Pebble-Bed Advanced High Temperature Reactor (PB-AHTR)

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FHR Workshop
Oak Ridge National Laboratory
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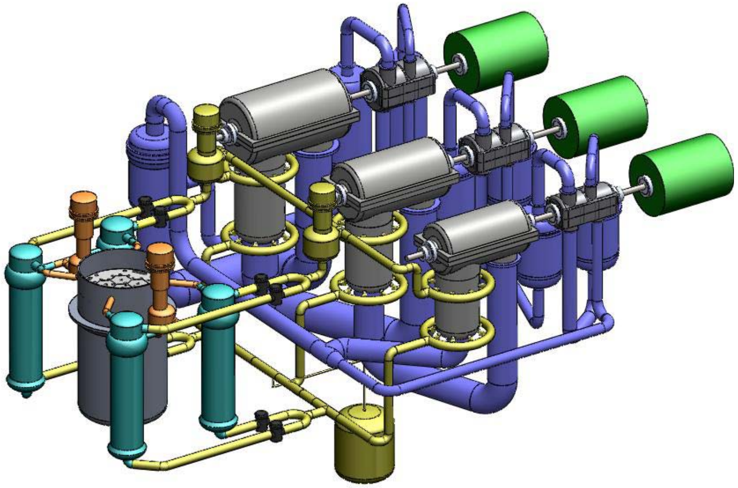
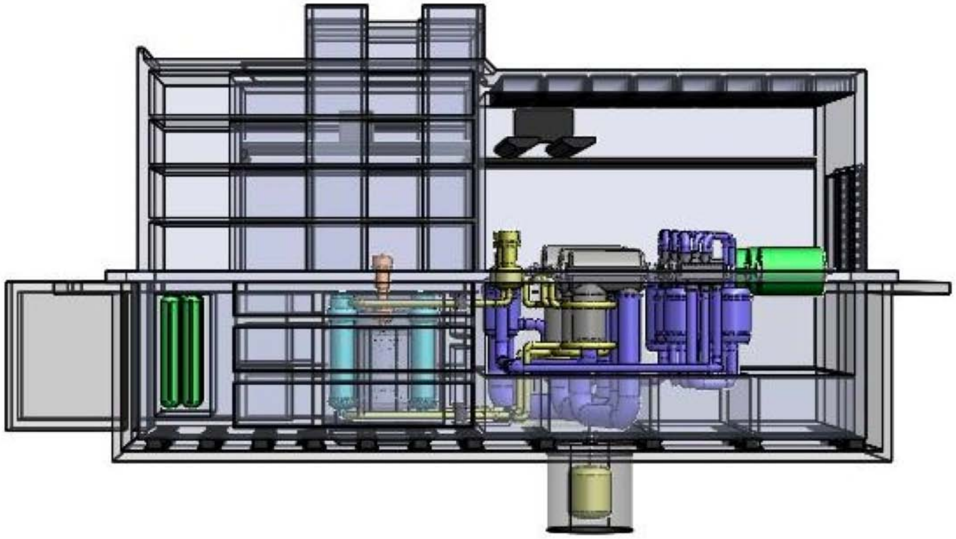
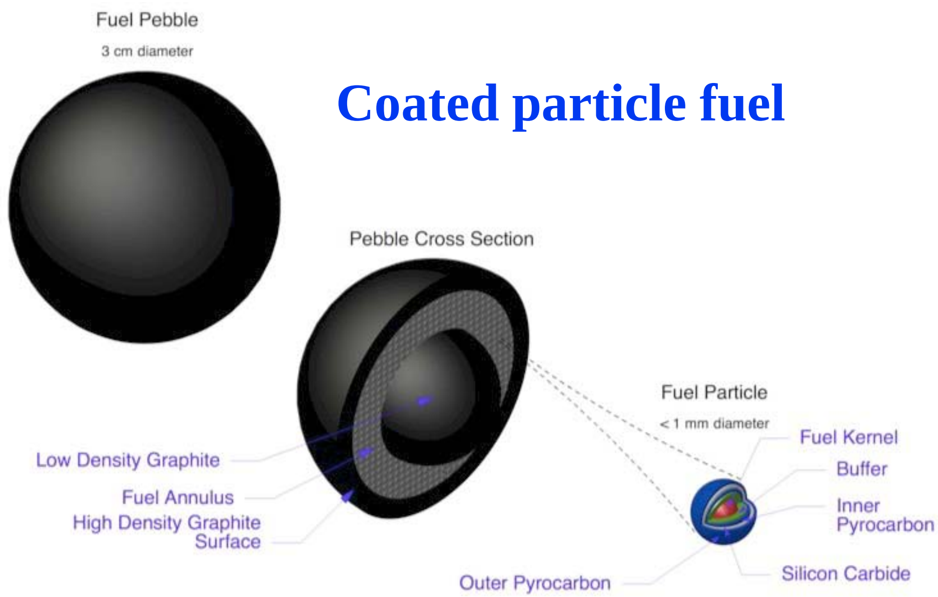


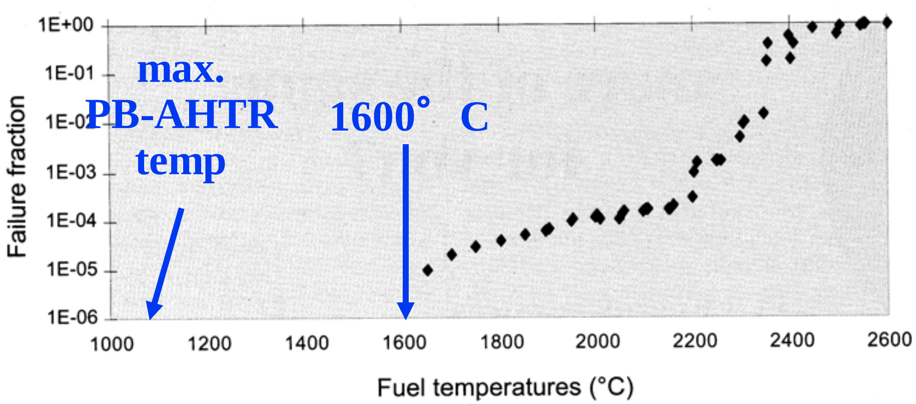


900 MWth, 410 MWe PB-AHTR (2008 NE-170 Senior Design Project)

Fluoride-Salt-Cooled High Temperature Reactors (FHRs) combine two older technologies

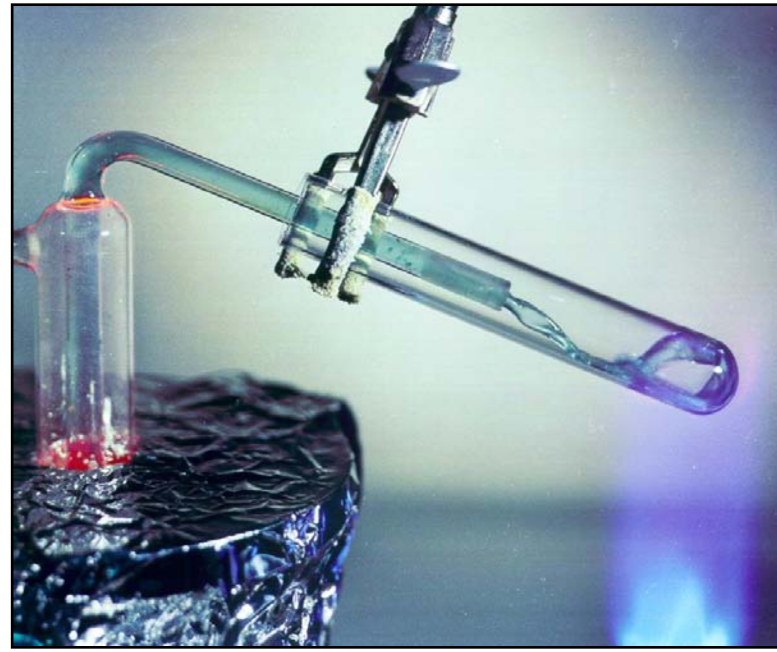
Coated particle fuel





Fuel performance chart (Source: PBMR [Pty] Ltd.)

