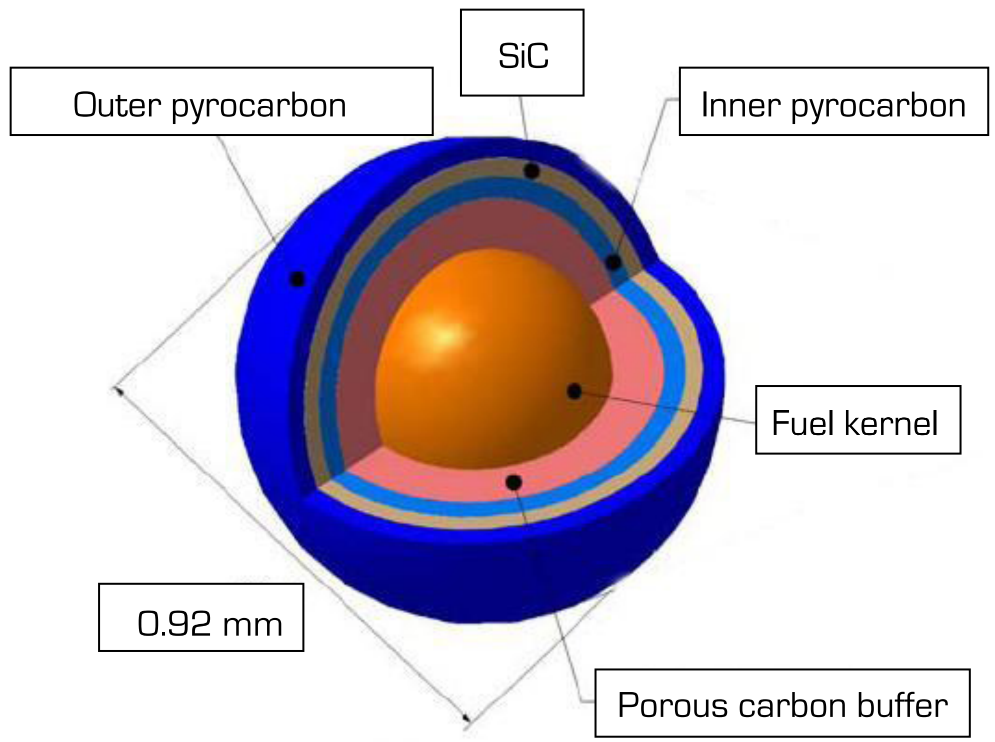
High temperature reactors (HTRs)



Helium cooled high temperature reactors are based on the use of coated particle fuels

- TRISO fuel coating withstands temperatures of up to 1600°C (cw 800°C for LWR cladding)
- Graphite moderator provides heat capacity
- Considered passively safe
- Two HTRs were in commercial operation:
- Fort St Vrain (330 MWe MWe, US)
- THTR (300 MWe, Germany)

Fort St Vrain

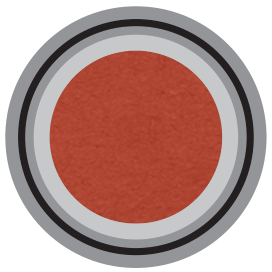
Fuel elements in HTRs

Pebble

60 mm

TRISO "microspheres" are embedded in a spherical (pebble) or cylindrical (compact) graphite matrix.

