, for a significantly long time.

The Indian AHWR-LEU illustrates the concepts presented in the context of Stage-A deployment option

AHWR-LEU is a 300 MWe vertical pressure tube type, boiling light water cooled and heavy water moderated reactor using LEU-Th MOX fuel.



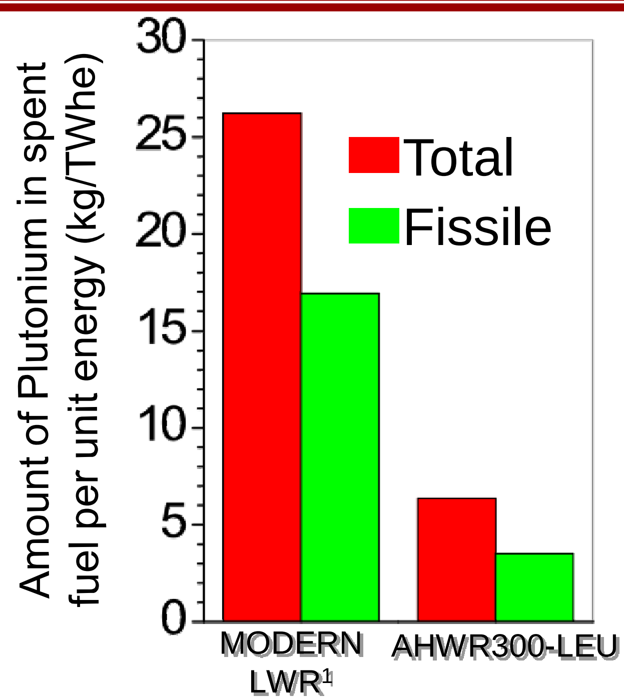
- Design validation through extensive experimental programme.
- Site selection in progress.

Major design features

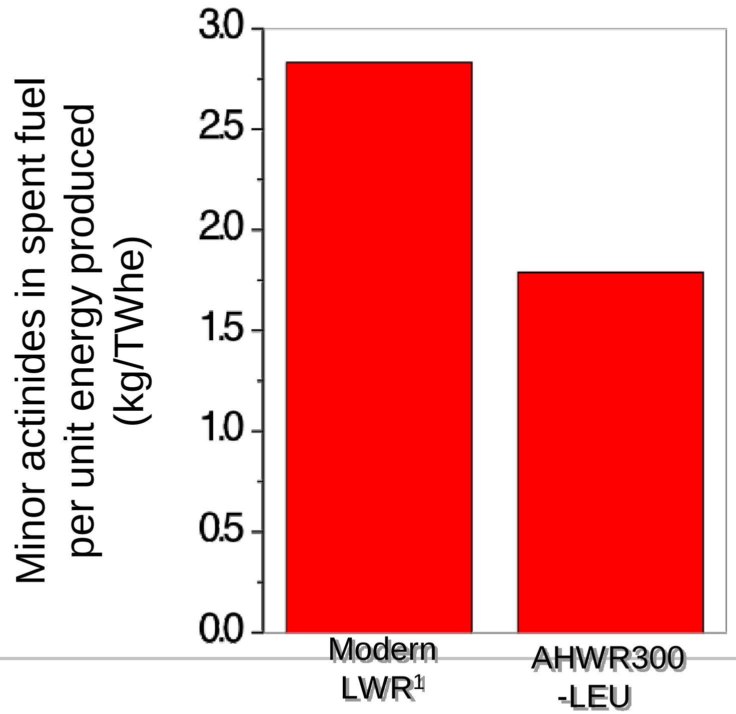
- ~40% of power from fission of ^{233}U (produced in-situ)
- Uses existing PHWR pressure tube technologies
- Several passive features, including full power heat removal by natural circulation, and passive shutdown system
- Easily replaceable coolant channels.

