Modular Helium Reactors for Electricity and Hydrogen Production

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General Atomics

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GENERAL ATOMICS

Gen IV Reactors
Should Satisfy Several Criteria

- Safety & Security
  - Passive emergency heat removal
  - Meet safety and licensing criteria with no public evacuation/sheltering
  - Sabotage/terrorist resistance
- Proliferation
  - Diversion security
- Environmental
  - Total waste stream minimization
- Economics
  - Capital protection
  - Availability >90%
  - Competitive COE

. . .and, more recently, the capability for H_2 production

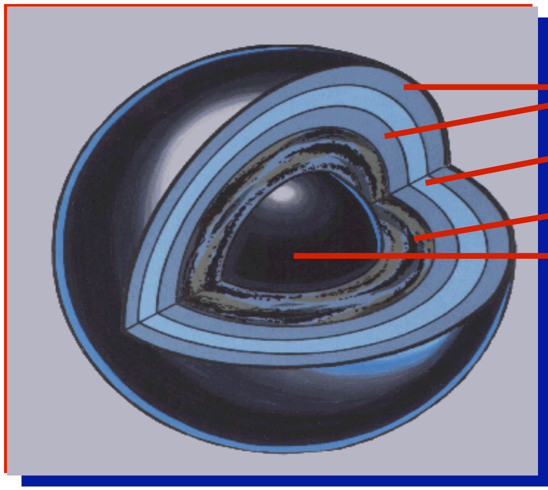
MHRs are Passively Safe By Design

- **Fission products retained in coated particles, with worst-case fuel temperature limited by design features**
  - **High temperature stability materials**
  - **Refractory coated fuel**
  - **Graphite moderator**
  - **Negative temperature coefficient**
  - **Low power density**
  - **High heat capacity**
- **Passive emergency heat removal**
  - **Core can shut down without active intervention**

… so they are meltdown proof

GENERAL ATOMICS

Ceramic Fuel Retains Its Integrity Under Severe Accident Conditions



Pyrolytic Carbon

Silicon Carbide

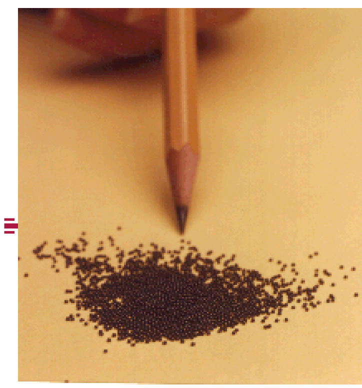
Porous Carbon Buffer

Uranium Oxycarbide

PBMR
<300 MW(t)

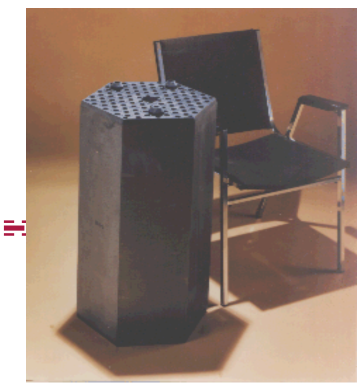
Prismatic
>300 MW(t)

TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).