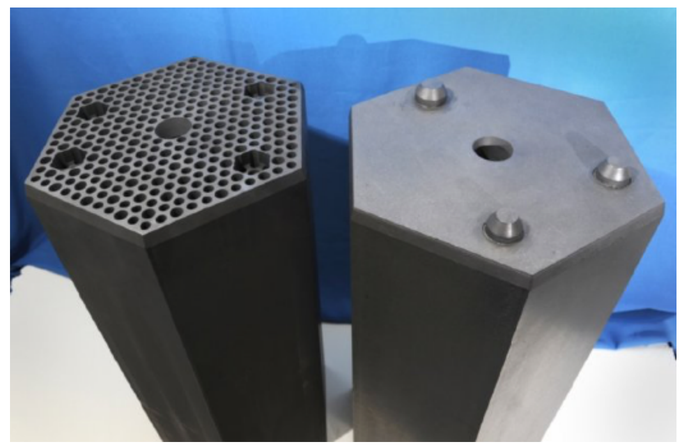
0.92 mm



Compact

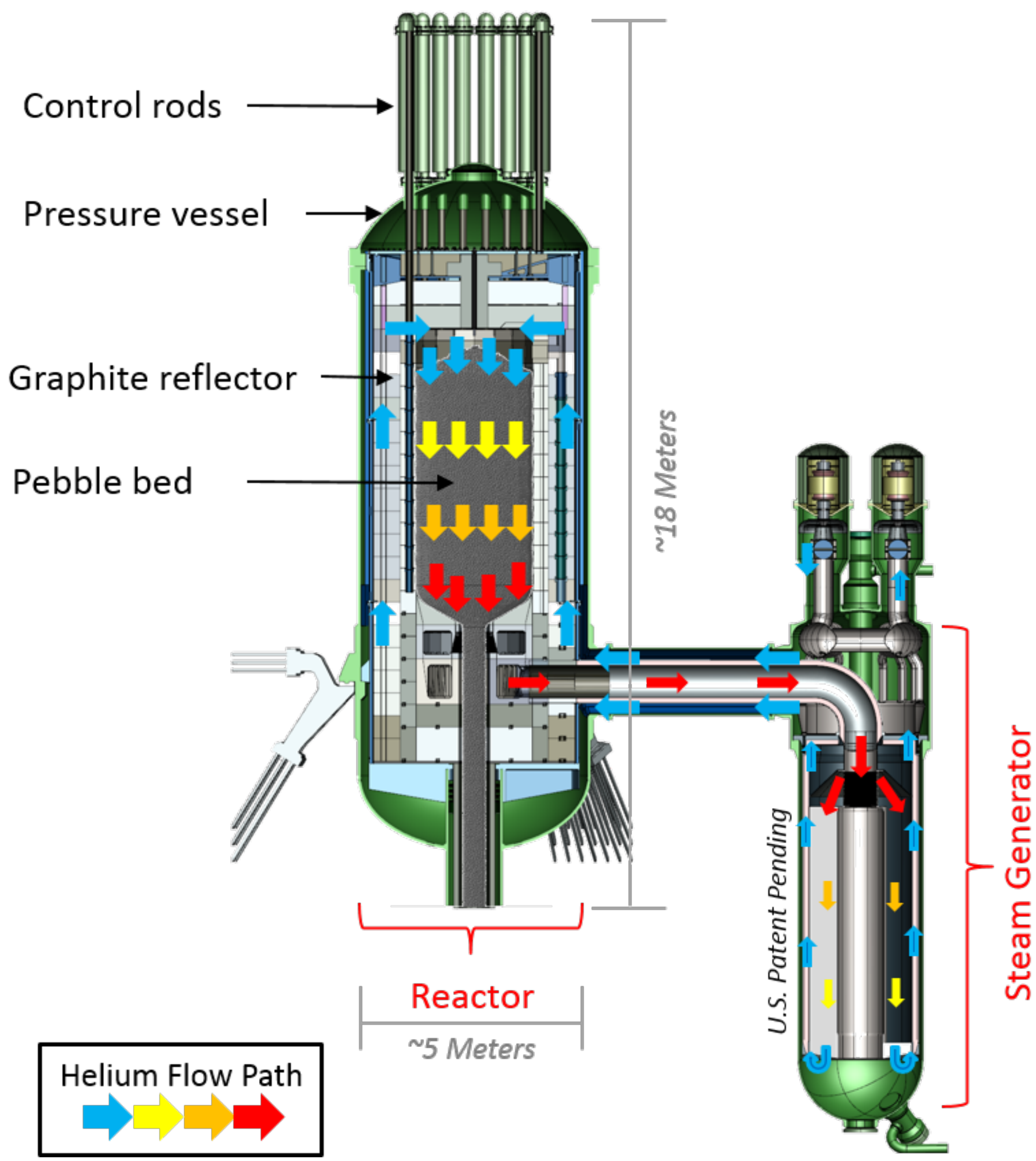
39 mm

26 mm



Compacts are stacked and inserted into a cylindrical holes in a "prismatic" graphite block.