Thorium usage leads to enhanced proliferation resistance and reduced long lived waste generation in AHWR-LEU

- Enhanced proliferation resistance
  - Reduced Pu generation
  - High fraction of ^{238}Pu (~10%)
  - ~200 ppm of ^{232}U in spent fuel



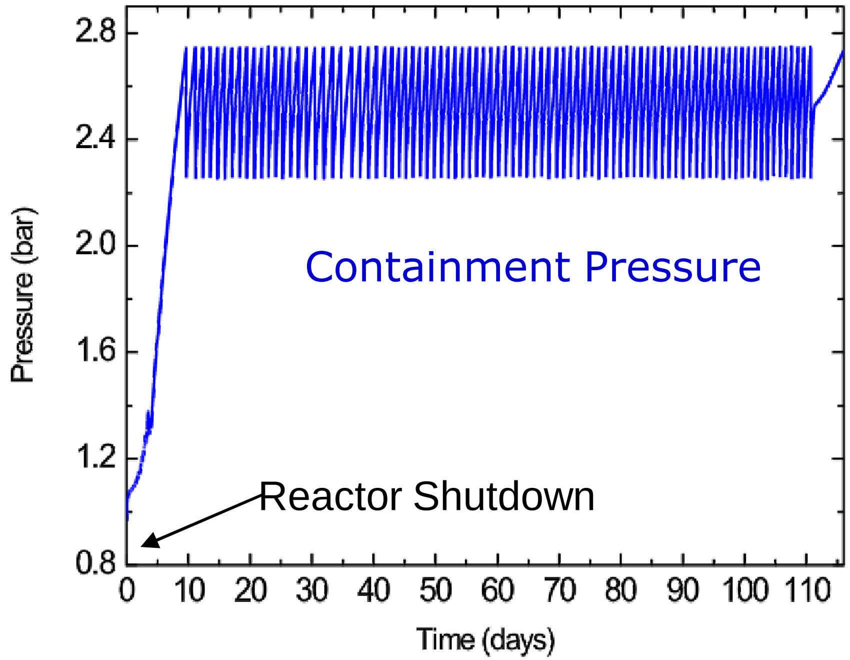
- Reduced long lived waste generation
  - Reduced minor actinide production

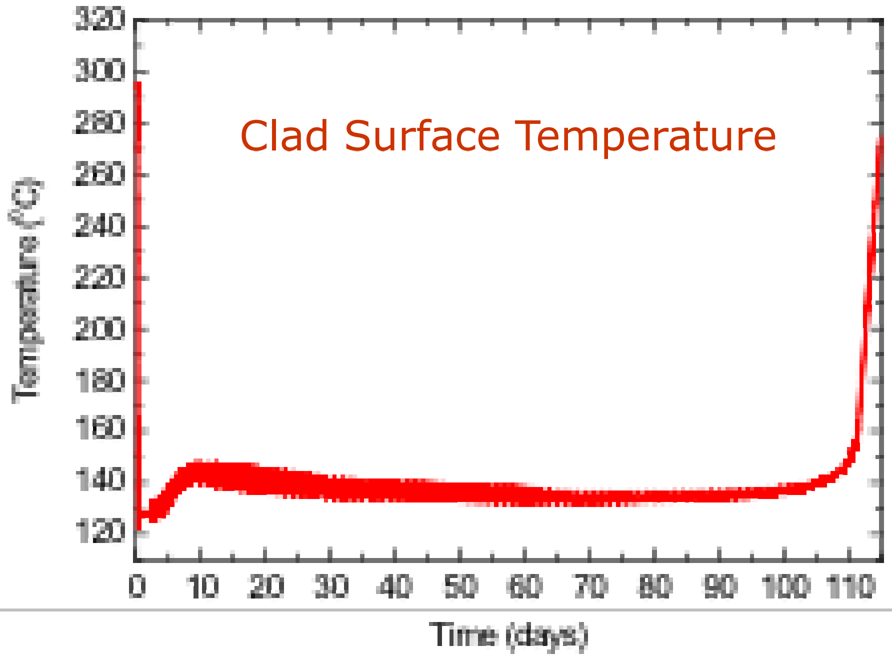


[1]The modern LWR is an advanced PWR (60 GWd/t) considered for INPRO Collaborative Project GAINS

In a Fukushima type scenario, decay heat can be removed in AHWR without any electrical power, external source of water or operator action for 110 days

- Prolonged SBO in AHWR with Decay Heat Removal by Isolation Condenser System
- Scenario considered
  - Reactor trips on earthquake signal (t = 0)
  - GDWP water can remove decay heat ~110 days
  - Periodic venting of containment is required in this case
  - Venting starts at 2.75 bar of containment pressure and resets at 2.25 bar of containment pressure





Concluding remarks

- In the near-term, thorium can enhance the reach of nuclear power globally while facilitating a reduction in the cost of implementation of IAEA safeguards.

- In the long-term, using advanced nuclear energy systems, thorium offers sustainable large scale deployment of nuclear power.


ThO_2 pellets sintered in air
Thank you
ThO_2 pellets sintered in Ar + H_2