GT-MHR OVERVIEW

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IEEE Subcommittee on Qualification

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GENERAL ATOMICS

GT-MHR/LWR COMPARISON

Item	GT-MHR	LWR
Moderator	Graphite	Water
Coolant	Helium	Water
Average core coolant exit temp.	850°C	310°C
Structural material	Graphite	Steel, aluminum
Fuel clad	Graphite & silicon	Zircalloy
Fuel	UCO	UO_2
Fuel damage temperature	>2000°C	1260°C
Power density, w/cc	6.6	58 - 105
Linear heat rate, kW/ft	1.6	19
Average thermal neutron energy, eV		0.22 0.17
Migration length, cms	57	6

PLANT USER REQUIREMENTS

- Plant sizes 300-1200 MW(e) range
- Equivalent availability >90%
- Meets existing safety and licensing criteria with no public sheltering
- 10% power cost advantage over U.S.Fossile Fuel

MODULAR HTGR DEVELOPMENT MEETS GEN IV GOALS

- Modular HTGR first conceptualized in early '80s to provide simple, enhanced SAFETY
- Gas Turbine - Modular Helium Reactor (GT-MHR) conceptualized in early '90s to provide enhanced ECONOMICS
- Gas reactor TRISO coated particle fuel form ideal for spent fuel WASTE
- Fissile fuel inventory, isotopic composition, and fuel form provides hi PROLIFERATION resistance

US HELIUM GAS REACTOR HAS OVER 40 YEARS OF DESIGN AND DEVELOPMENT

1959	Contracts for Peach Bottom 1 signed
1967	Peach Bottom 1 on line
1976	Fort St. Vrain on line
1971-1974	Commercial contracts for ten HTGRs
1984	Modular HTGR program begins
1985	350 MW(t) MHTGR steam cycle
1990	450 MW(t) MHTGR STEAM CYCLE
1994	GT-MHR 600 MW(t) chosen as reference

MHR DESIGN

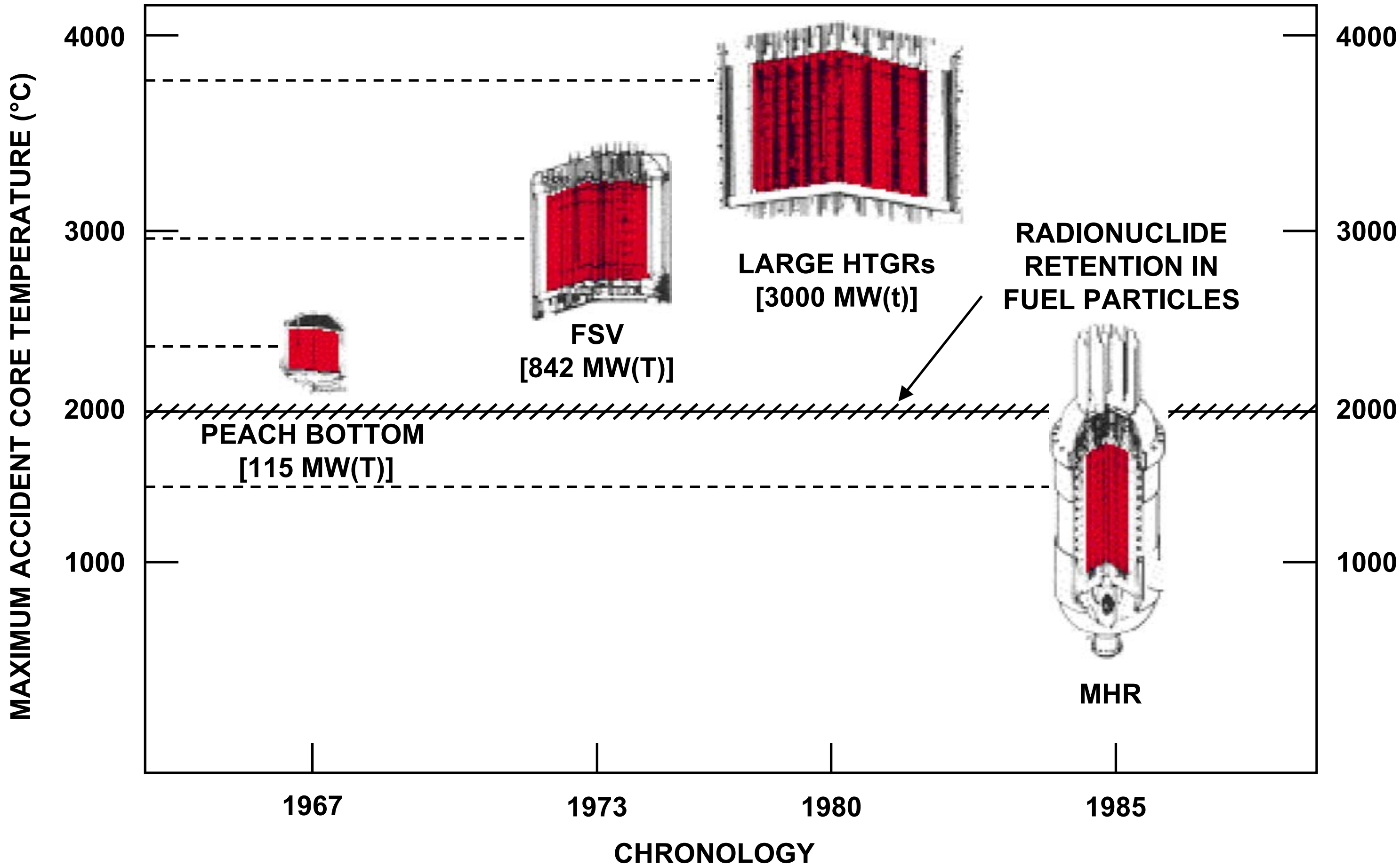
- **Utilize inherent characteristics**
  - Helium coolant - inert, single phase
  - Refractory coated particle fuel - high temp capability, low release
  - Graphite moderator - high temp stability, long response times

- **Utilize existing technology, successfully demonstrate components and experience**

- **Develop simple modular design**
  - Small unit rating per module
  - Below grade Silo installation

- **Passively safe design**
  - Annular core, large negative temperature coefficient
  - Passive decay heat removal system
  - Minimize powered reactor safety systems

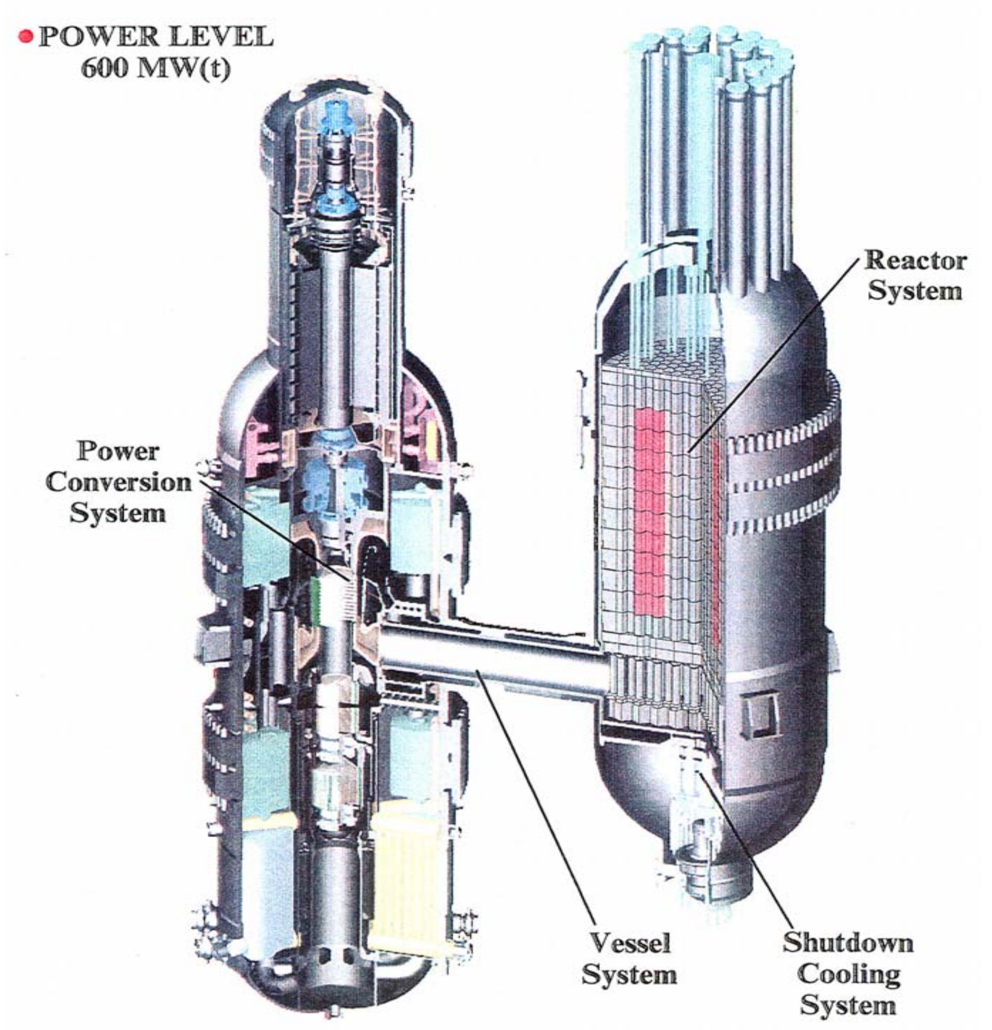
MODULAR HELIUM REACTOR REPRESENTS A FUNDAMENTAL CHANGE IN REACTOR DESIGN AND SAFETY PHILOSOPHY