FHRs have uniquely large fuel thermal margin



Liquid fluoride salt coolants

Excellent heat transfer
Transparent, clean fluoride salt
Boiling point ~1400°C
Reacts very slowly in air
No energy source to pressurize containment
But high freezing temperature (459° C)
And industrial safety required for Be

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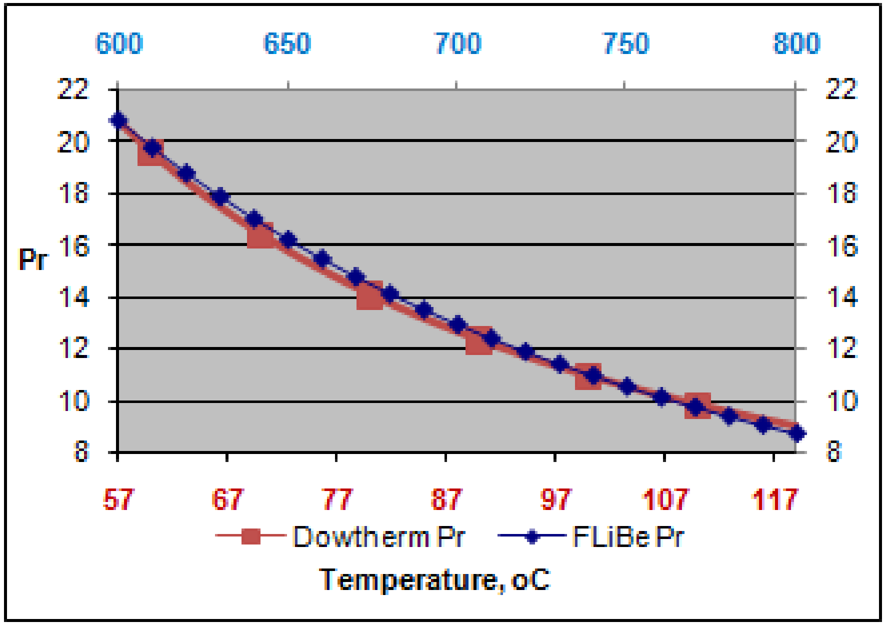
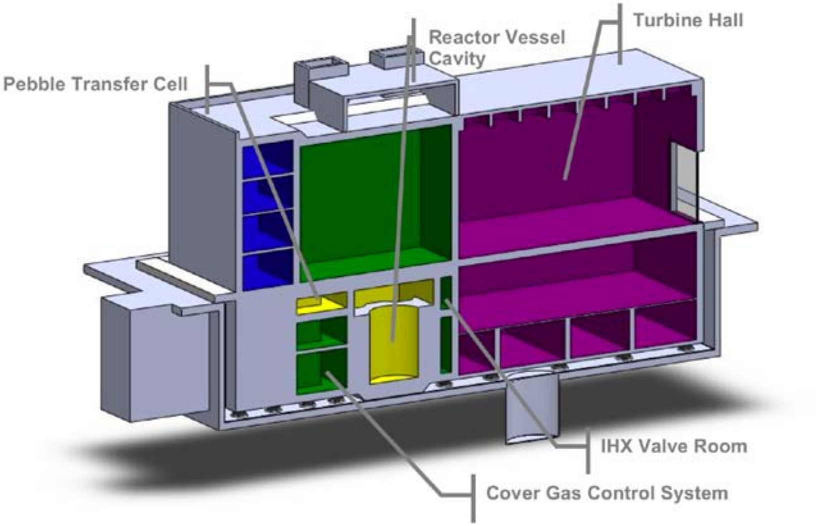
FHR's have unique characteristics

- **Capability to deliver heat at high average temperature**
  - **Fully ceramic core structures with high thermal margins**
  - **Low pressure allows primary loop structure construction with high-temperature alloys**
- **Unique capability for simulant fluid experiments to validate transient response codes (RELAP, TRACE)**
  - **Water: match Re and Fr**
  - **Oil: match Pr, Gr, Re, Fr**
- **Compact primary, containment, building, and power conversion systems**
  - **Fluoride salts have high volumetric heat capacity**
  - **Passive natural circulation decay heat removal eliminates active safety equipment**