Pebble bed HTR design

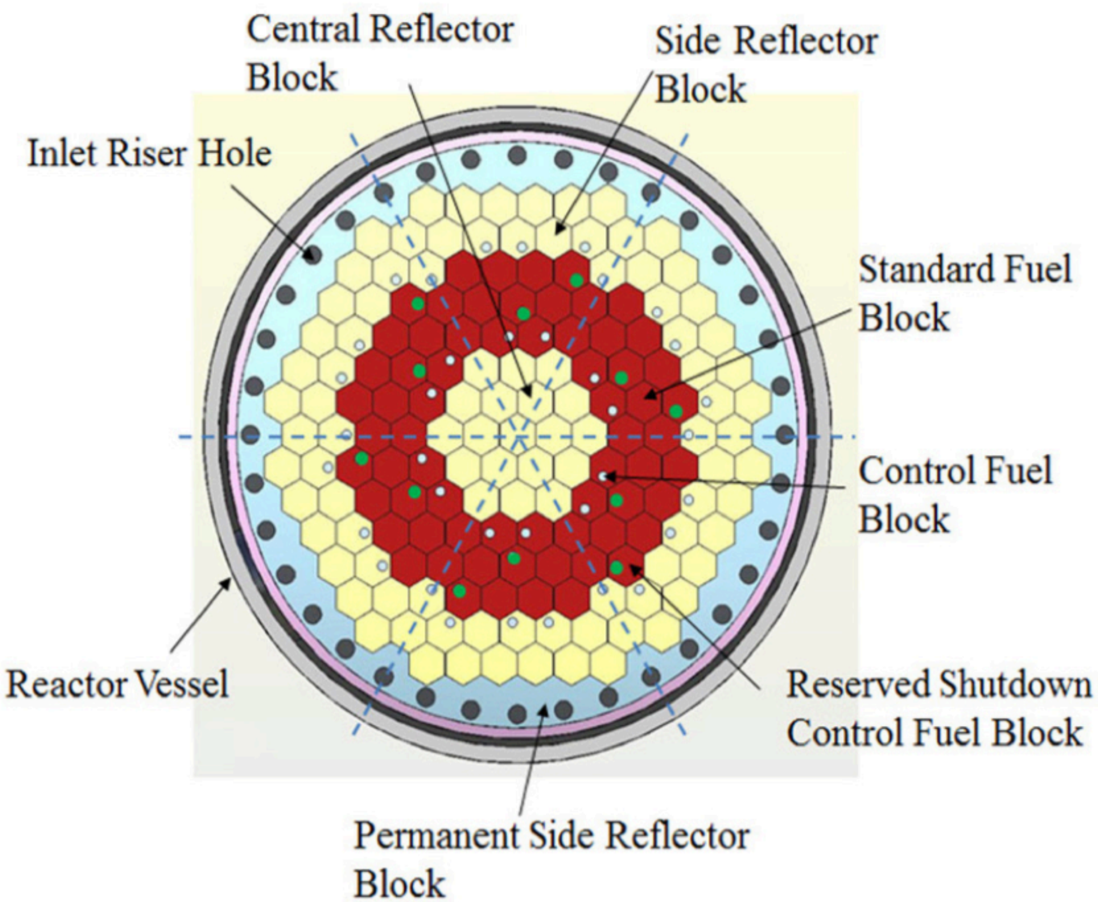


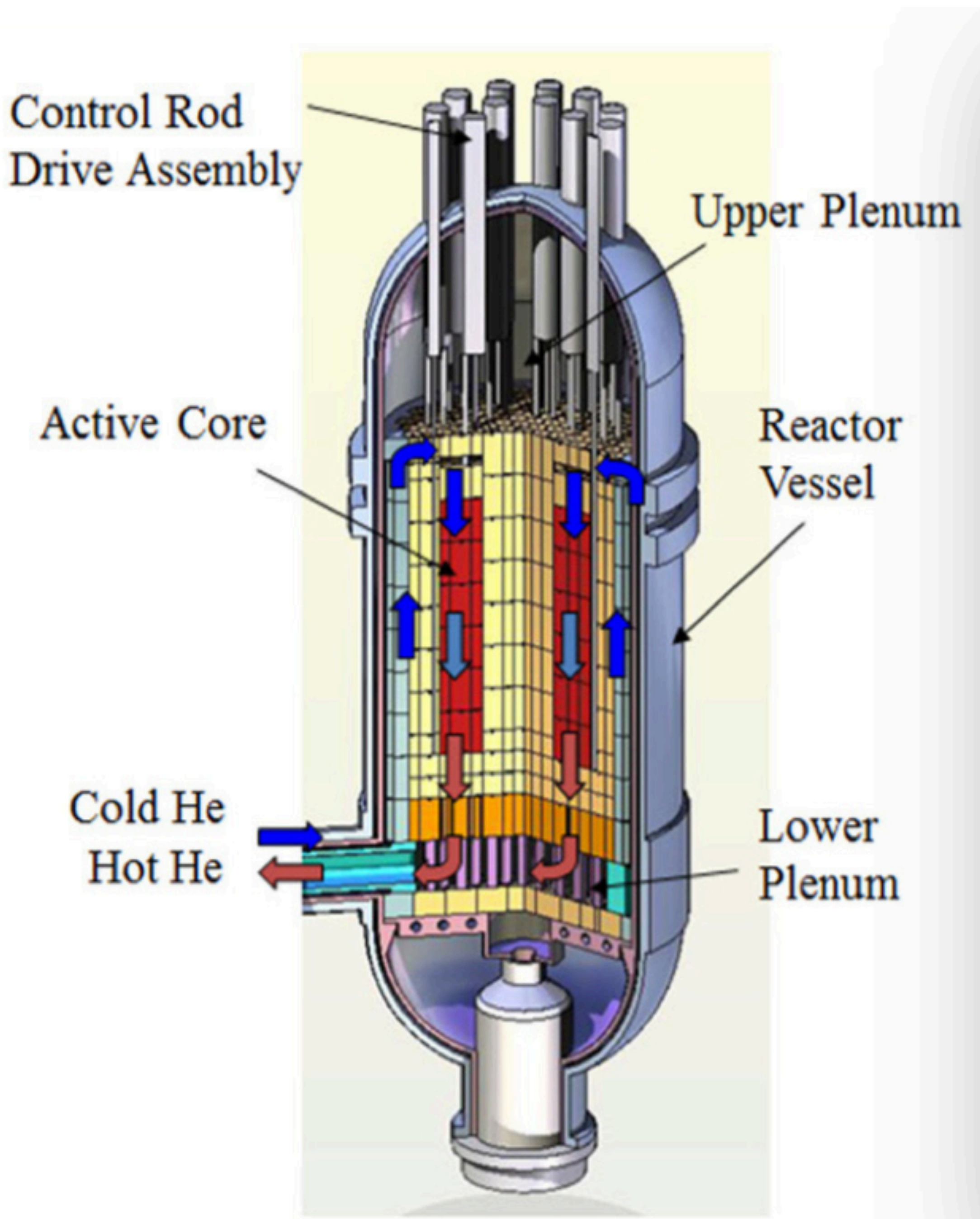
XE-100

Generic characteristics

- Pebbles extracted from bottom, reloaded at top
- He pressure: 7 MPa
- Fuel: UO_2 / UCO
- ^{235}U enrichment: > 8%
- Power density: 3 MW/m^3 (2 kW/pebble)
- Coolant outlet temperature: 750°C
- Pebble residence time: 15 x 25 days
- Fuel burn-up: 90 GWd/ton