PARTICLES

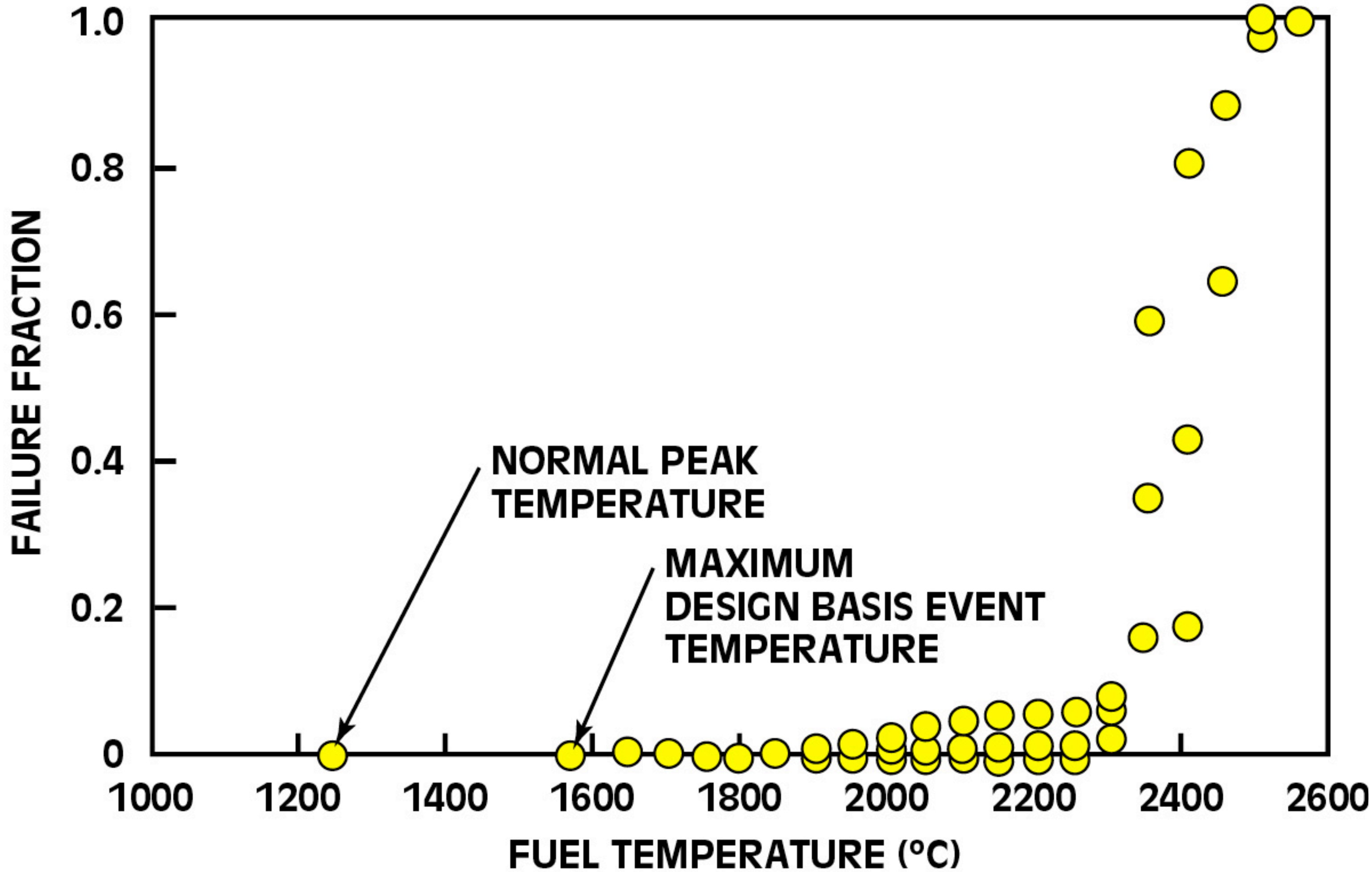
COMPACTS



FUEL ELEMENTS

GENERAL ATOMICS

Maximum Accident Temperatures Must Not Exceed Ceramic Fuel's Stable Limit



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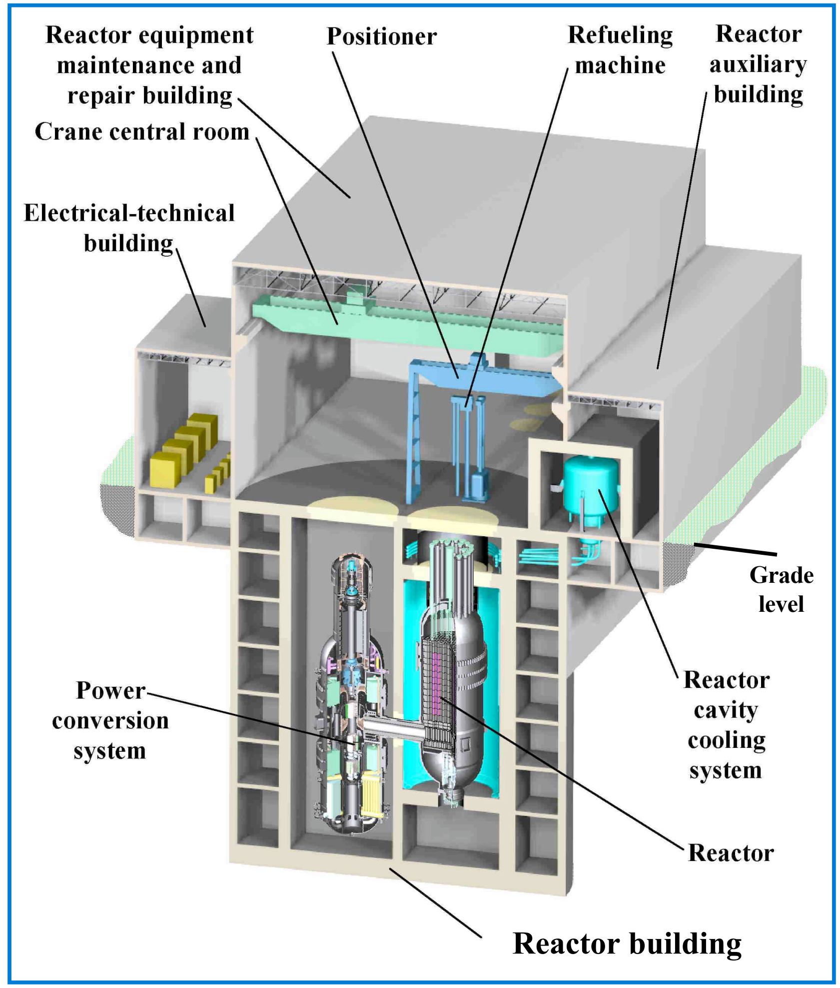
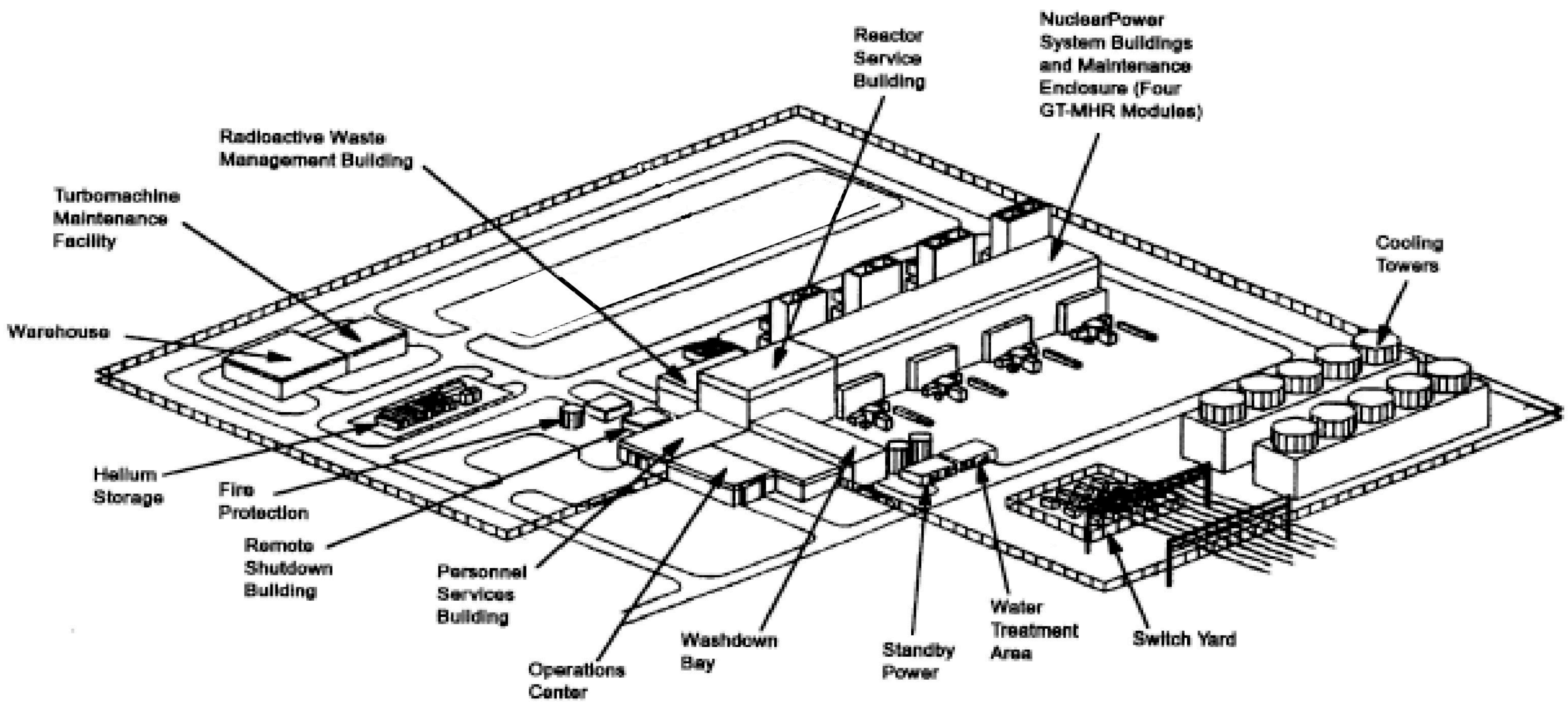
GENERAL ATOMICS