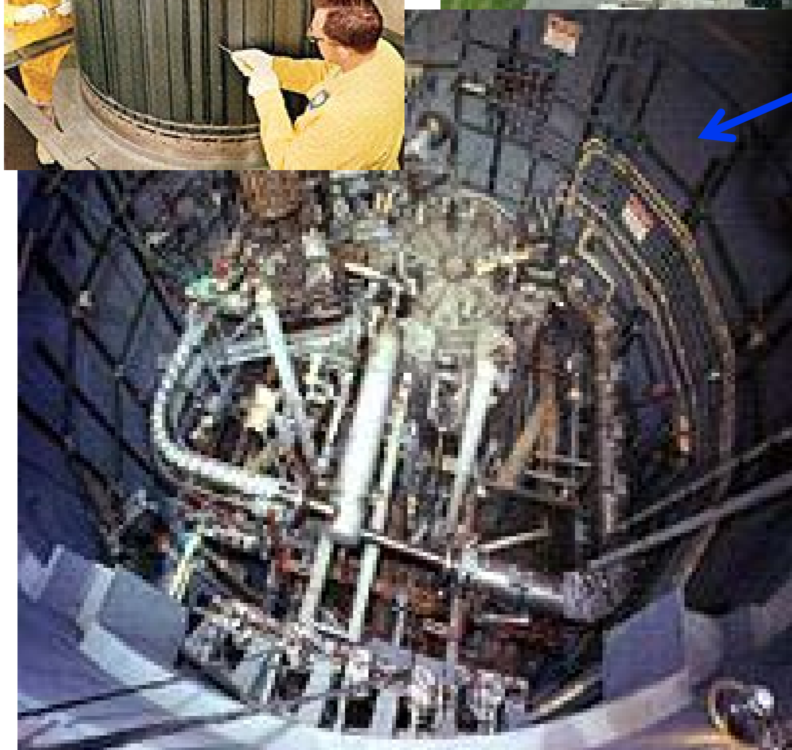


FHRs have a uniquely large number of robust safety barriers

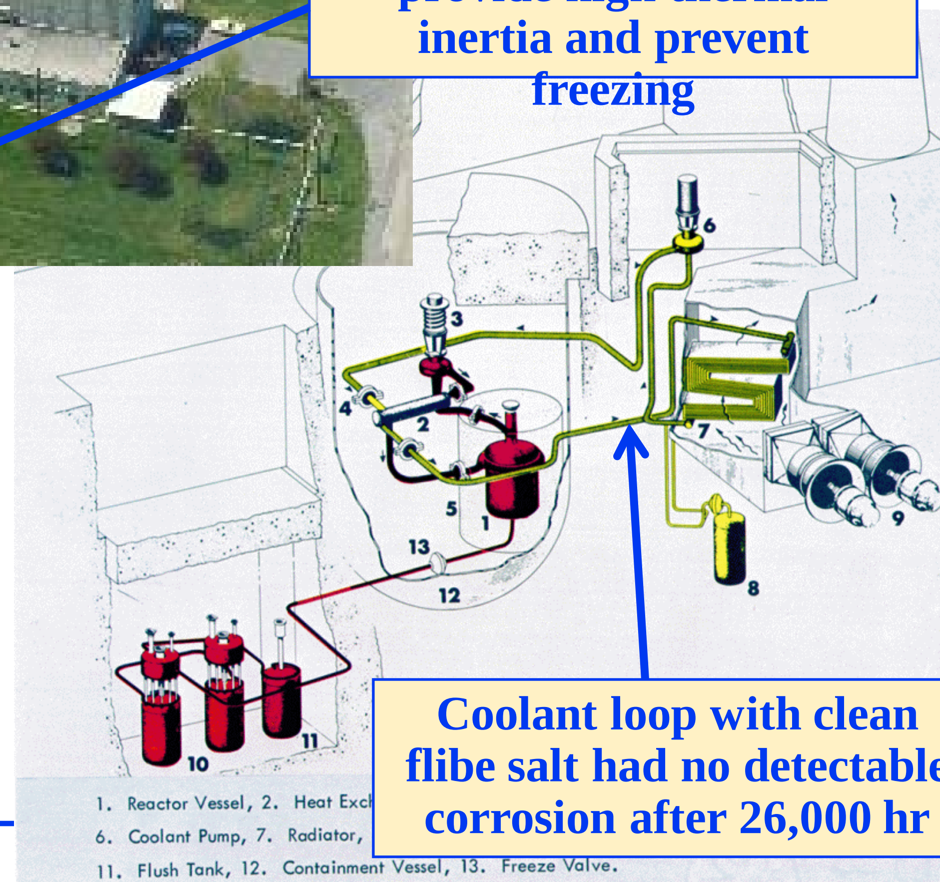
- Ceramic TRISO fuel
  - Over 500° C temperature margin to fuel failure under transients and accidents
  - Immersion in chemically inert coolant with high fission product sorption capacity makes air/steam ingress impossible
  - Negative coolant void/temperature reactivity feedback
  - Passive natural-circulation decay heat removal
- Reactor cavity acts as a low-pressure, low leakage containment
  - No stored energy sources to pressurize containment
  - Large thermal inertia of cavity provides long time constant to primary coolant freezing
- Reactor citadel acts as a filtered confinement
- External event shell and turbine hall provide additional hold up



The 8-MWth MSRE (1965-69) provided experience relevant to the development of a FHR Test Reactor



Reactor cavity acted as an insulated furnace to provide high thermal inertia and prevent freezing



Coolant loop with clean flibe salt had no detectable corrosion after 26,000 hr

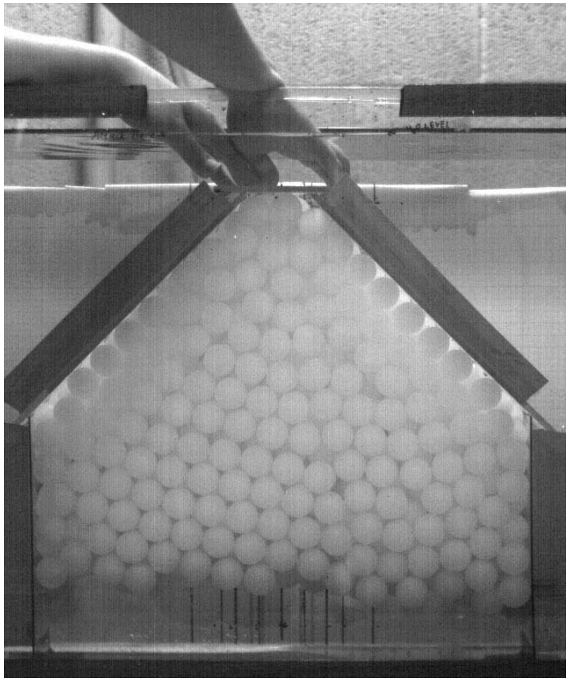
MSRE Systems and Components Performance, Oak Ridge National Laboratory, ORNL-TM- 3039, June 1973.

Pebble Fuels for FHRs

- **Pebble fuels and online refueling provide potential benefits**
  - **High power density possible (20 to 30 MW/m^3)**
  - **Rapid fuel depletion (< 1 year for seed pebbles)**
  - **Operation with low excess reactivity**

- **UC Berkeley has performed experimental and modeling studies to confirm viability of pebble fuel circulation**

PREX-0 provided proof-of-principal for buoyant pebble de-fueling in a 2-D geometry



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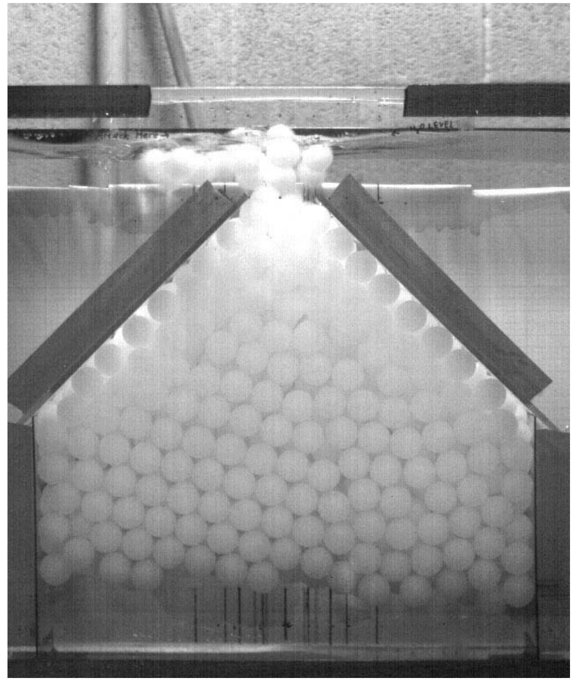

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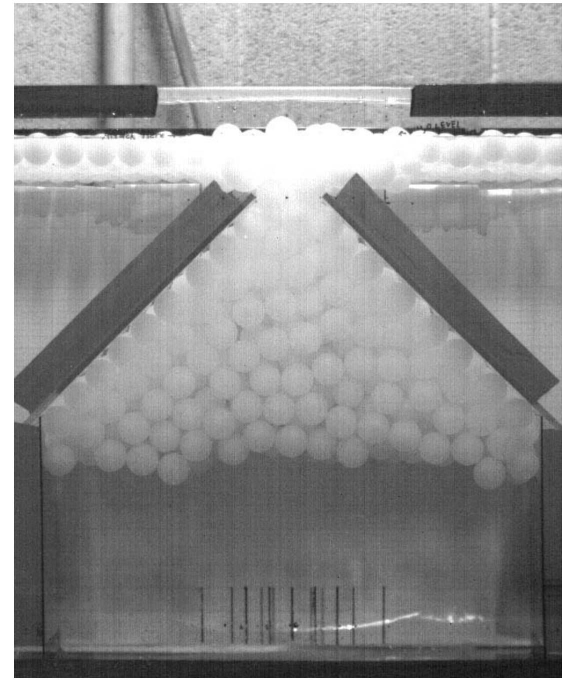

