Pre-Conceptual Hydrogen Production Modular Helium Reactor Designs

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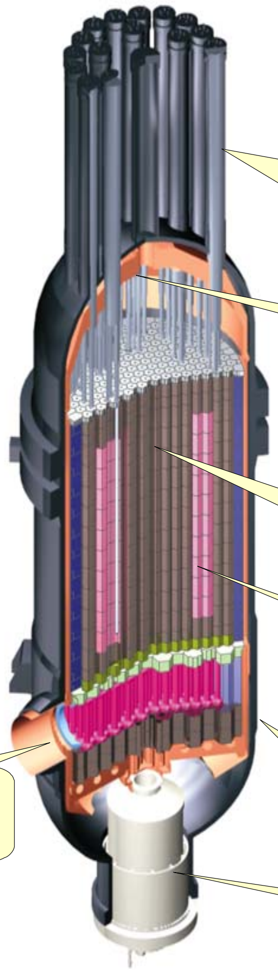
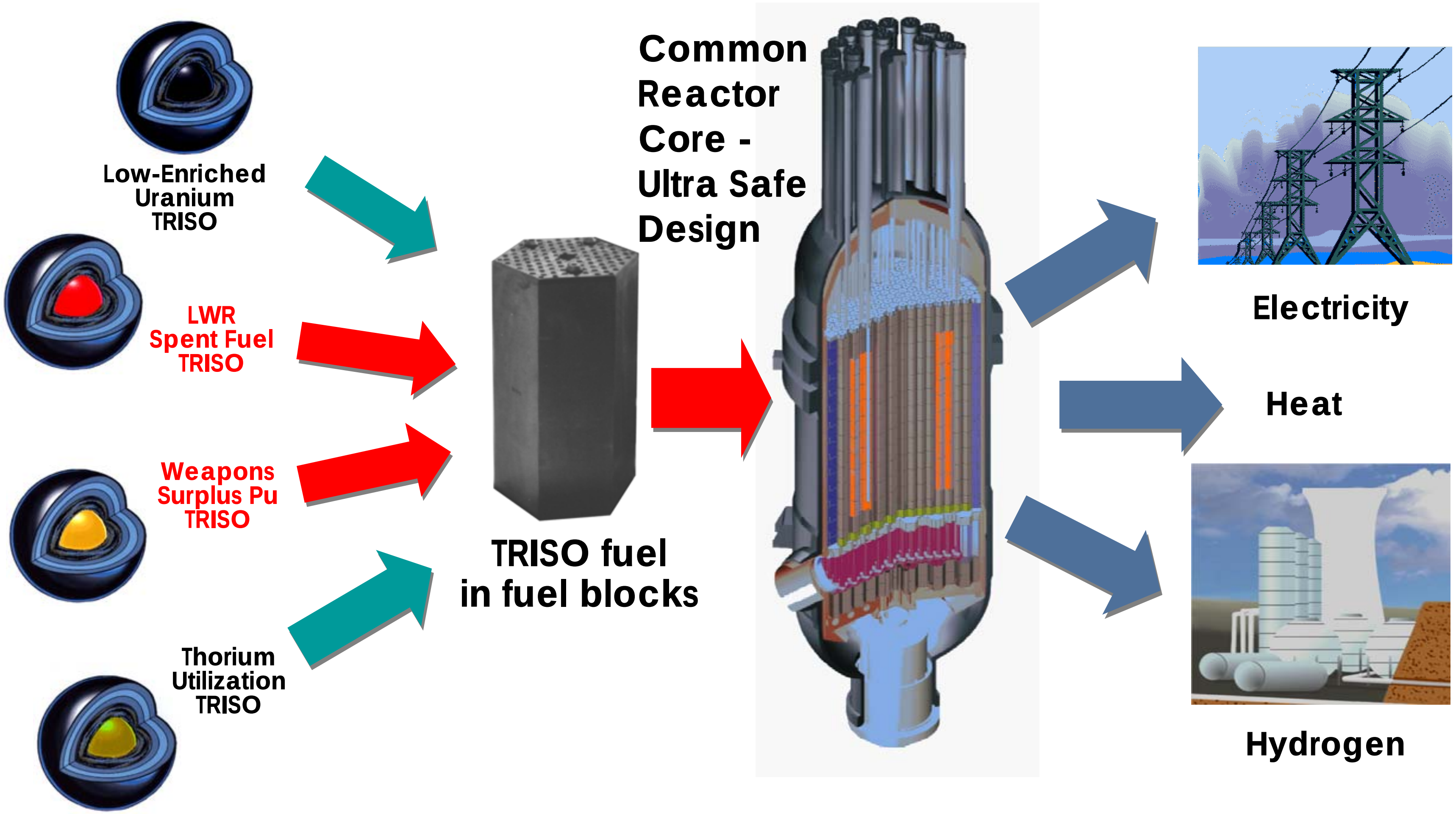
MHR Design Features Are Well Suited for Significant Expansion of Nuclear Energy

- **Passive Safety**
  - No active safety systems required
  - No evacuation plans required
- **Competitive Economics**
- **High Thermal Efficiency**
- **Siting Flexibility**
  - Lower waste heat rejection, reduced water cooling requirements
- **High-Temperature Capability with Flexible Energy Outputs**
  - Electricity
  - Hydrogen
  - Synfuels, etc.
- **Flexible Fuel Cycles**
  - LEU, HEU, Pu, TRU, Thorium



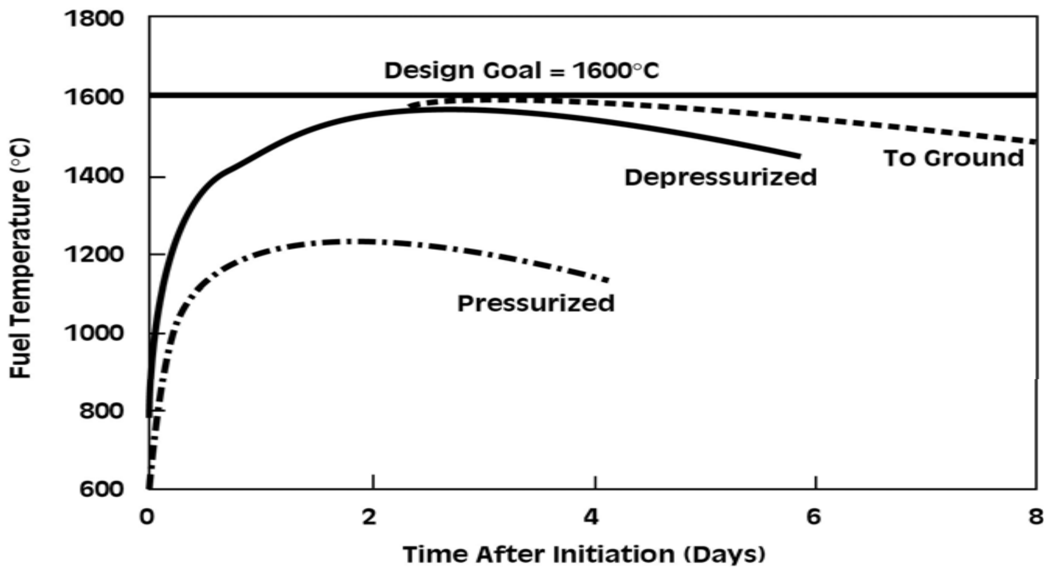
One Reactor Design Can Use Multiple Fuels for Multiple Applications