GT-MHR Module is Designed To Be Located in a Below Grade Silo

- Electrical output 286 MW(e) per module
- Each module includes Reactor System and Power Conversion System
- Reactor System 600 MW(t), 102 column, annular core, hexagonal prismatic blocks, very similar to successful FSV tests
- Power Conversion System includes generator, turbine, compressors on single shaft, surrounded by recuperator, pre-cooler and inter-cooler
- Natural sabotage protection



4 Modules Comprise a Standard ~1 GW Electric Plant

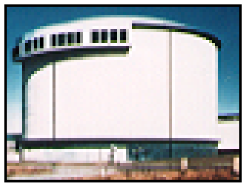


The Modern GT-MHR Derives from U.S. and European Experience

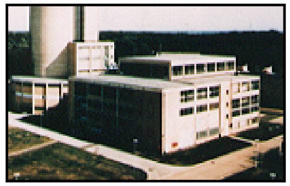
BROAD FOUNDATION OF HELIUM REACTOR TECHNOLOGY

EXPERIMENTAL REACTORS

DEMONSTRATION OF BASIC HTGR TECHNOLOGY

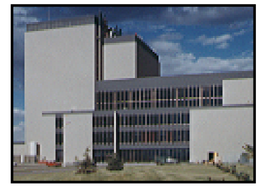


DRAGON
(U.K.)
1963 - 76