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High density polyethylene spheres (a standard commercial product) have same density ratio with water as fuel pebbles with salt

PREX-1 Construction Nears Completion (8/06)

Pebble Injection Standpipe

Outlet Plenum Drain Lines

Cold Leg Inlet Flow

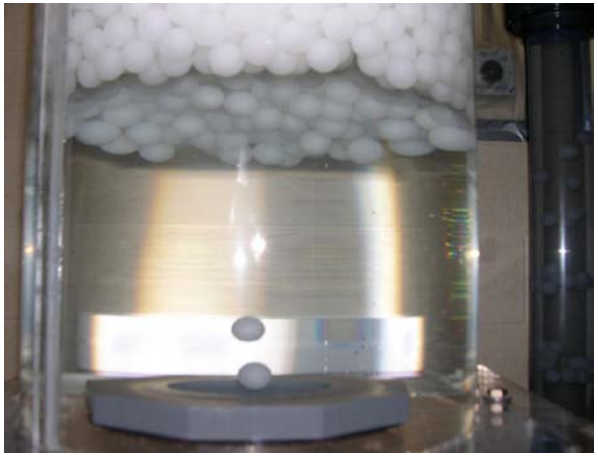
PREX Vessel

Proof-of-Principle for Pebble Injection (Note injected pebbles rising in vessel)

PREX-1 initial operation (10/06)

PREX-1

Manual Defueling

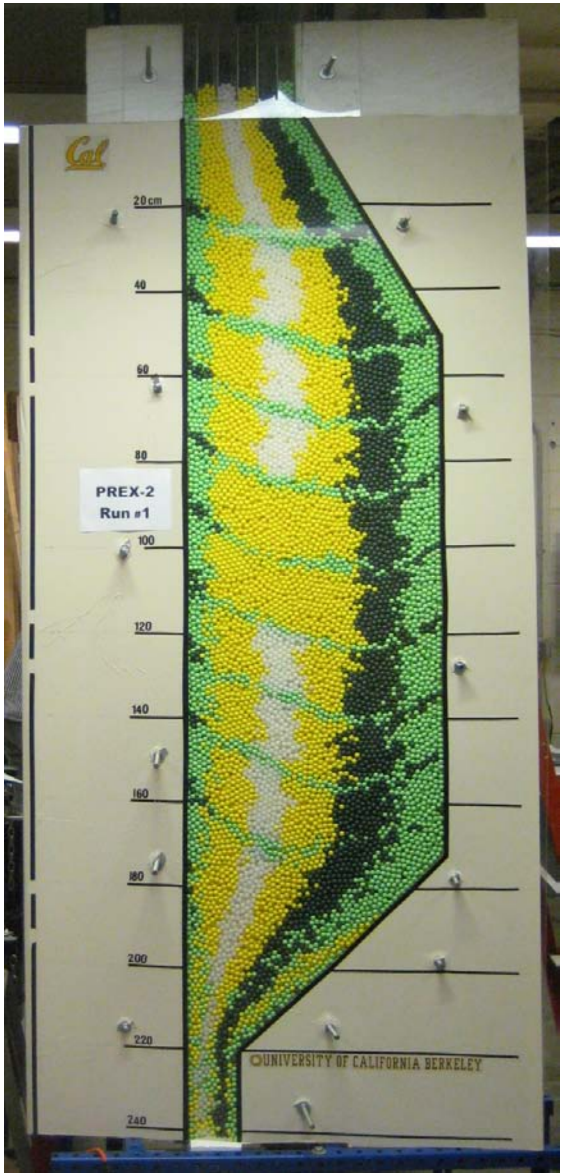


Pebbles Entering

Pebble Injection
Into Cold Leg

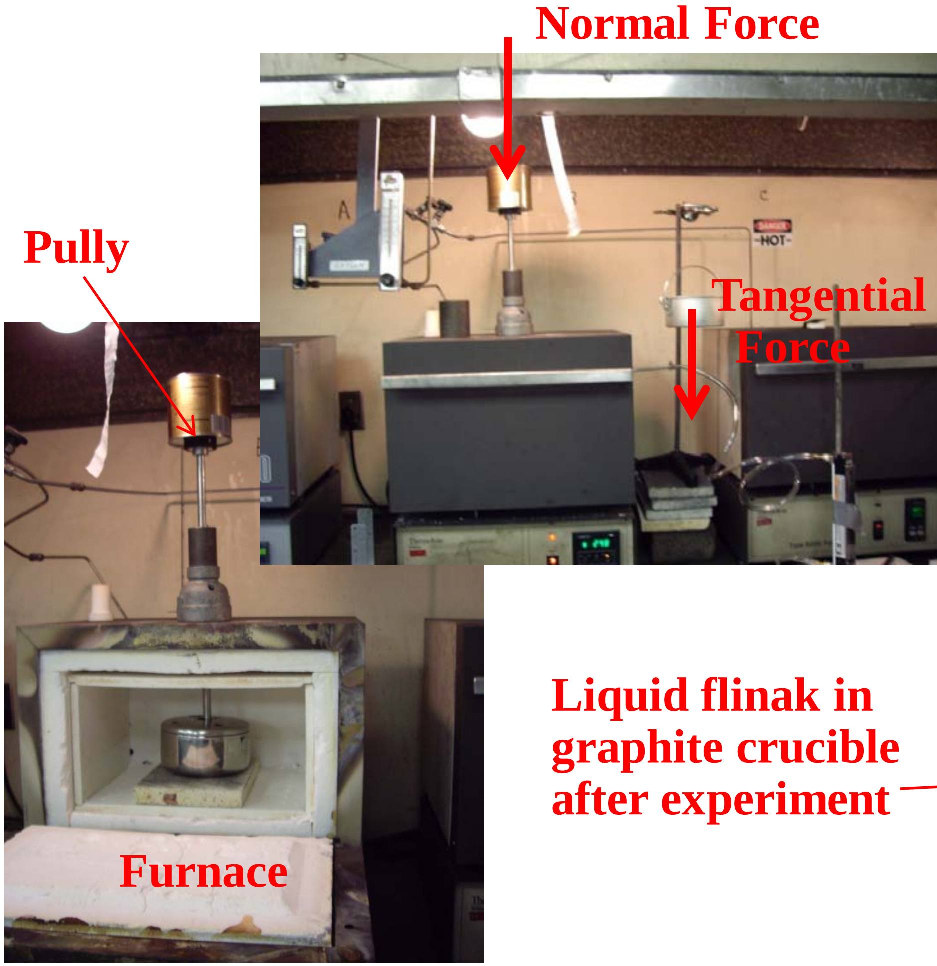
The current baseline UCB PB-AHTR uses a radially-zoned, annular seed/blanket core configuration

- **The PREX-2 experiments have demonstrated the generation of a radially and axially zoned pebble cores**
- **Benefits:**
  - **Effective neutron shielding of outer radial reflector**
  - **Greatly reduced core pressure drop (using a combination of axial and radial flow)**
  - **Zoning allows use of thorium blanket pebbles**
    - **External Pa-233 decay storage**
    - **Closed and once-through seed-blanket fuel cycles being studied**