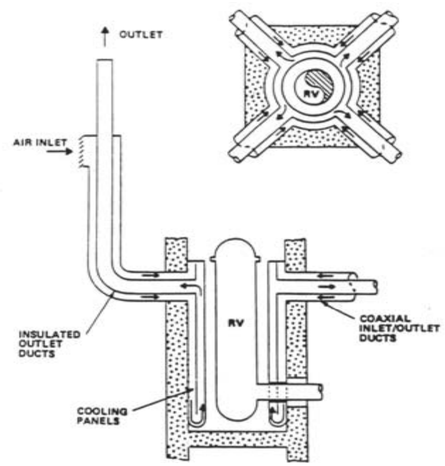


The MHR is a Passively Safe Design

Passive Safety Features

- **Ceramic, coated-particle fuel**
  - Maintains integrity during loss-of-coolant accident
- **Annular graphite core with high heat capacity**
  - Helps to limit temperature rise during loss-of-coolant accident
- **Low power density**
  - Helps to maintain acceptable temperatures during normal operation and accidents
- **Inert Helium Coolant**
  - Reduces circulating and plateout activity

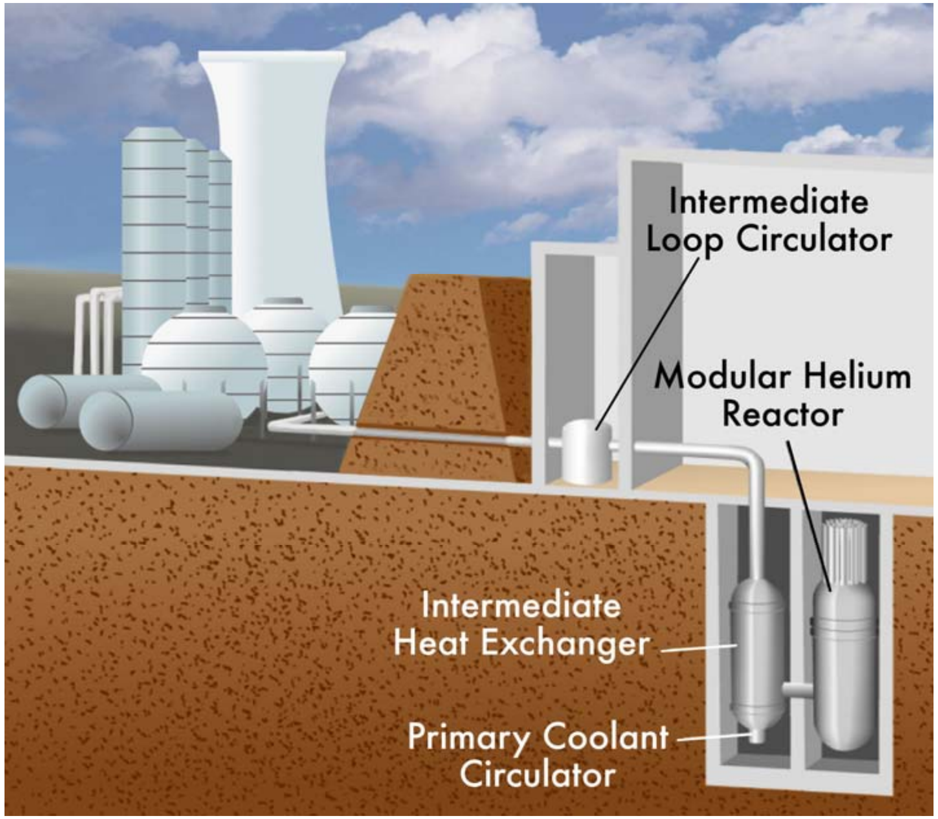




Passive Air-Cooled RCCS

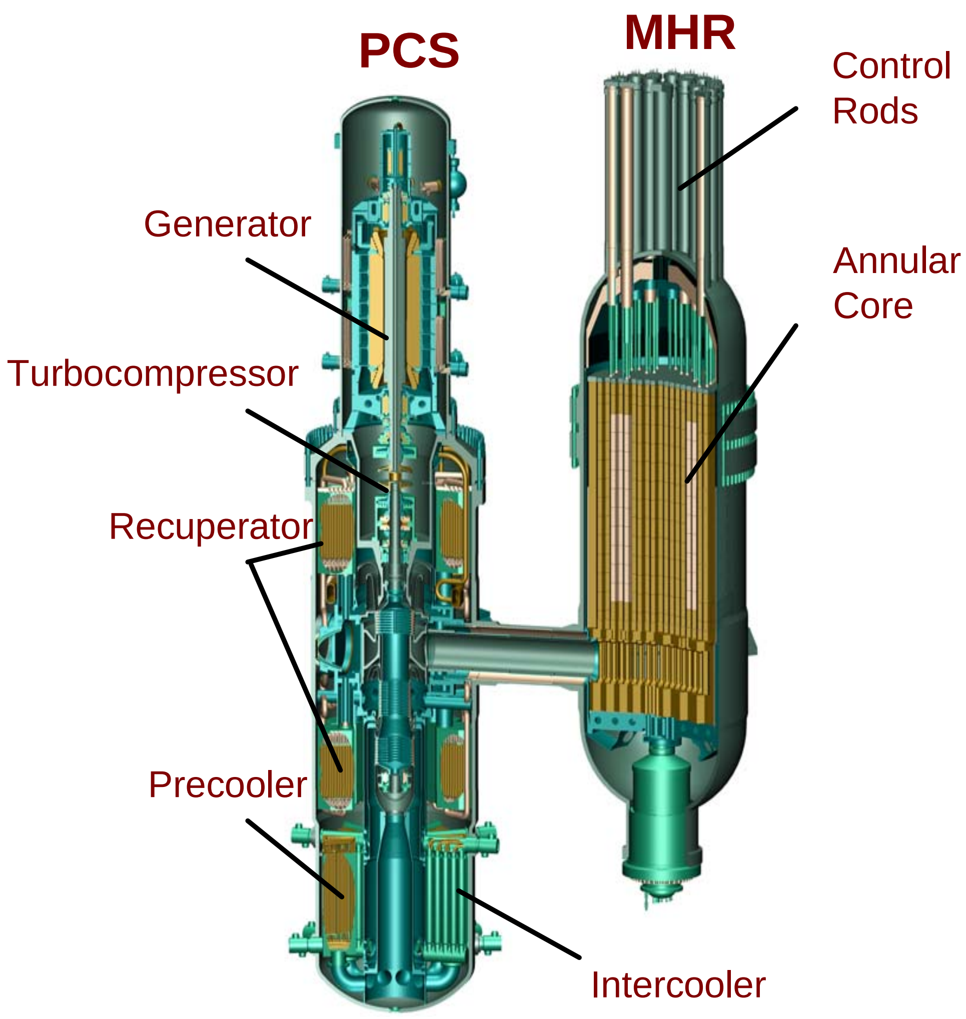
Hydrogen Plant Will Not Impact Passive Safety