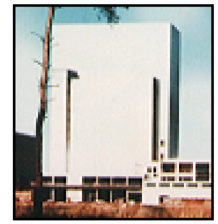


AVR
(FRG)
1967 - 1988

PEACH BOTTOM 1
(U.S.A.)
1967 - 1974



FORT ST. VRAIN
(U.S.A.)
1976 - 1989

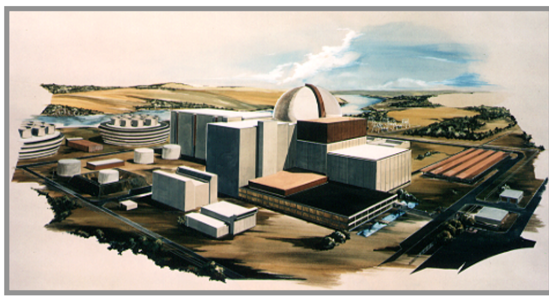


THTR
(FRG)
1986 - 1989

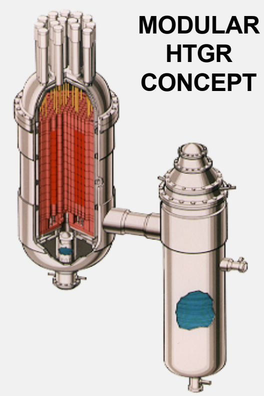
HTGR TECHNOLOGY PROGRAM

- MATERIALS
- COMPONENTS
- FUEL
- CORE
- PLANT TECHNOLOGY

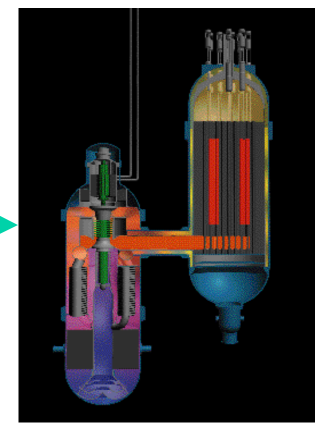
LARGE HTGR PLANTS



MODULAR HTGR CONCEPT

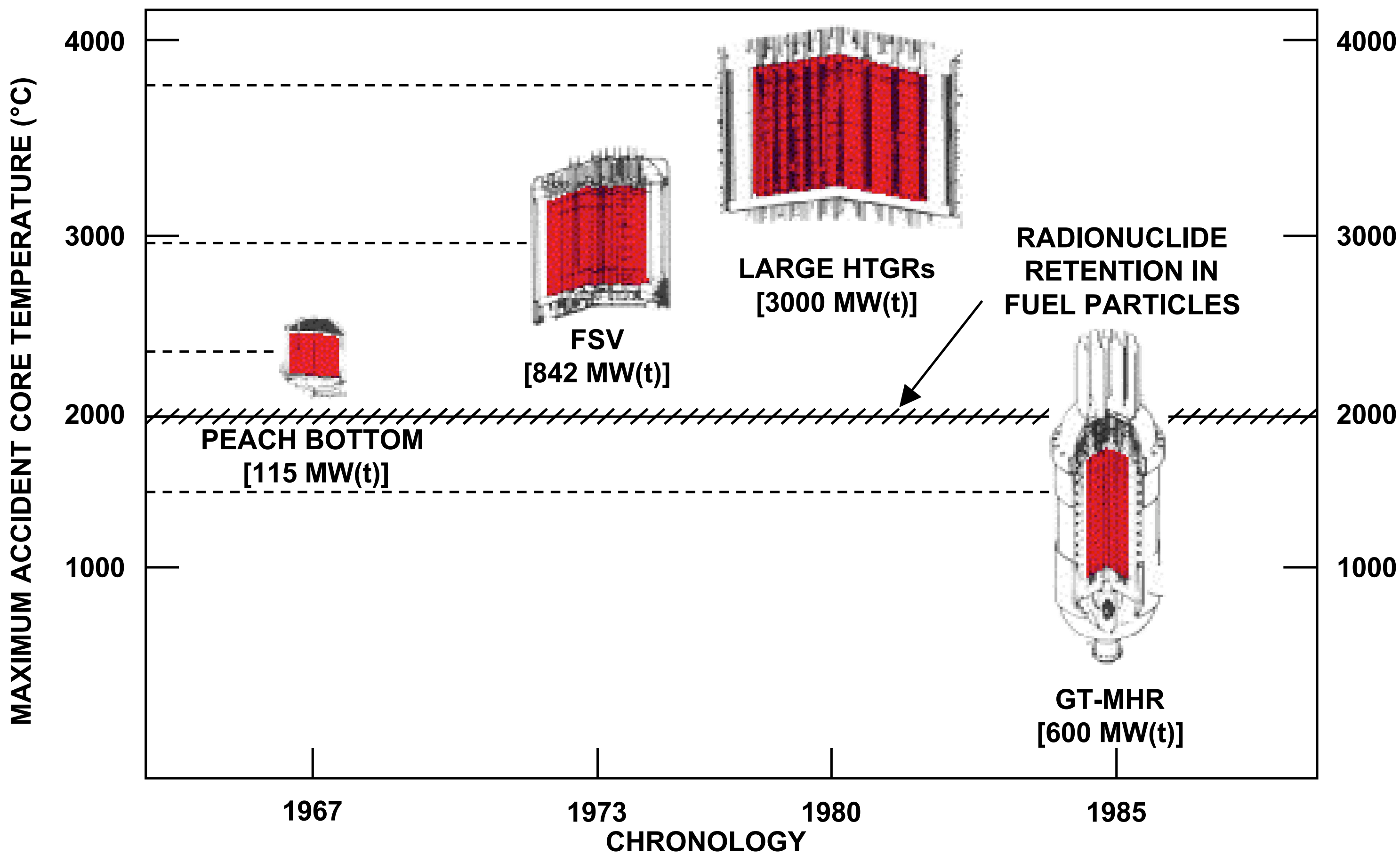


GT-MHR



GENERAL ATOMICS

The GT-MHR Represents a Fundamental Change in Reactor Design and Safety Philosophy



...sized and configured to tolerate even a severe accident

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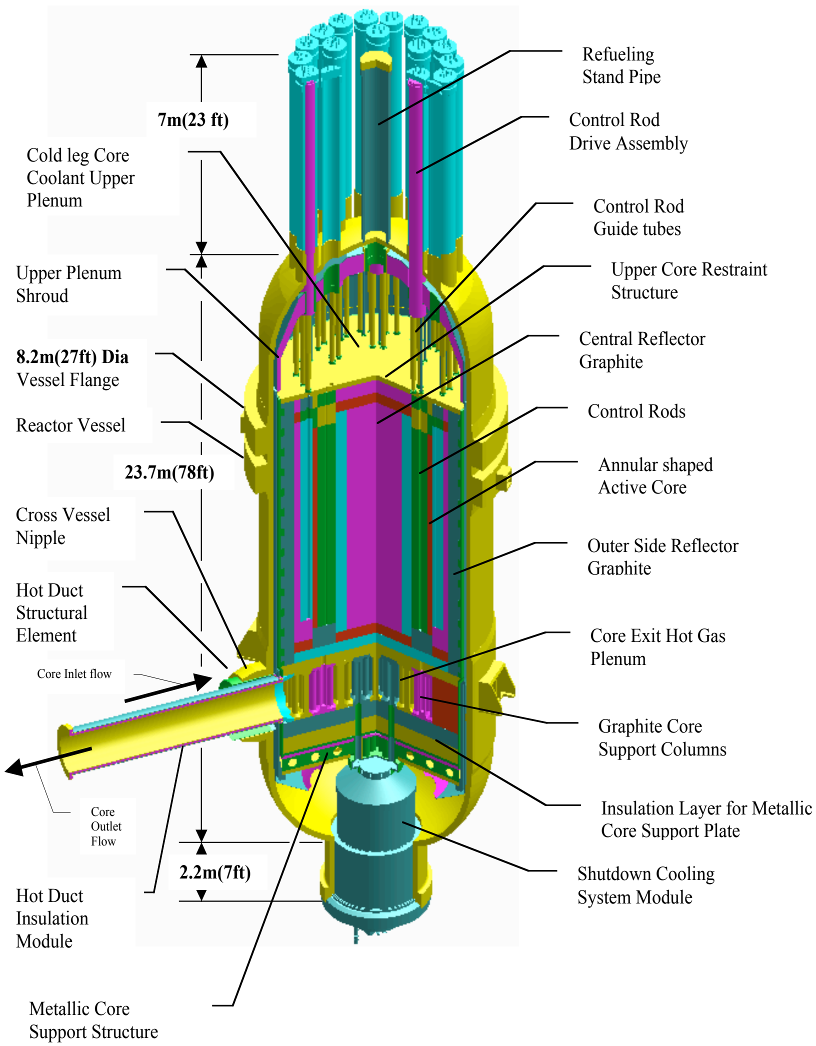
GENERAL ATOMICS

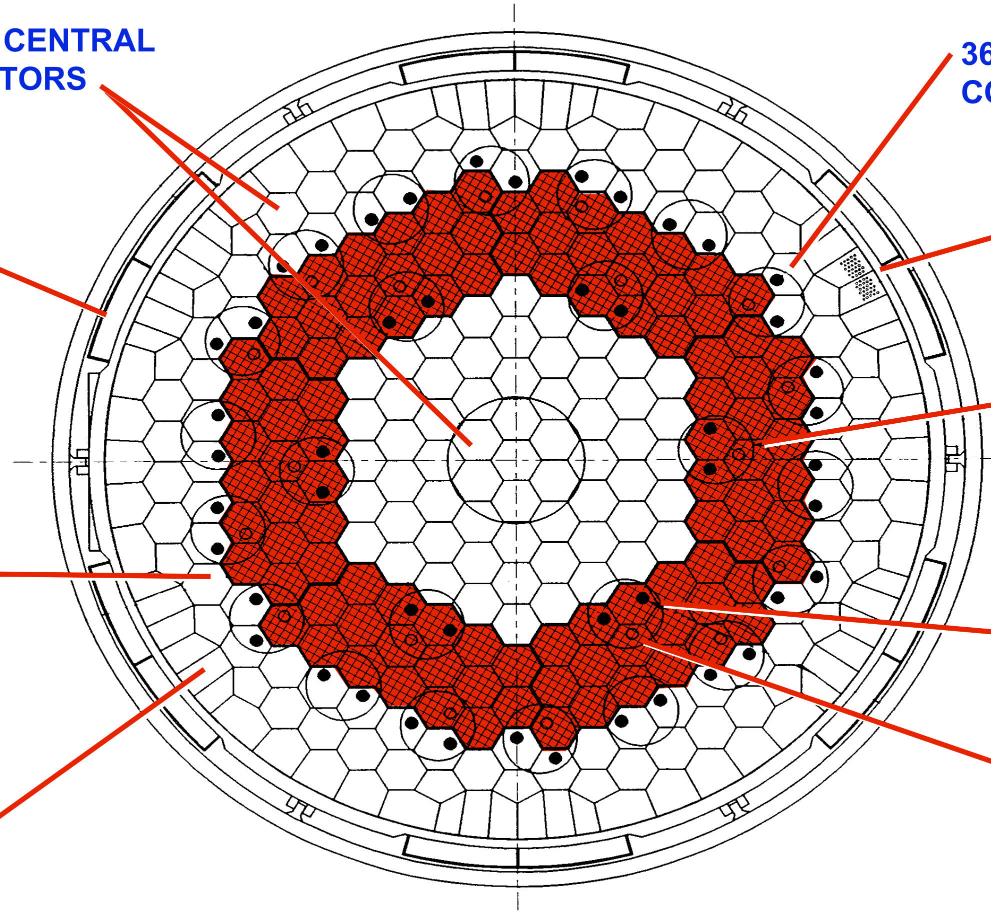
GT-MHR Reactor Internals Enable Gen IV Goals



