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Nuclear Renaissance and Role of SMR for Net Zero Power Systems

Application of High Temperature Thorium to Uranium-233 breeder

Kailash Mittal*, Ganapati Myneni**, Roger Barlow***, Asiya Rummana*

*BSCE BHARAT Ltd, ** BSCE Inc USA &GITAM Vizag, ***BSCE Inc, U. Huddersfeld

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Replacing fossil fuels

Many opportunities

- Renewables
- Flexible grids
- Nuclear power

Renewables, efficiency improvements are great - but they will not be enough to replace fossil fuels without nuclear as part of the mix.

Anyone arguing otherwise is, whether they know it or not, a shill for Big Oil.

Nuclear new and old

Old Nuclear

- Uranium fuel
- Low (350 C) temperatures
- Critical
- Large scale - like the computer mainframe
- Designed for base load
- Complicated mechanical pins & rods fuel structure
- Big problems with radioactive waste
- Danger of weaponising

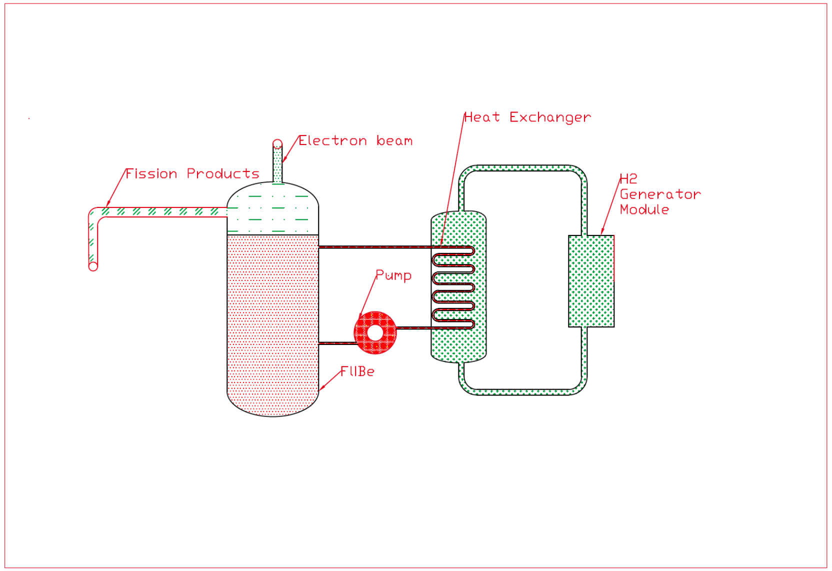
New Nuclear

- Thorium fuel
- High (800+ C) temperatures gives greater efficiencies and useful process heat
- Sub critical so simpler and safer
- Small scale - like the PC
- Can handle rapid load changes
- Molten salt for simple fuel structure
- Greatly reduced waste problem
- Harder to weaponise

The BSCE concept: the eMMR

Electron-based Micro Modular Reactor

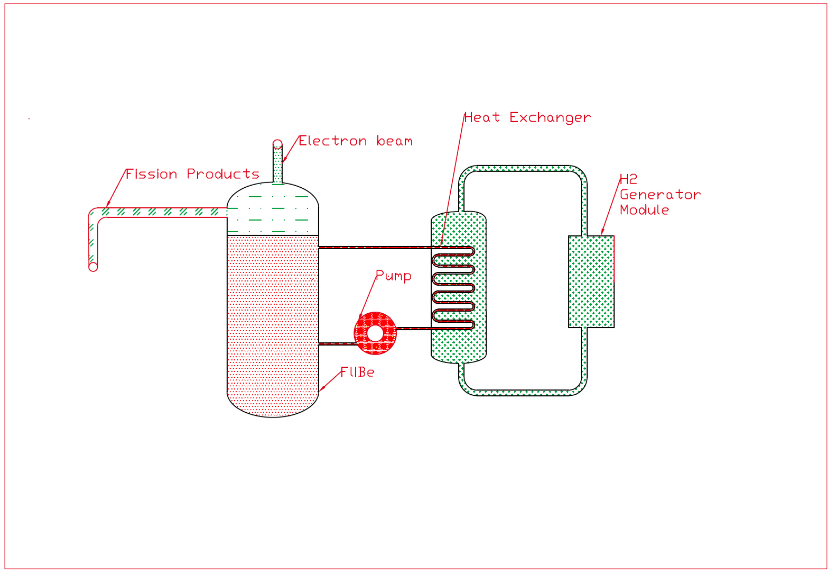
- Fuel is thorium+uranium dissolved in FLiBe molten salt
- Fissile ^{233}U fuel consumed and replaced by new from breeding, so long time before refuelling
- High temperature → greater efficiency, or process heat for industry
- Subcritical so simple and safe
- Uses electron accelerator - smaller and cheaper than proton accelerators