- **Potential Licensing issue is co-location of MHR and Hydrogen Plant**
  - Passive safety of MHR allows co-location
  - Earthen berm provides defense-in-depth
- **Other reactors located in close proximity to hazardous chemical plants and transportation routes**
  - NRC allows risk-based approach
  - INL recommends 60 to 100 m separation distance
  - JAEA studies also support close separation distance



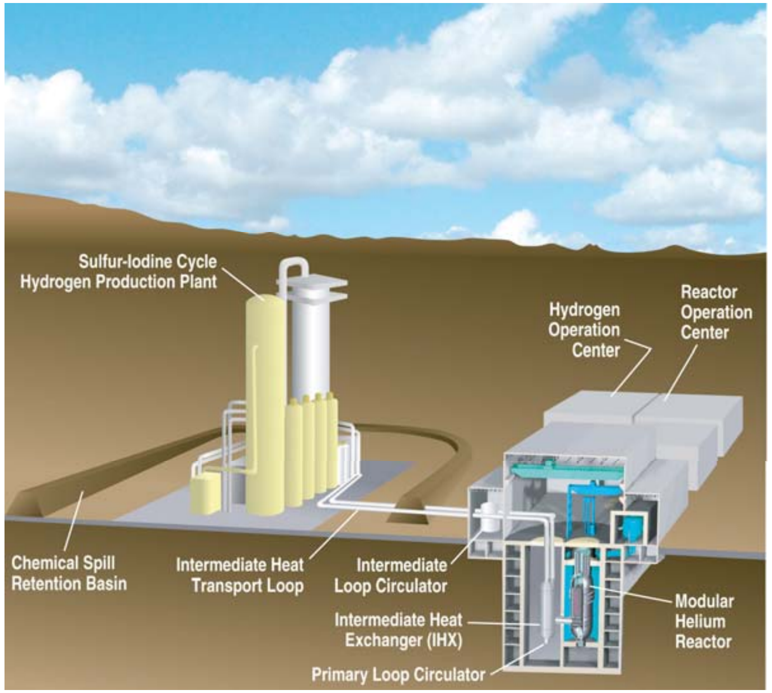
The GT-MHR Produces Electricity Economically with High Efficiency

- **MHR coupled to a direct-cycle Brayton power-conversion system**
- **600 MW(t), 102 column, annular core, prismatic blocks**
- **48% thermal efficiency with 850°C Outlet Temperature**
- **Installed capital costs of approximately $1000/kW(e)**
- **Busbar electricity generation costs of approximately 3.1 cents per kW(e)-h.**