- Secure fuel
- High fuel burn-up with attractive waste form
- Graphite moderation
- No internal metals
- Refueling ~ 1 mo. every 18 mo., in rotation among modules
- Passive emergency heat removal
- Match to H_2 or electricity with 850° C design amenable to 1000° C

GENERAL ATOMICS

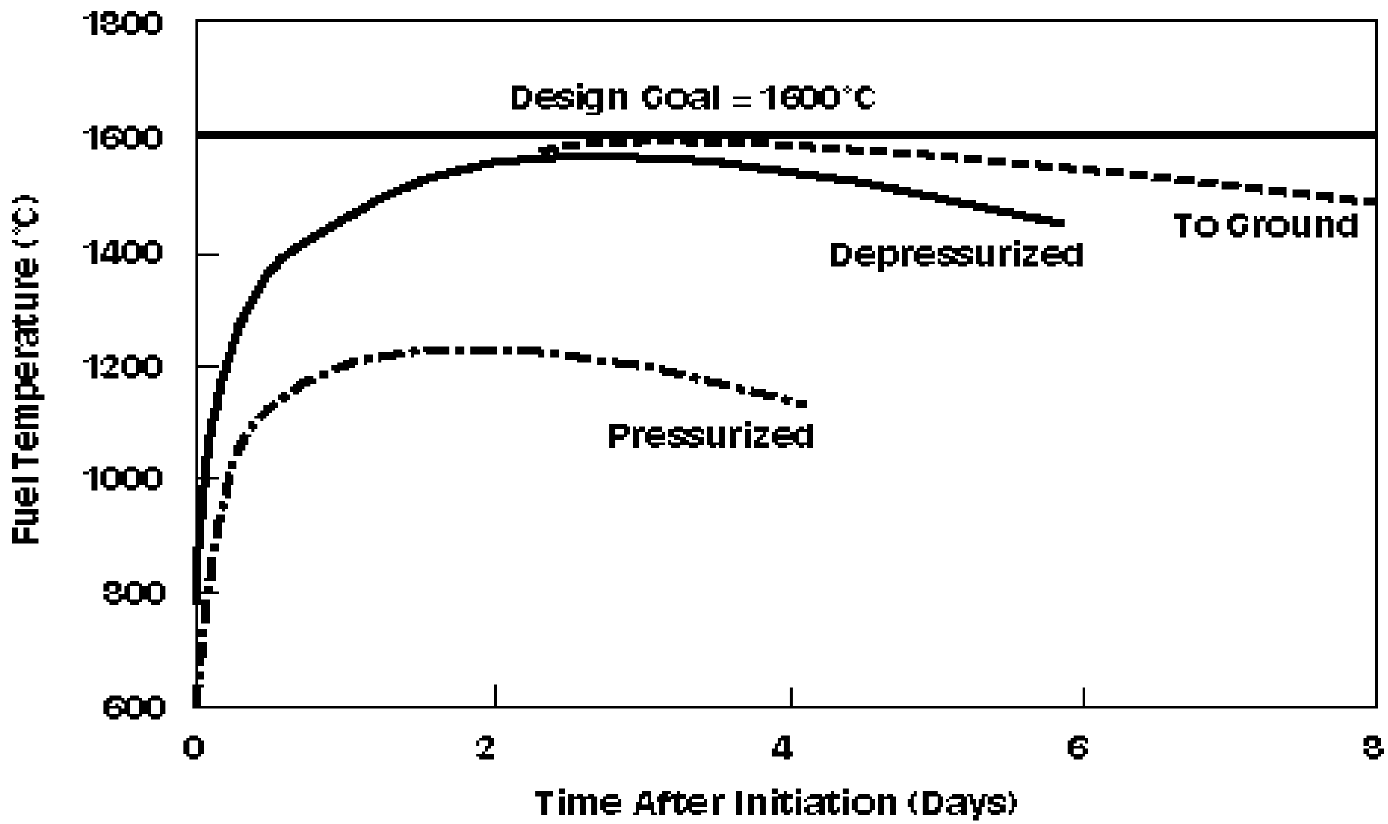
Annular Reactor Core Limits Fuel Temperature During Accidents



