High Temperature Gas Reactors
The Next Generation ?

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Fundamentals of Technology

- Use of Brayton vs. Rankine Cycle
- High Temperature Helium Gas (900 C)
- Direct or Indirect Cycle
- Originally Used Steam Generators
- Advanced Designs Use Helium w/wo HXs
- High Efficiency (45% - 50%)
- Microsphere Coated Particle Fuel

History of Gas Reactors in US

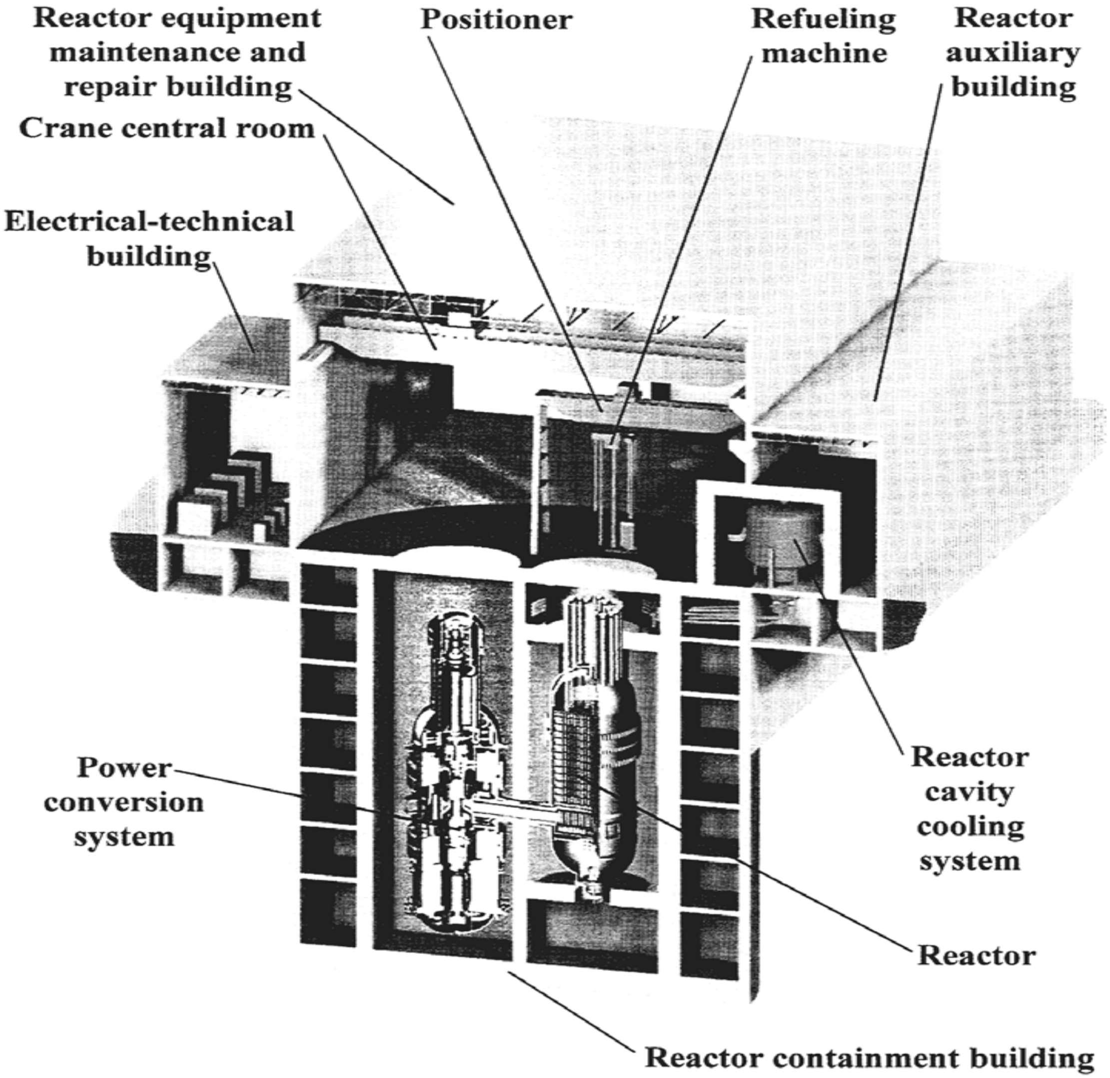
- Peach Bottom (40 MWe) 1967-1974
  - First Commercial (U/Thorium Cycle)
  - Generally Good Performance (75% CF)
- Fort St. Vrain (330 MWe) 1979-1989 (U/Th)
  - Poor Performance
  - Mechanical Problems
  - Decommissioned

Fort St. Vrain

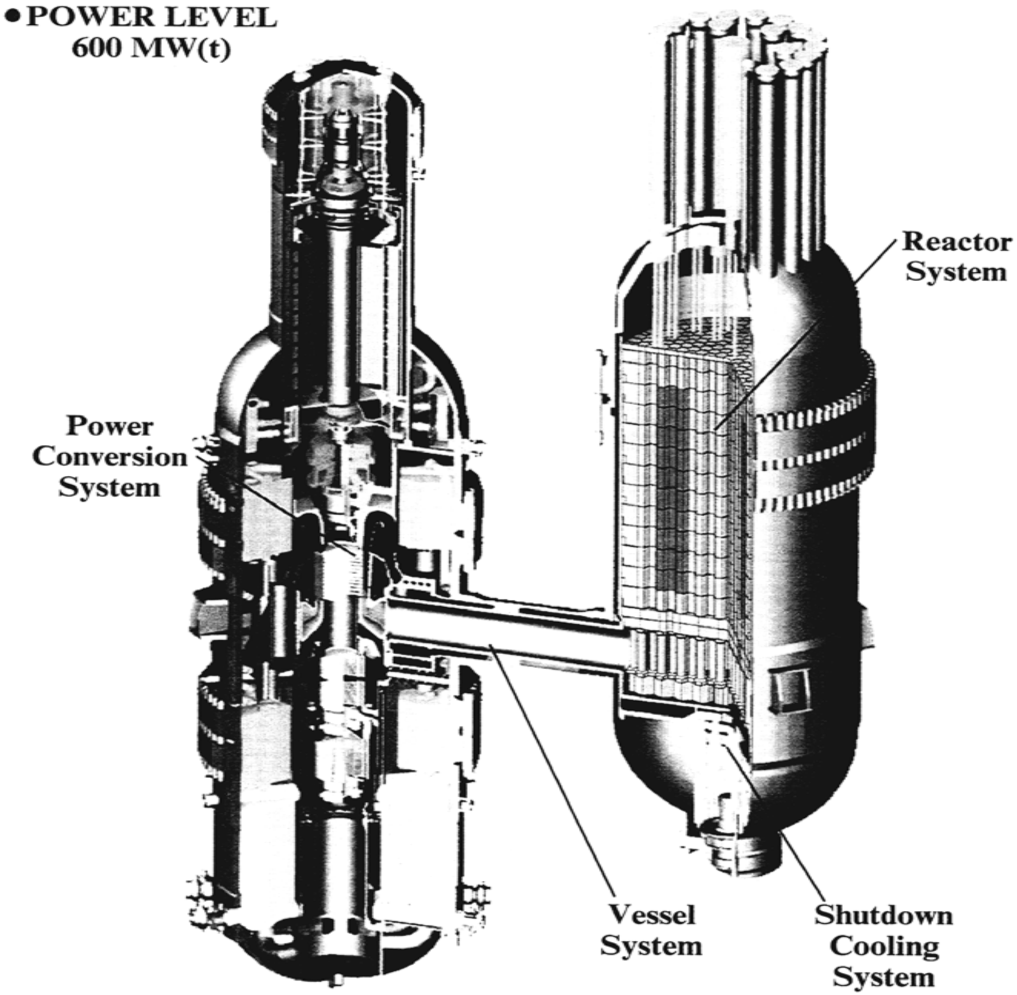
Different Types of Gas Reactors

- Prismatic (Block) - General Atomics
  - Fuel Compacts in Graphite Blocks
- Pebble Bed - German Technology
  - Fuel in Billiard Ball sized spheres
- Direct Cycle
- Indirect Cycle
- Small Modular vs. Large Reactors

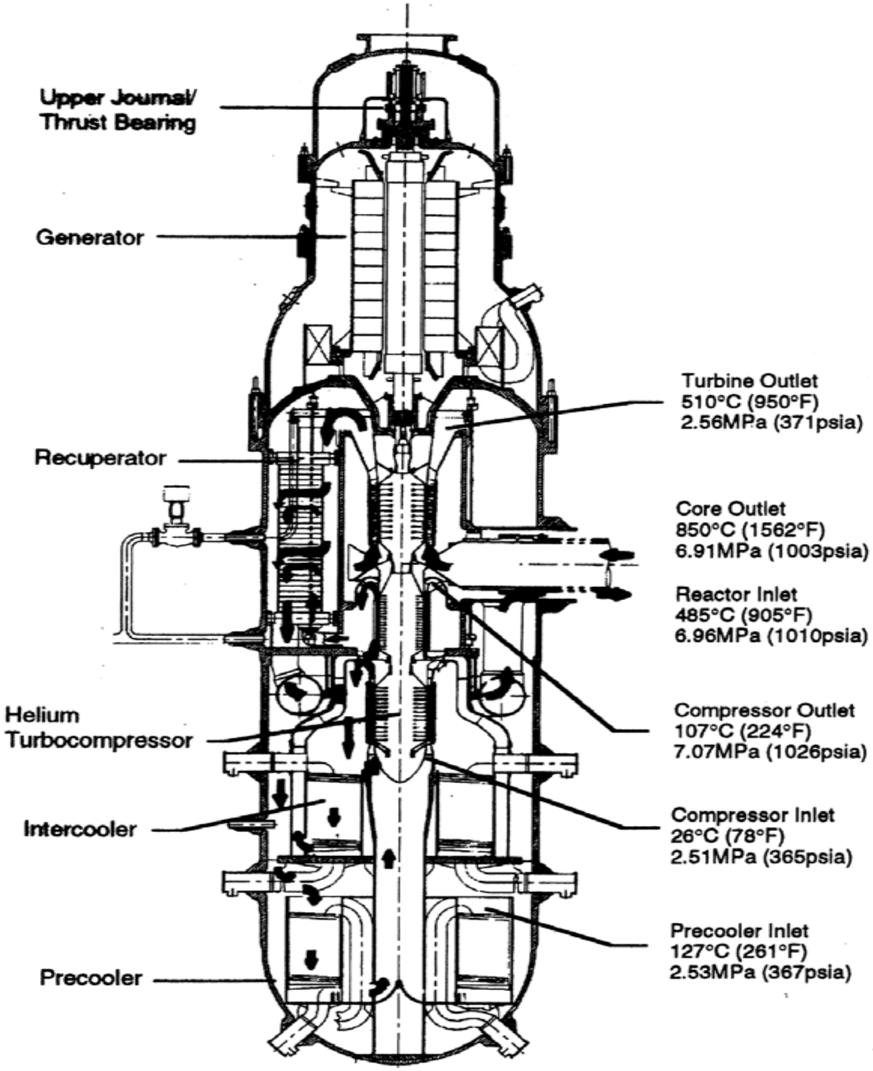
GT-MHR Module General Arrangement



GT-MHR Combines Meltdown-Proof Advanced Reactor and Gas Turbine

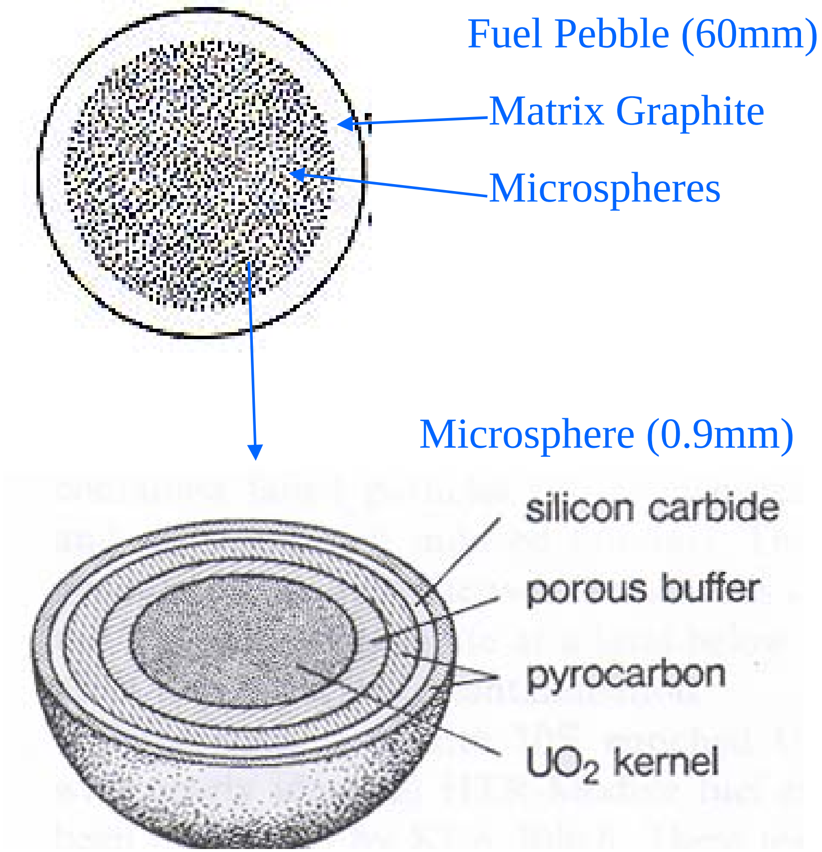


Flow through Power Conversion Vessel



GENERAL ATOMICS

TRISO Fuel Particle -- “Microsphere”


Fuel Pebble (60mm)

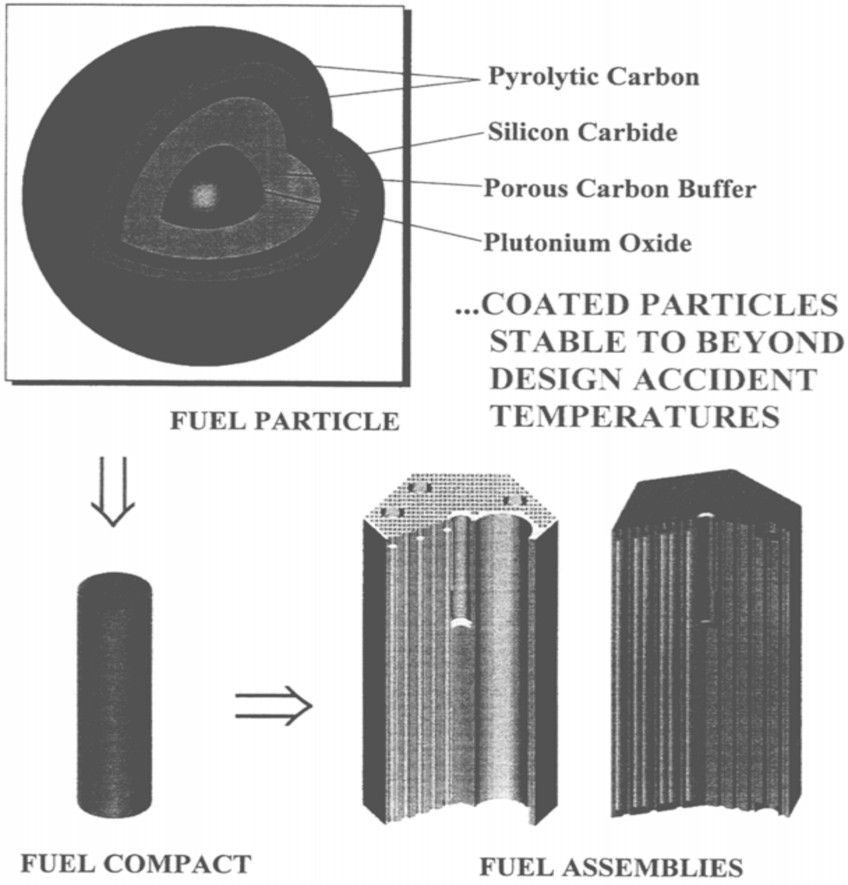
Matrix Graphite

Microspheres

Microsphere (0.9mm)

- 0.9mm diameter
- ~ 11,000 in every pebble
- 10^9 microspheres in core
- Fission products retained inside microsphere
- TRISO acts as a pressure vessel
- Reliability
  - Defective coatings during manufacture
  - ~ 1 defect in every fuel pebble

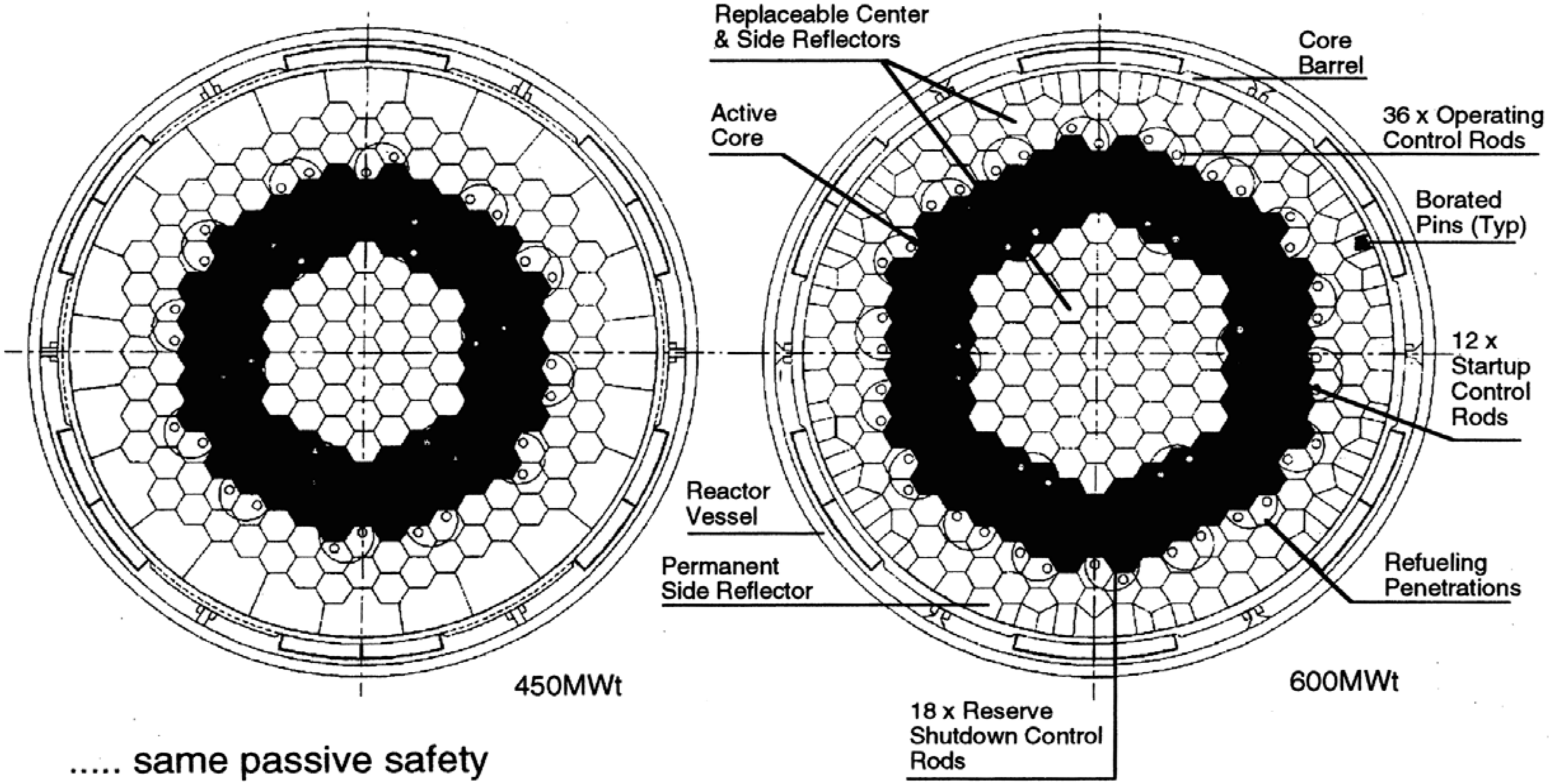
Fuel Components with Plutonium Load



...COATED PARTICLES STABLE TO BEYOND DESIGN ACCIDENT TEMPERATURES

- Fuel Normal Peak Temperature 1200 °C
- Fuel Maximum Design Basis Event Temperature 1600 °C