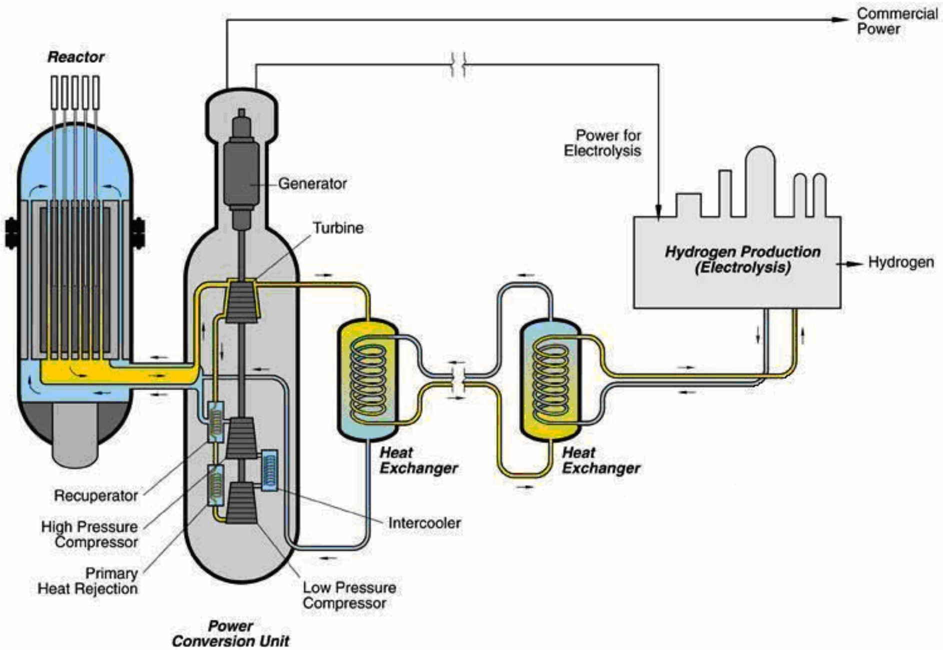


H2-MHR Can Produce Hydrogen with High Efficiency

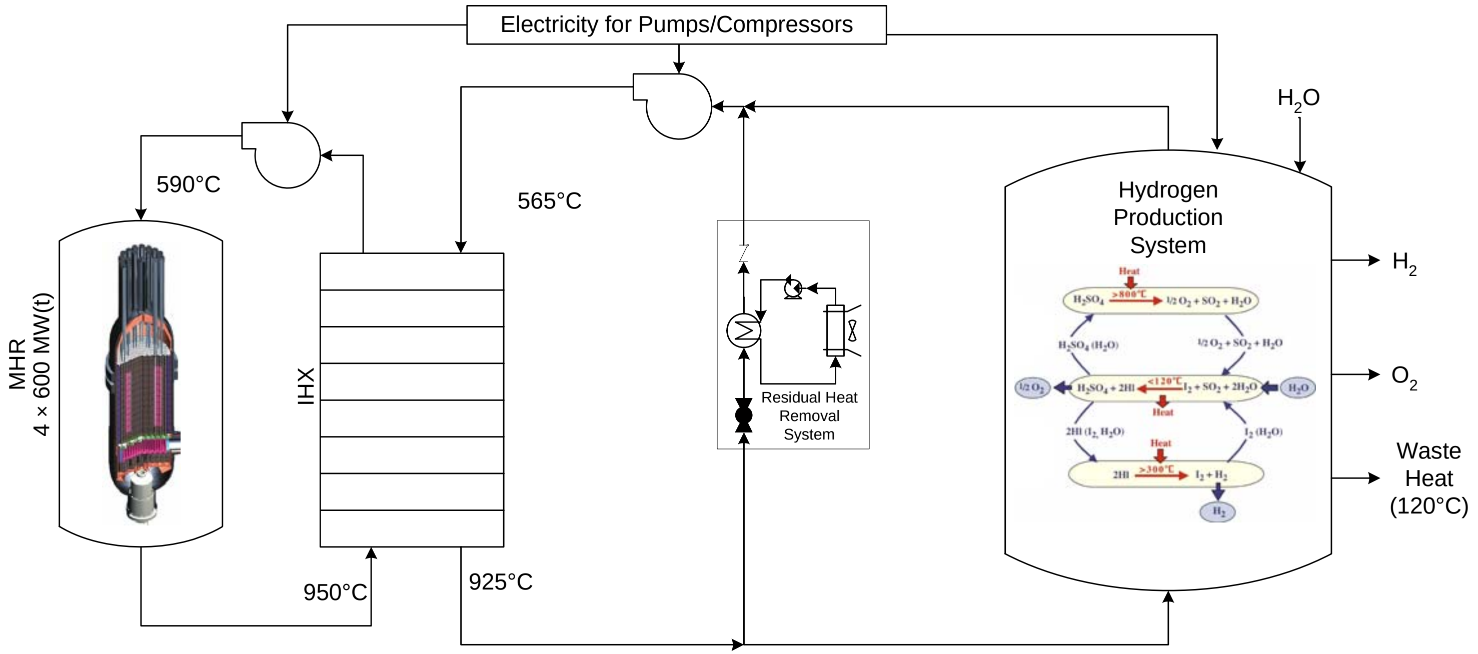
MHR Coupled to Thermochemical Water Splitting (Sulfur-Iodine Process)



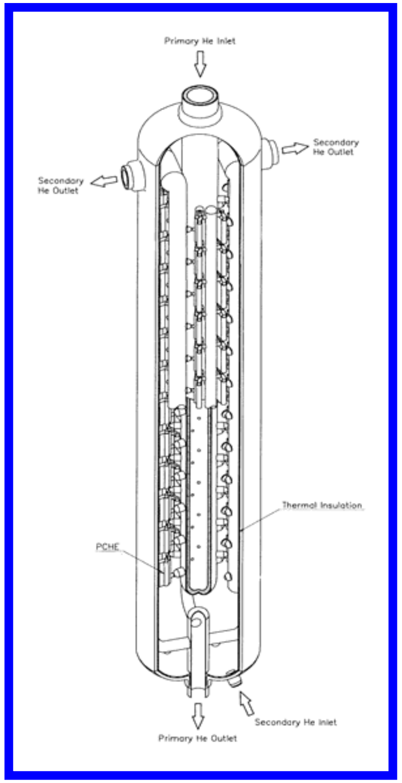
MHR Coupled to High-Temperature Electrolysis