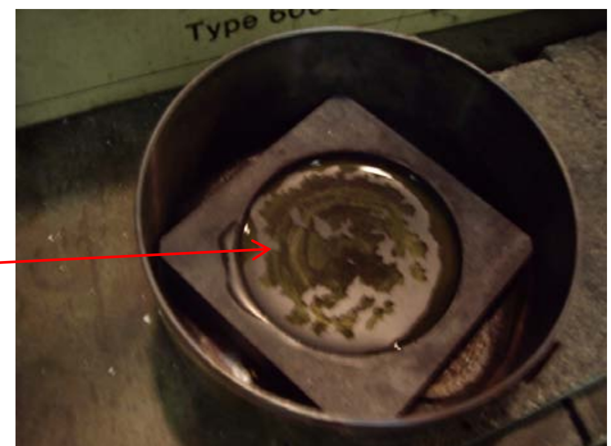
PREX-2

Friction experiments have shown that fluoride salts provide effective lubrication for graphite pebbles



1.5-cm radius graphite hemispheres

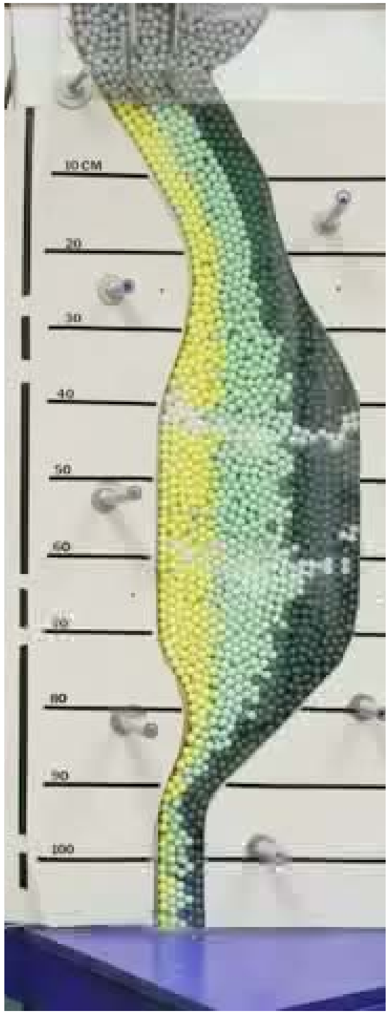
Liquid flinak in graphite crucible after experiment

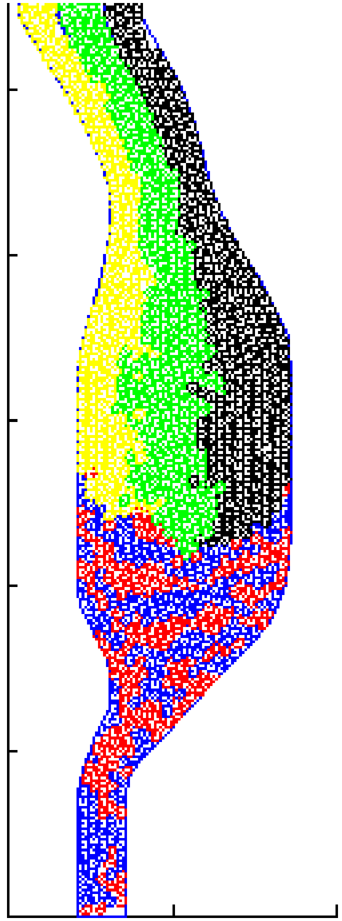


Friction coefficient measurement with flinak (simulant for flibe)

Credit: Patrick Purcell, 2009 NE 170 senior design class; thank you to UW Madison for flinak