Comparison of 450 MWt and 600 MWt Cores

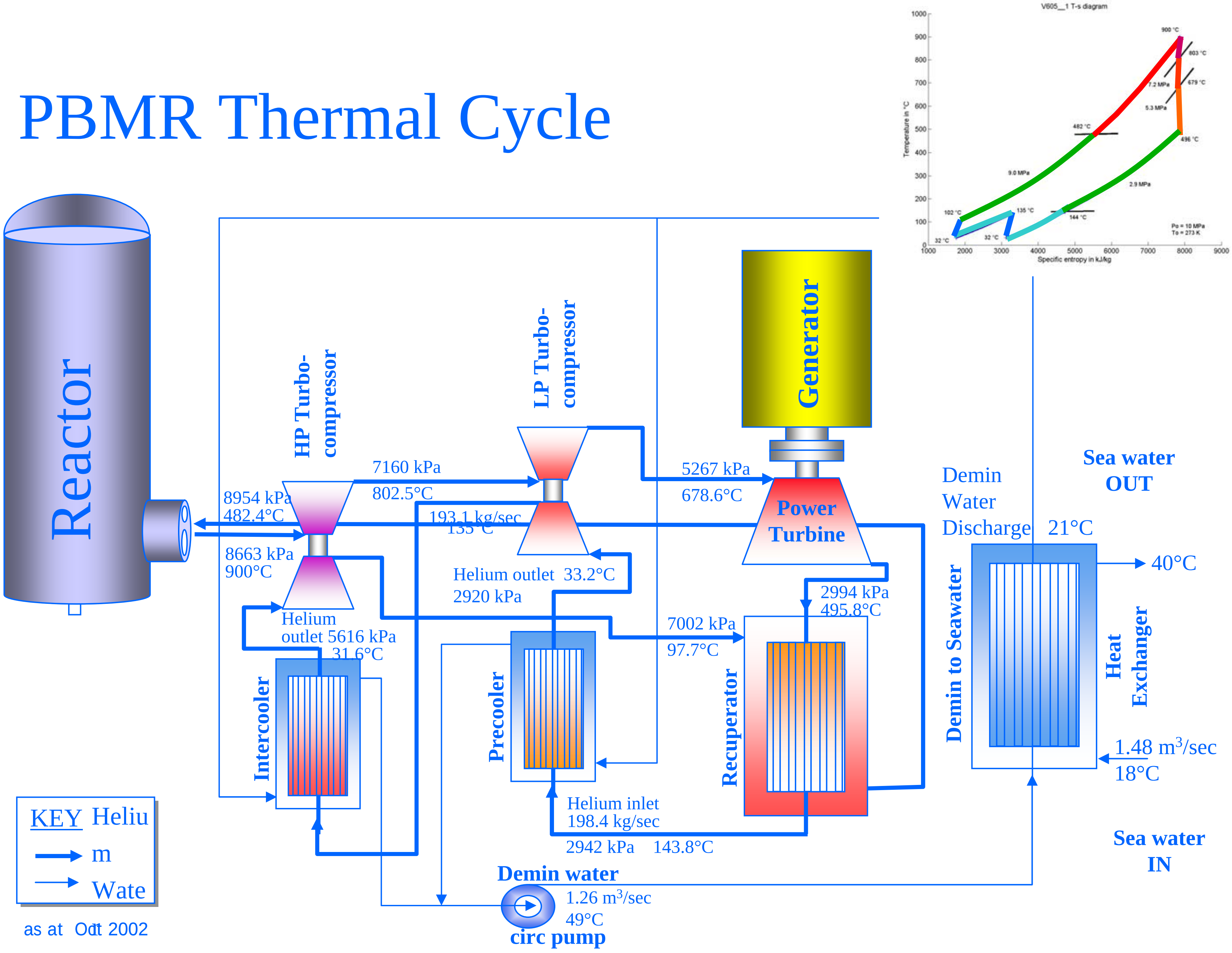


..... same passive safety

..... annular core using existing technology

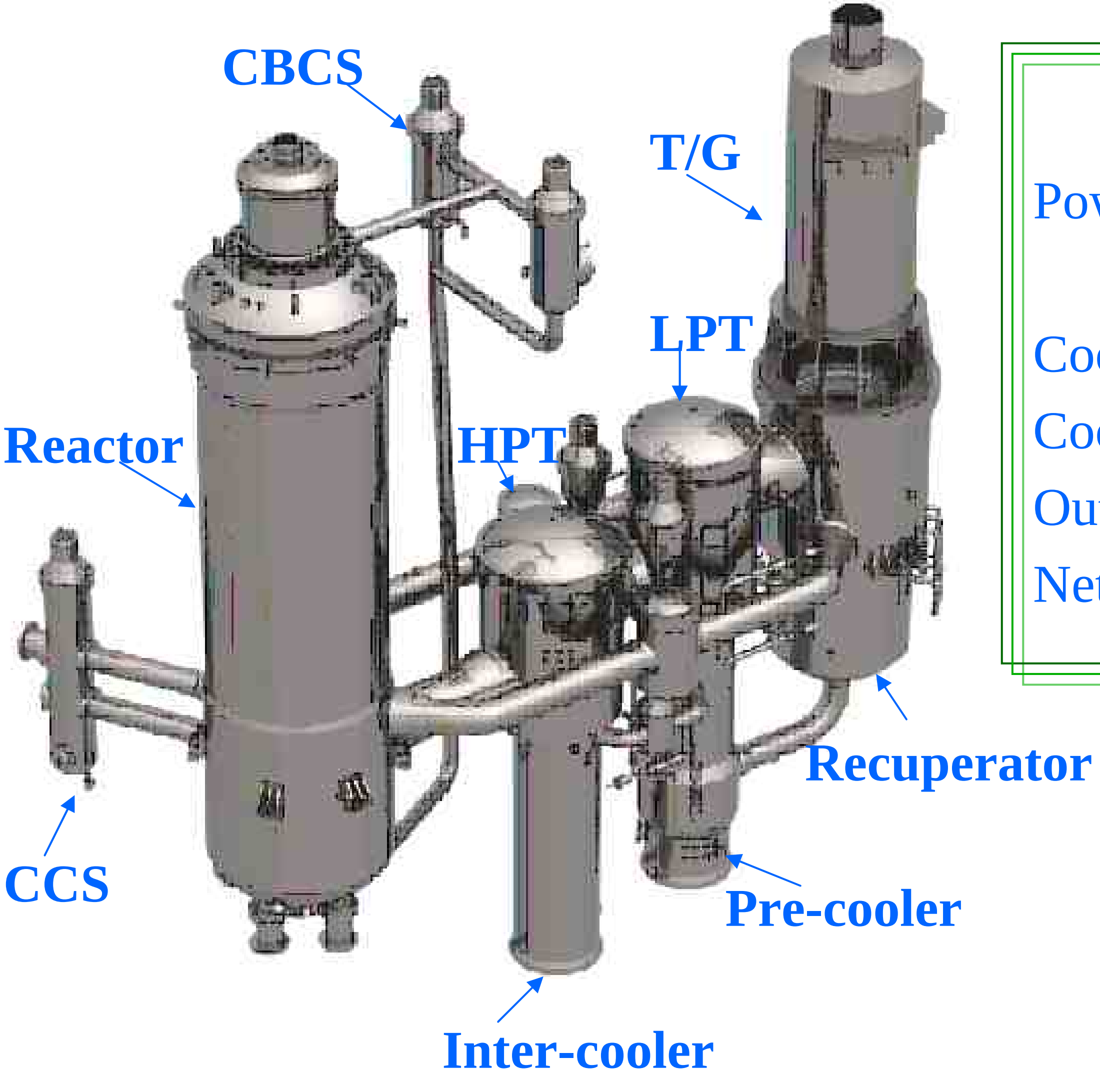
GENERAL ATOMICS

PBMR Thermal Cycle



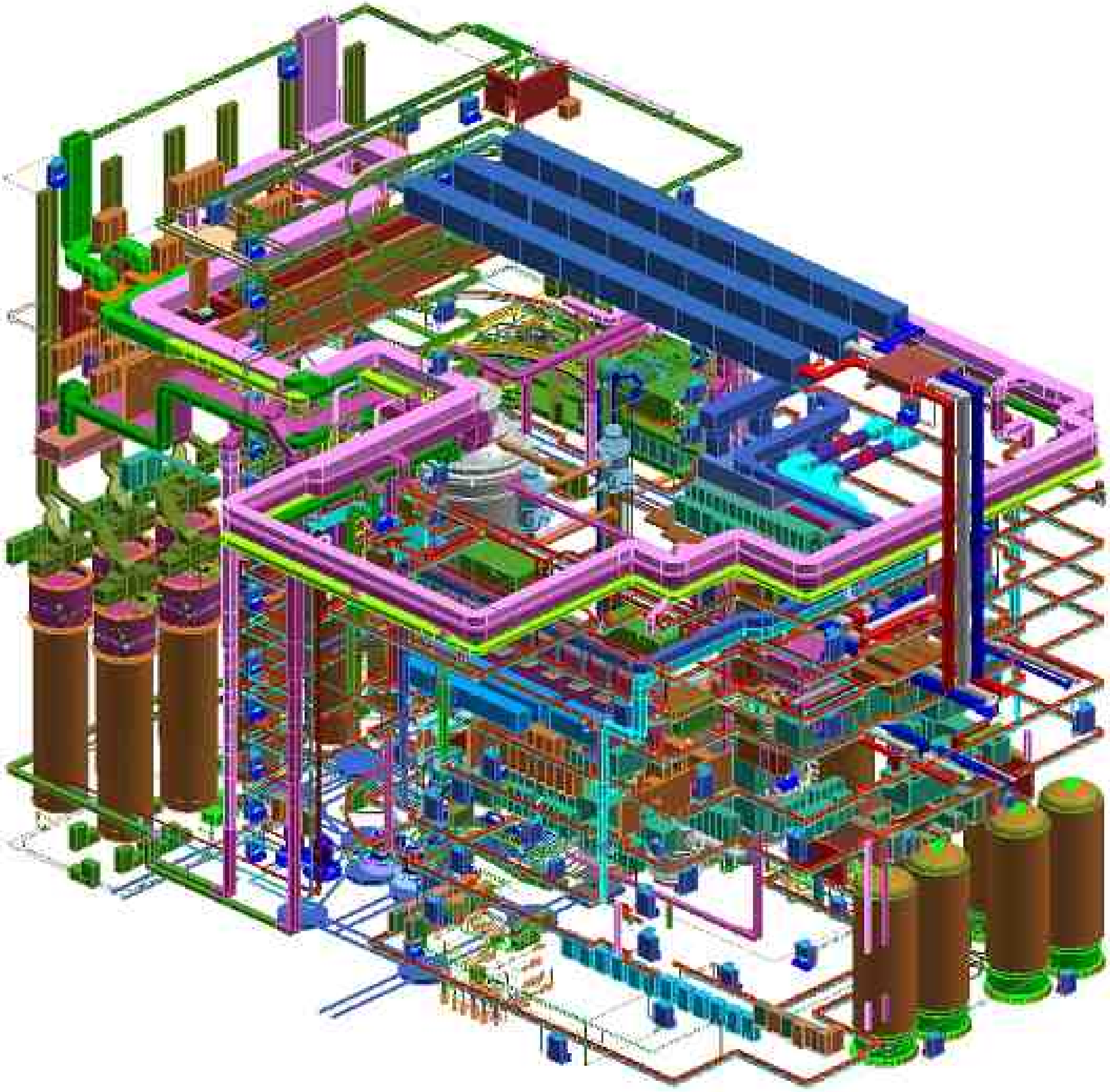
as at Oct 2002

Main Power System



Power output:	400MWt 165 MWe
Coolant:	Helium
Coolant pressure:	9 MPa
Outlet temperature:	900°C
Net cycle efficiency:	>41%

Integrated Plant Systems



Differences Between LWRS

- Higher Thermal Efficiencies Possible
- Helium inert gas - non corrosive
- Minimizes use of water in cycle
- Utilizes gas turbine technology
- Lower Power Density
- Less Complicated Design (No ECCS)

Advantages & Disadvantages

Advantages

- Higher Efficiency
- Lower Waste Quantity
- Higher Safety Margins
- High Burnup
  - 100 MWD/kg

Disadvantages

- Poor History in US
- Little Helium Turbine Experience
- US Technology Water Based
- Licensing Hurdles due to different designs

Advanced Nuclear Energy Plants (Generation IV)

- Competitive with Natural Gas
- Demonstrated Safety
- Proliferation Proof
- Disposable High Level Waste Form
- Used Internationally to Meet CO_2 Build-Up in the Environment

International Activities

Countries with Active HTGR Programs

- China - 10 MWth Pebble Bed - 2000 critical
- Japan - 40 MWth Prismatic
- South Africa - 250 MWth Pebble - 2006
- Russia - 290 MWe - Pu Burner Prismatic 2007 (GA, Framatome, DOE, etc)
- Netherlands - small industrial Pebble
- Germany (past) - 300 MWe Pebble Operated
- MIT - 250 MWth - Intermediate Heat Exch.

Pebble Bed Modular Reactor

South Africa

- 165 MWe Pebble Bed Plant - ESKOM
- Direct Helium High Temperature Cycle
- In Licensing Process
- Schedule for construction start 2006/7
- Operation Date 2010
- Commercial Reference Plant

AVR: Jülich

15 MWe Research Reactor

THTR: Hamm-Uentrop

300 Mwe Demonstration Reactor

Modular High Temperature Gas Reactor
Russia

- General Atomics Design
- 290 MWe - Prismatic Core
- Excess Weapons Plutonium Burner
- In Design Phase in Russia
- Direct Cycle
- Start of Construction - 2007

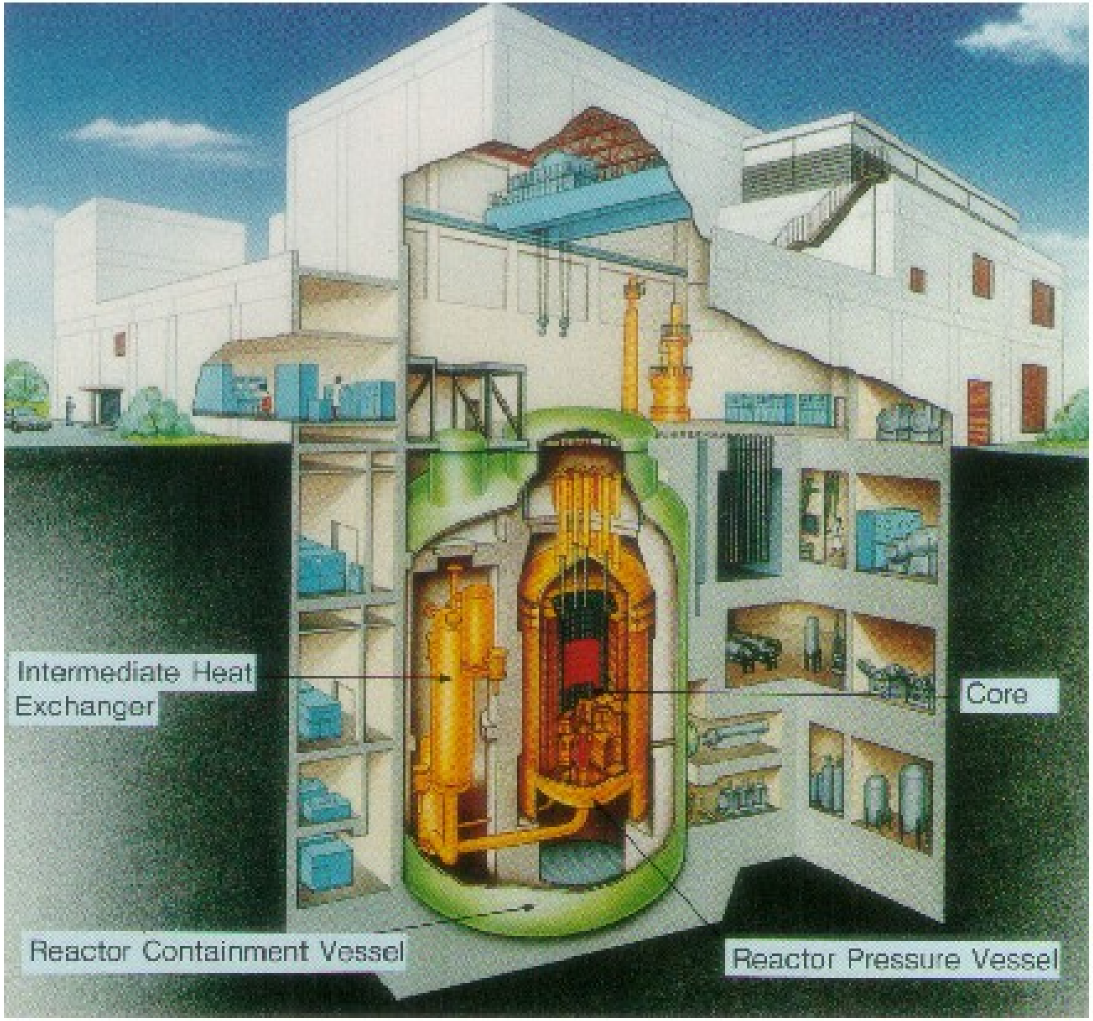
High Temperature Test Reactor

Japan

- 40 MWth Test Reactor
- First Critical 1999
- Prismatic Core
- Intermediate Heat Exchanger
- Currently in Testing for Power Ascension

High Temperature Test Reactor

High Temperature Test Reactor (HTTR)



High Temperature Reactor

China

- 10 MWth - 4 MWe Electric Pebble Bed
- Under Construction
- Initial Criticality Dec 2000
- Intermediate Heat Exchanger - Steam Cycle

HTR- 10 China
First Criticality Dec.1, 2000

Modular Pebble Bed Reactor
MIT/INEEL

- Pebble Bed Design
- 120 MWe
- Intermediate Heat Exchanger Helium/Helium
- Similar Core Design to ESKOM
- Balance of Plant Different

Project Objective

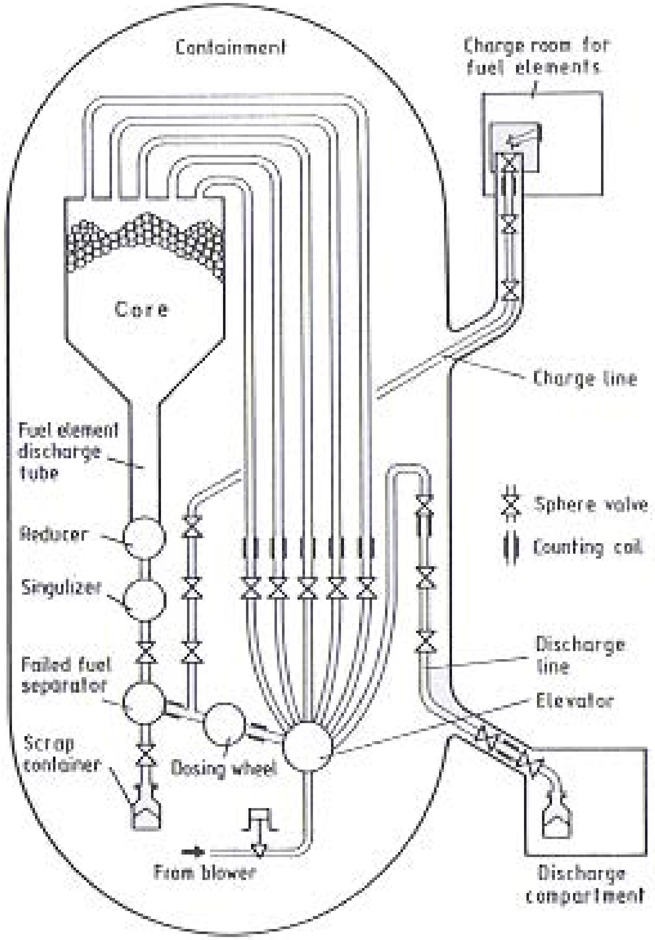
Develop a sufficient technical and economic basis for this type of reactor plant to determine whether it can compete with natural gas and still meet safety, proliferation resistance and waste disposal concerns.