. . . using successful FSV technology

GENERAL ATOMICS

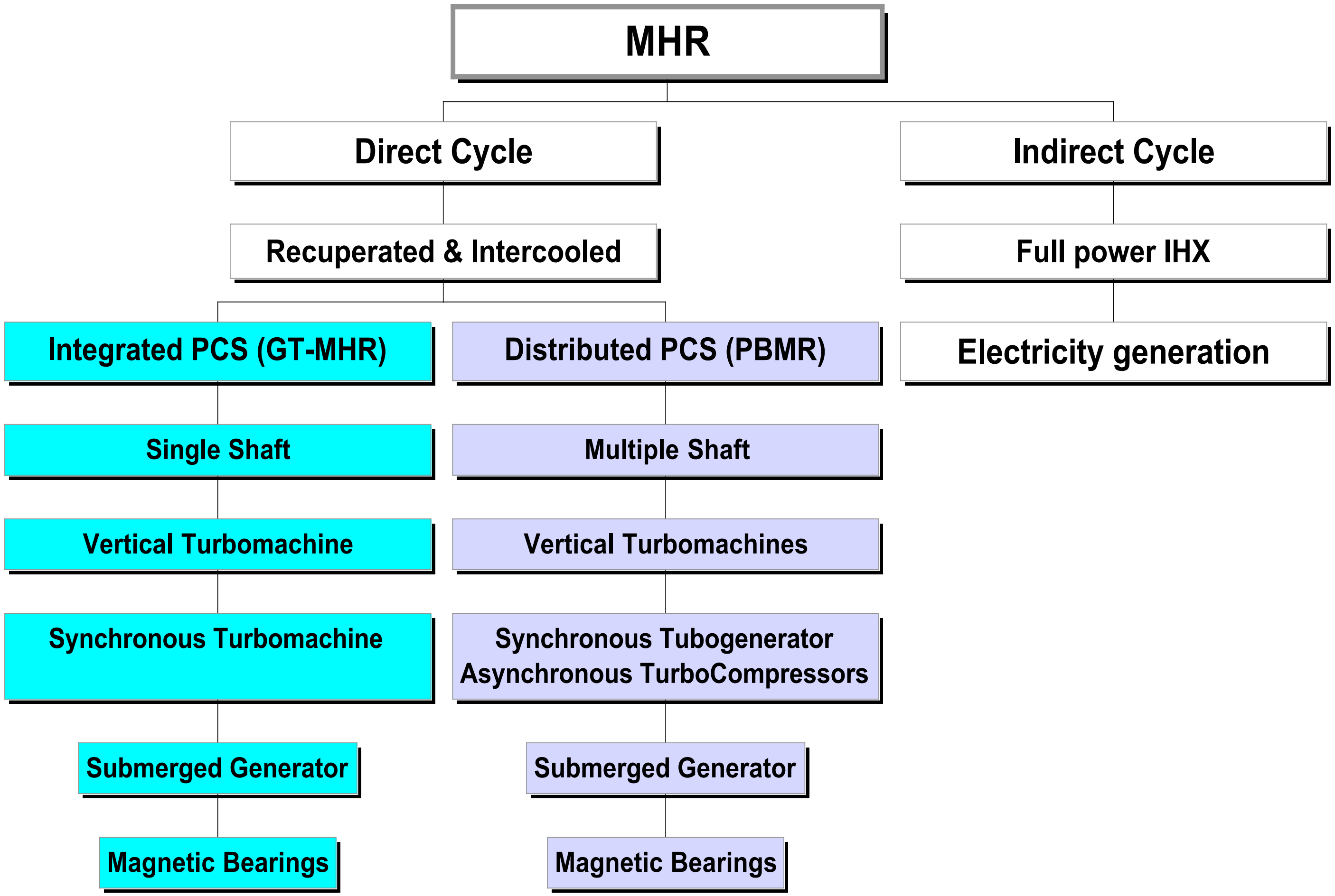
Fuel Temperatures Remain Below Design Limits During Loss of Cooling Events