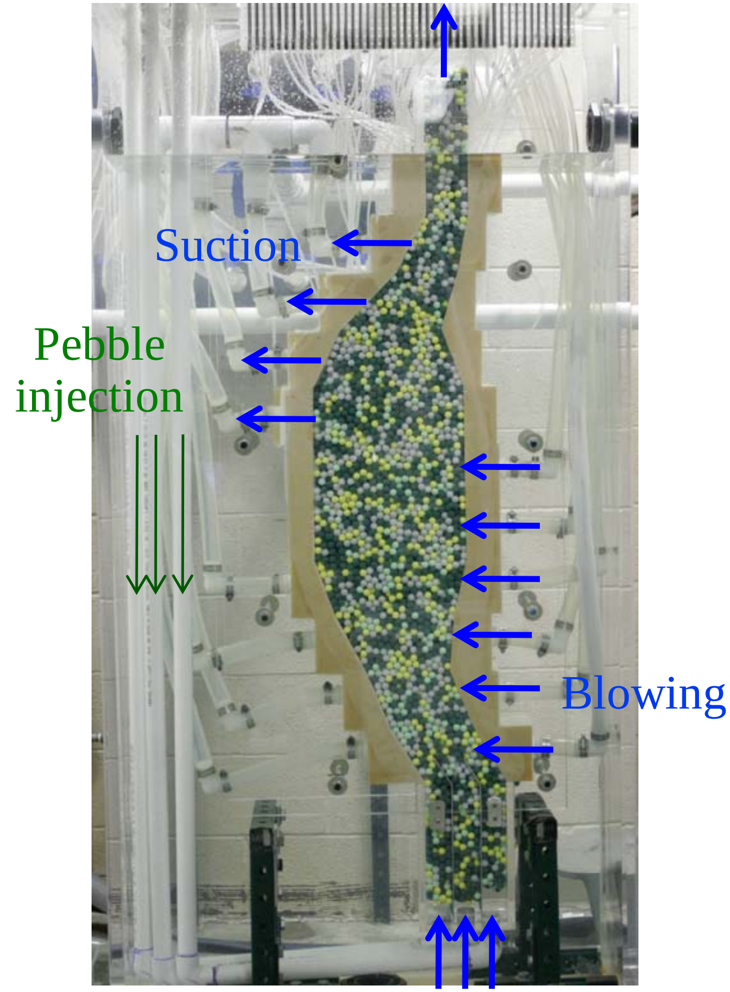
PREX 3.0





Dry experimental/simulation demonstration for radially-zoned pebble motion

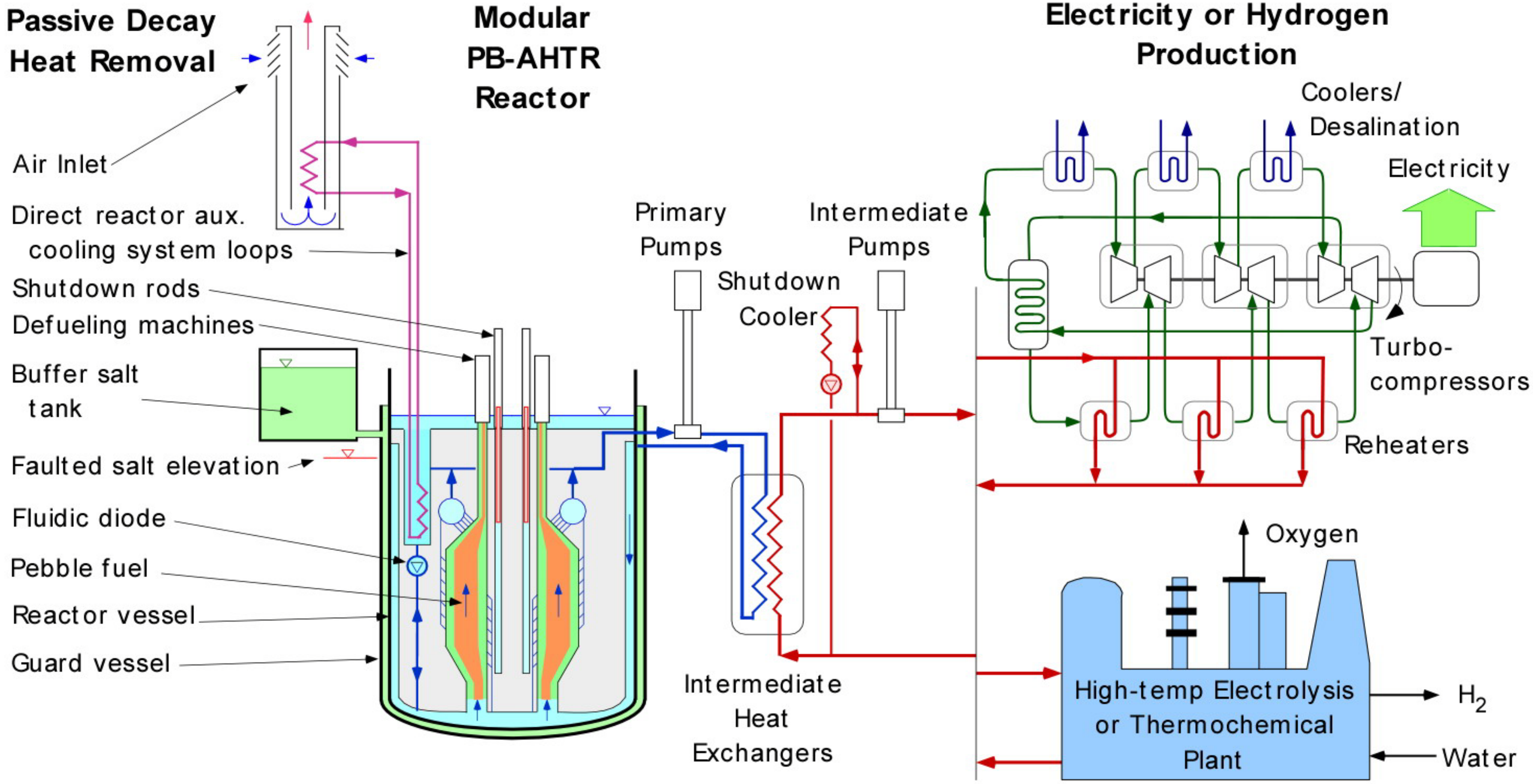
PREX 3.1



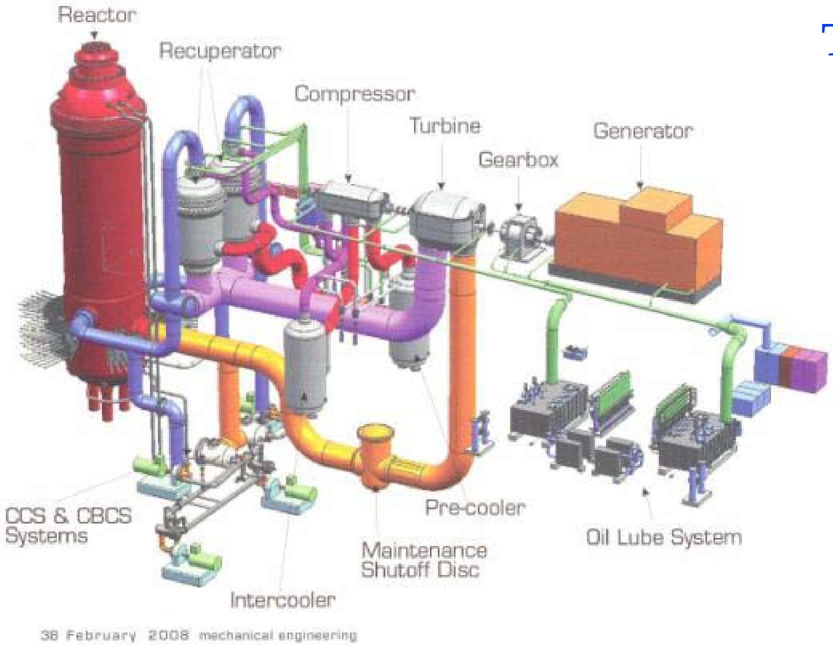
Wet experiment under construction

UCB Modular 410-MWe PB-AHTR Design Overview

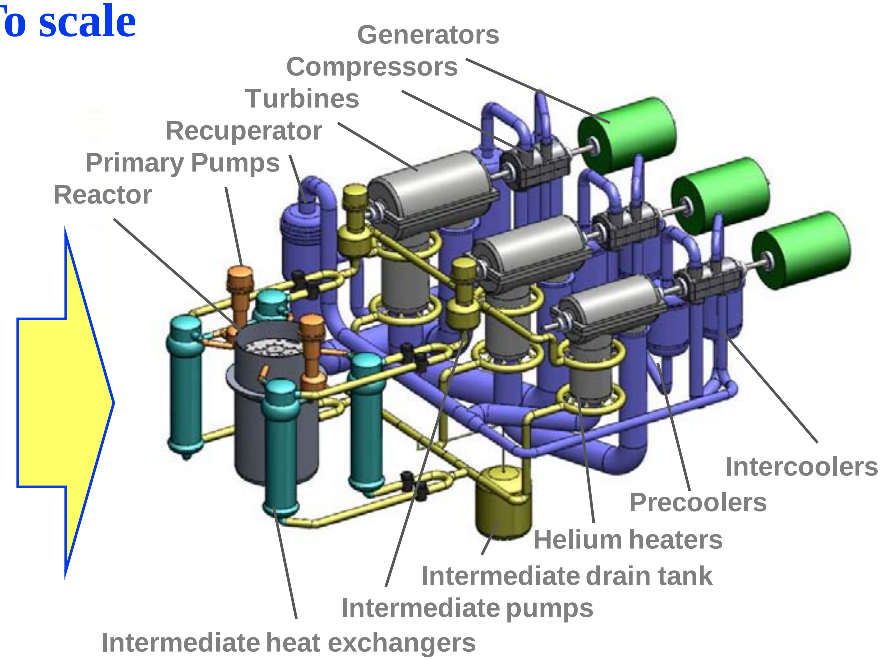
The modular PB-AHTR is a compact pool-type reactor with passive decay heat removal



The PB-AHTR power conversion system design is derived from the PBMR/Mitsubishi design