Modular High Temperature Pebble Bed Reactor

- 110 MWe
- Helium Cooled
- “Indirect” Cycle
- 8 % Enriched Fuel
- Built in 2 Years
- Factory Built
- Site Assembled

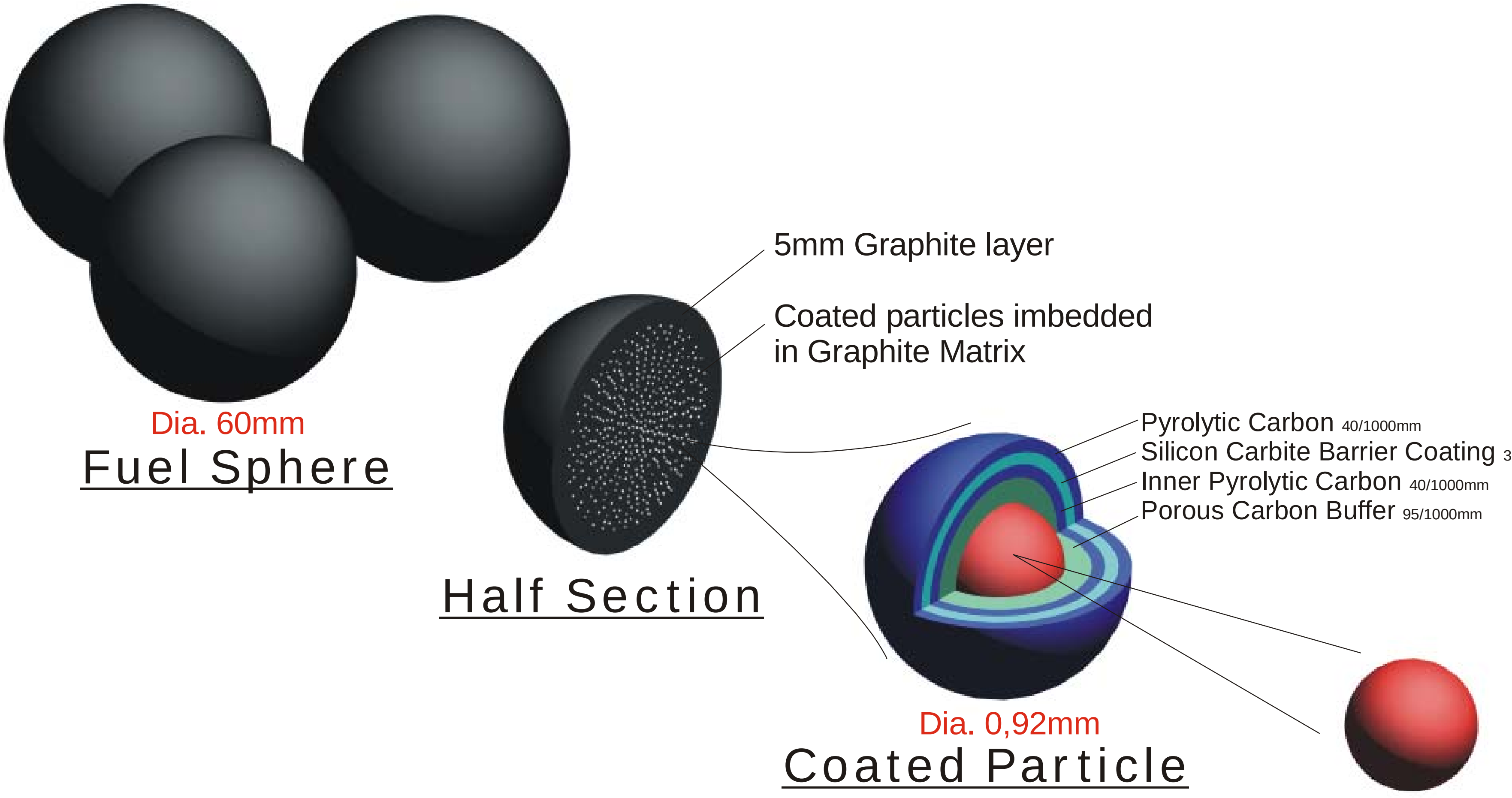
- On-line Refueling
- Modules added to meet demand.
- No Reprocessing
- High Burnup 90,000 MWd/MT
- Direct Disposal of HLW

What is a Pebble Bed Reactor ?



- 360,000 pebbles in core
- about 3,000 pebbles handled by FHS each day
- about 350 discarded daily
- one pebble discharged every 30 seconds
- average pebble cycles through core 15 times
- Fuel handling most maintenance-intensive part of plant

FUEL ELEMENT DESIGN FOR PBMR



Dia. 60mm

Fuel Sphere

5mm Graphite layer

Coated particles imbedded in Graphite Matrix

Half Section

Pyrolytic Carbon 40/1000mm

Silicon Carbite Barrier Coating 35/1000

Inner Pyrolytic Carbon 40/1000mm

Porous Carbon Buffer 95/1000mm

Dia. 0,92mm

Coated Particle

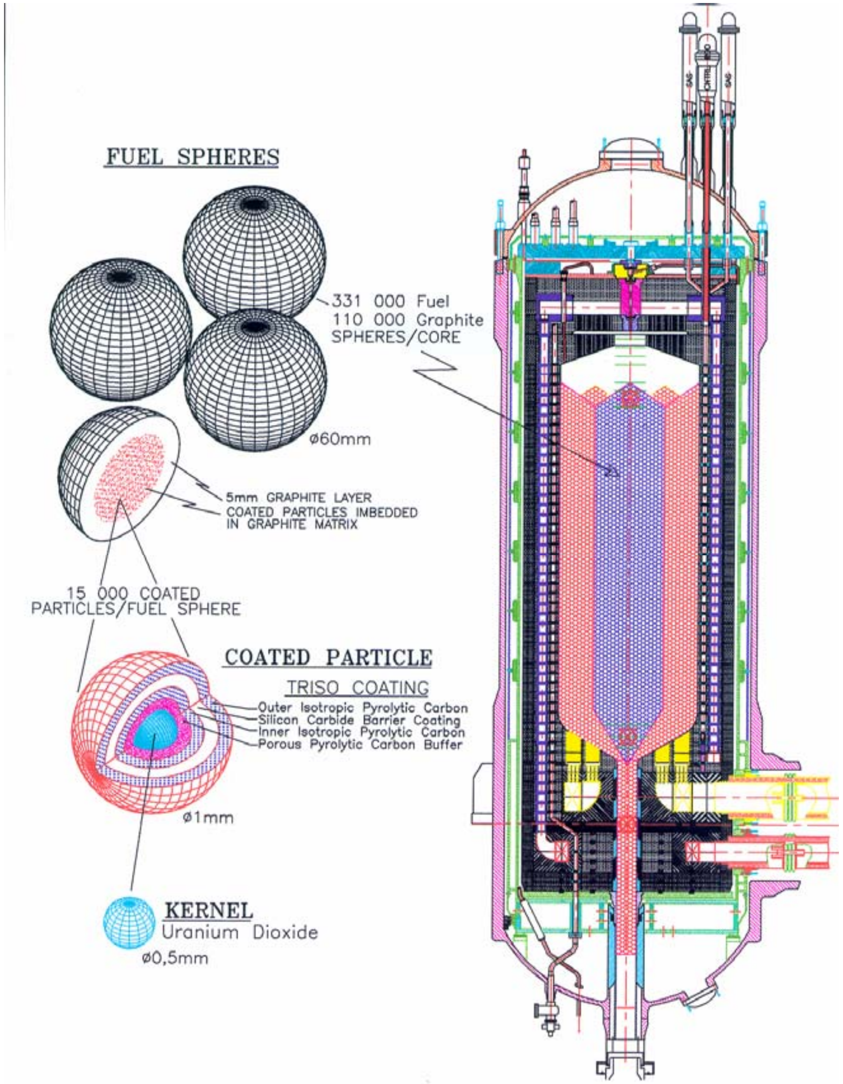
Dia.0,5mm

Uranium Dioxide

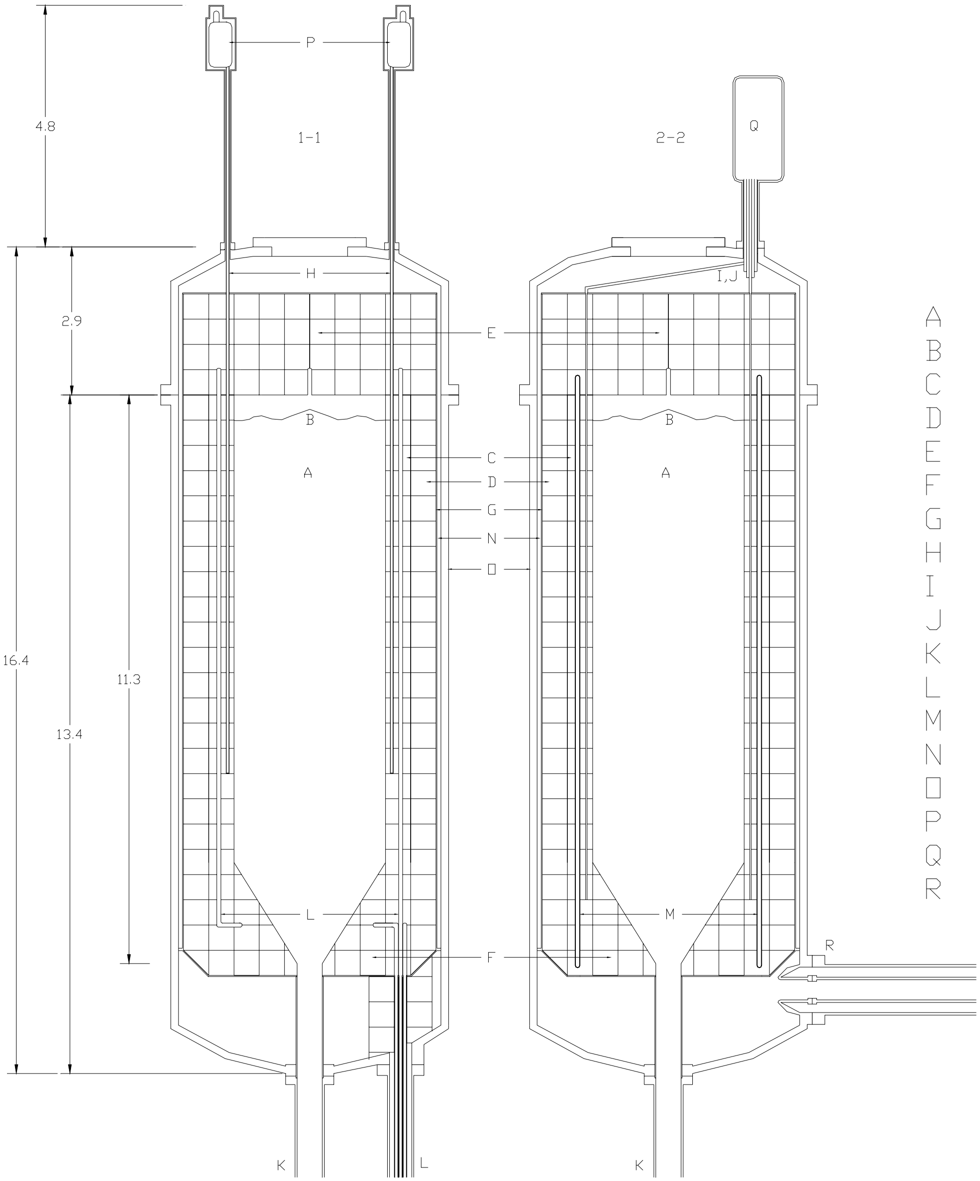
Fuel

Core Neutronics

- Helium-cooled, graphite moderated high-temp reactor
- ~360,000 fuel balls in a cylindrical graphite core
- central graphite reflector
- graphite fuel balls added and removed every 30 s
- recycle fuel balls up to 15 times for high burnup

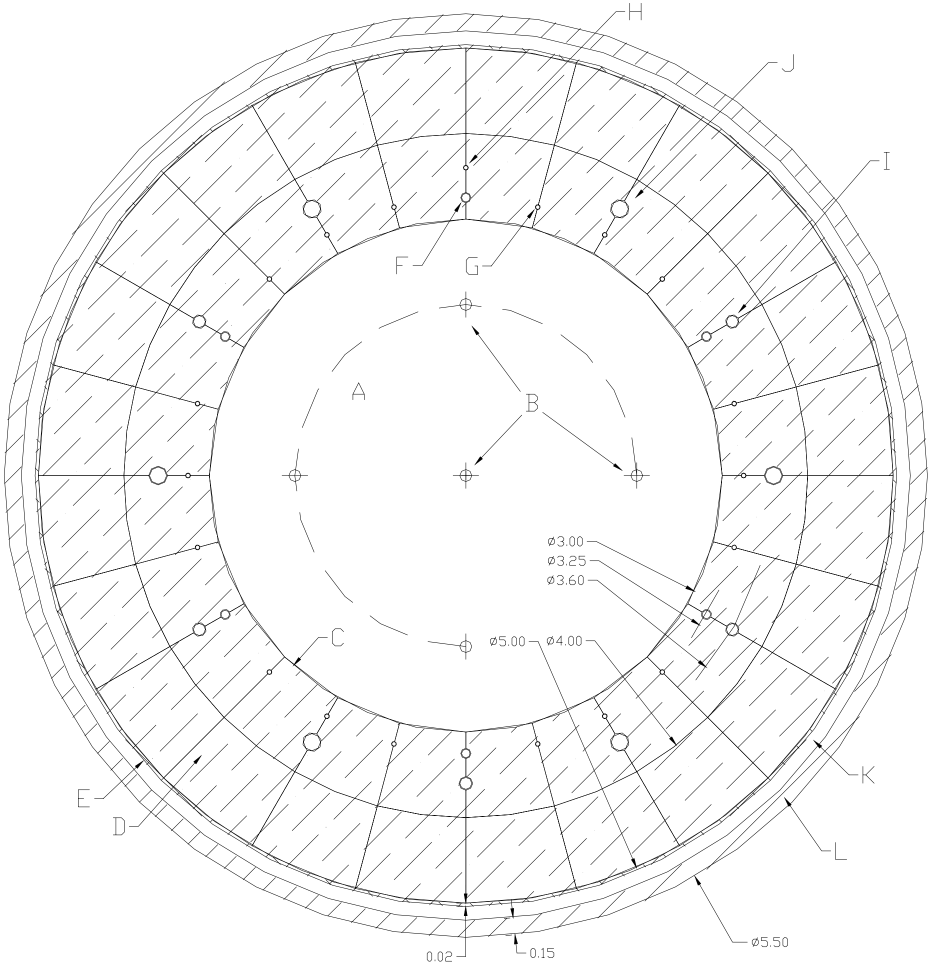


MPBR Side Views



A	Pebble Bed Core
B	Fuel Drop Points (5)
C	Inner Reflector
D	Outer Reflector
E	Top Reflector
F	Bottom Reflector
G	Core Barrel
H	Control Rod Channels (6)
I	Absorber Ball Drop Channels (18)
J	Absorber Ball Lift Channel (1)
K	Fuel Discharge Tube
L	Pebble Fuel Lift Channels (5)
M	Coolant Flow Channels (6)
N	Stagnant Helium Gap
O	Pressure Vessel
P	Control Rod Drivers
Q	Absorber Ball Container
R	Coaxial Pipe to IHX Module