SI-Based H2-MHR Uses IHX to Interface MHR with Hydrogen Production System



IHX Design Concept Using Heatric Modules
Height ~30 m
Diameter ~6 m

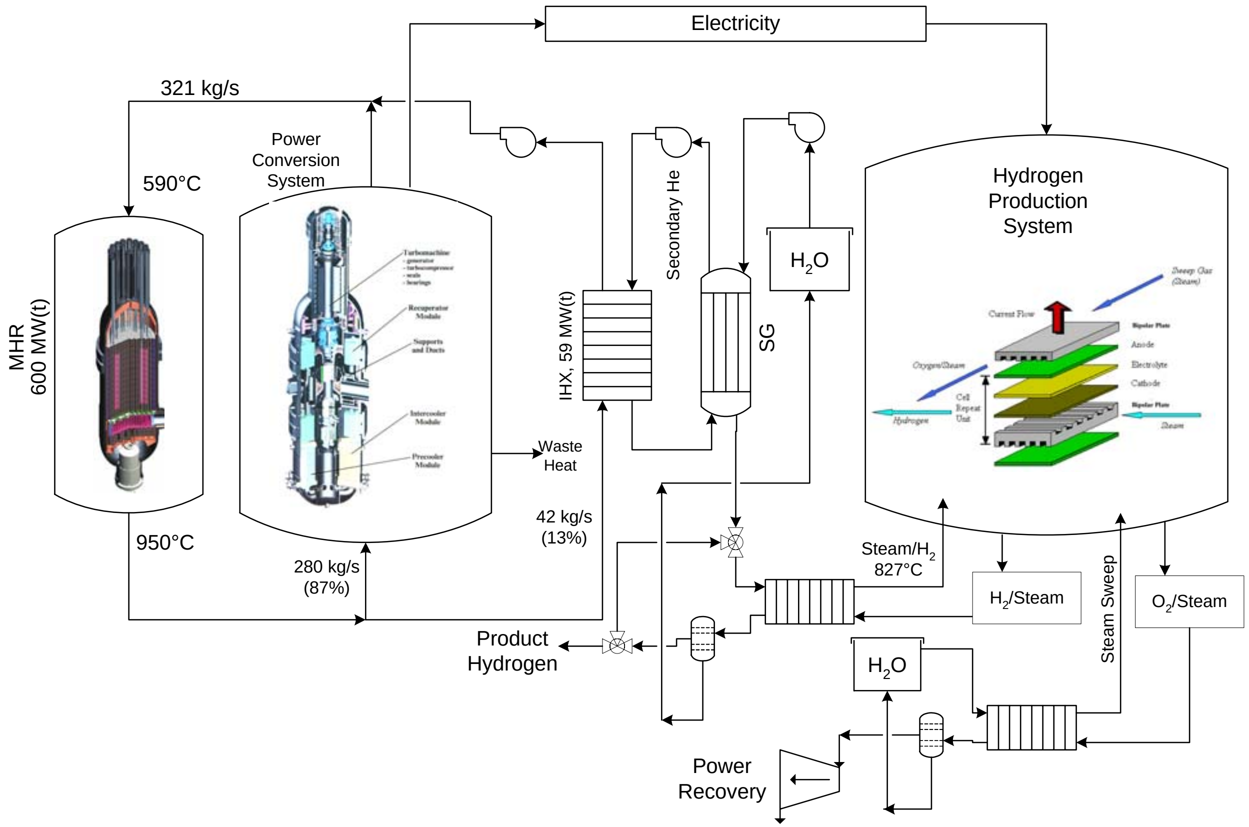


Annual H_2 Production (4-module plant): 3.68 x 10^5 metric tons

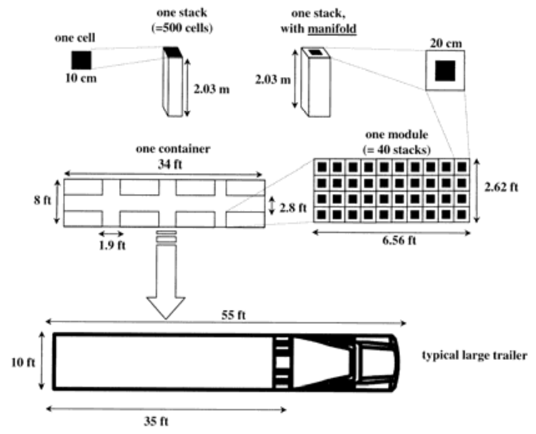
Hydrogen Production Efficiency: 45.0% (based on HHV of H_2)

Product H_2 Pressure: 4 MPa

HTE-Based H2-MHR Generates Both Electricity and High-Temperature Steam to Drive Solid-Oxide Electrolyzer Modules



SOE Module Concept
4 MW(e) per Trailer



Annual H_2 Production (4-module plant): 2.68 x 10^5 metric tons

Hydrogen Production Efficiency: 55.8% (based on HHV of H_2)

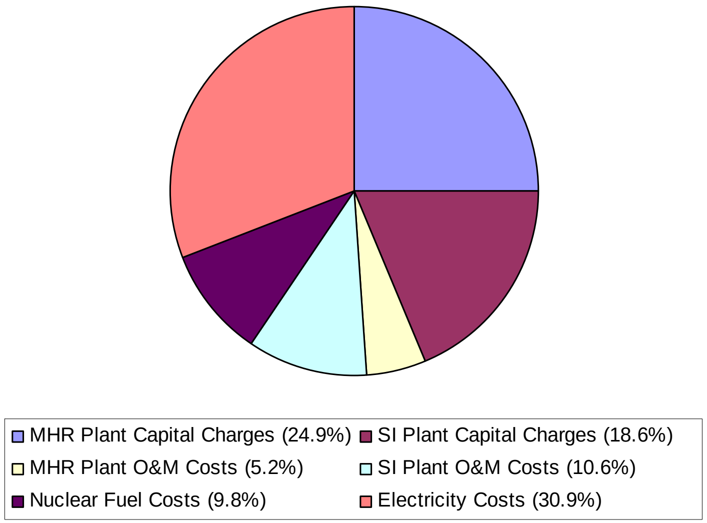
Product H_2 Pressure: 4.95 MPa

Toshiba developing tubular-cell concept as part of NGNP USIT Team.

N^{th}-of-a-Kind Hydrogen Production Costs are Approximately $2/kg for both SI-Based and HTE-Based Plants

SI-Based Plant

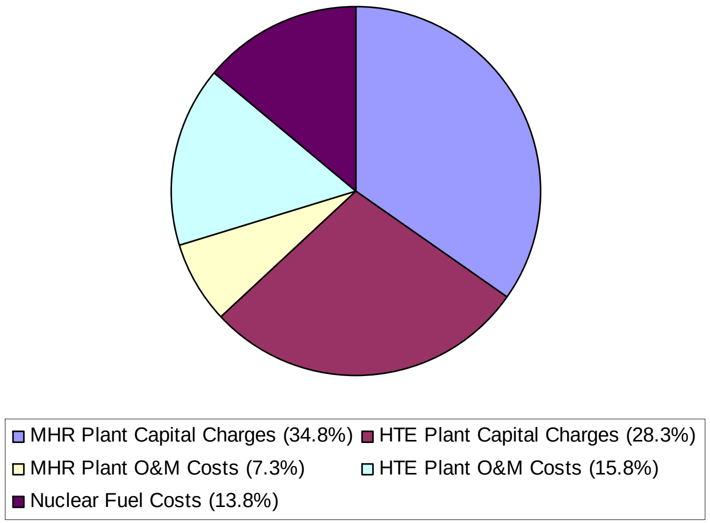
Total Hydrogen Production Cost = $1.97/kg



Electricity costs result mostly from pumping process fluids in the hydrogen plant (not from pumping helium). Efforts are being made to optimize the flow sheets to reduce pumping requirements.