...SIZED AND CONFIGURED TO TOLERATE EVEN A SEVERE ACCIDENT

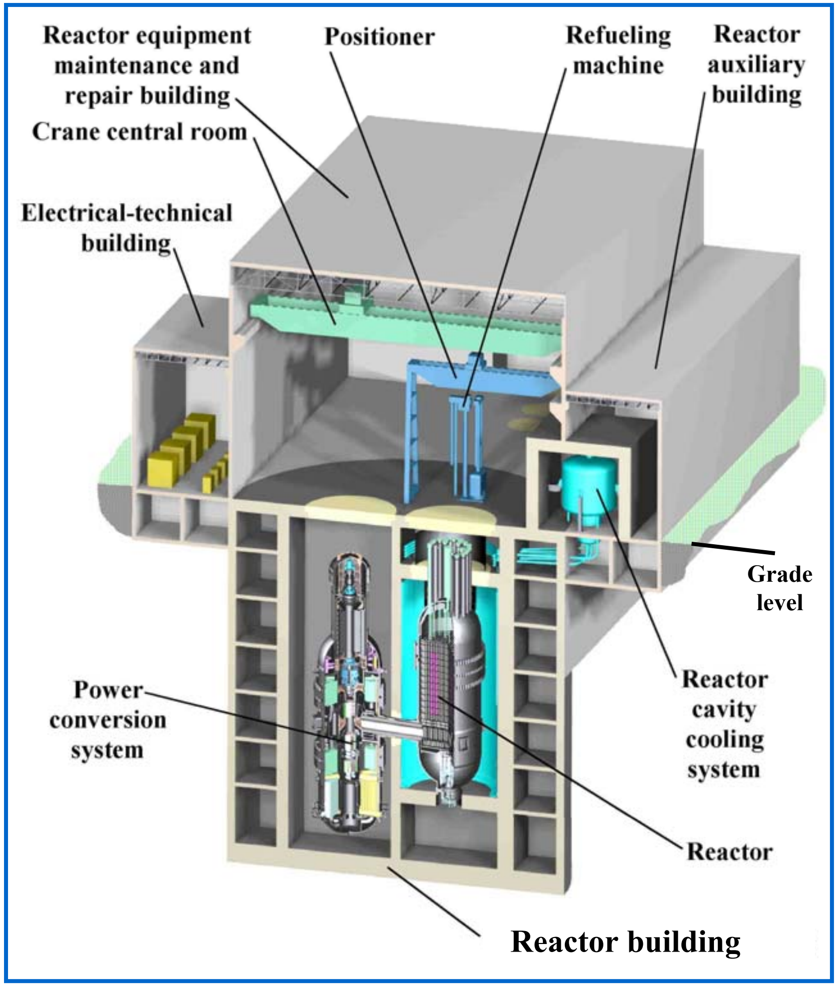
GT-MHR MODULE COMBINES MELTDOWN-PROOF ADVANCED REACTOR & HIGH EFFICENCY GAS TURBINE POWER CONVERSION SYSTEM

POWER LEVEL 600 MWt

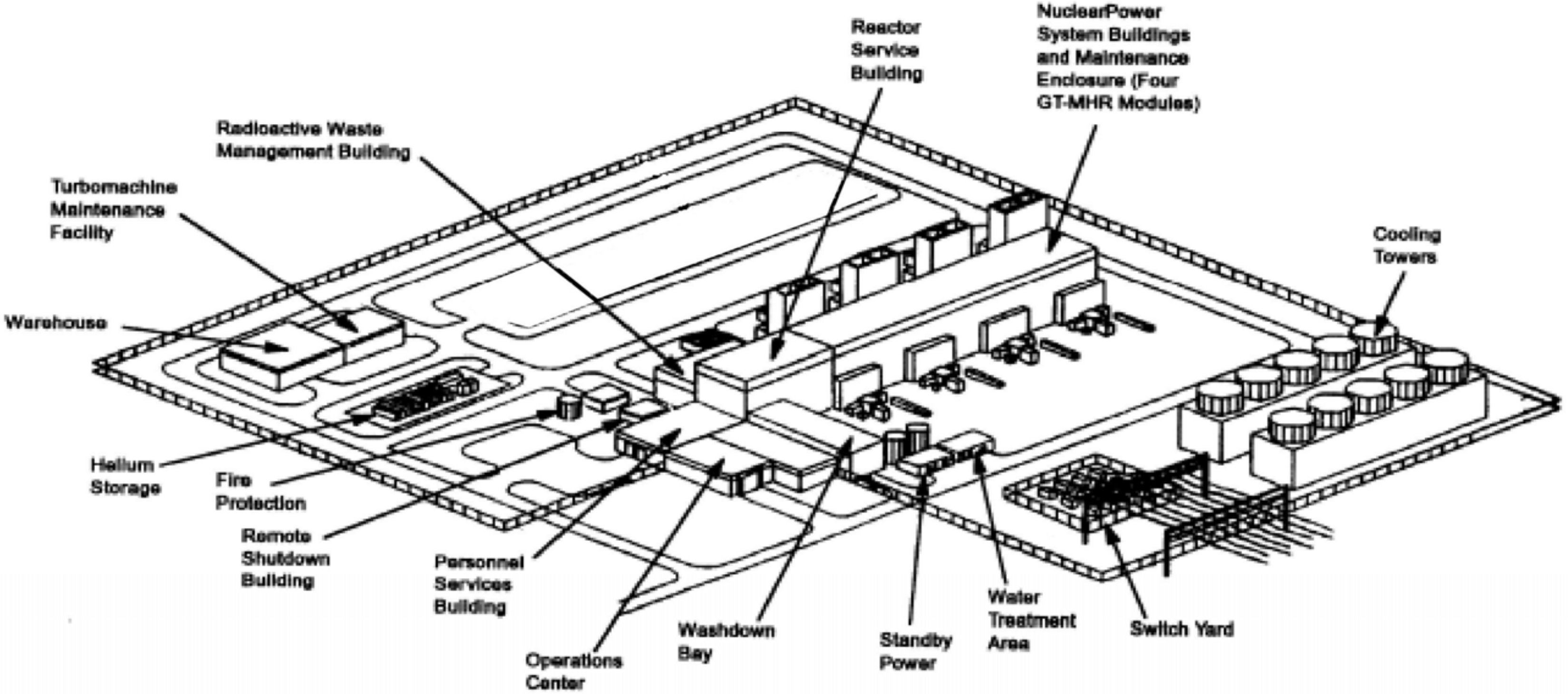


GT-MHR MODULE DESIGNED TO BE LOCATED IN BELOW GRADE SILO

- 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 similar to FSV
- Power Conversion System includes generator, turbine, compressors on single shaft, surrounded by recuperator, pre-cooler and inter-cooler