MPBR Core Cross Section



A Pebble Bed Core

B Pebble Deposit Points

C Inner Reflector

D Outer Reflector

E Core Barrel

F Control Rod Channels

G,H Absorber Ball Channels

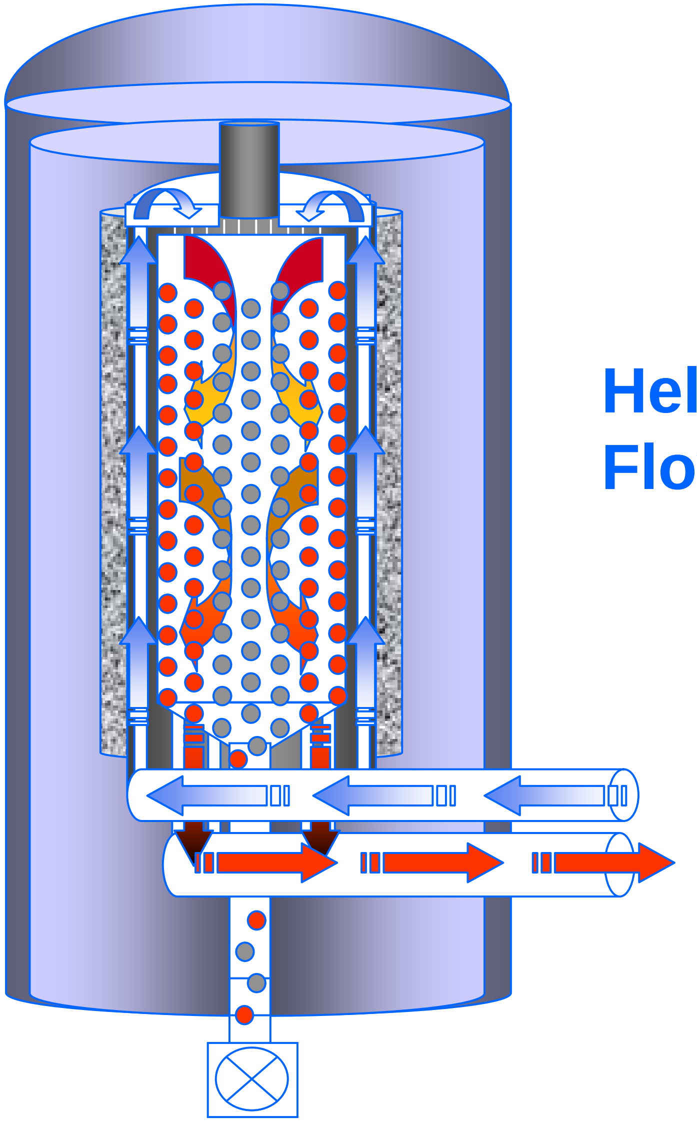
I Pebble Circulation Channels

J Helium Flow Channels

K Helium Gap

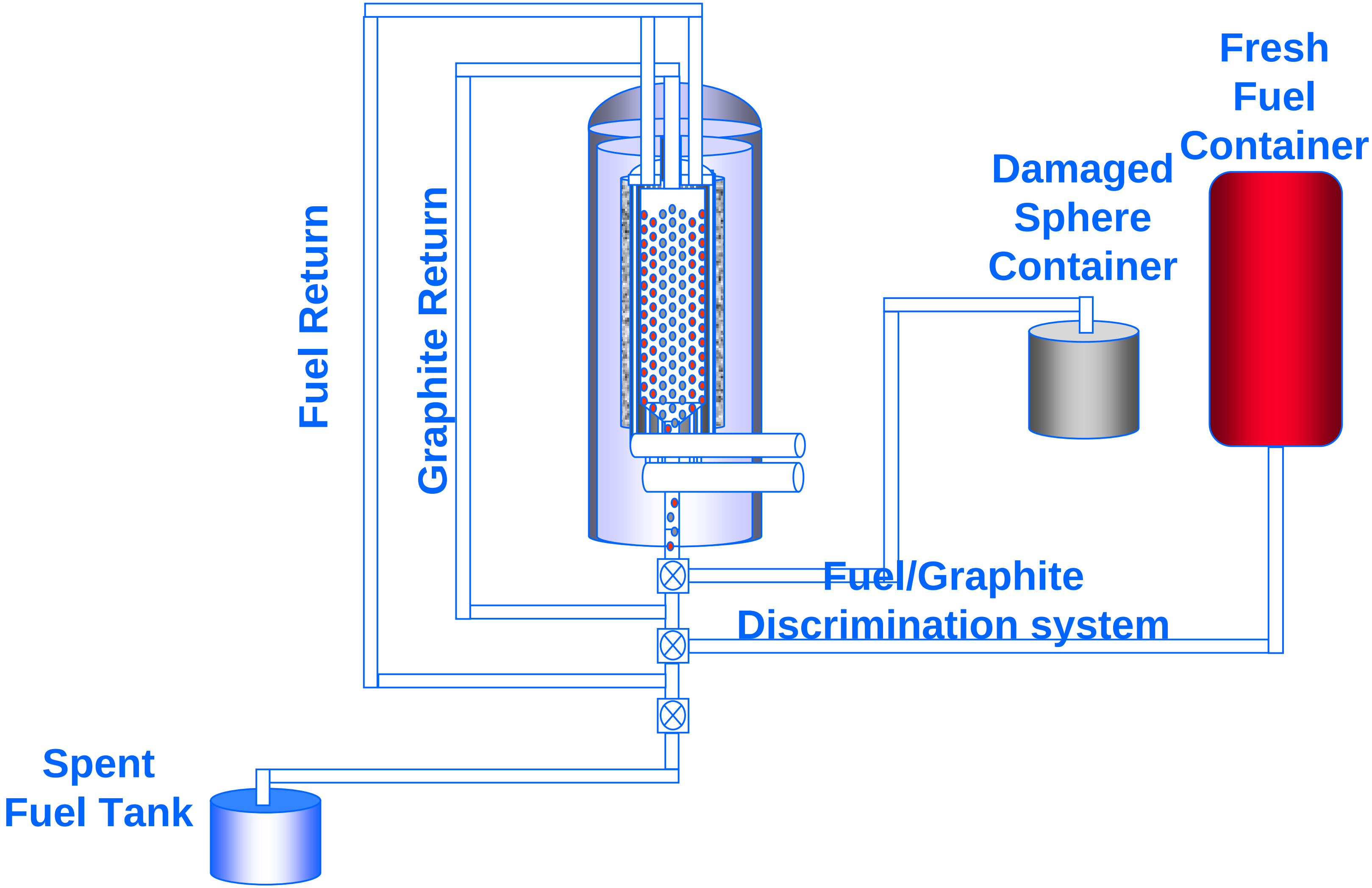
L Pressure Vessel

Reactor Unit

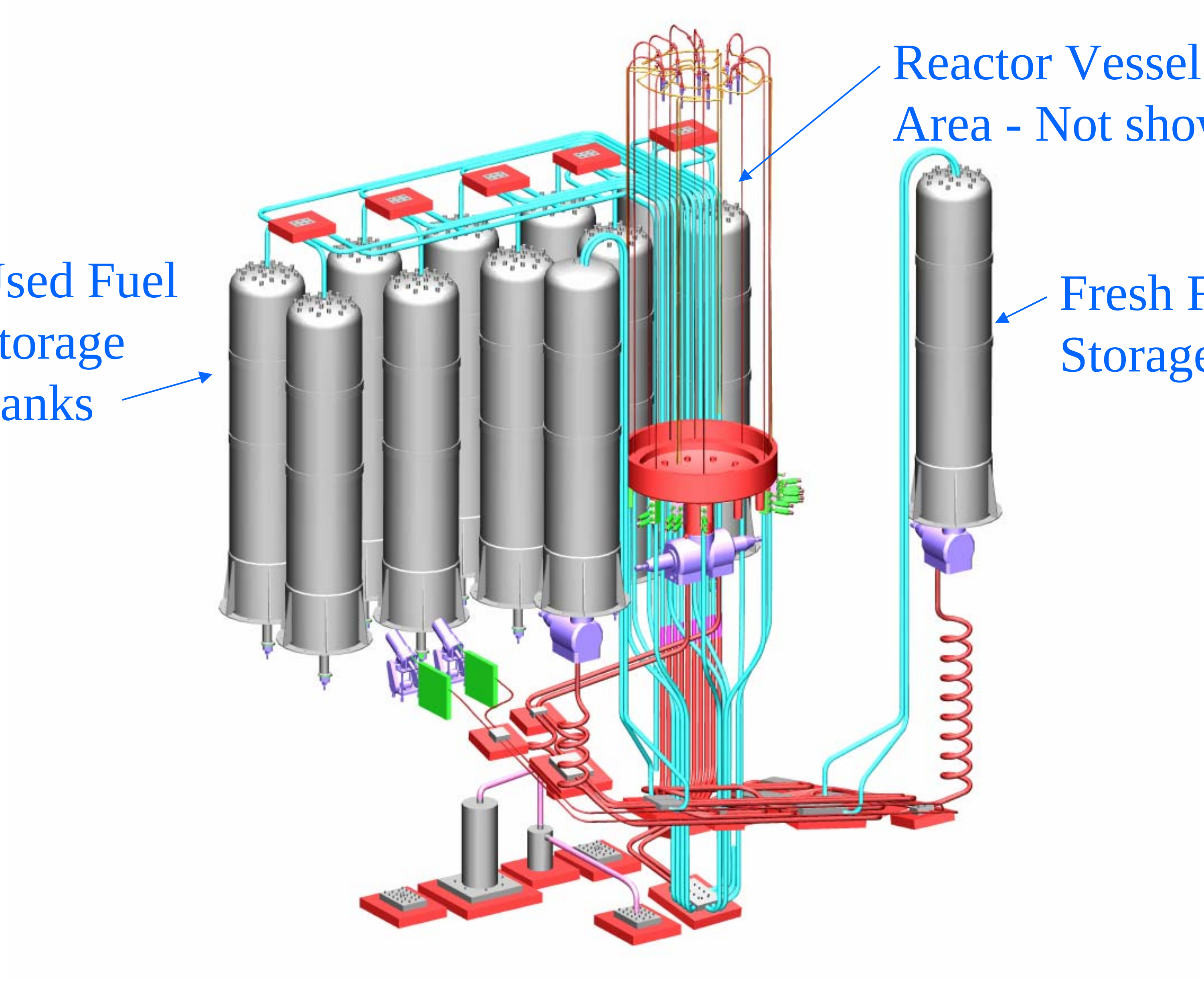


Helium Flowpath

Fuel Handling & Storage System



Fuel Handling System



Reactor Vessel in this Area - Not shown

Used Fuel Storage Tanks

Fresh Fuel Storage

MPBR Specifications

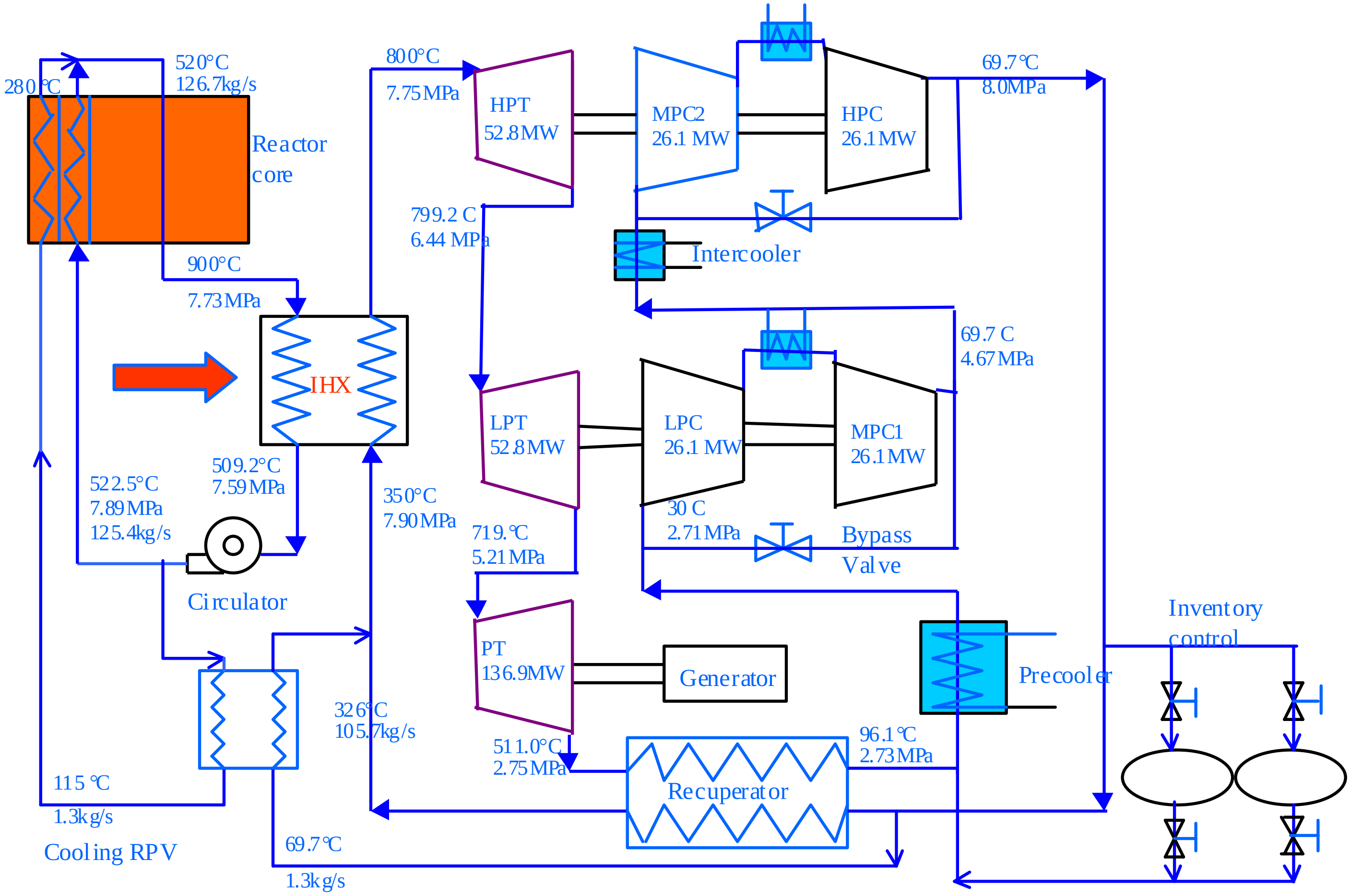
Thermal Power	250 MW
Core Height	10.0 m
Core Diameter	3.5 m
Pressure Vessel Height	16 m
Pressure Vessel Diameter	5.6 m
Number of Fuel Pebbles	360,000
Microspheres/Fuel Pebble	11,000
Fuel	UO$_2$
Fuel Pebble Diameter	60 mm
Fuel Pebble enrichment	8%
Uranium Mass/Fuel Pebble	7 g
Coolant	Helium
Helium mass flow rate	120 kg/s (100% power)
Helium entry/exit temperatures	520^{o}C/900^{o}C
Helium pressure	80 bar
Mean Power Density	3.54 MW/m^3
Number of Control Rods	6
Number of Absorber Ball Systems	18

Features of Current Design

Thermal Power	250 MW
Gross Electrical Power	132.5 MW
Net Electrical Power	120.3 MW
Plant Net Efficiency	48.1% (Not take into account cooling IHX and HPT. if considering, it is believed > 45%)
Helium Mass flowrate	126.7 kg/s
Core Outlet/Inlet T	900°C/520°C
Cycle pressure ratio	2.96
Power conversion unit	Three-shaft Arrangement

Indirect Cycle with Intermediate Helium to Helium Heat Exchanger

Current Design Schematic



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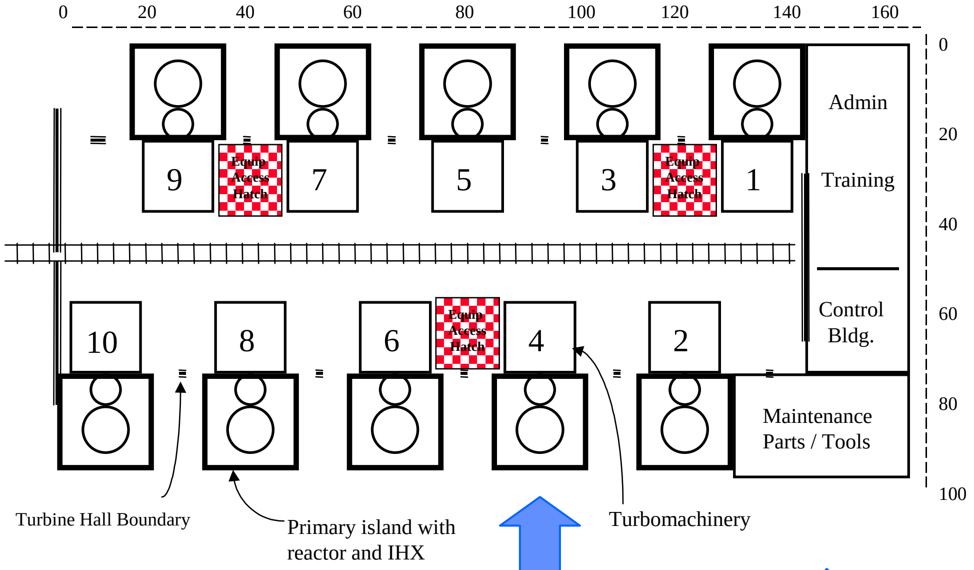
1150 MW Combined Heat and Power Station

VHTR Characteristics
- Temperatures > 900 C
- Indirect Cycle
- Core Options Available
- Waste Minimization

Ten-Unit VHTR Plant Layout (Top View)

(distances in meters)



Oil Refinery

Hydrogen Production

Desalinization Plant

Modularity Progression

- Conventional Nuclear Power Systems
    - Assembled on site
    - Component-level transportation
    - Extensive Site Preparation
- Advanced Systems
    - Mass Produced / “Off the Shelf” Designs
    - Construction / Assembly Still Primarily on Site
- MPBR
    - Mass Produced Components
    - Remote Assembly / Simple Transportation & Construction

This is different than other Generation IV approaches in that modularity is the objective which means smaller units.