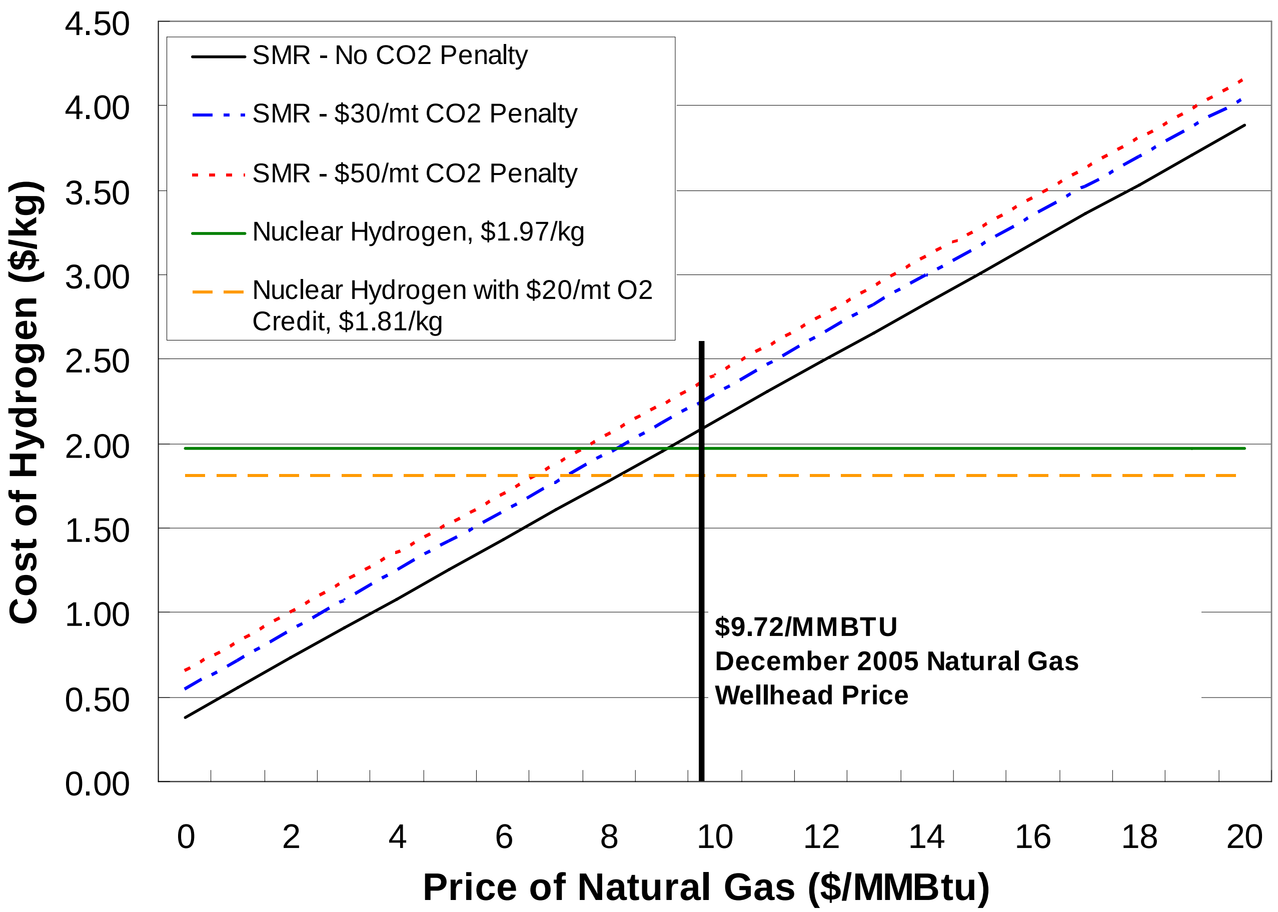
HTE-Based Plant

Total Hydrogen Production Cost = $1.92/kg



SOE module unit costs assumed to be $500/kW(e). If module unit costs are increased to $1000/kW(e), hydrogen production cost increased to $2.52/kg.

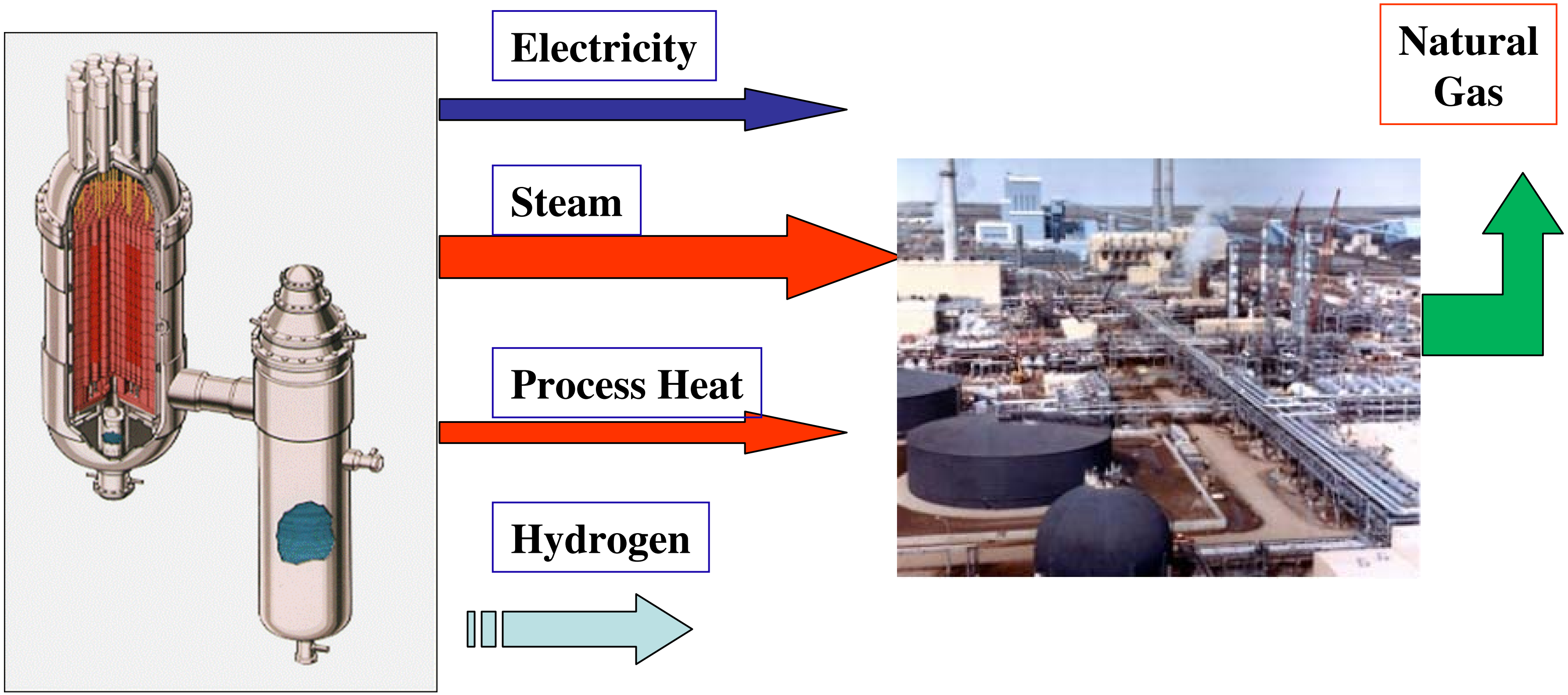
Nuclear Hydrogen Production Costs Compare Favorably with Steam-Methane Reforming



Economic comparisons are especially favorable if carbon dioxide penalties and oxygen credits are taken into account.