. . . passive design features ensure fuel remains below 1600°C

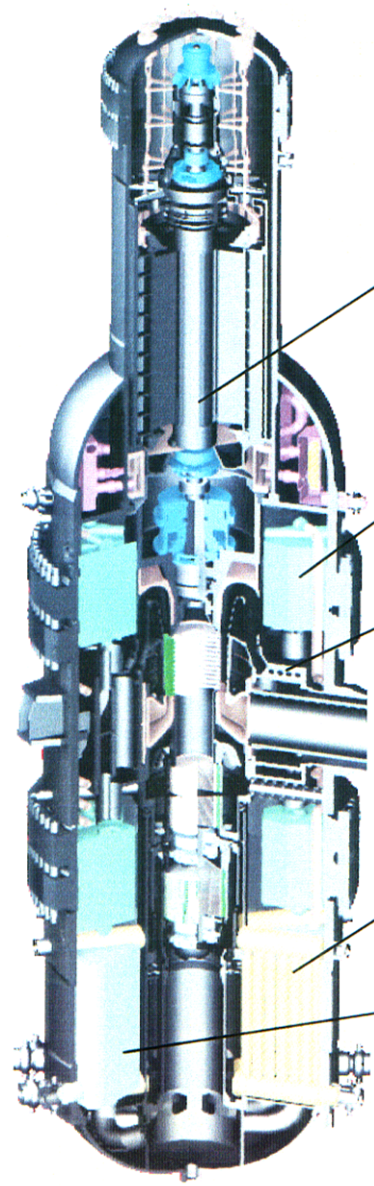
GENERAL ATOMICS

Efficiency Determined the PCS Choice for the GT-MHR

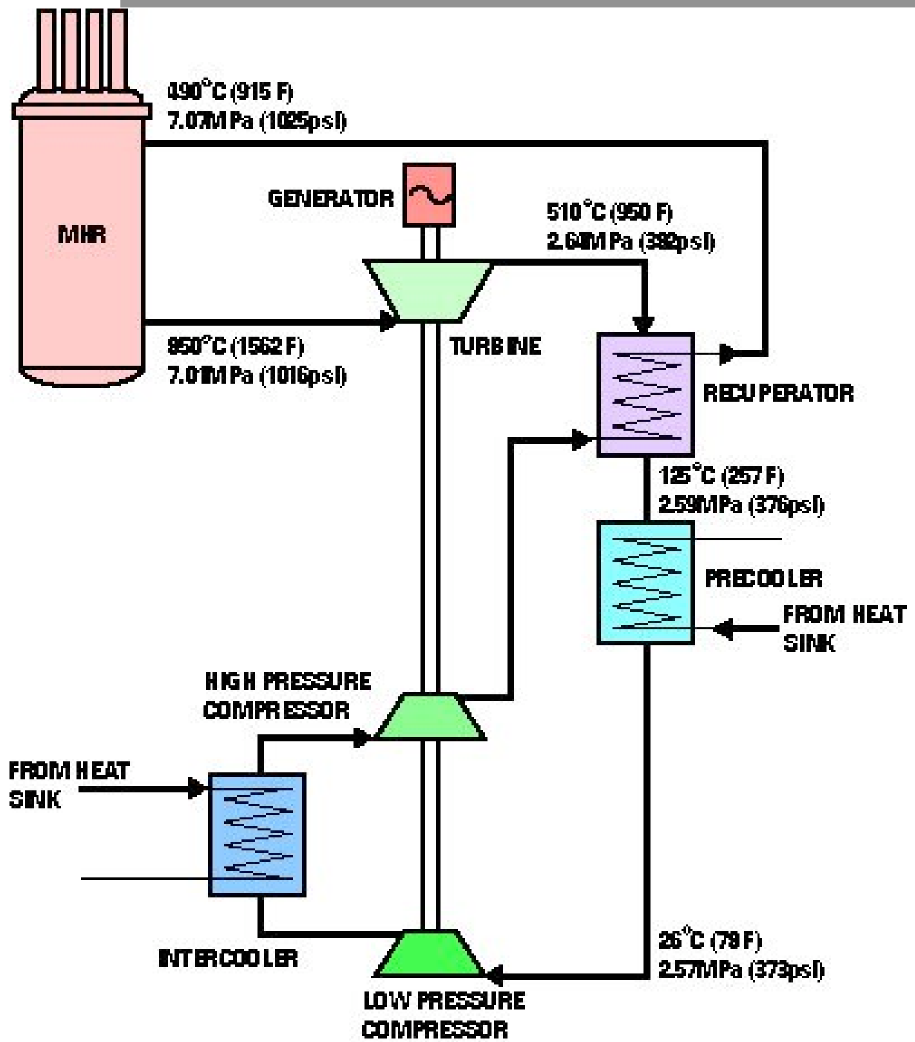


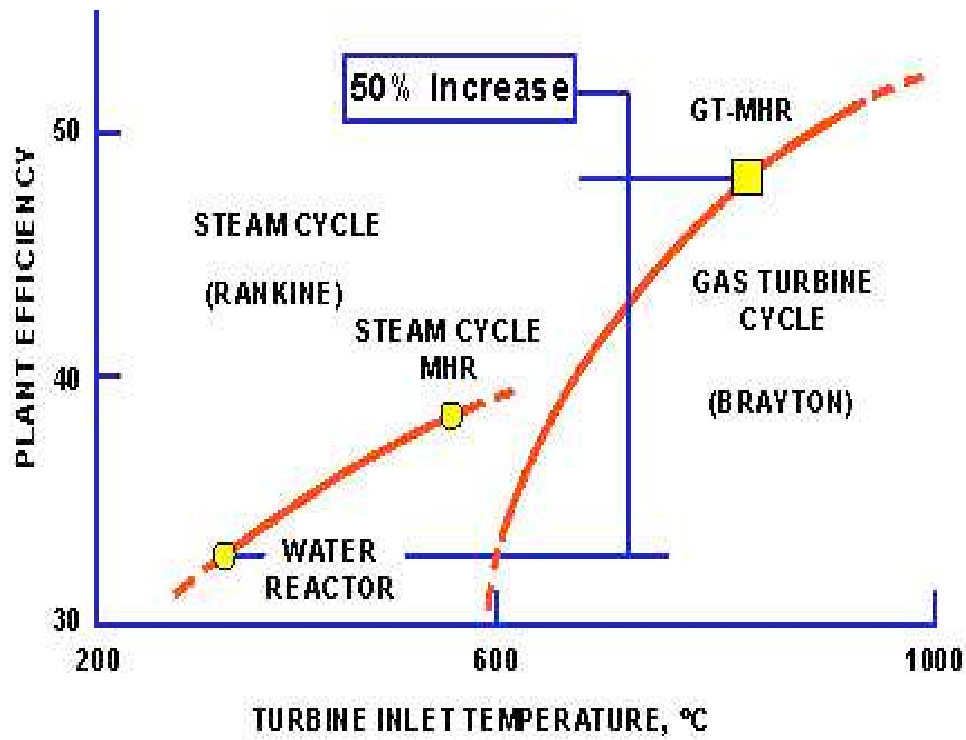
GENERAL ATOMICS

The Power Conversion System (PCS) integrates all elements into one assembly for maximum efficiency and lowest cost



The Electricity Generation Efficiency is Increased by the Direct Brayton Cycle





GENERAL ATOMICS

Hydrogen Fuel Now Has National Attention

Energy

- Growing Demand for Electricity
- Oil Imports ~ 60% & Growing
- Long-Term Supply

Economy

- Energy is Major Part of Trade Deficit
- Fuel Diversity - Reduced Risk
- Ability to Grow a Robust Economy

E^3

Environment

- Better Utilize Oil & Gas (Too Valuable to Burn)
- Preserve Natural Resources for Future Generations
- Reduce Air Pollution & Greenhouse Gases

"So long as I am in this job, I will make sure <u>energy security</u> is my primary concern"

- Secretary of Energy Spencer Abraham

GENERAL ATOMICS

MHR is Well Suited for Hydrogen Production by Several Processes

- Electricity >>> Electrolysis
  - Proven technology
  - Overall efficiency ~36%

- Electricity + Heat >>> High Temperature Electrolysis
  - Need both electricity generation and high temperature process heat
  - Efficiencies up to ~ 50% at ~900°C
  - Developing technology

- High Temperature Heat >>> Thermochemical Water-Splitting
  - A set of chemical reactions that use heat to decompose water
  - Net plant efficiencies of up to ~50% at ~900°C
  - Developing technology

Capital cost, etc., will separate the latter two

The Sulfur-Iodine Cycle is Well Matched to the MHR

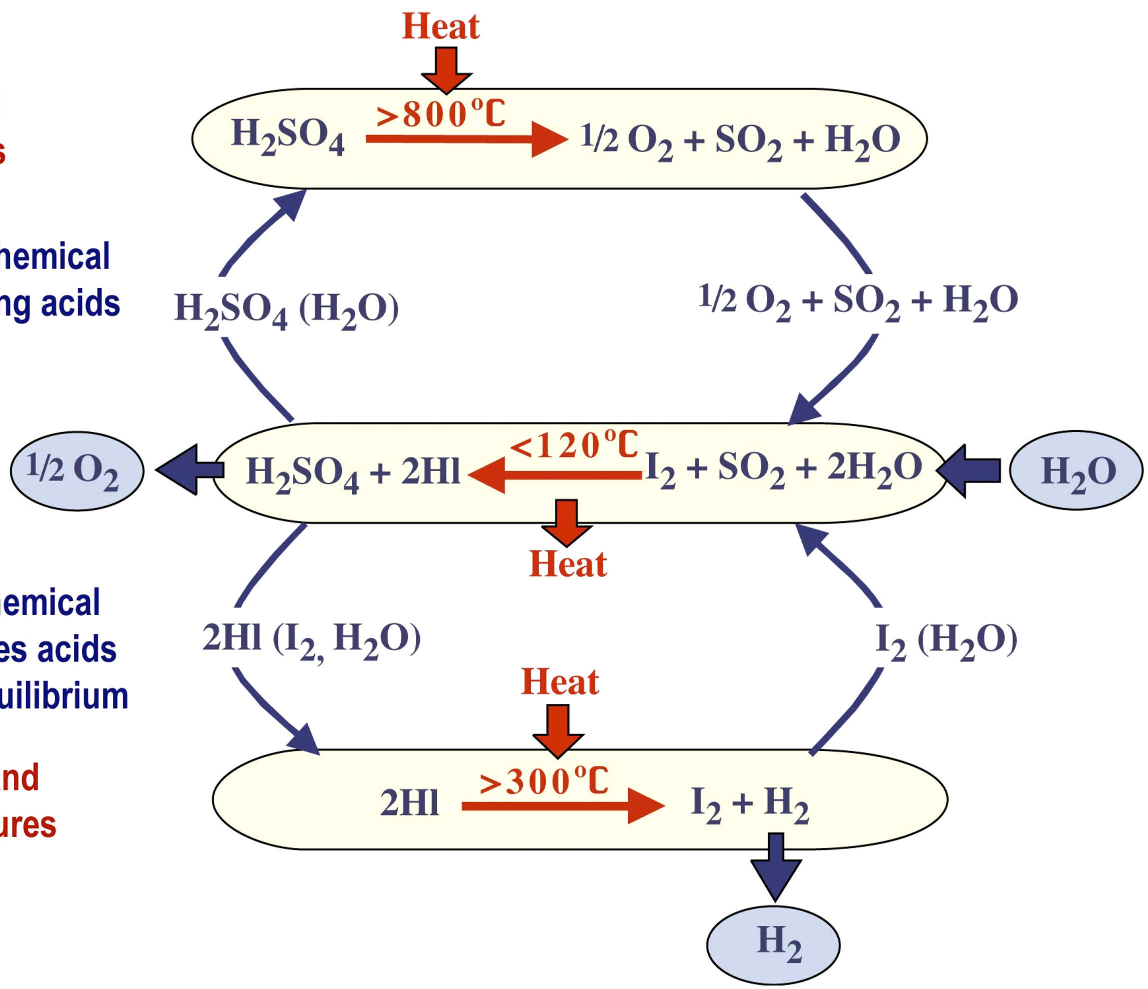
Sulfuric acid is concentrated and decomposed at high temperatures