MPBR Modularity Plan

- Road- Truck / Standard-Rail Transportable
  - 8 x 10 x 60 ft. 100,000 kg Limits

- Bolt-together Assembly
  - Minimum labor / time on site required
  - Minimum assembly tools
  - Goal: Zero Welding

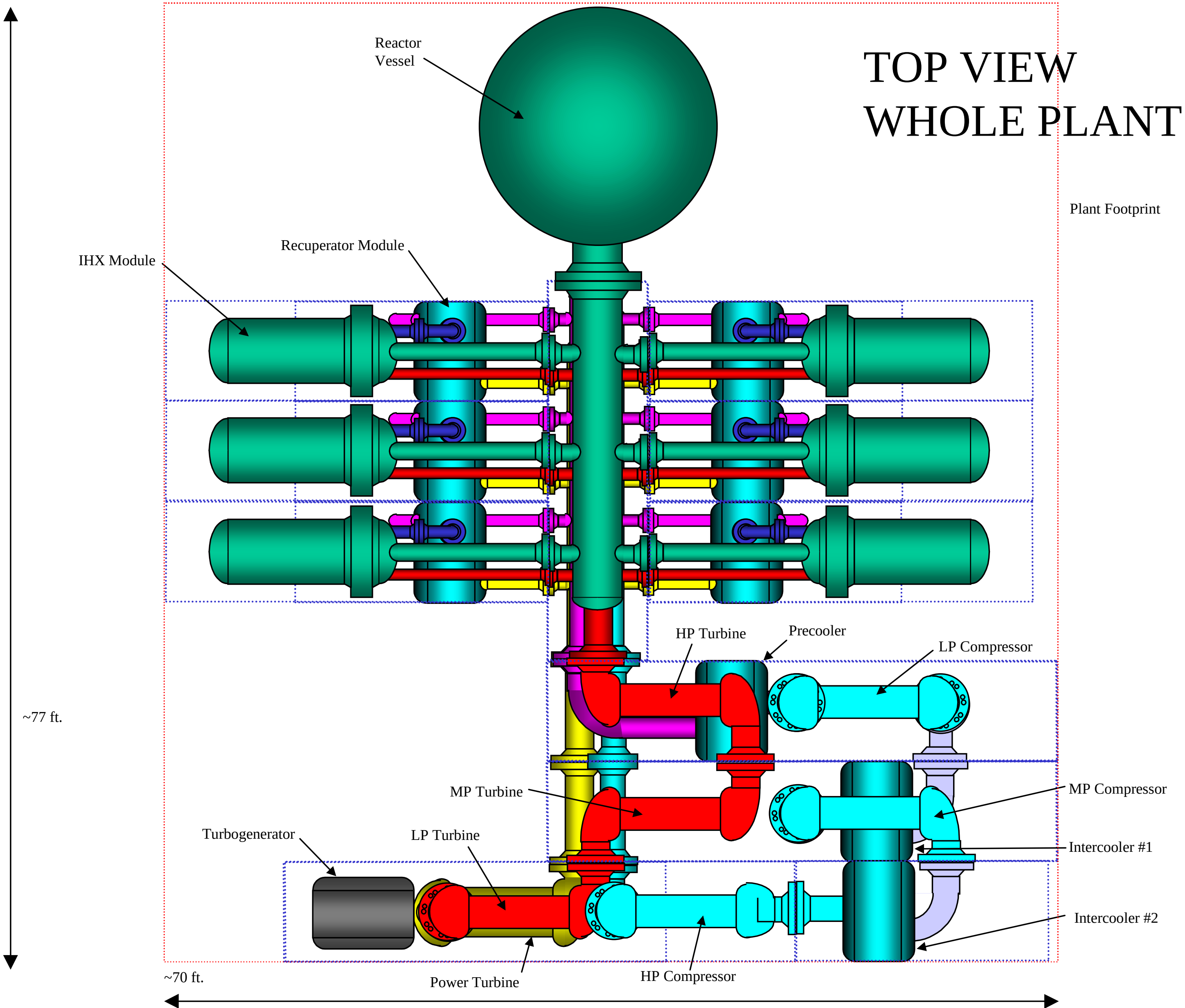
- Minimum Site Preparation
  - BOP Facilities designed as “Plug-and-Play” Modules
  - Single Level Foundation
  - System Enclosure integrated into modules

- ASME Code compliant
  - Thermal expansion limitations
  - Code material limitations

Design Elements

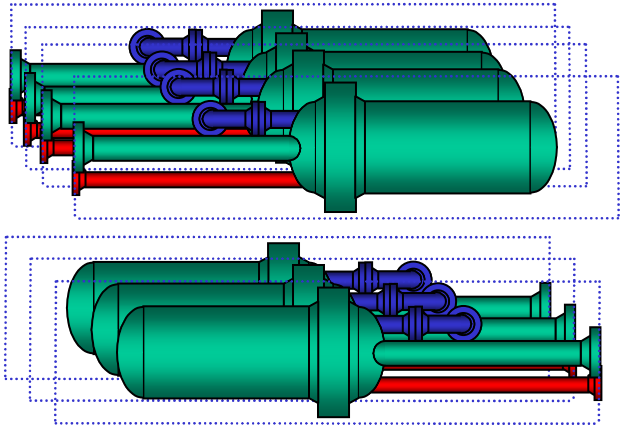
- Assembly
    - Self-locating Space-frame Contained Modules and Piping.
    - Bolt-together Flanges Join Module to Module
    - Space-frame Bears Facility Loads, No Additional Structure
- Transportation / Delivery
    - Road-mobile Transportation Option
        - Reduces Site Requirements (Rail Spur Not Required)
    - Module Placement on Site Requires Simple Equipment
- Footprint
    - Two Layer Module Layout Minimizes Plant Footprint
    - High Maintenance Modules Placed on Upper Layer

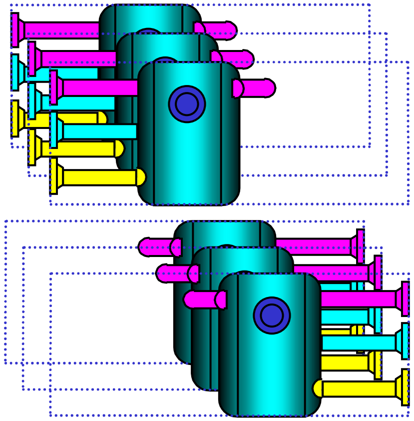
Top Down View of Pebble Bed Reactor Plant

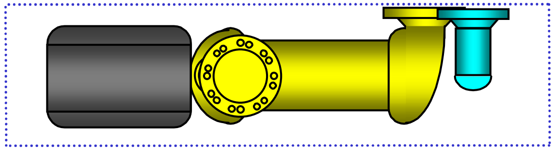


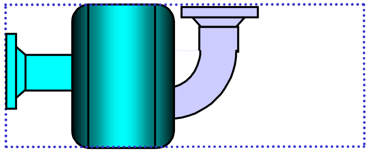
PLANT MODULE SHIPPING BREAKDOWN

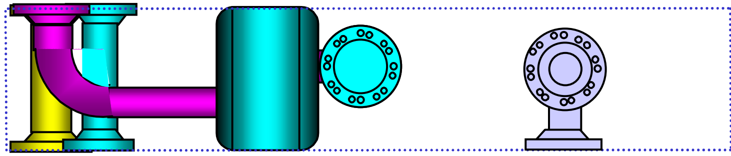
Total Modules Needed For Plant Assembly (21): Nine 8x30 Modules, Five 8x40 Modules, Seven 8x20 Modules

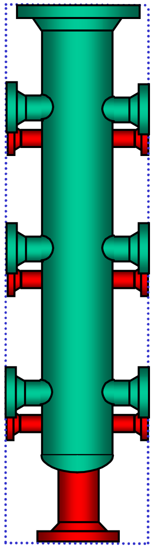

Six 8x30 IHX Modules

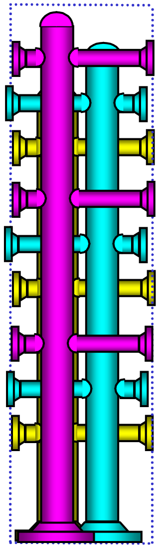

Six 8x20 Recuperator Modules

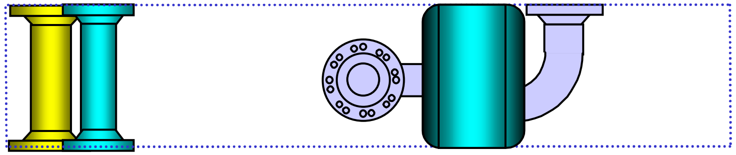

8x30 Power Turbine Module

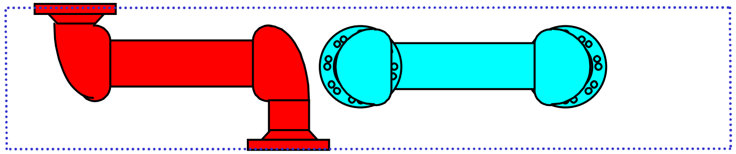

8x20 Intercooler #2 Module

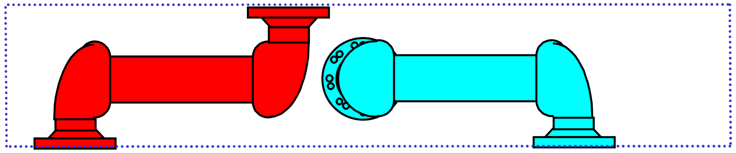

8x40 Piping and Precooler Module

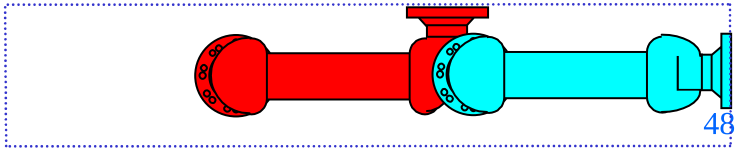

8x30 Upper Manifold Module


8x30 Lower Manifold Module


8x40 Piping & Intercooler #1 Module

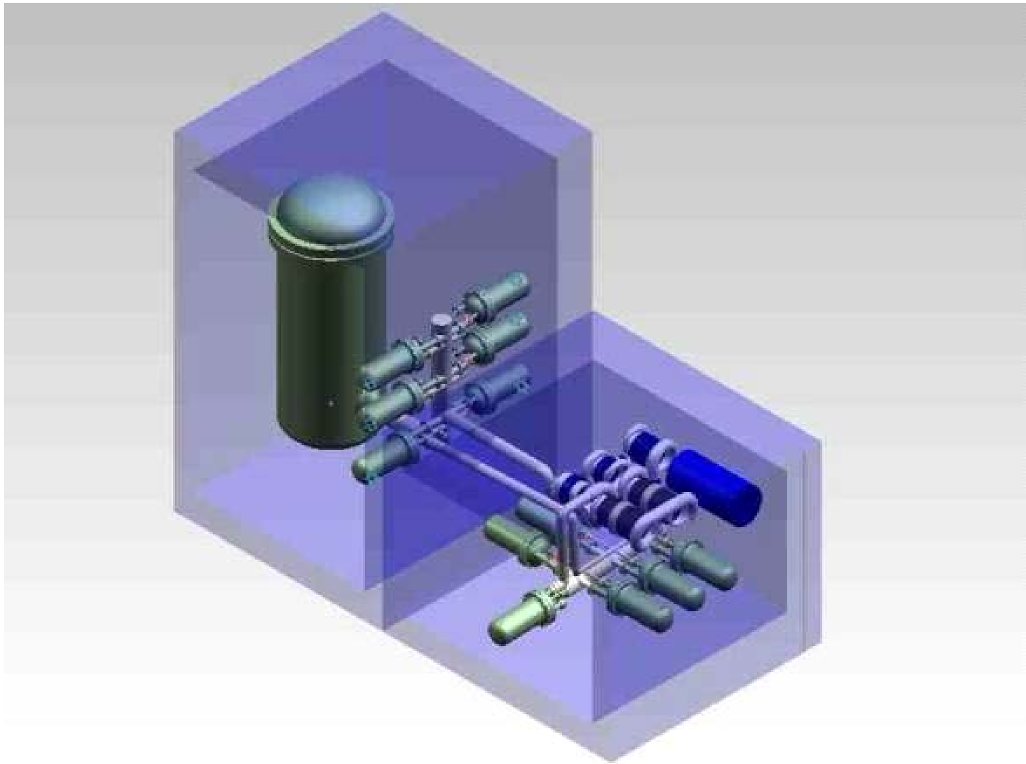

8x40 HP Turbine, LP Compressor Module


8x40 MP Turbine, MP Compressor Module

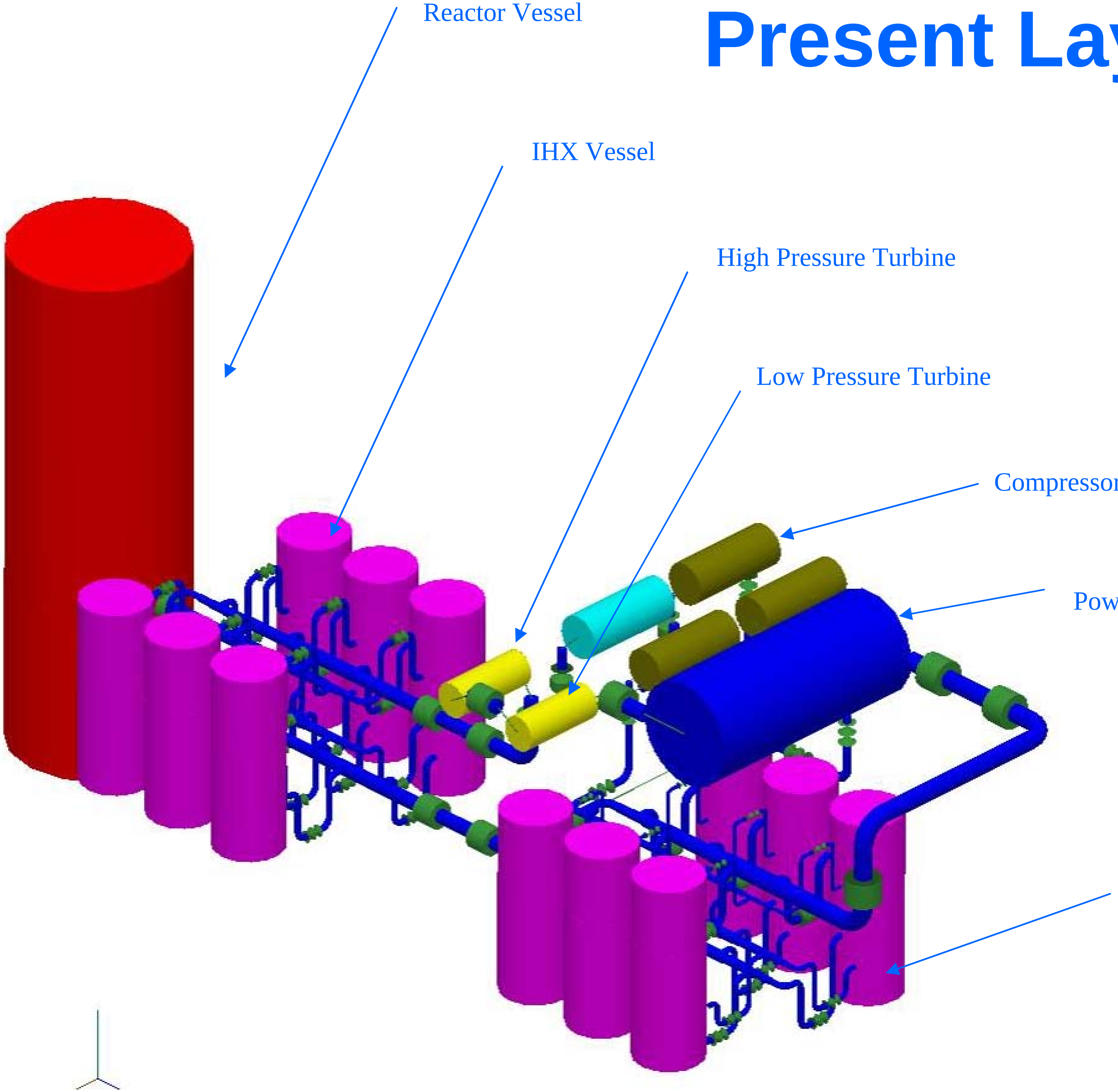

8x40 LP Turbine, HP Compressor Module

Concept

- **Modular Construction**
  - Space-frame modules
    - Stackable
    - Self-aligning
    - Pre-constructed off-site
  - Minimal Assembly On-Site
    - Connect Flanges / Fluid Lines / Utilities
    - Pre-Assembled Control Facilities
- **Distributed Production**
  - Common, Simple Module Design
  - Minimizes Transportation Req.
  - Eliminates Manufacturing Capital Expense
  - Module Replacement Instead of Repair—Modules Returned to Fabricator
- **Road-mobile Transportation**
  - Reduces Cost—Construction of Rail Spur / Canal Not Required
  - Reduces Location Requirements