4 MODULES COMPRISE STANDARD PLANT



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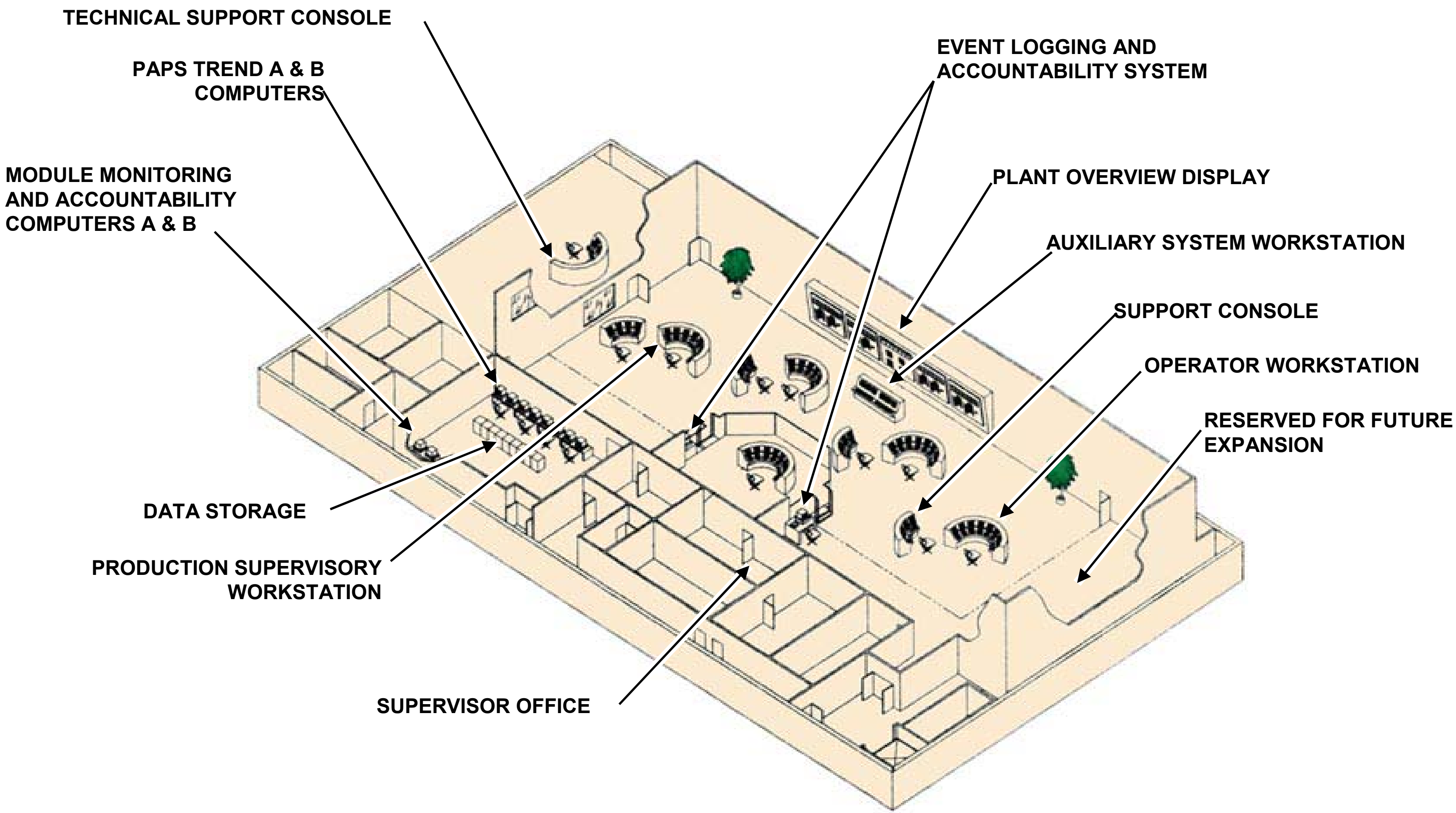
CONTROL ROOM COMPLEX



4-Module GT-MHR Plant Control Complex

U.S. AND EUROPEAN TECHNOLOGY BASES FOR MODULAR HIGH TEMPERATURE REACTORS

BROAD FOUNDATION OF HELIUM REACTOR TECHNOLOGY

EXPERIMENTAL REACTORS

DRAGON
(U.K.)
1963 - 76

AVR
(FRG)
1967 - 1988

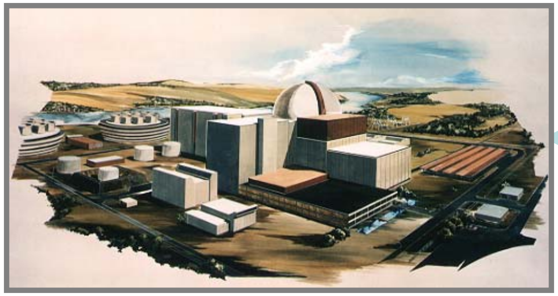
DEMONSTRATION OF BASIC HTGR TECHNOLOGY

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

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

THTR
(FRG)
1986 - 1989

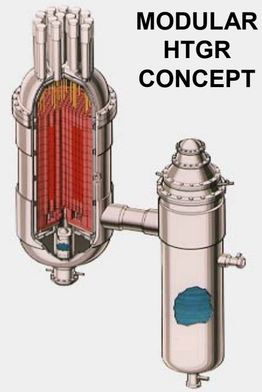
LARGE HTGR PLANTS



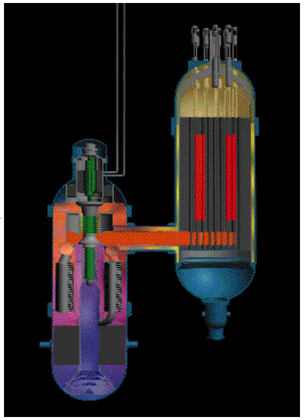
HTGR TECHNOLOGY PROGRAM

- MATERIALS
- COMPONENTS
- FUEL
- CORE
- PLANT TECHNOLOGY

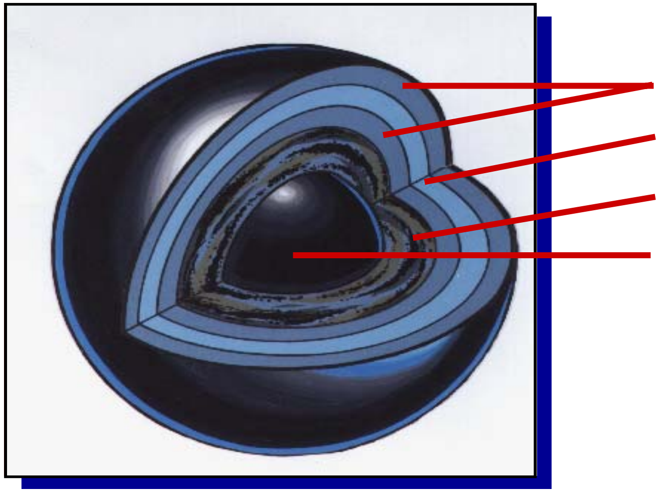
MODULAR HTGR CONCEPT



GT-MHR



CERAMIC FUEL RETAINS ITS INTEGRITY UNDER SEVERE ACCIDENT CONDITIONS



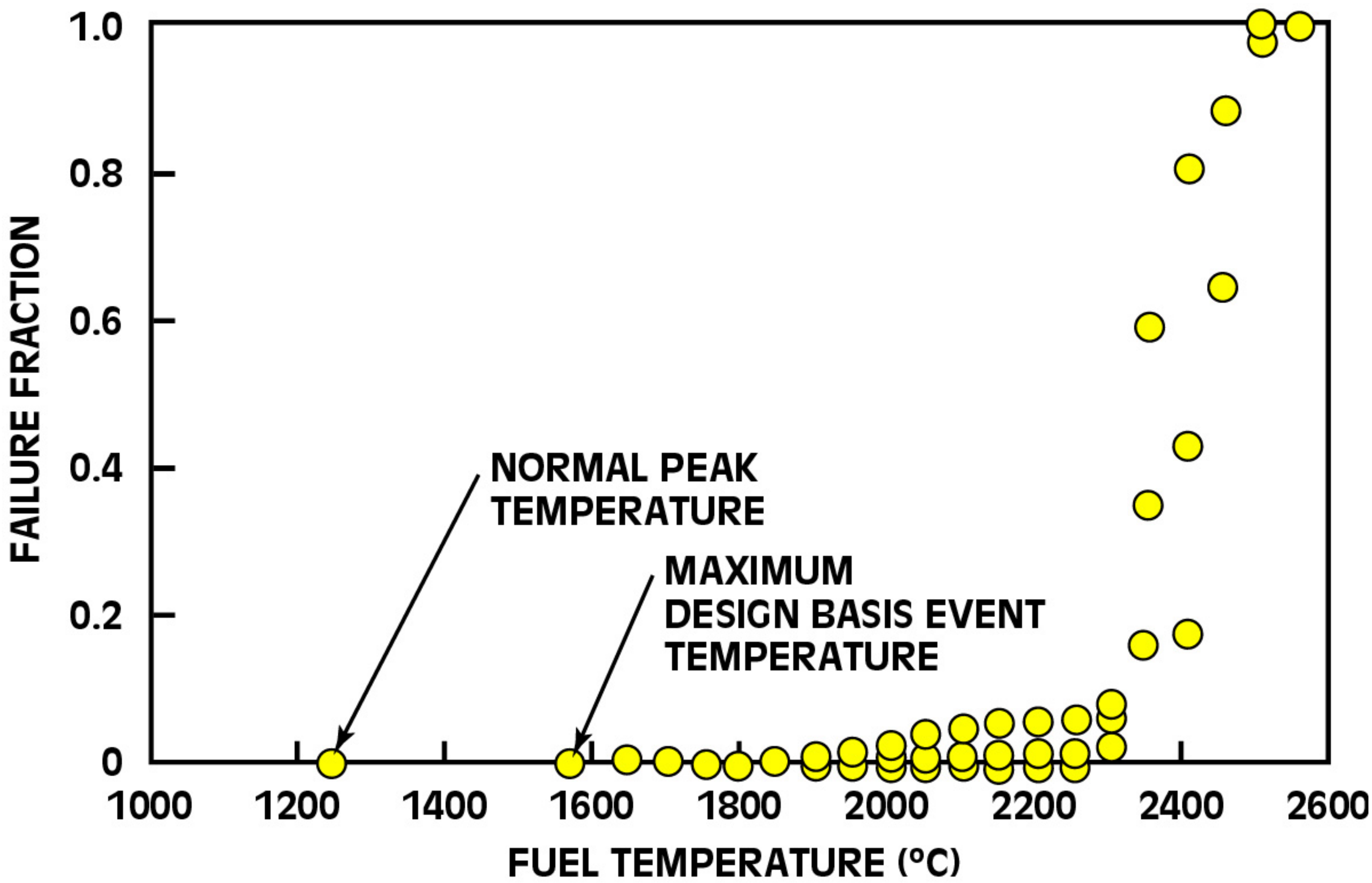
TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).