The eMMR

More details

- Heat extracted through heat exchanger for power, or hydrogen generation through sulfur-iodine cycle, or other industrial applications
- Gas fission products removed and disposed of safely. Others accumulate in fuel until canister renewal
- **Electron beam current easily controlled to follow demand (including switching off and on)**
- Pump used, but unassisted convection enough to remove decay heat if the power fails.



Electron-based ADSR

Most ADSR proposals use Proton accelerators - large and expensive
Electron accelerators are smaller and much cheaper

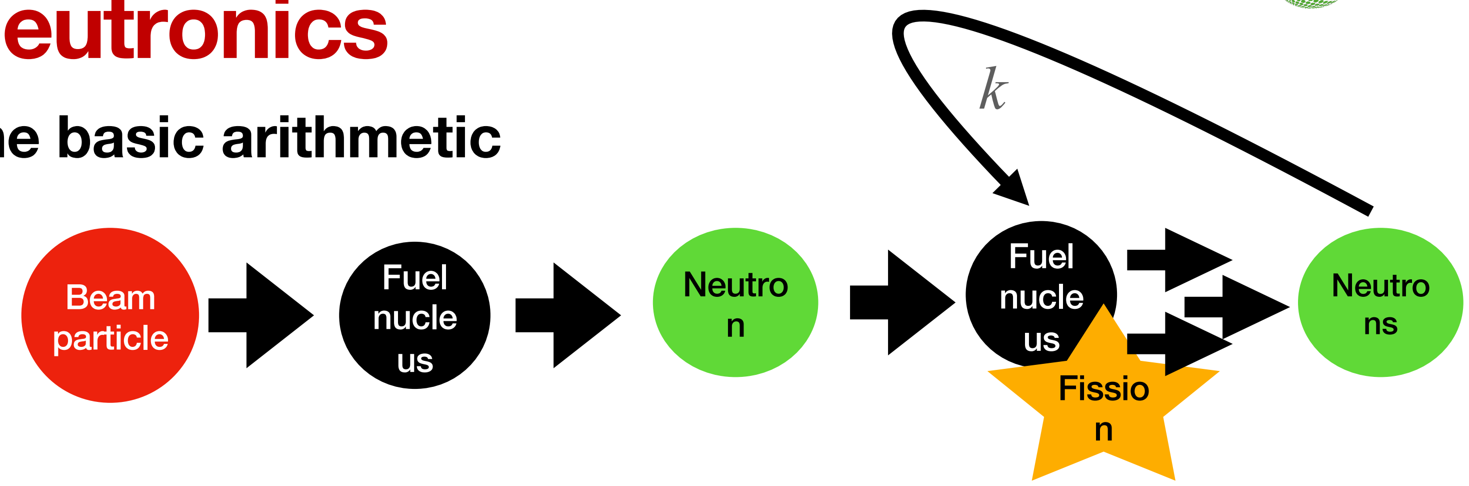
MYRRHA, under construction in Belgium has a 600 MeV proton accelerator, 400 m long

The IBA 40 MeV 120 KW electron accelerator

They are also not nearly as effective for producing neutrons
A 1 GeV proton produces ~20 neutrons
A 60 MeV electron produces ~0.02 neutrons

Neutronics

The basic arithmetic



Each beam particle has energy E and gives n neutrons. (n=20 for 600 MeV protons or 0.02 for 60 MeV electrons)
Each fission gives 180 MeV of energy and ~2.5 neutrons:
k (<1) of these go on to produce another fission, geometric series gives $\frac{1}{(1-k)}$ fissions and $E_{out} = \frac{180n}{1-k}$