Present Layout



Reactor Vessel

IHX Vessel

High Pressure Turbine

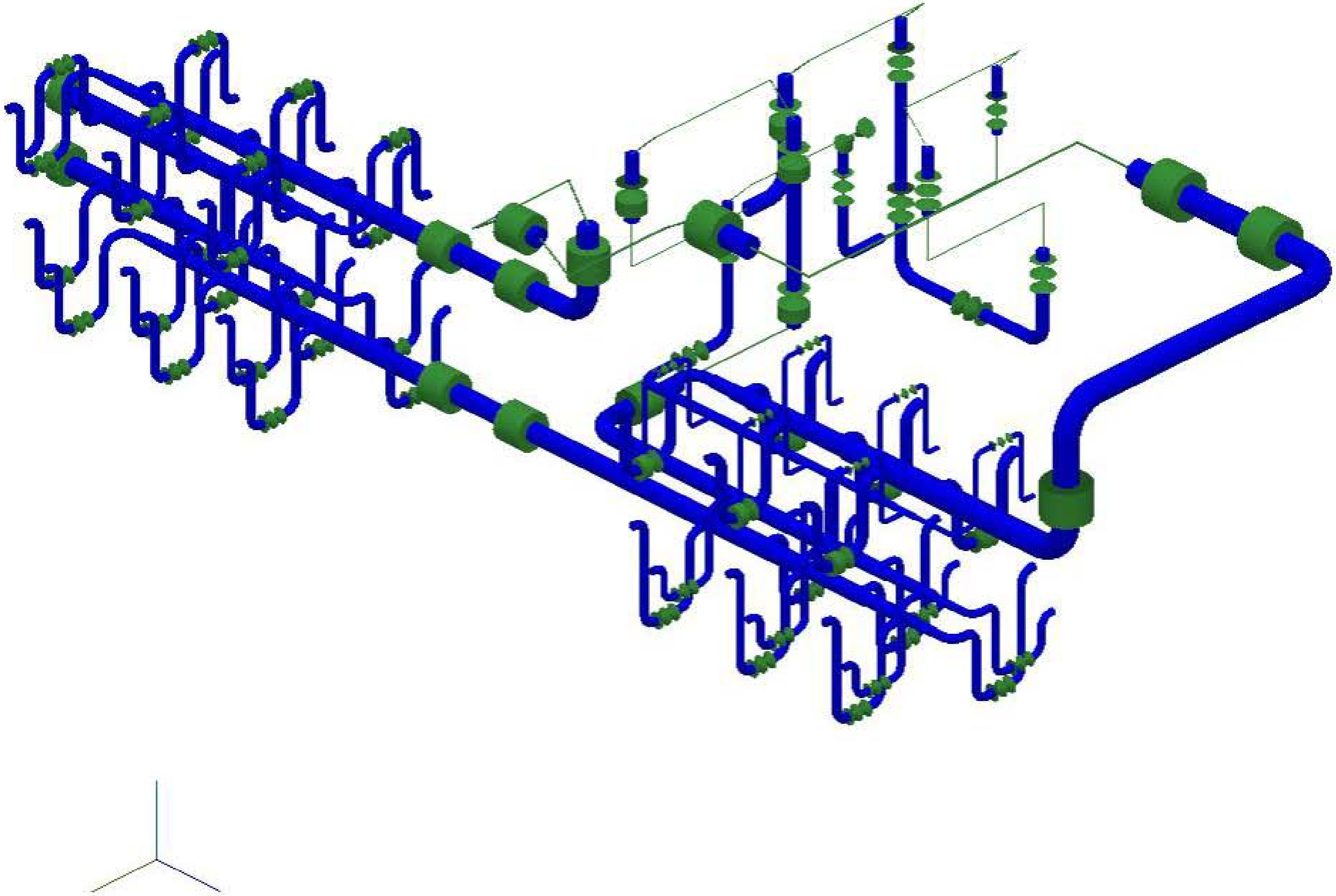
Low Pressure Turbine

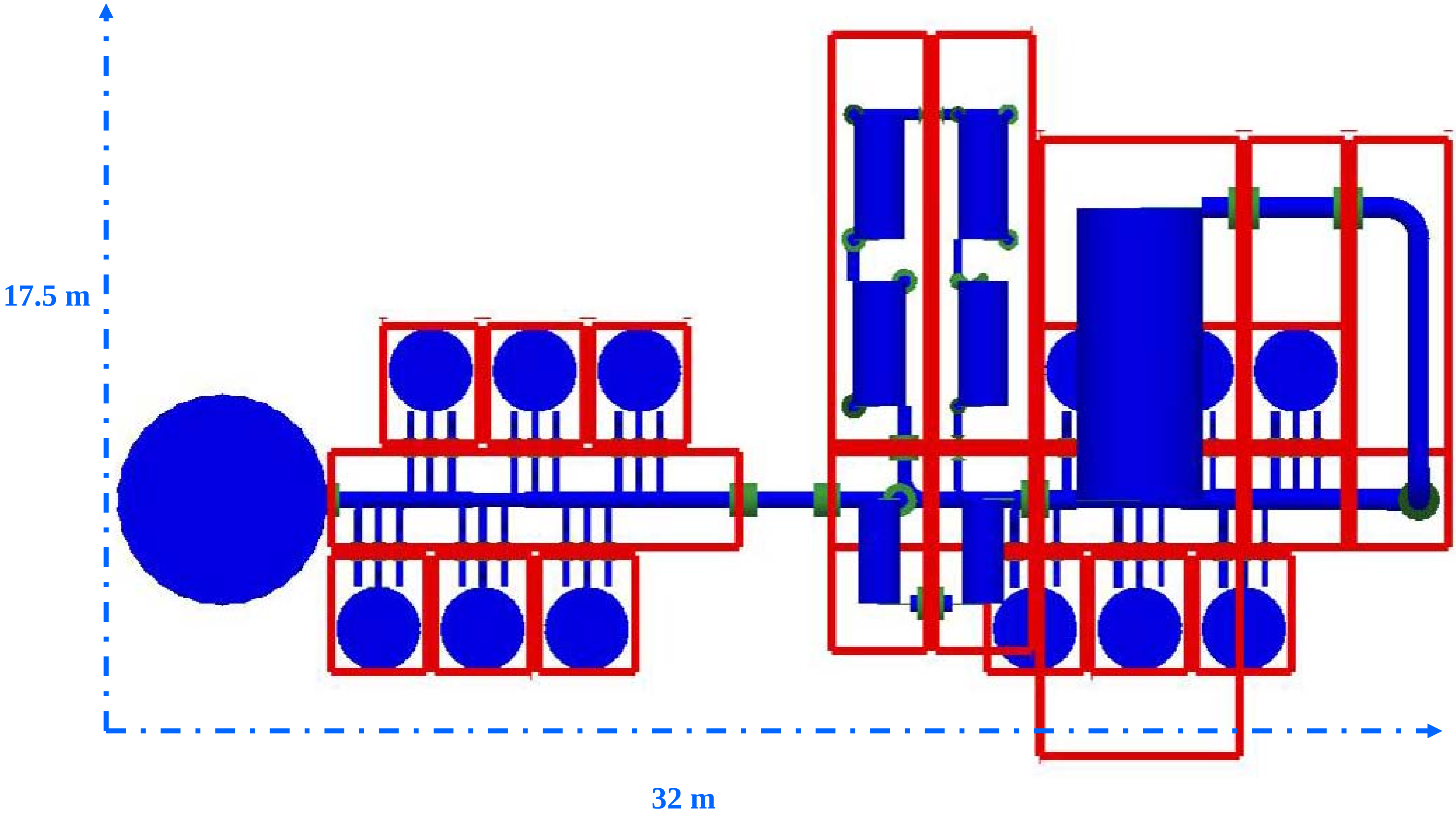
Compressor (4)

Power Turbine

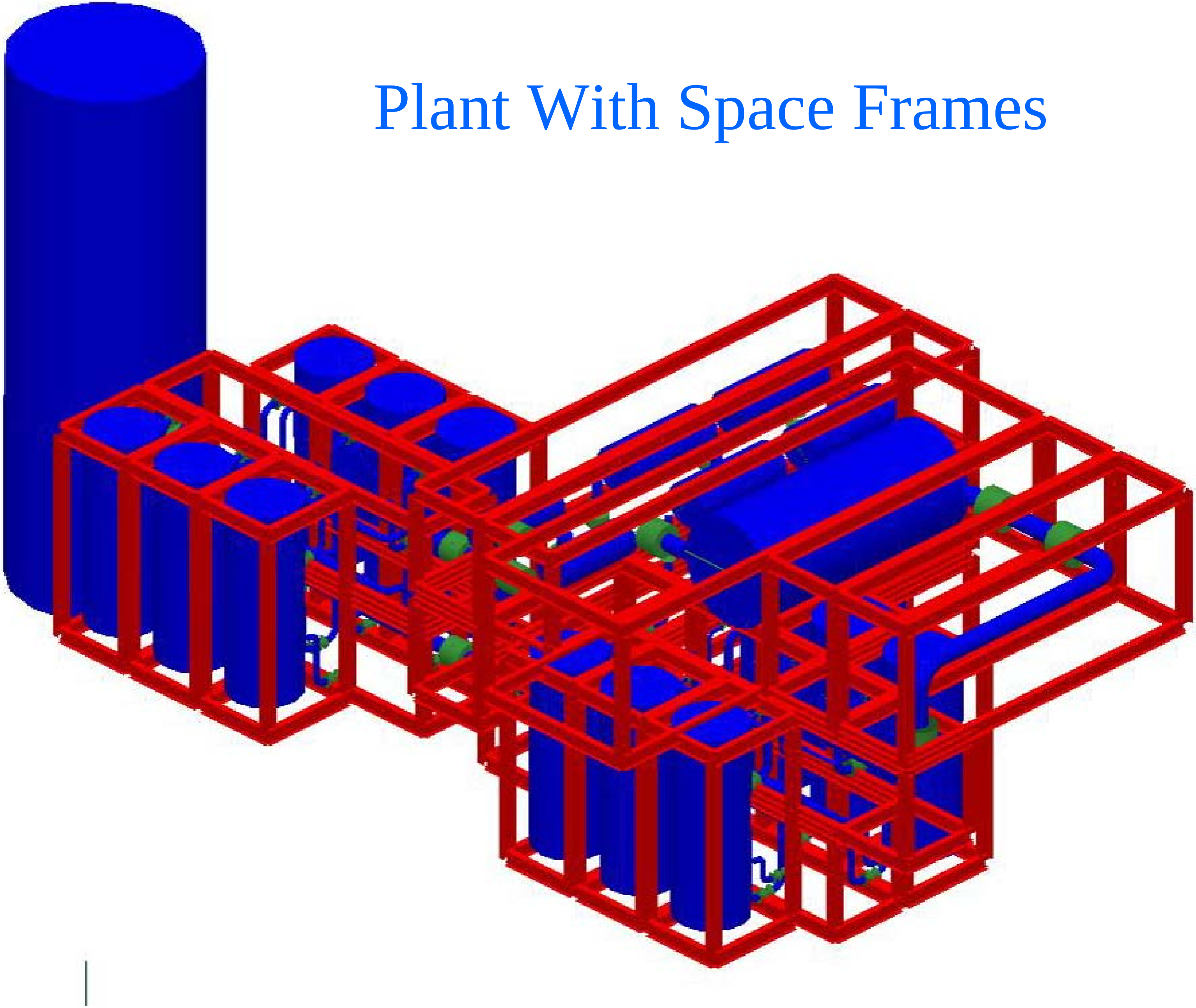
Recuperator Vessel

Detail of Connecting Piping

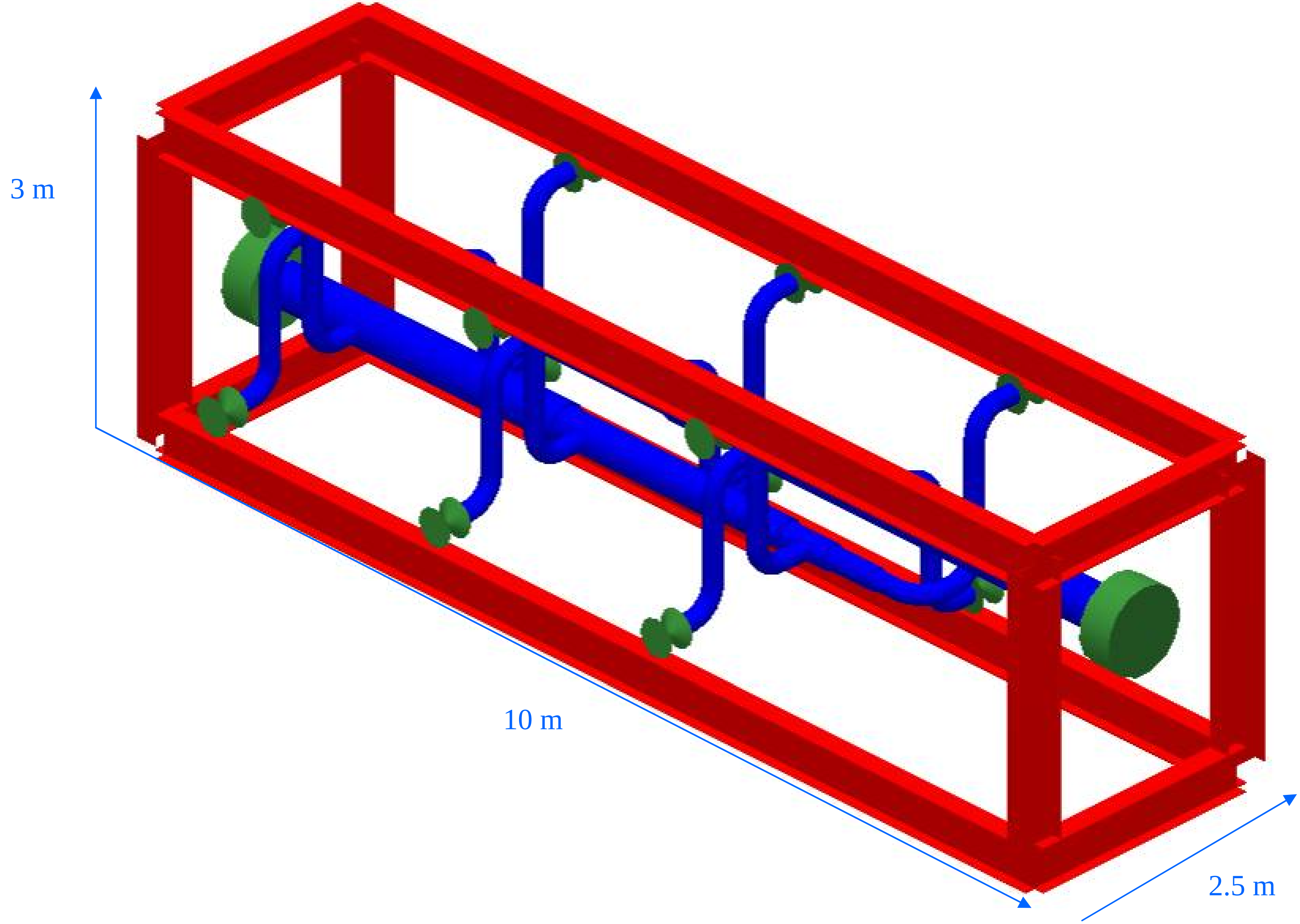



17.5 m
32 m

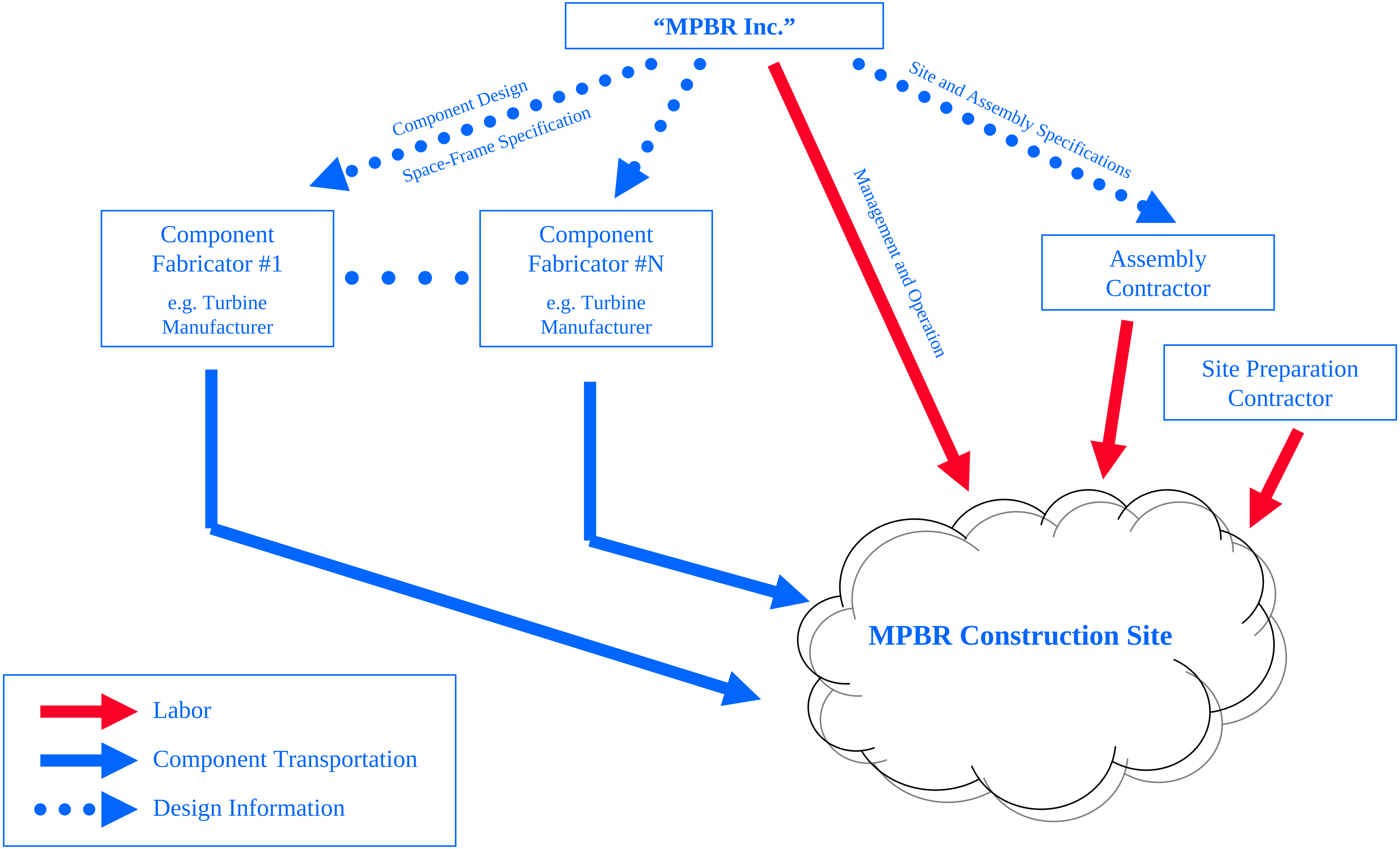
Plant With Space Frames



Upper IHX Manifold in Spaceframe



Distributed Production Concept



“MPBR Inc.”

Component Design

Space-Frame Specification

Site and Assembly Specifications

Management and Operation

Component Fabricator #1

e.g. Turbine Manufacturer

Component Fabricator #N

e.g. Turbine Manufacturer

Assembly Contractor

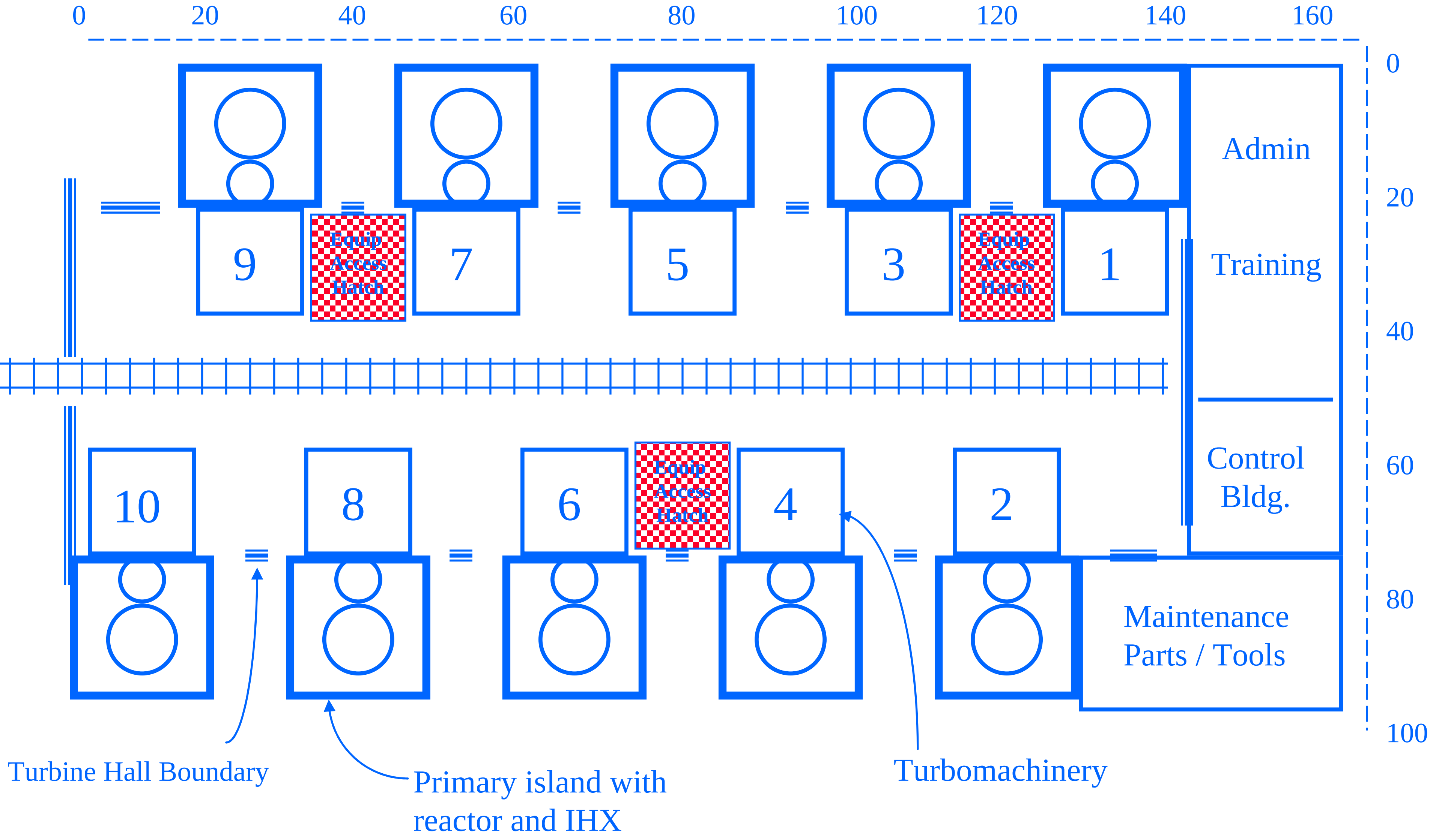
Site Preparation Contractor

MPBR Construction Site

- Labor
- Component Transportation
- Design Information

Ten-Unit MPBR Plant Layout (Top View)