PARTICLES

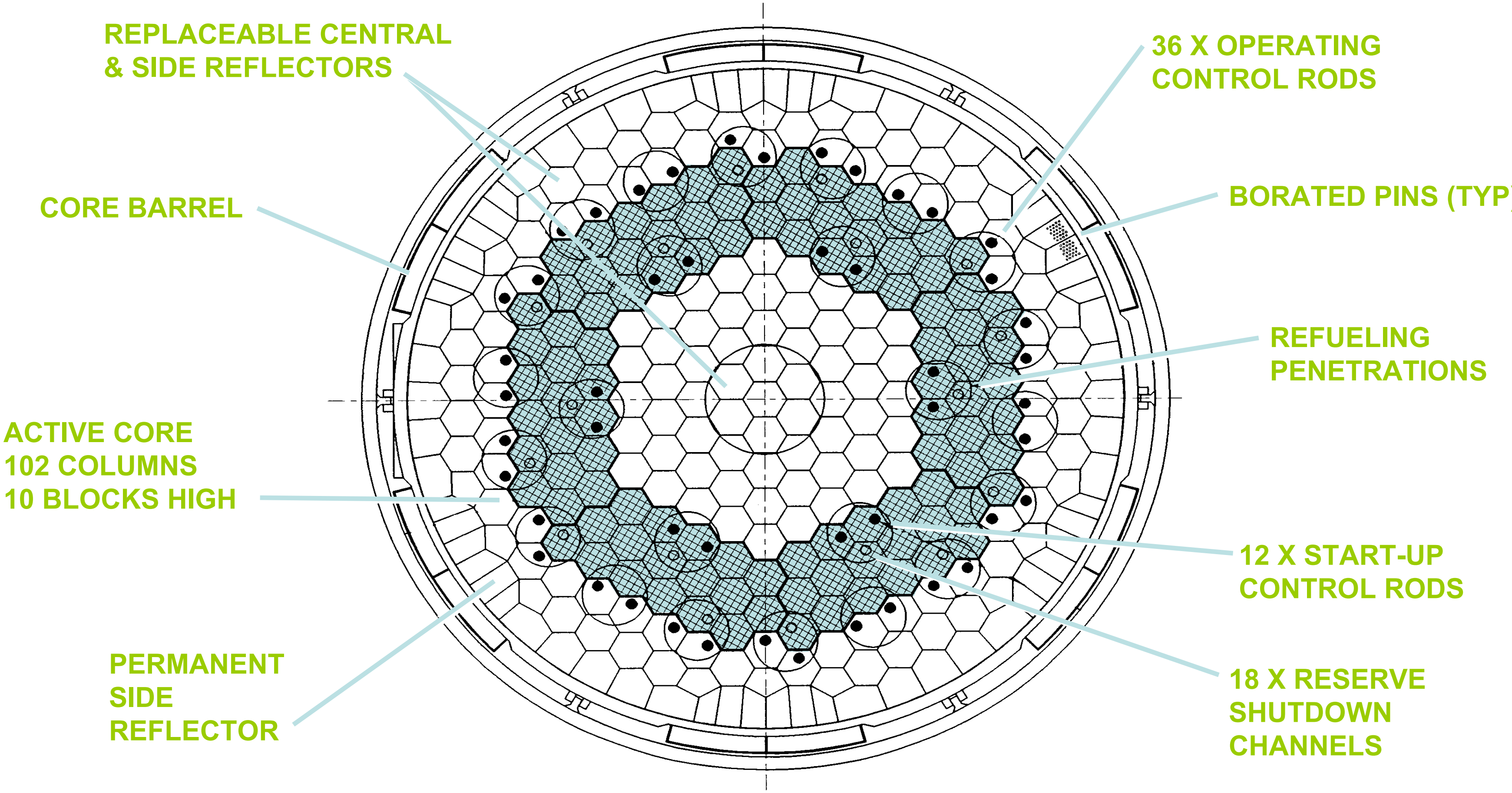
COMPACTS

FUEL ELEMENTS

COATED PARTICLES STABLE TO BEYOND MAXIMUM ACCIDENT TEMPERATURES

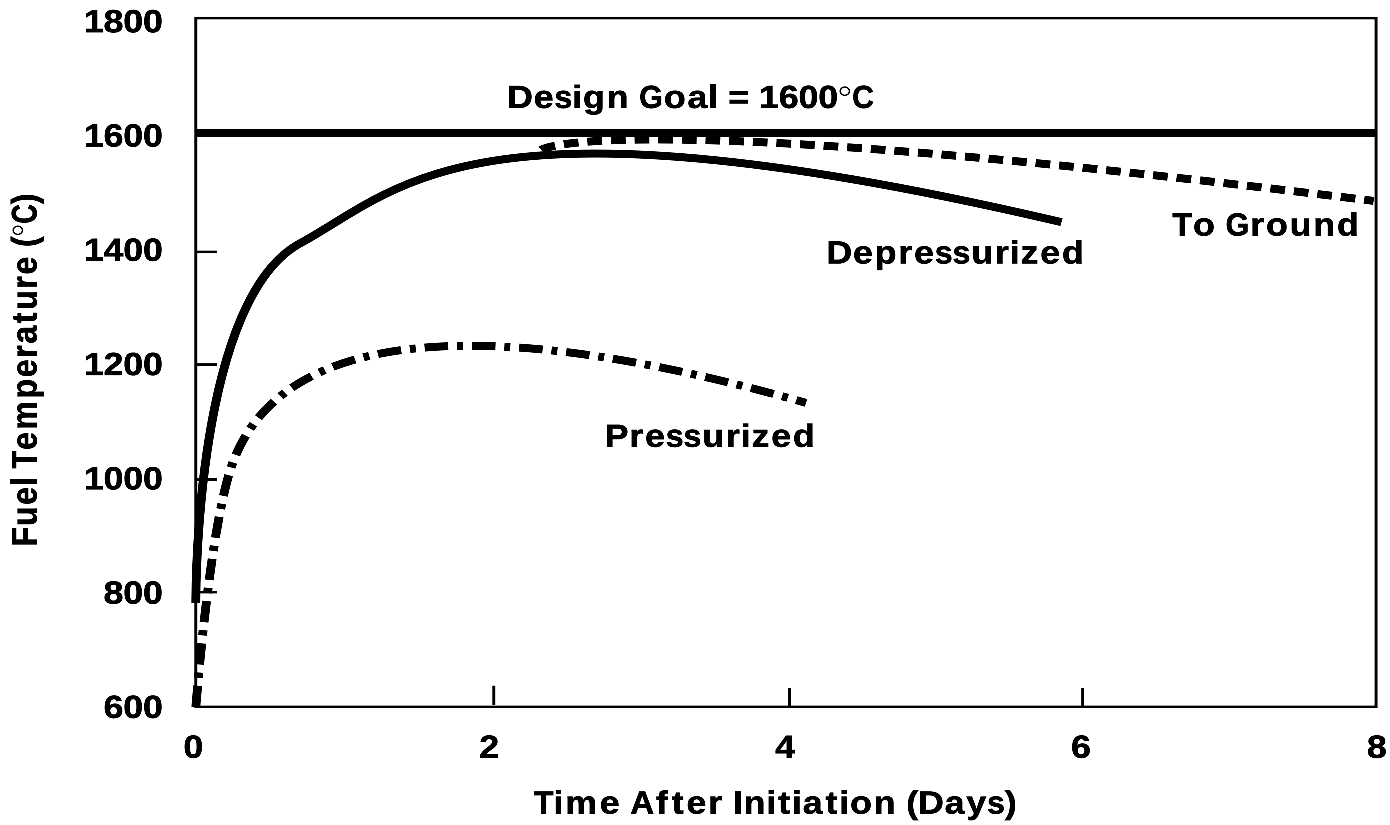


ANNULAR REACTOR CORE LIMITS FUEL TEMPERATURE DURING ACCIDENTS



. . . ANNULAR CORE USES EXISTING TECHNOLOGY

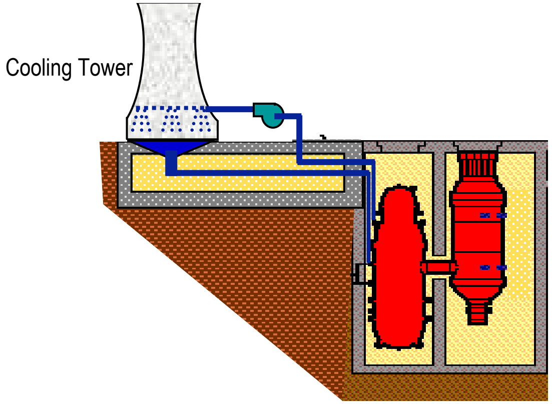
FUEL TEMPERATURES REMAIN BELOW DESIGN LIMITS DURING LOSS OF COOLING EVENTS



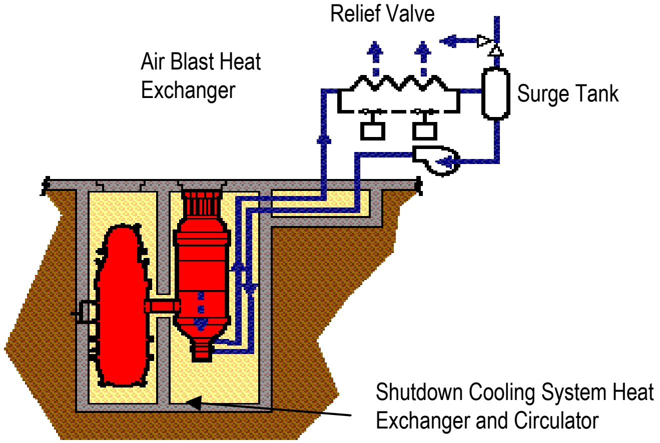
. . . PASSIVE DESIGN FEATURES ENSURE FUEL REMAINS BELOW 1600°C

Decay Heat Removal Paths:

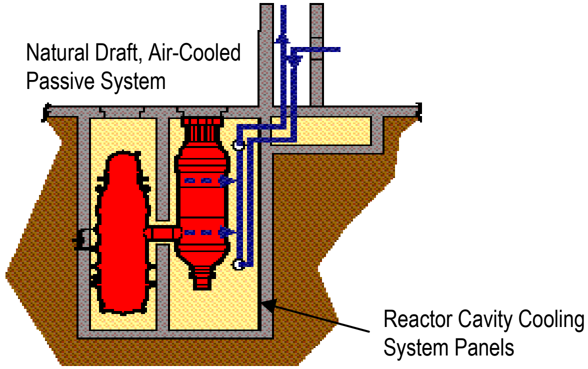
A. Normal - Using Power Conversion System



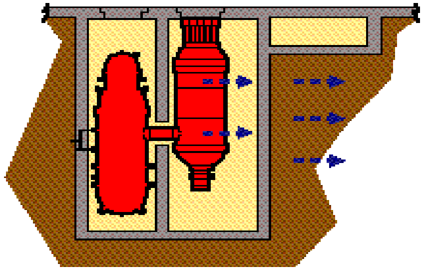
B. Active Shutdown Cooling System



C. Passive Reactor Cavity Cooling System



D. Passive Radiation & Conductive Cooling



GT-MHR REACTIVITY CONTROL

- Core excess reactivity over each cycle is limited by the use of lumped burnable poison to minimize the number of control rods needed
- Control rods are operated in banks of three (120° symmetry)
- Only outer reflector control rods are used for normal power operation to minimize effects on core power distribution