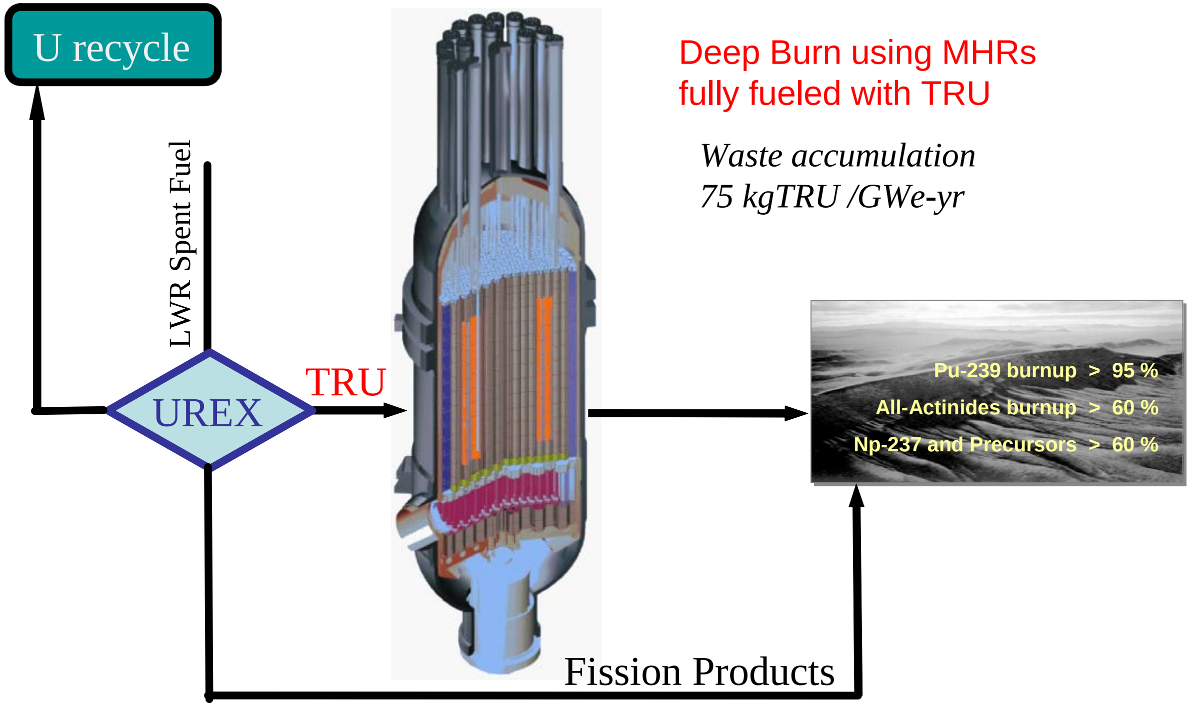
VHTR Can Provide a Wide Variety of Energy Outputs

Coal Gasification



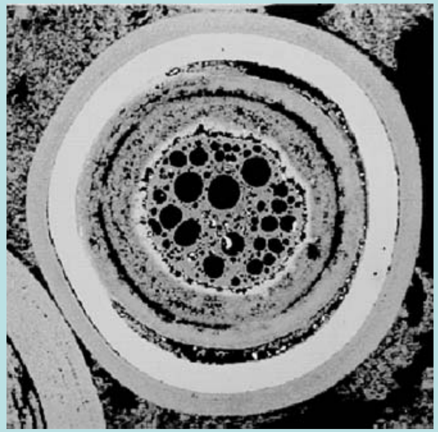
GT-MHRs and H2-MHRs Can Be Deployed with Advanced Fuel Cycles to Address Spent Fuel Management and Sustainability Issues

MHRs can be used to process legacy LWR spent fuel



Successful Deep-Burn Irradiation of Coated-Particle Pu-Fuel

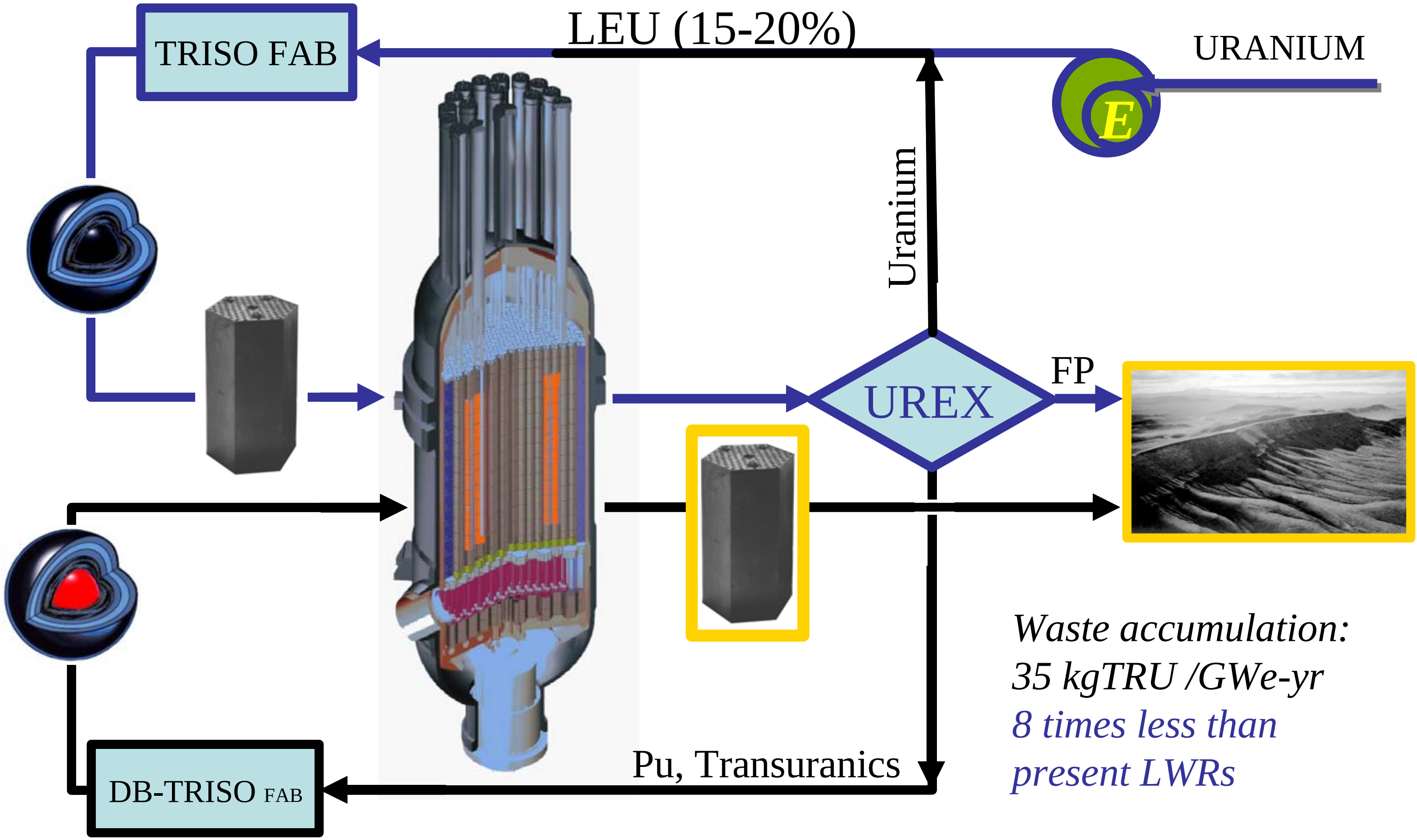
Pu Oxide ($PuO_{1.68}$)