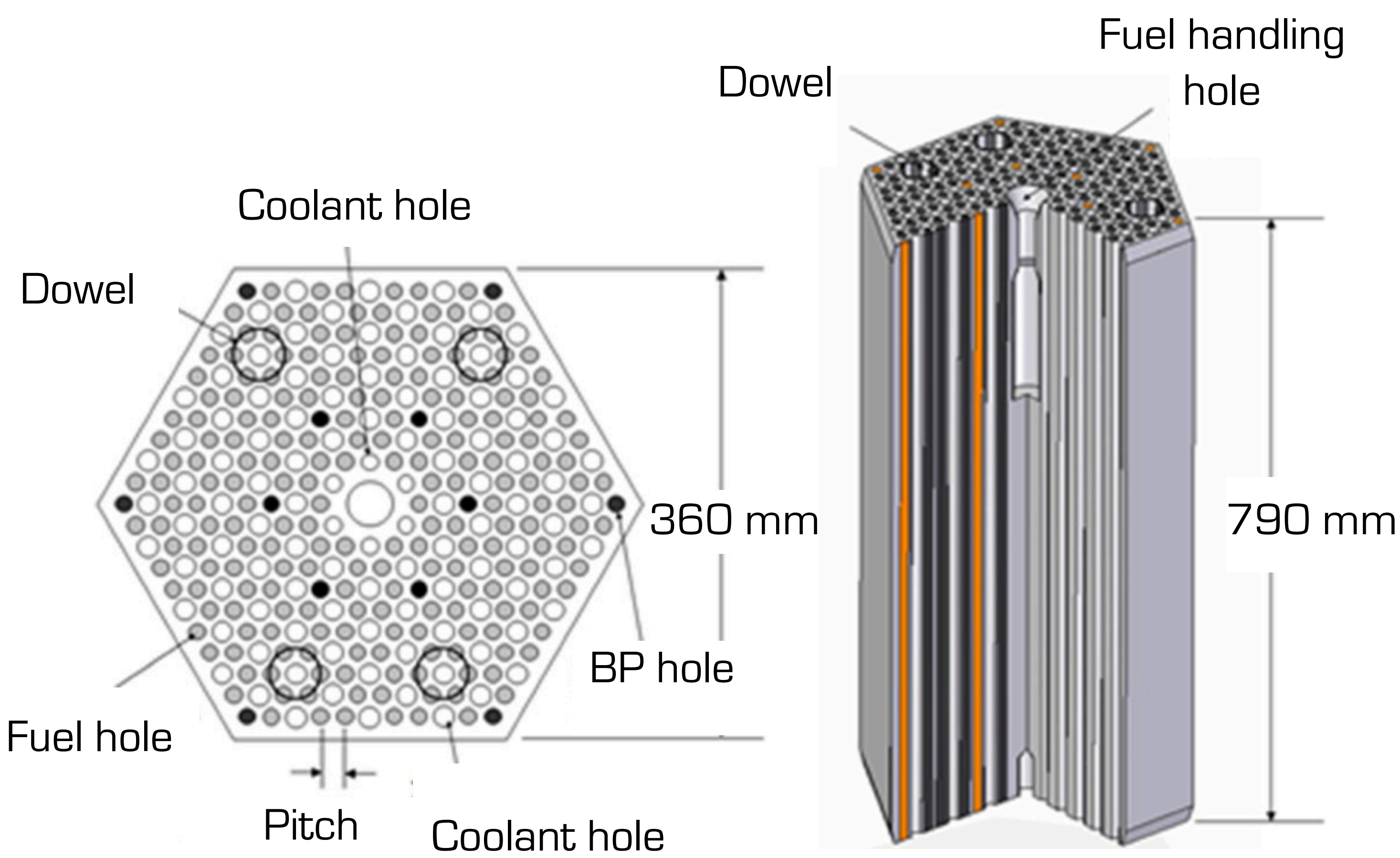
Prismatic HTR design





- Annular core
- Coolant flow from top to bottom

Prismatic HTR fuel block design



Fuel block characteristics

- 204 fuel holes (D = 12.7 mm)
- 6 central coolant holes (D = 12.7 mm)
- 102 coolant holes (D = 15.9 mm)
- 12 burnable poison holes (D = 12.7 mm)
- Hole pitch: 18.8 mm
- Refueling cycle: 18 months
- Fuel burn-up: 100 GWd/ton

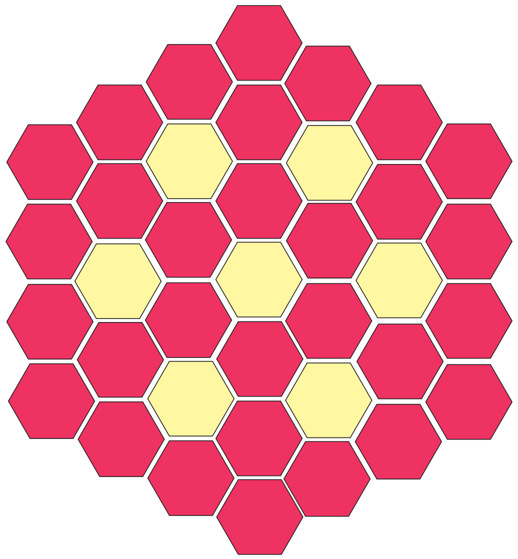