- Hot shutdown can be achieved with reflector rods only
- Long-term cold shutdown requires all control rods
- Reserve shutdown system is an independent system of different design and operation

GT-MHR TEMPERATURE COEFFICIENT OF REACTIVITY

- **Except for control rod motion, the only significant reactivity effect in the GT-MHR is that caused by changes in core temperature**
- **Reactivity always decreases as core temperature increases:**
  - Negative feedback effect
  - Ensures the passive safety of the system
- **This effect is caused by the Doppler broadening of the U-238 and Pu-240 resonance absorption cross sections as the neutron spectrum changes with increasing core temperature**

PASSIVE SAFETY BY DESIGN

- **Fission Products Retained in Coated Particles**
  - *High temperature stability materials*
  - *Refractory coated fuel*
  - *Graphite moderator*

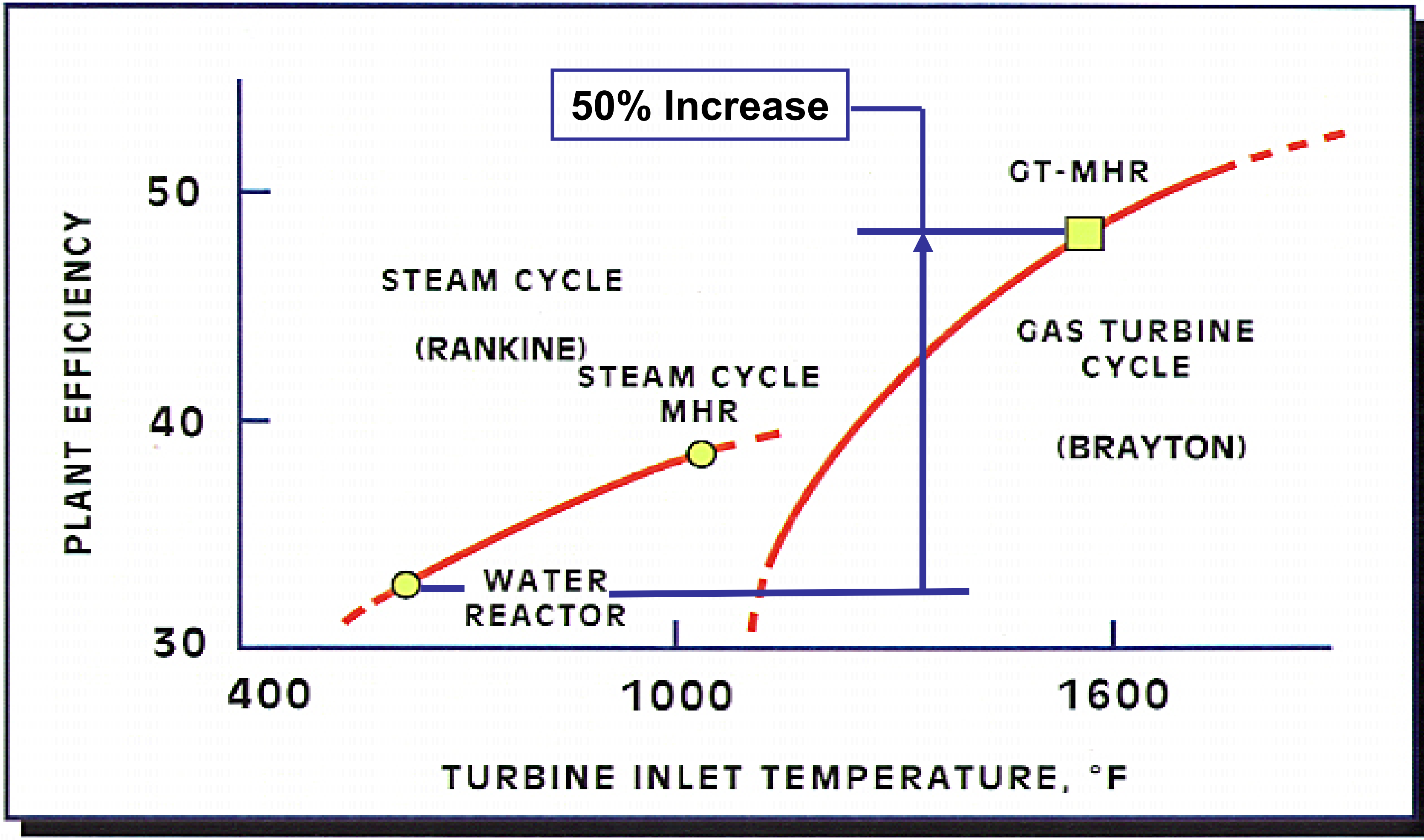
- **Worst case fuel temperature limited by design features**
  - *Low power density*
  - *Low thermal rating per module*
  - *Annular Core*
  - *Passive heat removal ….CORE CAN'T MELT*