To scale

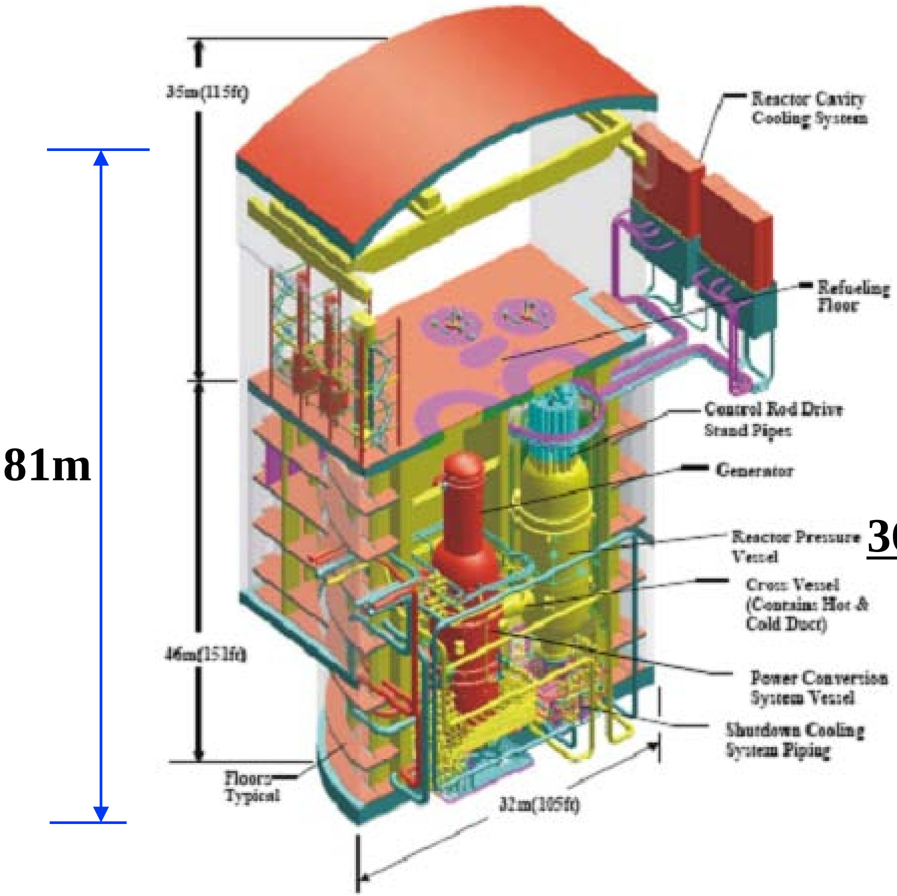


168-MWe PBMR/Mitsubishi helium cooled HTR

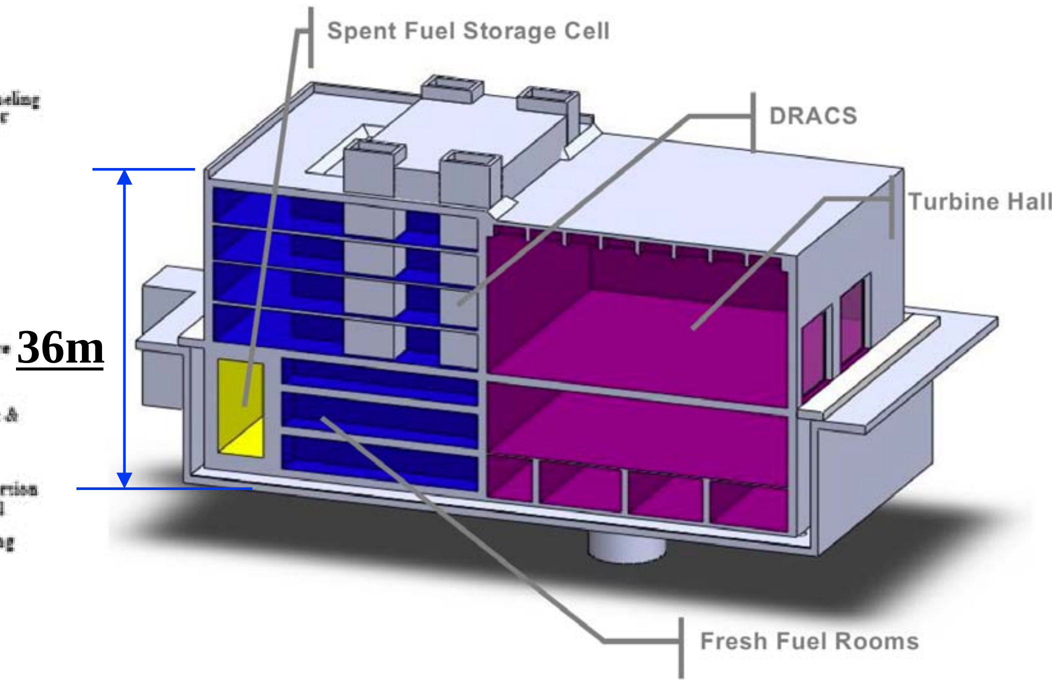
410-MWe PB-AHTR liquid cooled HTR

Trade study needed for multi-reheat helium Brayton vs. combined cycle vs. supercritical-CO_2

GT-MHR and PB-AHTR reactor buildings (to scale)



GT-MHR reactor building (287MWe)



PB-AHTR reactor/turbine building (410 MWe)

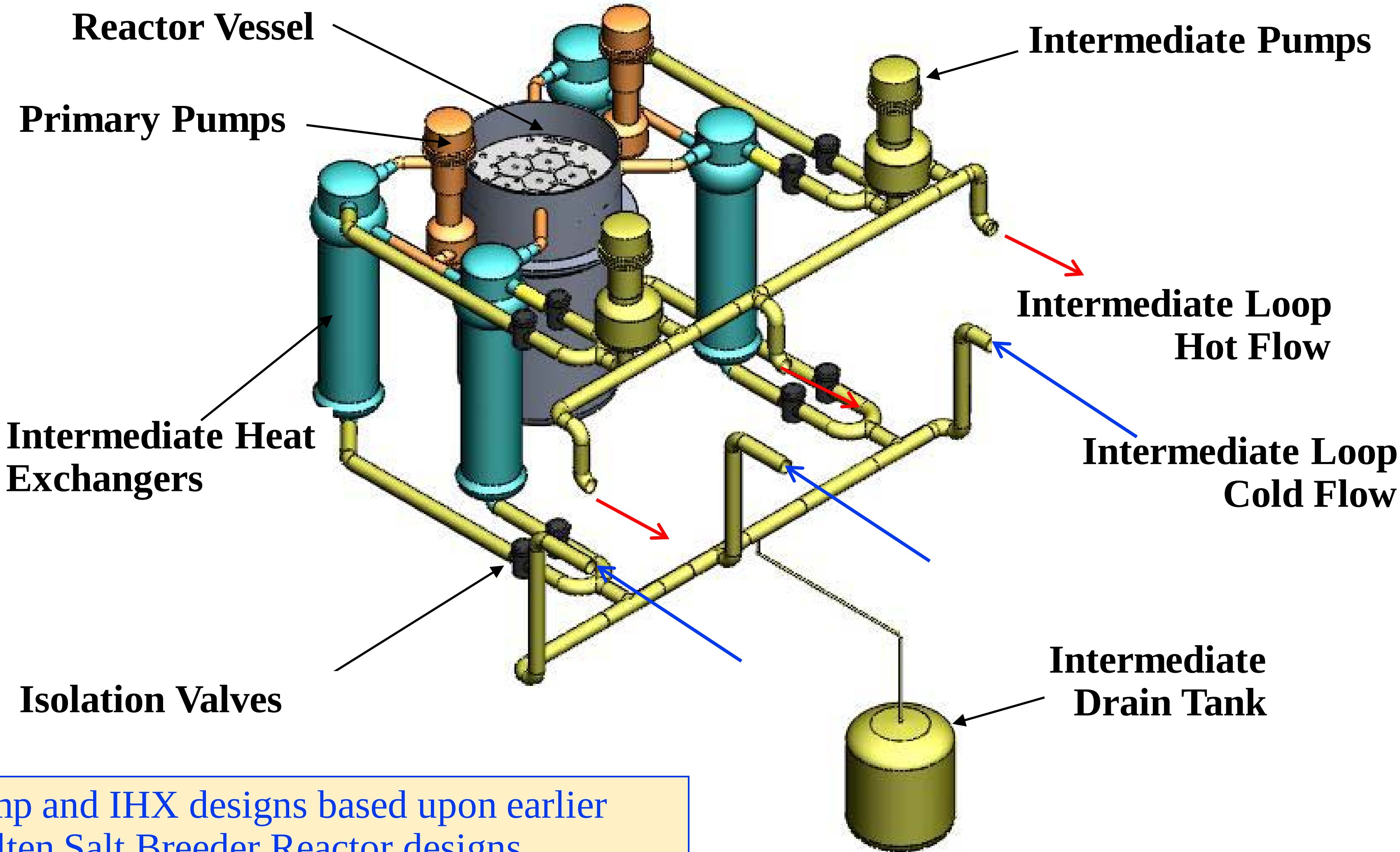
Typical LWR and SFR buildings are ~75m high