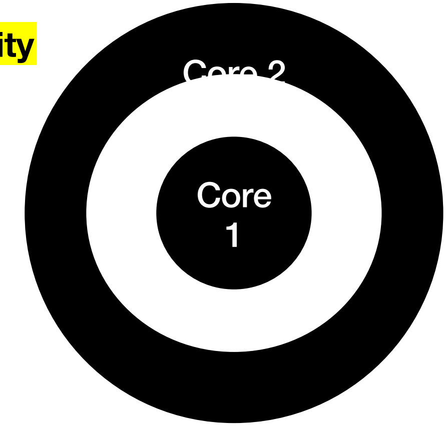
Suppose you want 100x as much energy out as you put in

For protons that needs k=0.94
For electrons that needs k=0.999

A reactor with k close to 1 is worrying because small changes in field composition can push it over the limit

Coupled-core systems

Not a new idea, but little studied
Gives the large neutron multiplication electrons need without risking near-criticality



Both cores subcritical

- **Accelerator neutron strikes Core 1**
  Neutrons can travel 1→2 but not 2→1
  (Through geometry and thermalisation)
- **Suppose for each fission in Core 1, 0.9 neutrons cause fission in Core 1, and 0.9 cause fission in Core 2**
- **A produced neutron in core 1 gives 10 fissions in core 1, and 9 neutrons travel to Core 2, where they give 90 fissions**

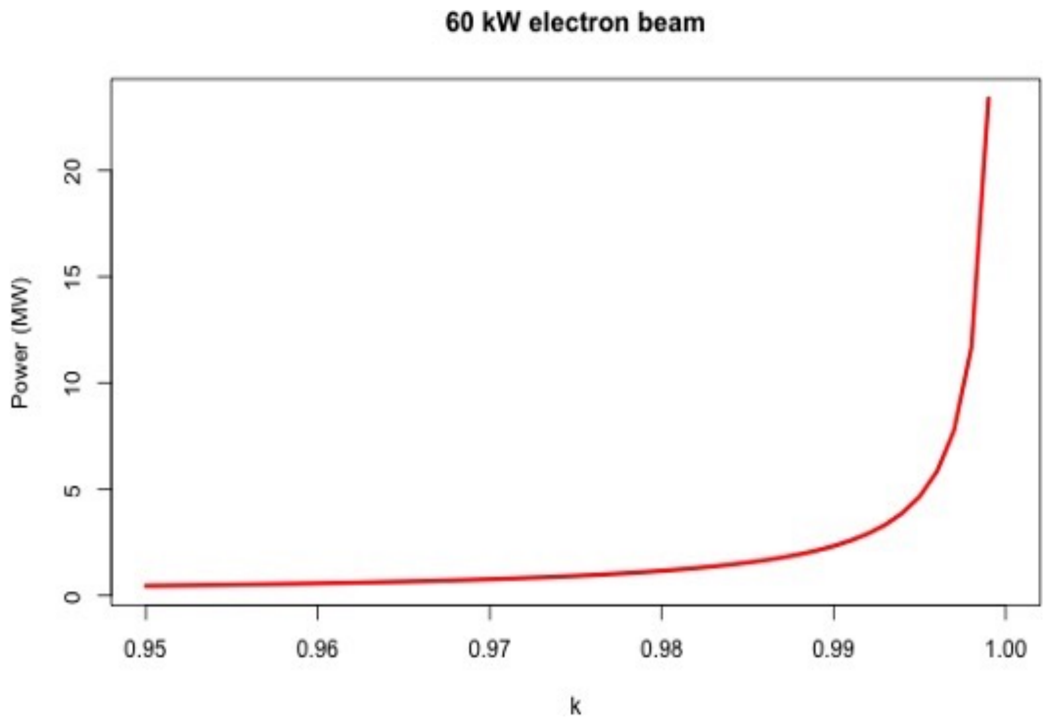
That gives 100 fissions from 1 primary - though k=0.9 not 0.99

Core 1 is a fast reactor and the beam target. Needs to be highly enriched, but size is small (large surface losses to Core 2)

Core 2 is a thermal reactor and where the breeding happens.