- **Core Shuts Down Without Rod Motion**

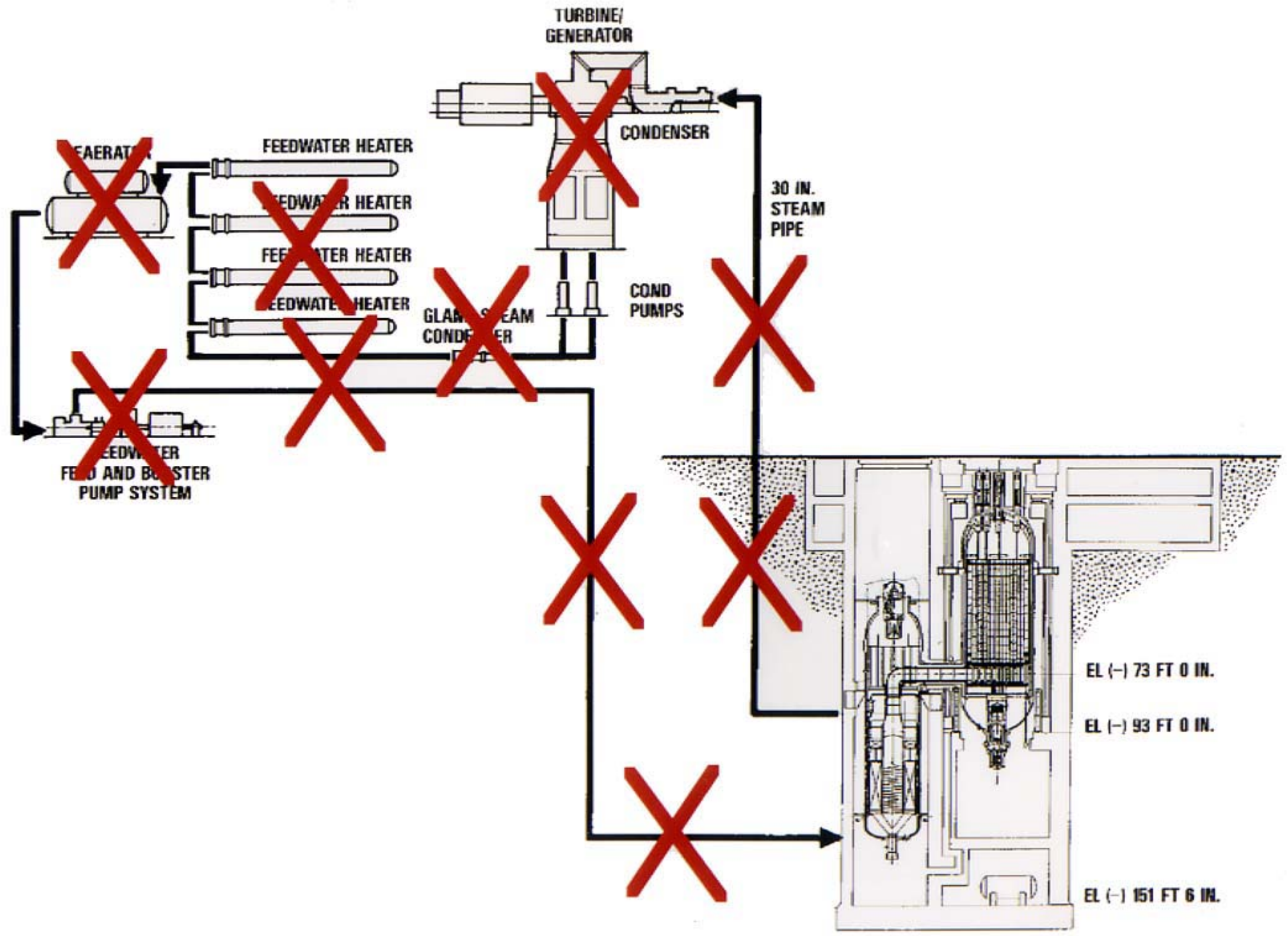
GAS TURBINE - MODULAR HELIUM REACTOR DEVELOPED FOR ENHANCED ECONOMICS

- **Thermal Efficiency of HTGR Power Plants with Rankine (Steam) Cycle Limited to ~38%**
- **Direct Gas Turbine (Brayton) Cycle Long Time Vision and Incentive for HTGR Development**
- **Gas Turbine Brayton Cycle Improves Economics**
  - *Significantly increases thermal efficiency*
  - *Significantly reduces plant equipment requirements*