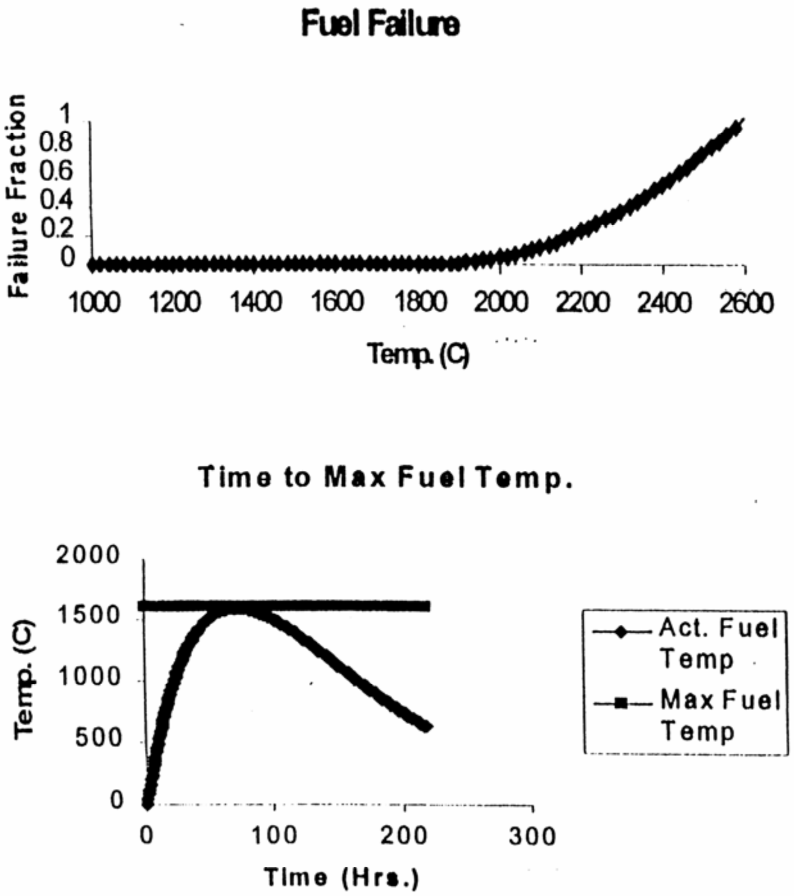
(distances in meters)



Safety Advantages

- Low Power Density
- Naturally Safe
- No melt down
- No significant radiation release in accident
- Demonstrate with actual test of reactor

“Naturally” Safe Fuel

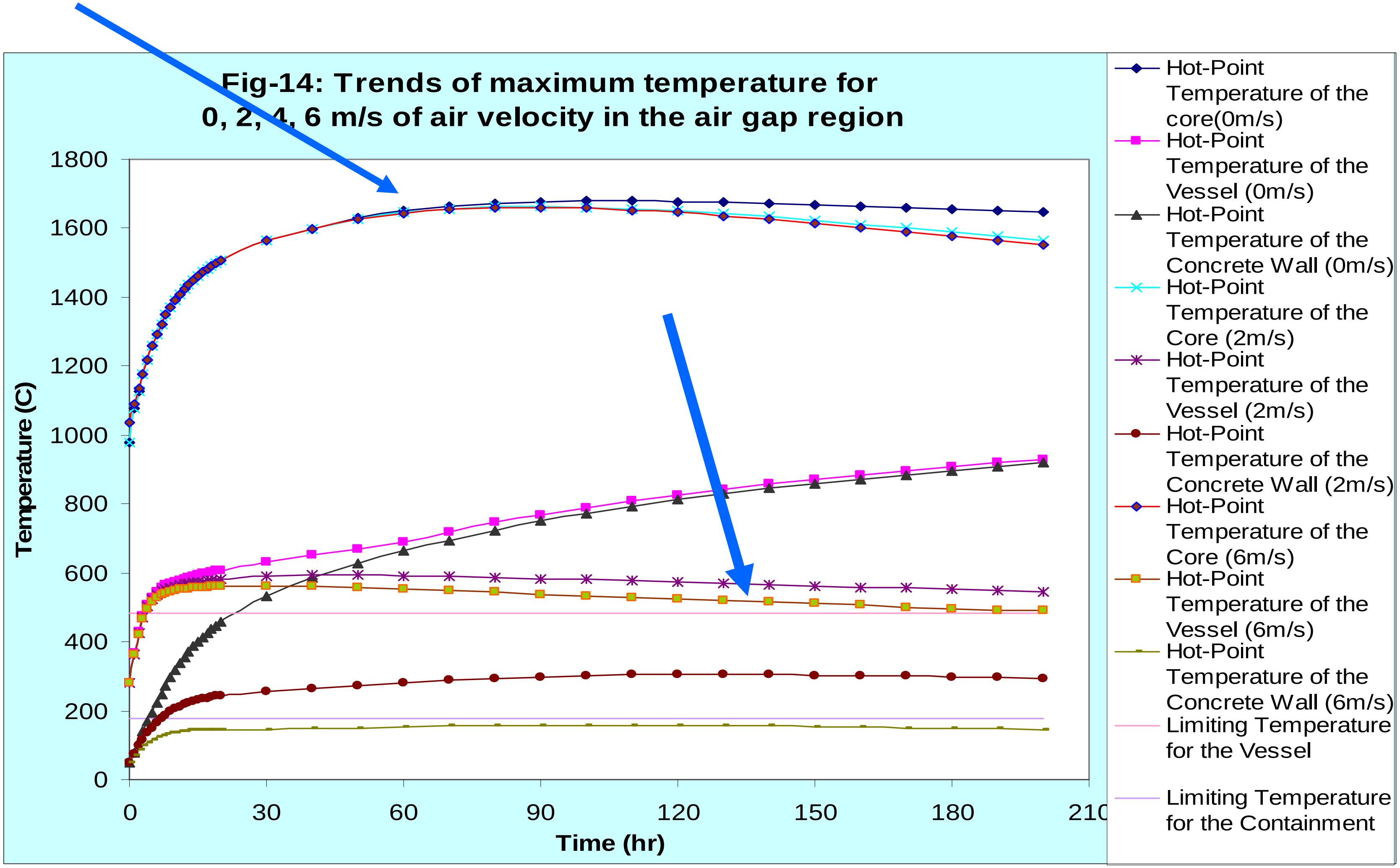


- Shut Off All Cooling
- Withdraw All Control Rods
- No Emergency Cooling
- No Operator Action

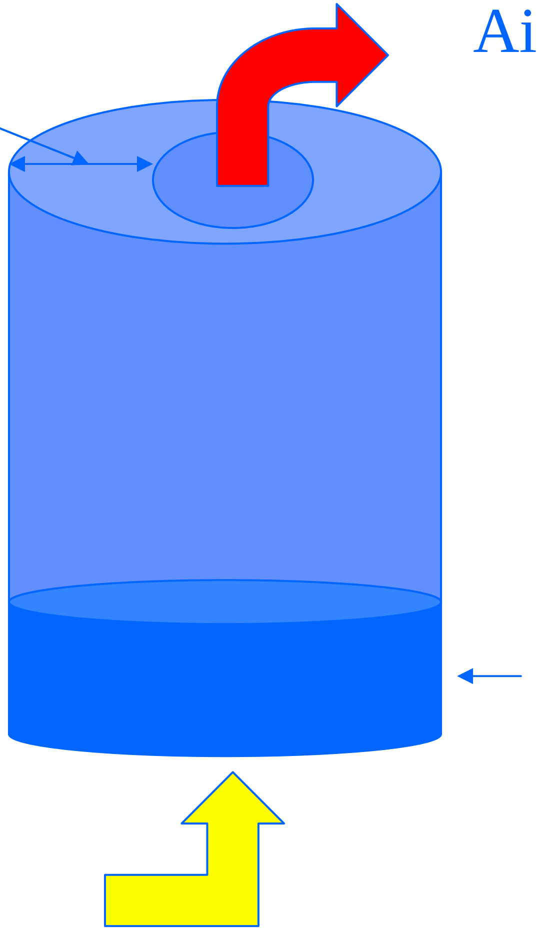
Safety

- LOCA Analysis Complete - *No Meltdown*
- Air Ingress now Beginning focusing on fundamentals of phenomenon
- Objectives
  - Conservative analysis show no “flame”
  - Address Chimney effect
  - Address Safety of Fuel < 1600 C
  - Use Fluent for detailed modeling of RV

The Prediction of the Air Velocity
(By Dr. H. C. No)



Air Ingress Fundamentals



Vary Choke Flow

Air/Co_x Out

Graphite Lower Reflector

Air In

Preliminary Conclusions
Air Ingress

For an open cylinder of pebbles:

- Due to the very high resistance through the pebble bed, the inlet air velocity will not exceed 0.08 m/s.
- The negative feedback: the Air inlet velocity does not always increase when the core is heated up. It reaches its peak value at 300 °C.
- Preliminary combined chemical and chimney effect analysis completed - peak temperatures about 1670 C.

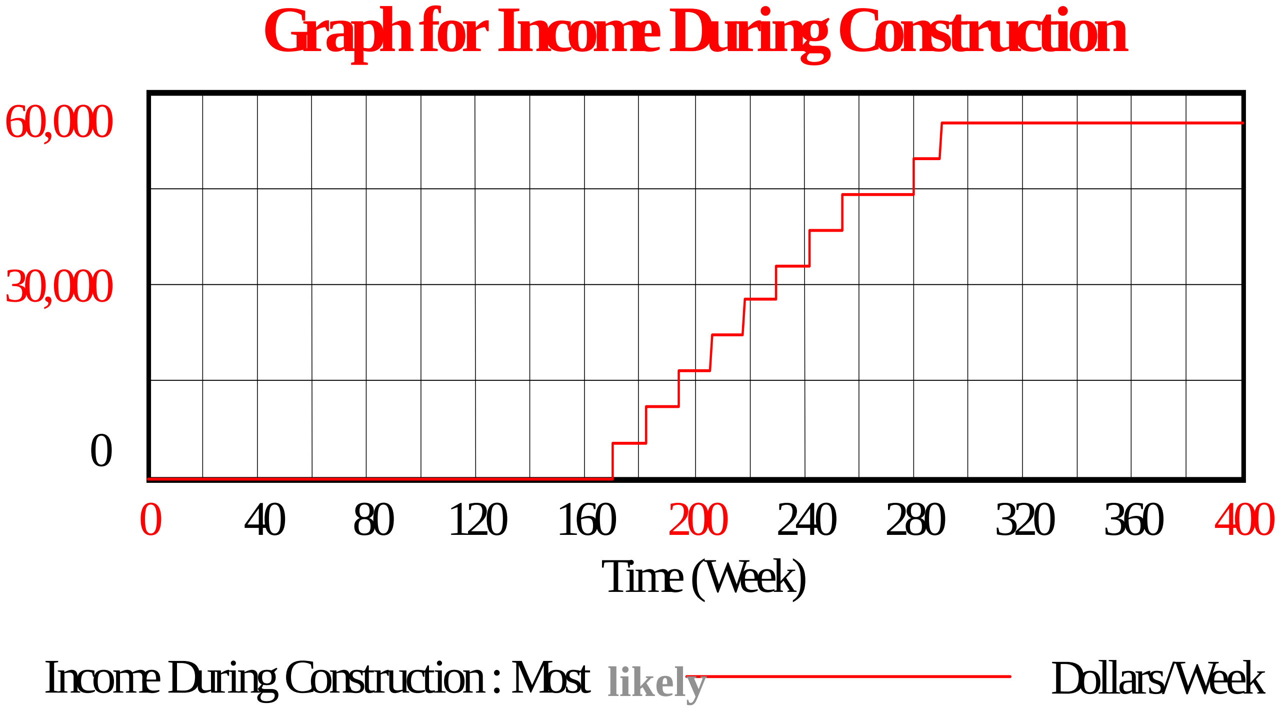
MPBR BUSBAR GENERATION COSTS (‘92$)

Reactor Thermal Power (MWt)	10 x 250
Net Efficiency (%)	45.3%
Net Electrical Rating (MWe)	1100
Capacity Factor (%)	90
Total Overnight Cost (M$)	2,046
Levelized Capital Cost ($/kWe)	1,860
Total Capital Cost (M$)	2,296
Fixed Charge Rate (%)	9.47
30 year level cost (M$/YR):	
Levelized Capital Cost	217
Annual O&M Cost	31.5
Level Fuel Cycle Cost	32.7
Level Decommissioning Cost	5.4
Revenue Requirement	286.6
Busbar Cost (mill/kWh):	
Capital	25.0
O&M	3.6
FUEL	3.8
DECOMM	0.6
TOTAL	**33.0 mills/kwhr**

This number is important but not not as important as this number

This is the number that counts

INCOME DURING CONSTRUCTION ?



Generating Cost

PBMR vs. AP600, AP1000, CCGT and Coal

(Comparison at 11% IRR for Nuclear Options, 9% for Coal and CCGT[1])

(All in ¢/kWh)		AP1000 @			Coal[2]		CCGT @ Nat. Gas = [3]		
	AP600	3000Th	3400Th	PBMR	'Clean'	'Normal'	$3.00	$3.50	$4.00
Fuel	0.5	0.5	0.5	0.48	0.6	0.6	2.1	2.45	2.8
O&M	0.8	0.52	0.46	0.23	0.8	0.6	0.25	0.25	0.25
Decommissioning	0.1	0.1	0.1	0.08	-	-	-	-	-
Fuel Cycle	0.1	0.1	0.1	0.1	-	-	-	-	-
Total Op Costs	1.5	1.22	1.16	0.89	1.4	1.2	2.35	2.70	3.05
Capital Recovery	3.4	2.5	2.1	2.2	2.0	1.5	1.0	1.0	1.0
Total	4.9	3.72	3.26	3.09	3.4	2.7	3.35	3.70	4.05

[1] All options exclude property taxes

[2] Preliminary best case coal options: "mine mouth" location with $20/ton coal, 90% capacity factor & 10,000 BTU/kWh heat rate

[3] Natural gas price in $/million Btu

Next Generation Nuclear Plant
NGNP

- High Temperature Gas Reactor (either pebble or block)
- Electricity and Hydrogen Production Mission
- Built at the Idaho National Laboratory
- No later than 2020 (hopefully 2013)
- Research and Demonstration Project
- Competition to begin shortly to decide which to build

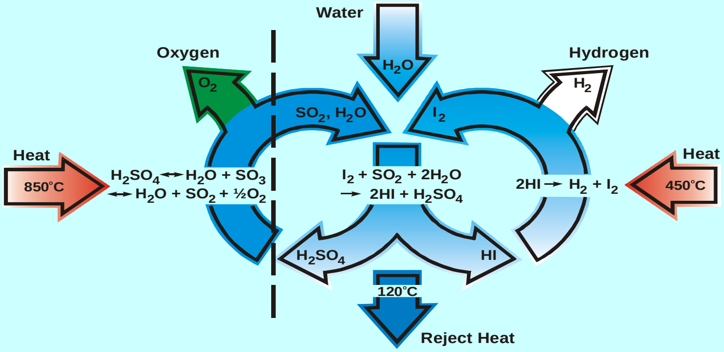
Technical Challenges

- Fuel is the safety system - need to prove that fuels operating at these and higher temperatures don’t fail.
- Develop high temperature gas safety analysis codes that are verified and validated
- Above 950 C huge materials challenges
- Graphite properties need to be better understood at high temperatures and irradiation.
- Want to make hydrogen either thermo-chemically or with high temperature electrolysis. - 900 to 1000 C
- Thermo-chemical production of hydrogen in lab.

There Are Families of Thermochemical Cycles

Sulfur Iodine

(Both sides)



Water

H_2O

Oxygen

O_2

Hydrogen

H_2

SO_2, H_2O

I_2

Heat

850°C

$H_2SO_4 \leftrightarrow H_2O + SO_3$
$\leftrightarrow H_2O + SO_2 + ½O_2$

$I_2 + SO_2 + 2H_2O$
$\rightarrow 2HI + H_2SO_4$

$2HI \rightarrow H_2 + I_2$

Heat

450°C

H_2SO_4

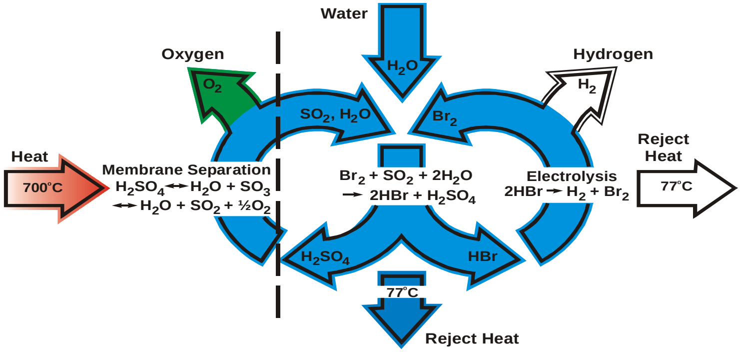
HI

120°C

Reject Heat

Inorganic Membrane

Ispra Mark 13



Water

H_2O

Oxygen

O_2

Hydrogen

H_2

SO_2, H_2O

Br_2

Heat

700°C

Membrane Separation
$H_2SO_4 \leftrightarrow H_2O + SO_3$
$\leftrightarrow H_2O + SO_2 + ½O_2$

$Br_2 + SO_2 + 2H_2O$
$\rightarrow 2HBr + H_2SO_4$

Electrolysis
$2HBr \rightarrow H_2 + Br_2$

Reject Heat

77°C

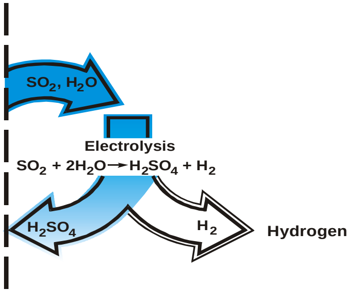
H_2SO_4

HBr

77°C

Reject Heat

Westinghouse



SO_2, H_2O

Electrolysis
$SO_2 + 2H_2O \rightarrow H_2SO_4 + H_2$

H_2SO_4

H_2

Hydrogen

Hydrogen Generation Options

- **Sulfur Iodine S/I Process -** three T/C reactions

  $H_2SO_4 \rightarrow SO_2 + H_2O + .5O_2$ (>800°C heat required)

  $I_2 + SO_2 + 2H_2O \rightarrow 2HI + H_2SO_4$ (200°C heat generated)