Pebble bed vs block design

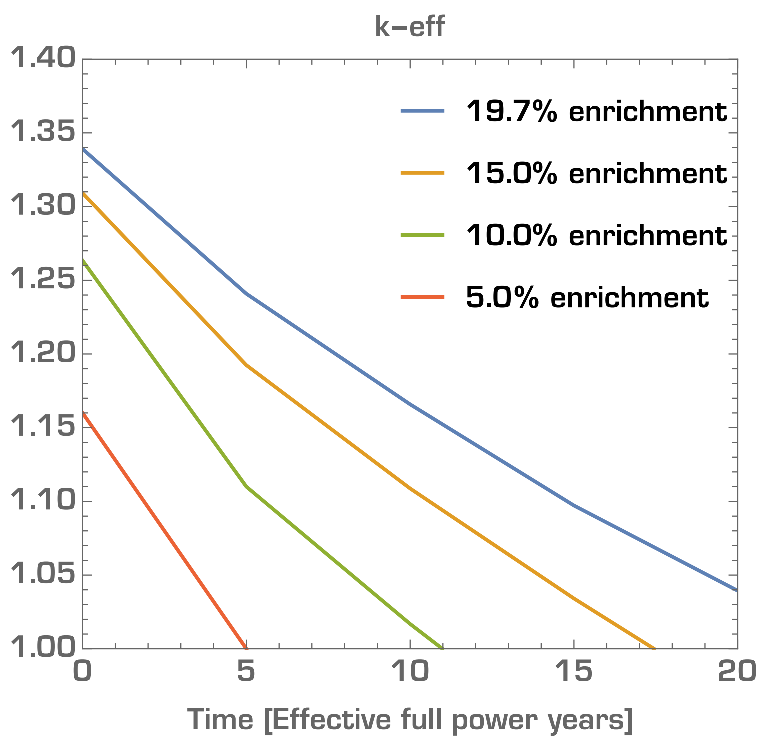
- Advantages pertaining to pebble bed design
  - Online-refuelling possible
- Dis-advantages of pebble-bed design
  - Risk for mechanical damage to pebbles
  - Spatial distribution of fuel-burnup difficult to determine
  - Difficult to measure local gas temperature in core
  - Need to measure pebble burn-up before re-load
- Dis-advantage of prismatic block design:
  - Fuel reload is complicated