HIGH TEMPERATURE GAS REACTORS HAVE UNIQUE ABILITY TO USE BRAYTON CYCLE

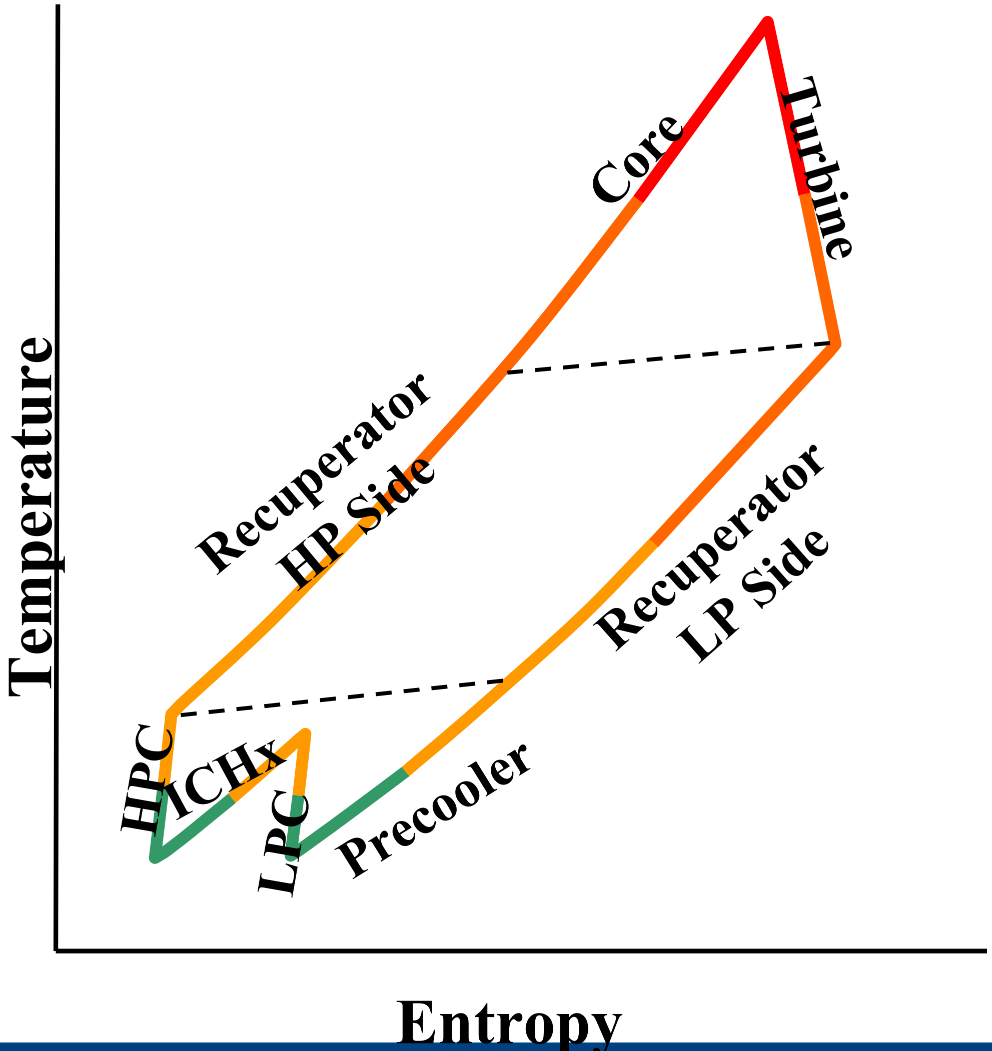


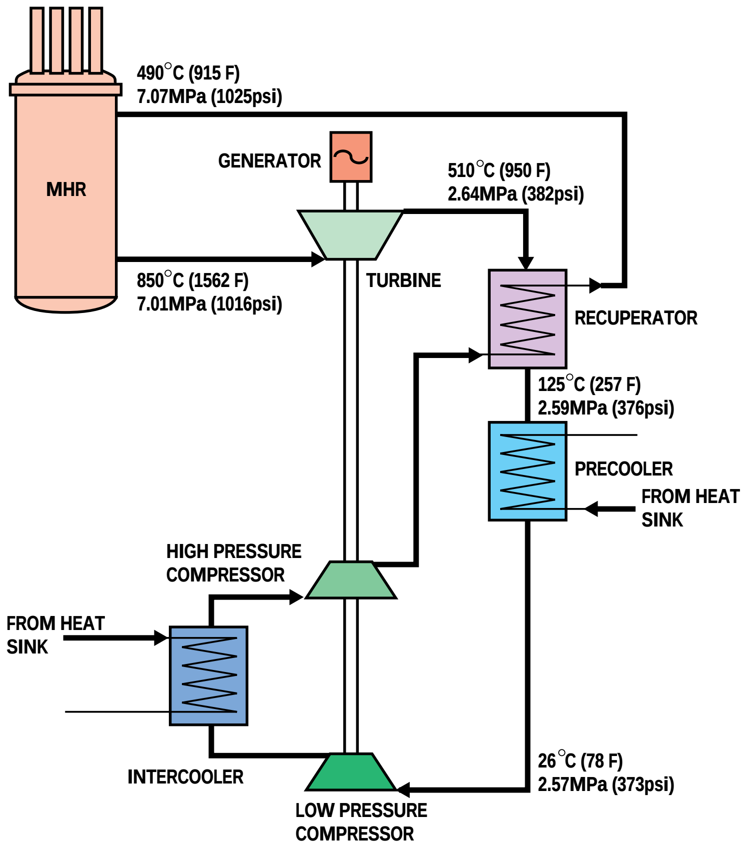
DIRECT CYCLE ELIMINATES MANY COMPLICATED AND EXPENSIVE COMPONENTS



. . . **REDUCES O&M / IMPROVES PLANT AVAILABILITY**

Brayton Cycle





POWER CONVERSION COMPONENTS

Compressors & Turbines

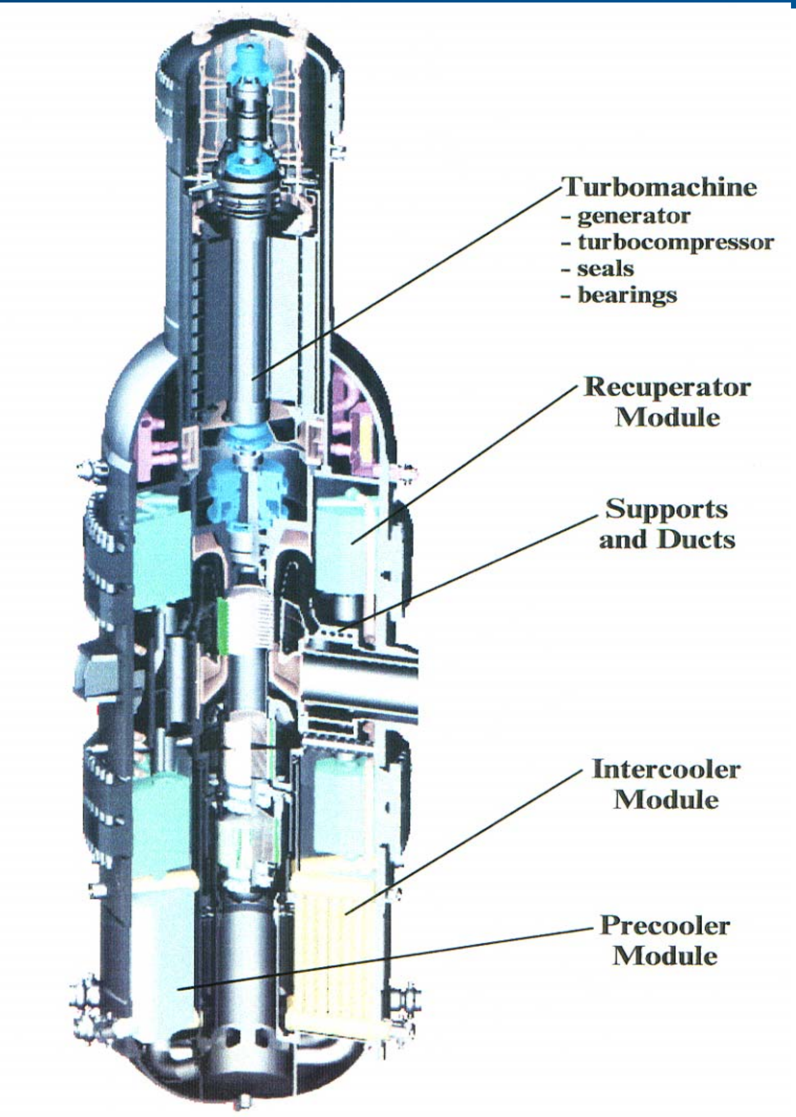
Generators

Bearings

Recuperator

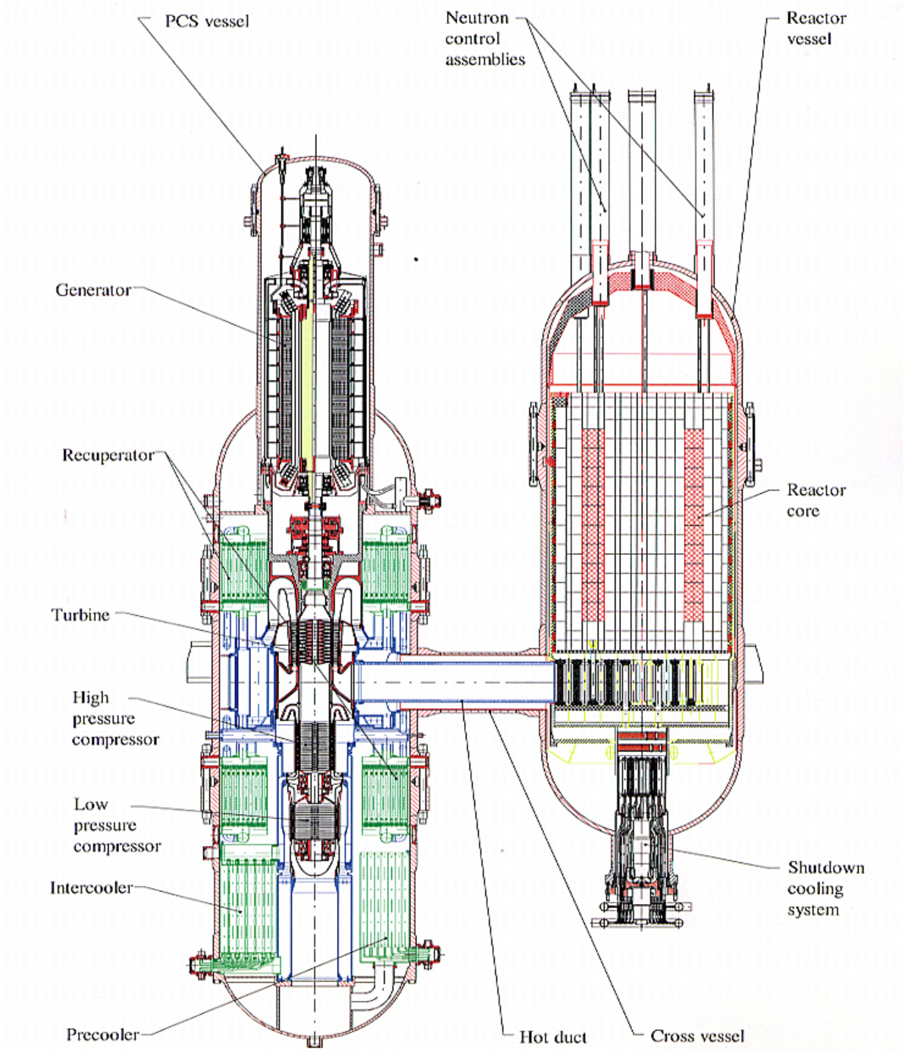
Precoolers

Intercoolers

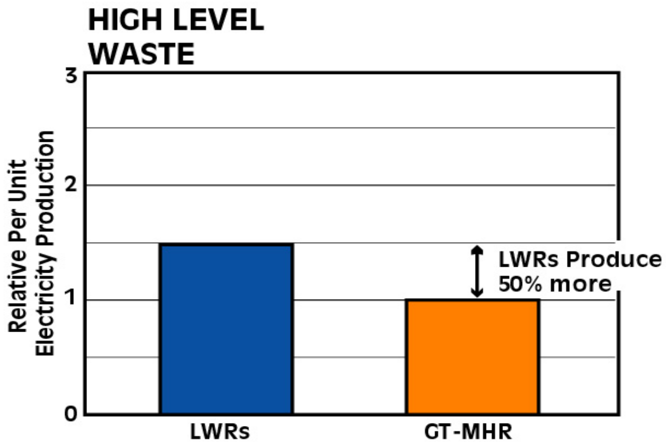


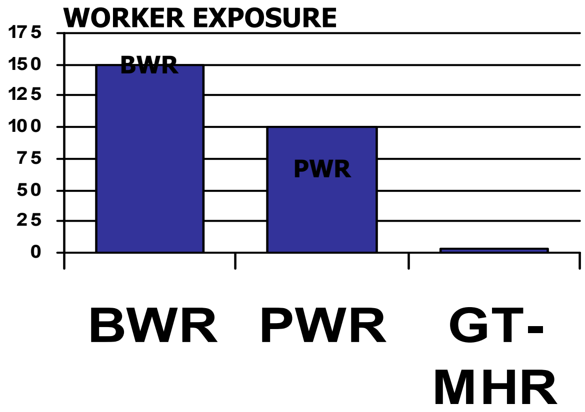
GT-MHR COMBINES MELTDOWN-PROOF ADVANCED REACTOR AND GAS TURBINE

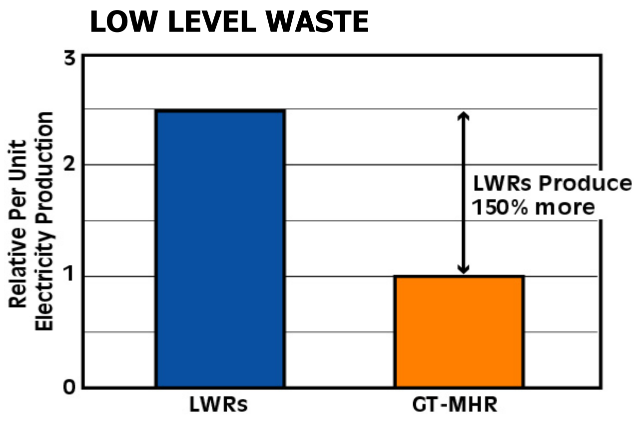
POWER LEVEL 600 MWt

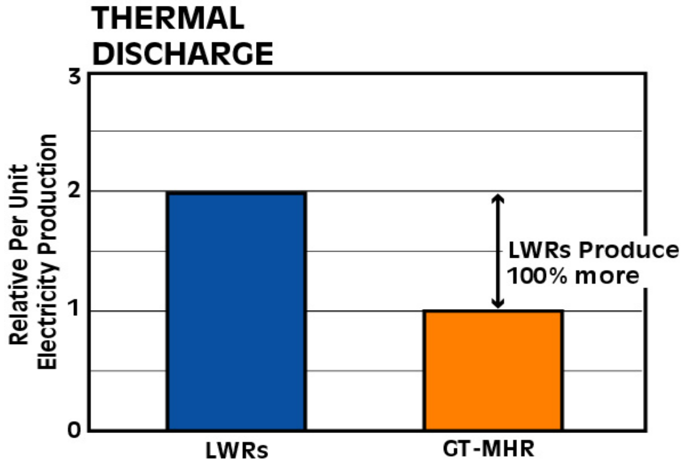


Very Low Environmental Impact









GT-MHR HAS HIGH PROLIFERATION RESISTANCE AND SATISFIES SAFEGUARD REQUIREMENTS

- **GT-MHR utilizes low enriched fuel**
- **Fuel particle refractory coatings make fissile material retrieval difficult**
- **Low fissile material volume fraction makes diversion of adequate heavy metal quantities difficult**
- **High spent fuel burnup degradation of Pu isotopic composition make it unattractive for weapons**
- **Neither a developed process nor capability anywhere in world for separating fissionable material from GT-MHR spent fuel**

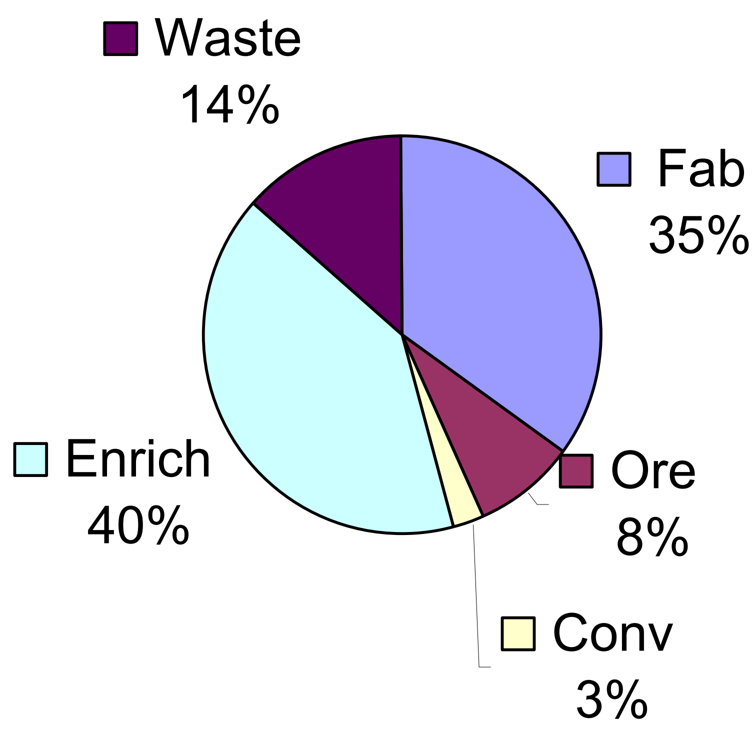
GT-MHR CAPITAL COST ESTIMATES