Excess water shifts chemical equilibrium by hydrating acids

Bunsen reaction produces acids and releases waste heat to the environment at low temperatures

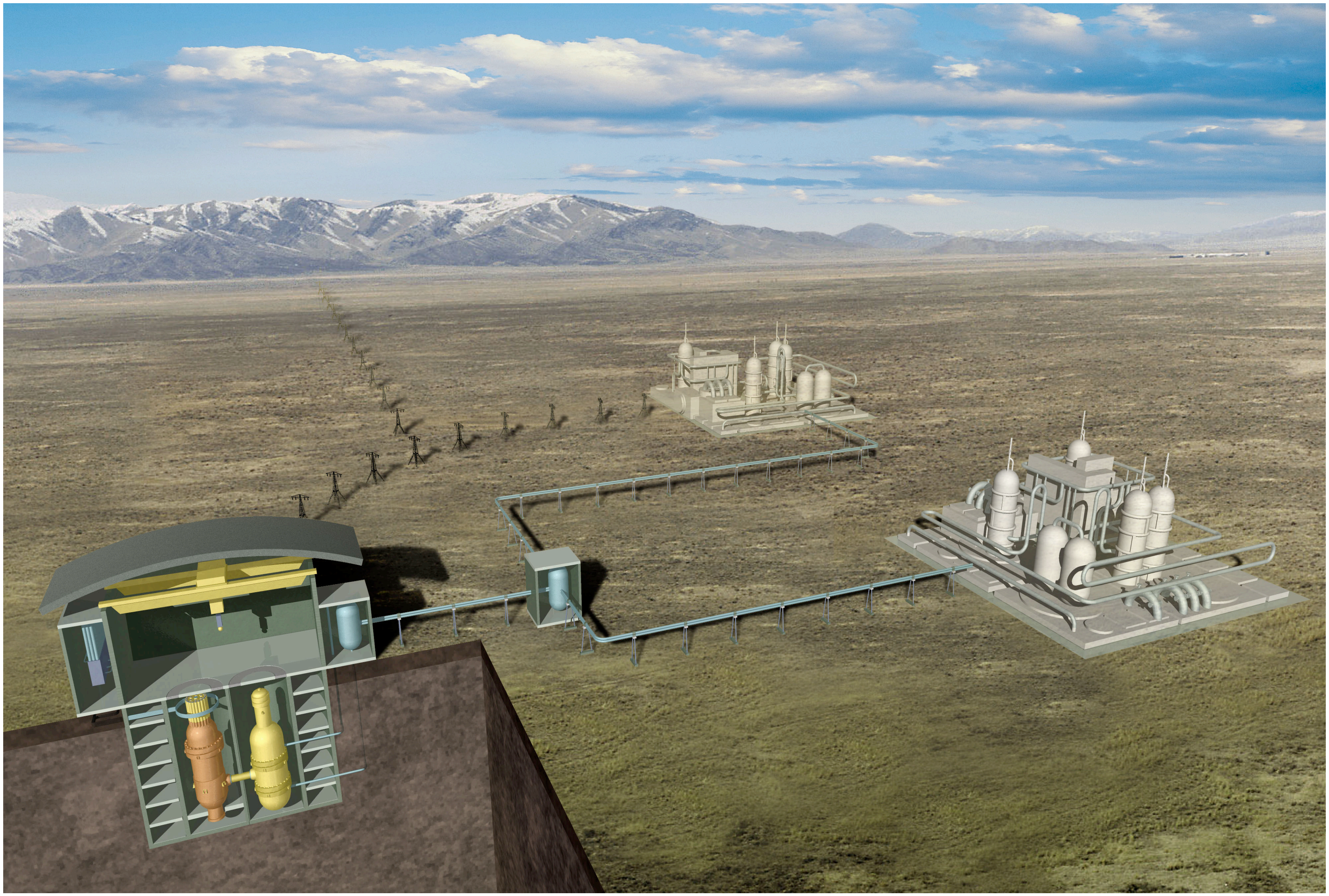
Excess iodine shifts chemical equilibrium and separates acids by liquid-liquid phase equilibrium

Hydrogen iodide is concentrated and decomposed at moderate temperatures



GENERAL ATOMICS

The NGNP at INL will Demonstrate the MHR with Electricity and Hydrogen Production



Major Advantages of the MHR will be Demonstrated by NGNP

- High level of inherent safety, eliminating core melt without operator action
- Brayton cycle power conversion system for high thermal efficiency
- Once-through fuel cycle with reduced high level waste
- Superior radionuclide retention for normal operation and long-term spent-fuel disposal
- Preferred hydrogen production technique
- Competitive electricity/hydrogen production costs (reduced equipment capital and O&M; high efficiency)