Gap could be air, or could be gadolinium (stops slow neutrons) and then graphite (to thermalise)

Power Estimation in Coupled Core System



Neutron-generating Target And Two-core Subcritical Blanket With Fast And Thermal Neutron Spectrum

Schematic Diagram Of The Design Of Subcritical Blanket:

1 - Target;

2 - Fast neutron zone; Th232

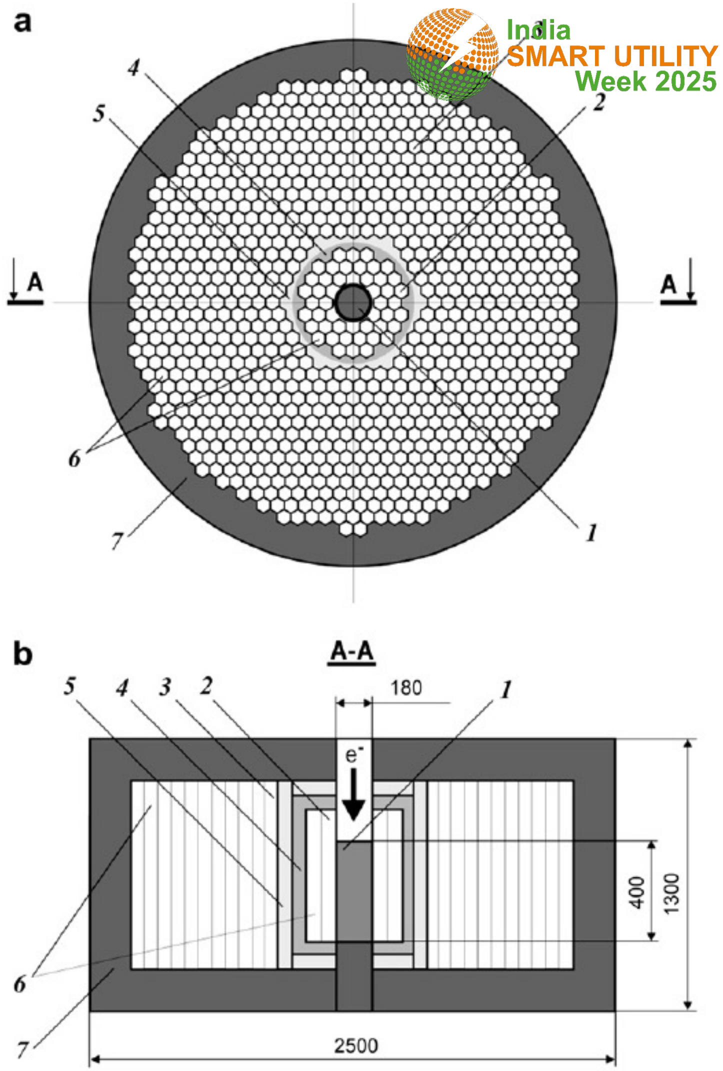
3 - Thermal neutron zone;

4 - layer of B4C;

5 - layer of ZrH2;

6 - fuel assembly; Zi hydride +Thorium Zirconium

7 - external reflector of neutrons



Going forward to a high temperature thorium eADSR

- It all looks good!
- Simulation studies in progress to check details
- Considering micro (10MW) and small (300MW) architectures
- Lots of details (fission product build up, protactinium, depletion) not studied yet.
- Lots of challenging (but possible) engineering with molten salt systems

The BSCE concept: the eMMR Summary

- Electron Beam Accelerator is Robust Technology
- 1 to 10 MeV, 100 kW Electron Beams are routinely employed for Industrial Radiation Processing
- 10 MeV, 100 kW -500 kW Beams available in industry
- **IBA 40 MeV 120 kW beam is commercially available and up to 1 MW beam are feasible today if required**
- **Electron Based ADSR are very compact**
- **Coupled Core Systems with k=0.9 and above provide a gain of > 10. For k=0.99, gain of >100 is possible**
- **A 60 kW ebeam with k=0.997can produce 10 MW power**
- **Power and Criticality can be controlled by Beam Current.**
- A Program to develop BSCE eMMR with 40 MeV 120 kW beam and Coupled Core System should be taken up at earliest

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THANK YOU

For discussions/suggestions/queries email: isuw@isuw.in

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Links/References (If any)