Four Module Plant (Millions 2002 US Dollars)

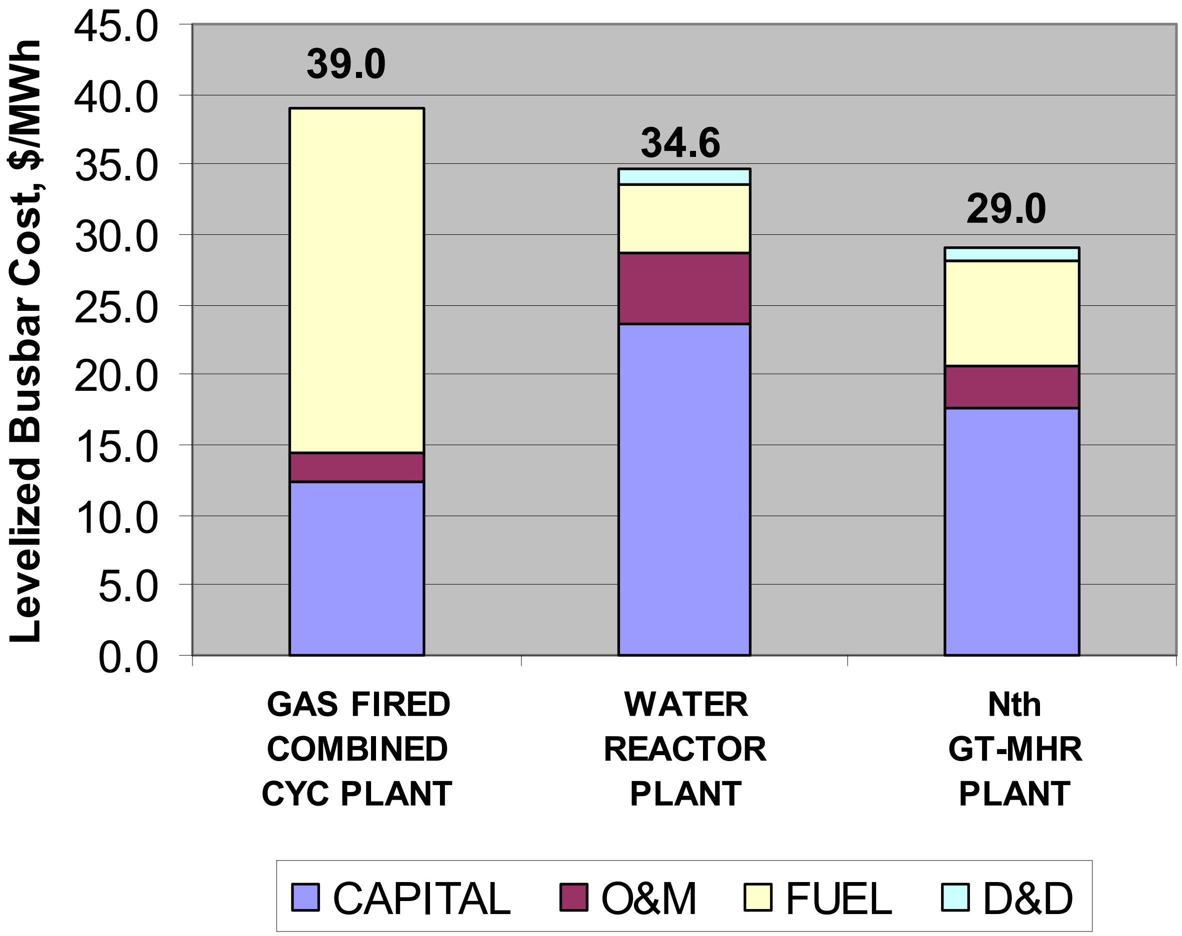
	Replica Plant	Target Plant
Direct Cost	902	789
Indirect Cost	318	274
Contingency	122	53
Total Cost	1342	1116
$/KW(e)	1172	975

GT-MHR FUEL CYCLE COST COMPONENTS

NOAK PLANT FUEL CYCLE COST = 7.4 $/MWh



BUSBAR GENERATION COST COMPARISON



BENEFITS OF MODULAR CONSTRUCTION

- **Less total capital funds at risk during construction period**
- **Reduced interest during construction expense**
- **Capability to better match generation capacity to load growth**
  - Potential to operate fewer modules should load growth not materialize
  - Potential to add more modules should load demand increase

GT-MHR NOW BEING DEVELOPED IN INTERNATIONAL PROGRAM

- In Russia under joint US/RF agreement for management of surplus weapons Plutonium
- Sponsored jointly by US (DOE) and RF (Minatom); supported by Japan and EU through ISTC.
- Conceptual design completed; preliminary design complete early 2002
- Developmental testing underway

SUMMARY

- High level of inherent safety eliminating core melt without operator action
- Brayton cycle power conversion system for high thermal efficiency (~50% higher than LWRs)
- Low electricity generation cost (reduced equipment capital and O&M; high thermal efficiency)
- Significantly reduced environmental impact
- Superior radionuclide retention for long-term spent disposal
- High proliferation resistance