The current Modular PB-AHTR plant design is compact compared to LWRs and MHRs

Reactor Type	Reactor Power (MWe)	Reactor and Auxiliaries Volume (m^3/MWe)	Turbine Building Volume (m^3/MWe)	Ancillary Structures Volume (m^3/MWe)	Total Building Volume (m^3/MWe)
1970Õs PWR	1000	129	161	46	336
ABWR	1380	211	252	23	486
ESBWR	1550	132	166	45	343
EPR	1600	228	107	87	422
GT-MHR	286	388	0	24	412
PBMR	170	1015	0	270	1285
Modular PB-AHTR	410	105	115	40	**260**

The ESBWR power and reactor building volume are updated values based on the Design Certification application arrangement drawings.

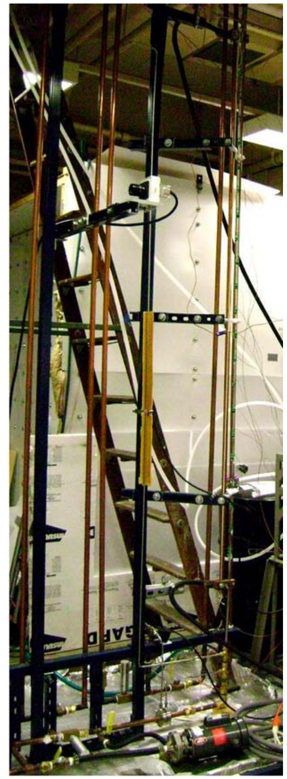
The Modular PB-AHTR primary and intermediate loops facilitate natural circulation shutdown cooling



Pump and IHX designs based upon earlier Molten Salt Breeder Reactor designs

Examples of UCB thermal hydraulics test facilities

PREX-1
Pebble recirculation IET
Match Re, Fr, pebble/salt density ratio w/ water

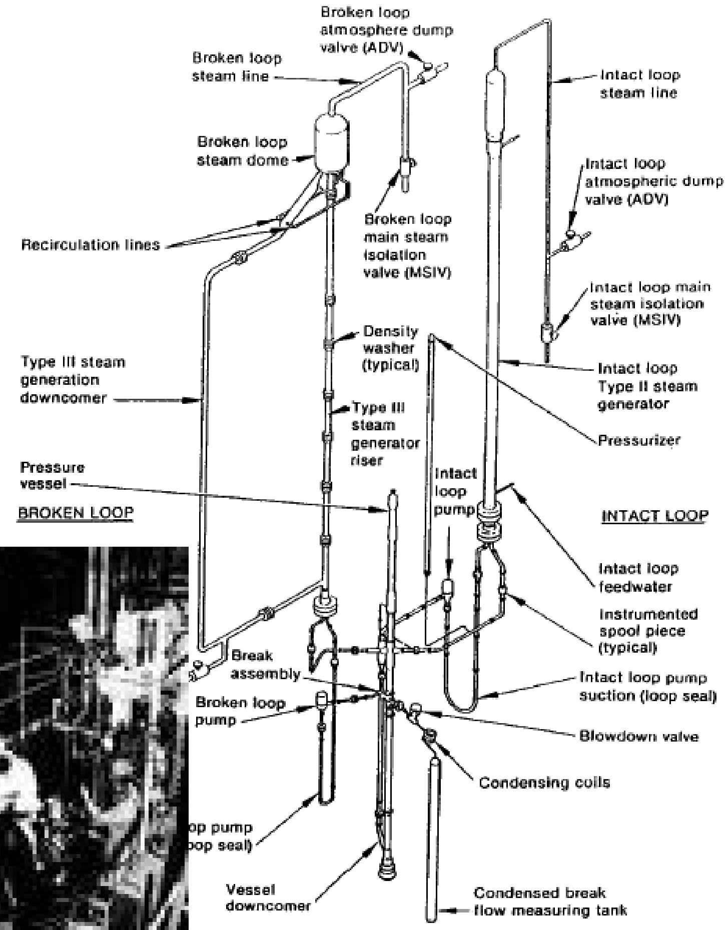


S-HT^2
Salt heat transfer SET
Match Re, Fr, Pr, Gr w/ Dowtherm A

PRISM
Passive shutdown rod IET
Match Re, Fr, rod/salt density ratio w/ sugar water

The new UCB Compact Integral Effects Test (CIET) facility can be compared to the INL Semiscale facility

- **Semiscale simulation of PWR LOCA**
  - **1:1 height**
  - **1:1705 flow area**
  - **1:1705 power (2 MW)**
  - **1:1 time**
  - **prototype temperature / pressure**
- **CIET simulation of the PB-AHTR LOFC/ATWS**
  - **1:1 effective height (1:2 actual)**
  - **1:190 effective flow area (1:756 actual)**
  - **1:190 effective power (1:9000 actual, 100 kW)**
  - **1:(2)$^{1/2}$ time**
  - **reduced temperature / pressure**
  - **reduced heat loss**
  - **small distortion from thermal radiation**



re 2.2.1 Semiscale Mod-2C. (From Ref. 2.2.2.)

Semiscale, INL

UC Berkeley

See http://users.owt.com/smsrpm/nksafe/testfac.html for a list of other LWR IET's

Selected key activities needed for FHR development

- **Separate effect and integral effect tests (SET/IET) with prototypical and simulant fluids to validate safety models**
  - **Can use existing LWR safety codes (RELAP/TRACE) with minor modifications**
  - **Room-temperature simulant fluid experiments for AHTRs are easy/inexpensive compared to conventional SET/IET experiments for ALWRs (e.g., Semiscale, APEX)**
- **Component testing and development of monitoring and maintenance methods in a liquid salt Component Test Facility (CTF)**
  - **Compact facility size relative to component test facilities for sodium/helium**
  - **Leverage NGNP materials development**
- **Fuel fabrication, irradiation, and post-irradiation examination using the existing NGNP infrastructure**
  - **Accelerated qualification possible due to rapid fuel burn up**
  - **Leverage NGNP fuel fabrication and test capability**

- **Design, licensing, construction, and operation of an MSRE-sized test reactor**
  - **MSRE design and operating experience reduce development risk**