747,000 MW-days/tonne
>95% ^{239}Pu Transmuted at Peach Bottom I

Residual radioactivity is contained by ceramic coatings over geologic time scales

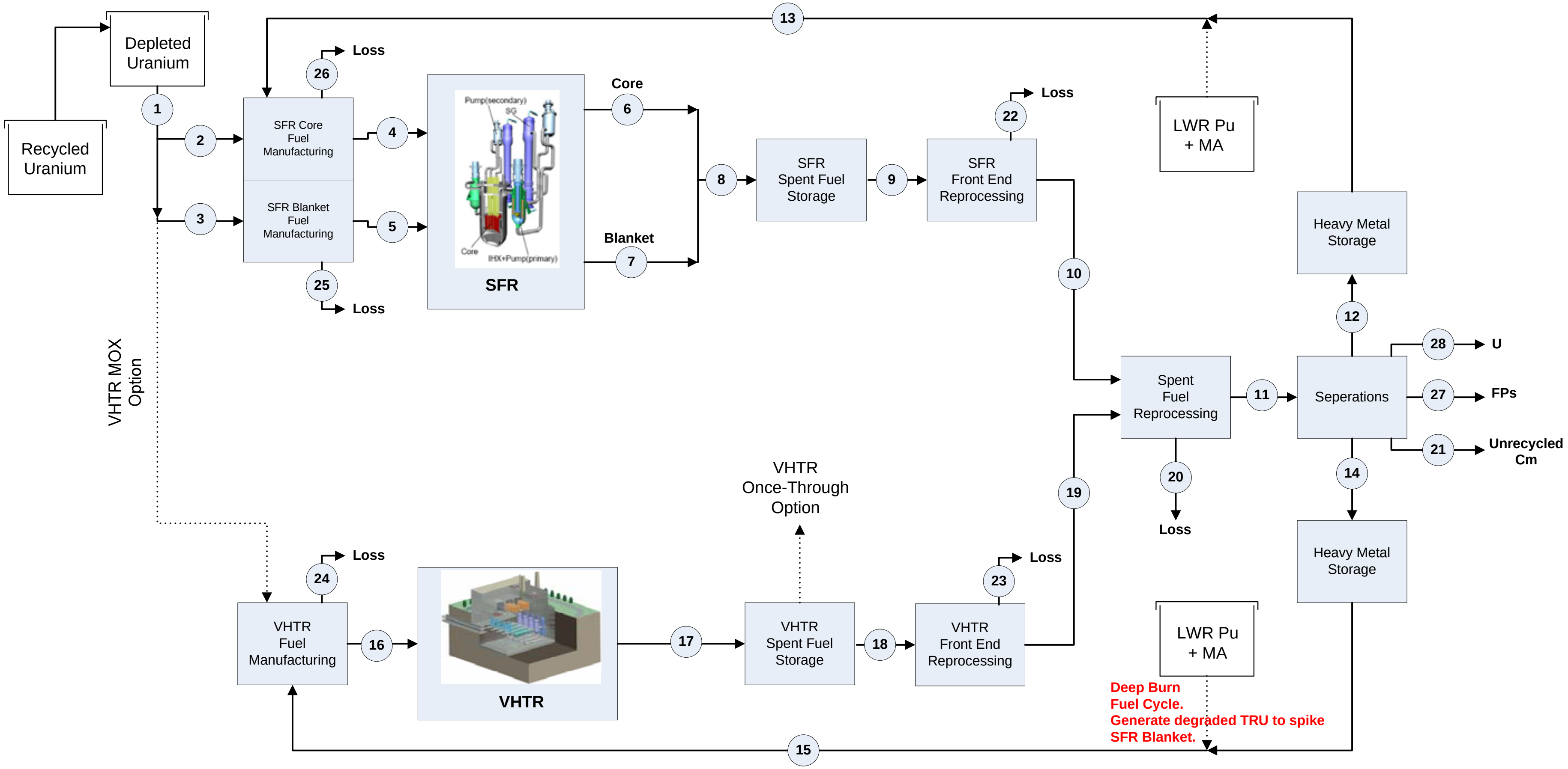
MHRs Can Be Deployed Using a Self-Cleaning Fuel Cycle to Relieve Repository Burdens



Waste accumulation:
35 kgTRU /GWe-yr
8 times less than present LWRs

Sustainability: 200 – 300 years in U.S.

FBR/VHTR System Deployment Provides Sustainability, Proliferation Resistance, and Energy Flexibility



Long-term sustainability for resource-deficient countries (e.g., Japan)

JAEA/GA jointly investigating FBR/VHTR deployment scenarios in Japan.

Conclusions

- **MHR design features make it an outstanding choice for future deployment of nuclear energy**
  - Passive safety
  - High-temperature capability
  - High thermal efficiency, flexible siting
  - Flexible fuel cycles and energy outputs
- **MHR deployment supports significant, sustainable expansion of nuclear energy**
  - Better utilization of repository space with greatly reduced requirements for recycle of nuclear fuel
  - Deployment in symbiosis with FBRs can provide virtually unlimited sustainability

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Thank you for your kind attention.

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