Incidents in HTRs

- Release of Sr-90 from AVR in Jülich
  - 100 TBq of Sr-90 (2-3% of core inventory) released due to pebble temperatures exceeding design value.
- Damaged fuel pebbles in THTR, Hamm
  - 1-3 % of all pebbles were found to be mechanically damaged at extraction.
  - On May 5th 1986, pebble damage occurred after forceful extraction of pebble stuck in fuel feed pipe channel, leading to a release of 100 MBq Co-60, Cs-137 and Pa-233.

Reactivity evolution in small prismatic core (U-Battery)





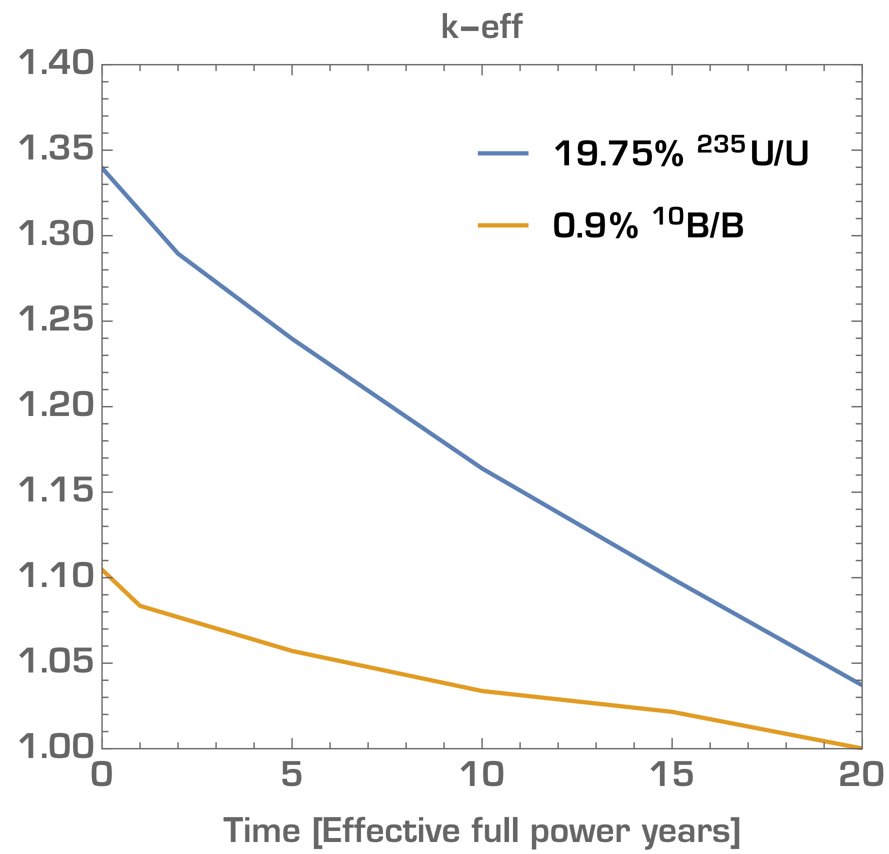
21 MWth ≈ 9 MWe prismatic core

- 30 x 4 =120 fuel blocks
- 1.8 tons of UO_2 fuel
- No burnable poison
- Internal moderator blocks
- Packing fraction of microspheres in compact: 30%
- > 20 years of residence time (9% burnup) w/o reload appears possible for 19.7% enrichment.

Burnable poisons in HTRs

Options studied for HTRs

- Gd_2O_3 particles - mixed with fuel spheres in pebble
- B_4C - in coated particles (pebble bed)
- B_4C - in poison channel (prismatic core)
- Er_2O_3 dispersed in graphite moderator



Small prismatic core having 6 channels filled with depleted B_4C