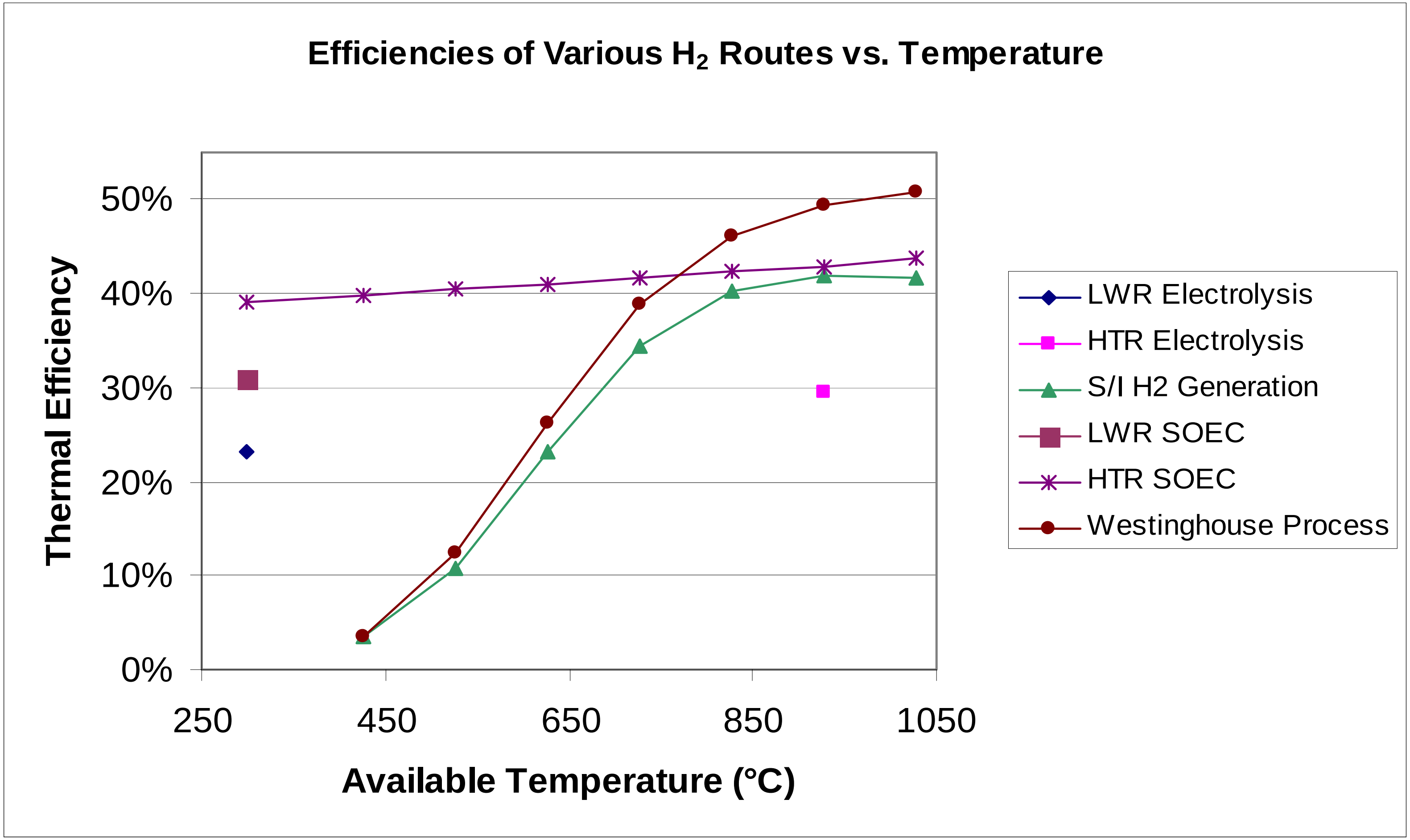
  $2HI \rightarrow H_2 + I_2$ (>400°C heat required)

- **Westinghouse Sulfur Process -** single T/C reaction

  $H_2SO_4 \rightarrow SO_2 + H_2O + .5O_2$ (>800°C heat required)

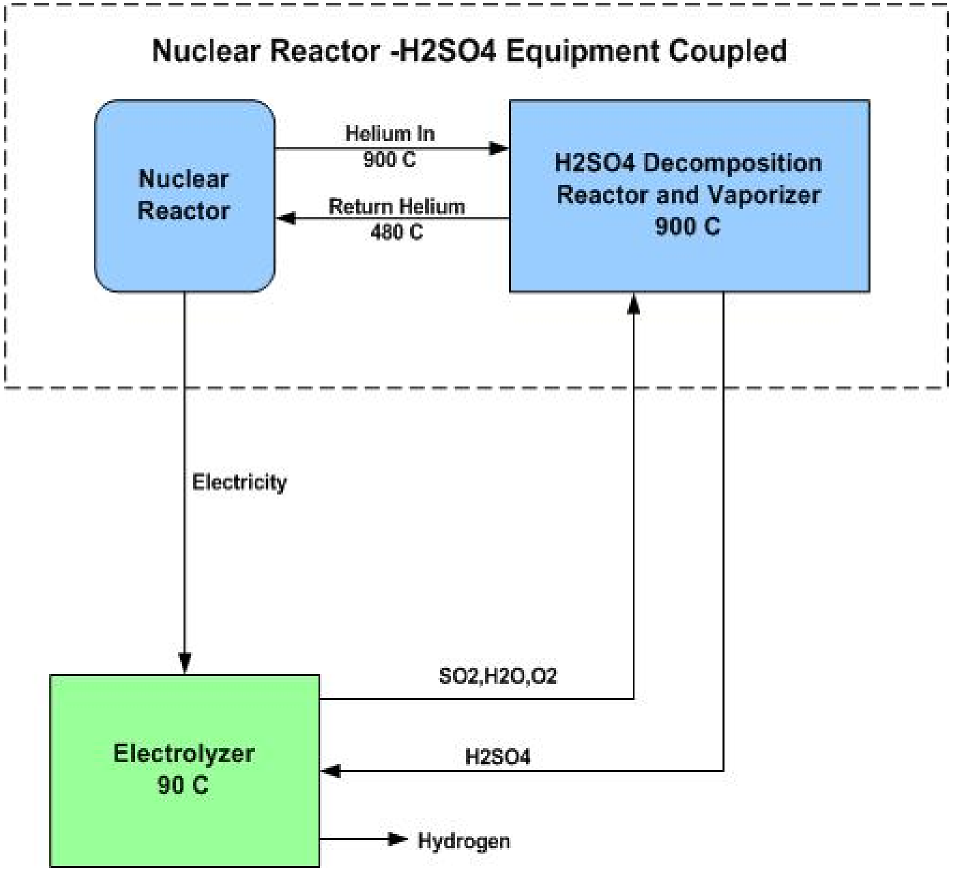
  $2H_2O + SO_2 \rightarrow H_2 + H_2SO_4$ (electrolytic at 100°C using HTGR electricity)

Summary of H_2 Production Efficiencies

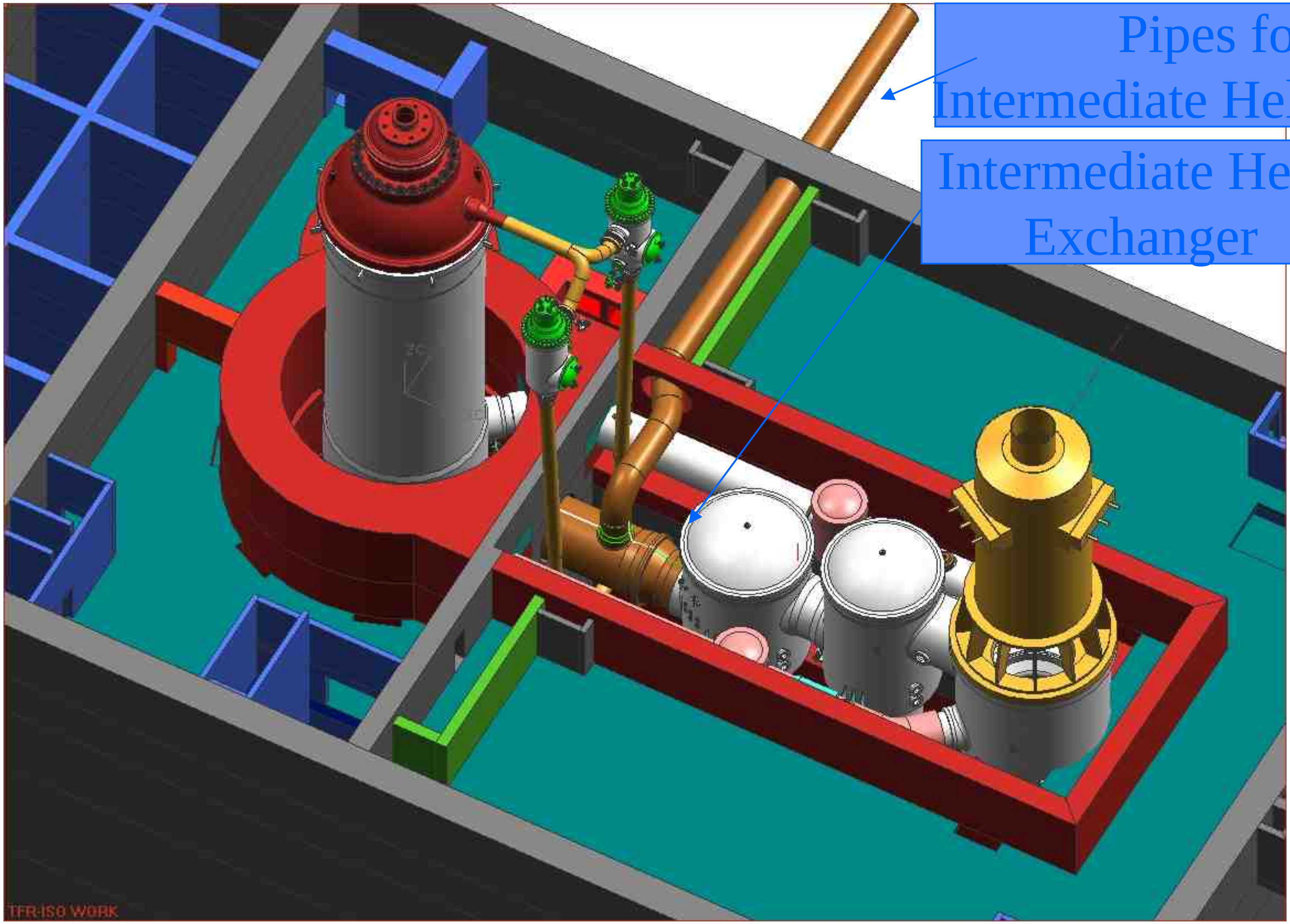


HTGR (assumed as PMBR)– Westinghouse Process Interface

- 0.25 mile separation of nuclear and H_2 plant
- Circulates H_2SO_4 and products from the reactor at low temperatures (single chemical reaction)
- Single heat transmission required



Intermediate Heat Exchanger (IHX) Installed In Hot Pipe for PBMR NGNP



Pipes for
Intermediate Helium Loop

Intermediate Heat
Exchanger

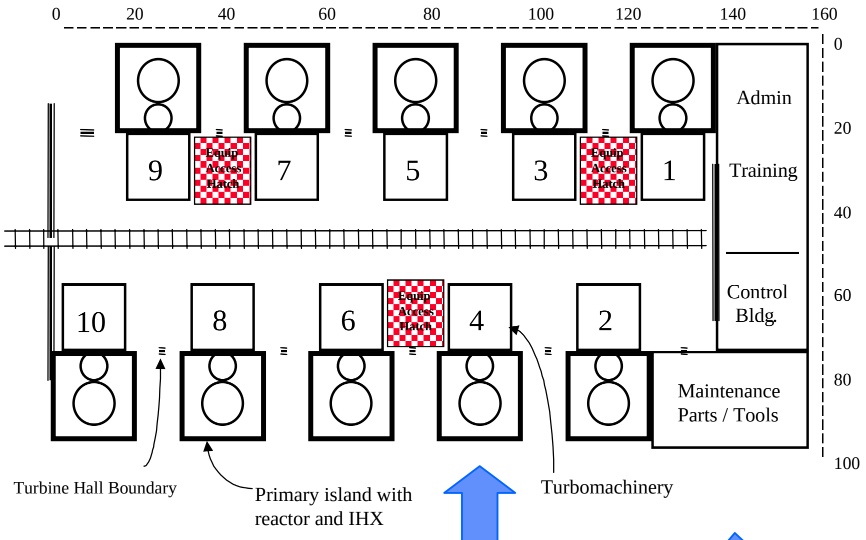
So What Does the Future Look Like ?

For 1150 MW Combined Heat and Power Station

VHTR Characteristics
- Temperatures > 900 C
- Indirect Cycle
- Core Options Available
- Waste Minimization

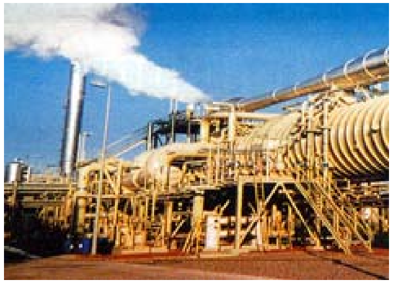
Ten-Unit VHTR Plant Layout (Top View)

(distances in meters)



Oil Refinery

Hydrogen Production



Desalinization Plant

Project Overview

- **Fuel Performance**
- **Fission Product Barrier (silver migration)**
- **Core Physics**
- **Safety**
    - **Loss of Coolant**
    - **Air Ingress**
- **Balance of Plant Design**
- **Modularity Design**
- **Intermediate Heat Exchanger Design**
- **Core Power Distribution Monitoring**
- **Pebble Flow Experiments**
- **Non-Proliferation**
- **Safeguards**
- **Waste Disposal**
- **Reactor Research/ Demonstration Facility**
- **License by Test**

Fuel Performance Model

- Detailed modeling of fuel kernel
- Microsphere
- Monte Carlo Sampling of Properties
- Use of Real Reactor Power Histories
- Fracture Mechanics Based
- Considers Creep, stress, strains, fission product gases, irradiation and temperature dependent properties.

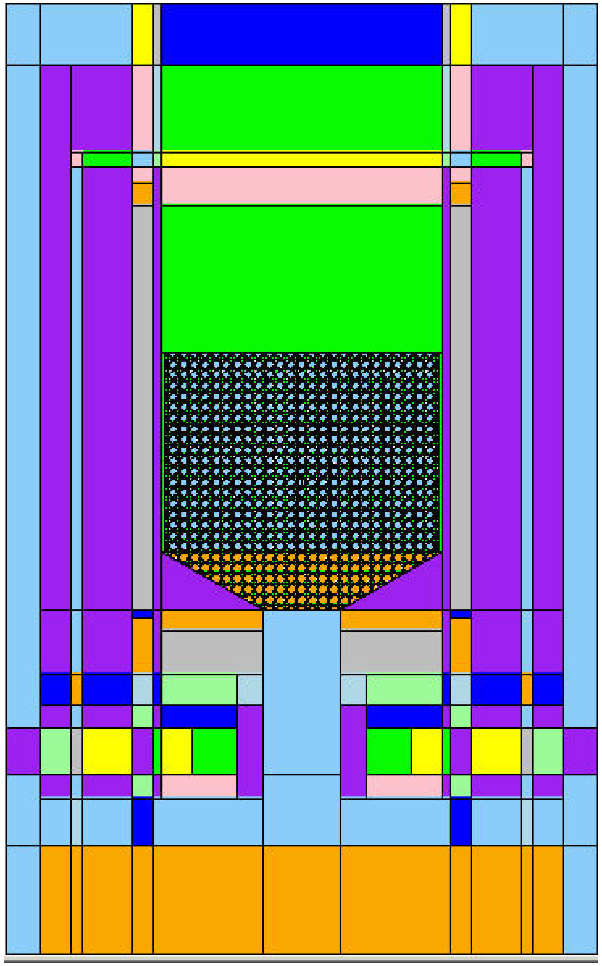
Barrier Integrity

- Silver Diffusion observed in tests @ temps
- Experiments Proceeding with Clear Objective - Understand phenomenon
- Palladium Attack Experiments Underway
- Zirconium Carbide being tested as a reference against SiC.
- Focus on Grain SiC Structure Effect
- Will update model with this information

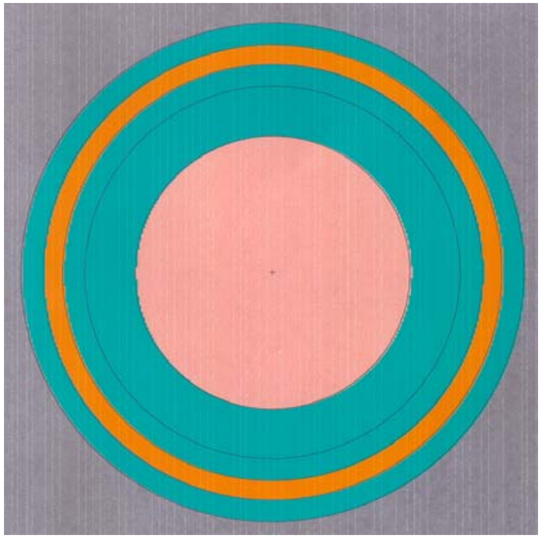
Core Physics

- Basic tool Very Special Old Programs (VSOP)
- Developing MNCP Modeling Process
- Tested Against HTR-10 Benchmark
- Tested Against ASTRA Tests with South African Fuel and Annular Core
- VSOP Verification and Validation Effort Beginning
- Working on International Benchmark

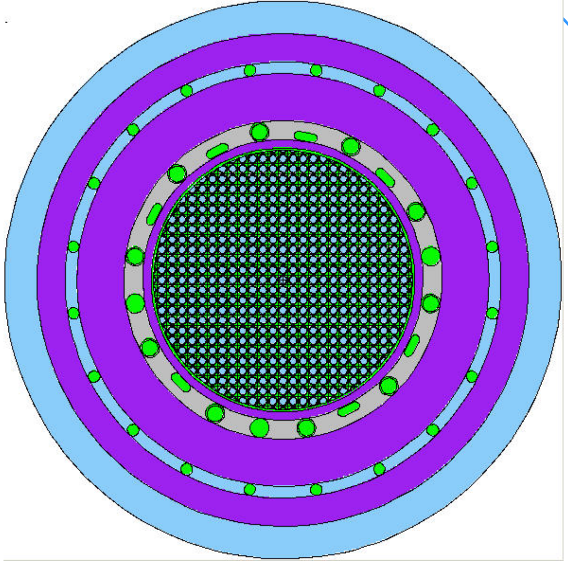
HTR-10
MCNP4B Model



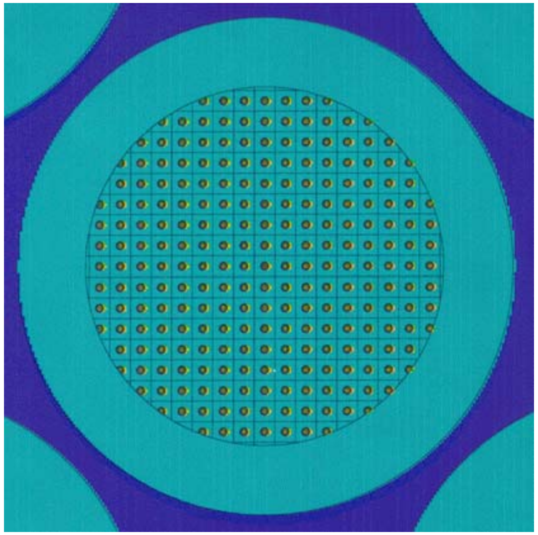
Reactor



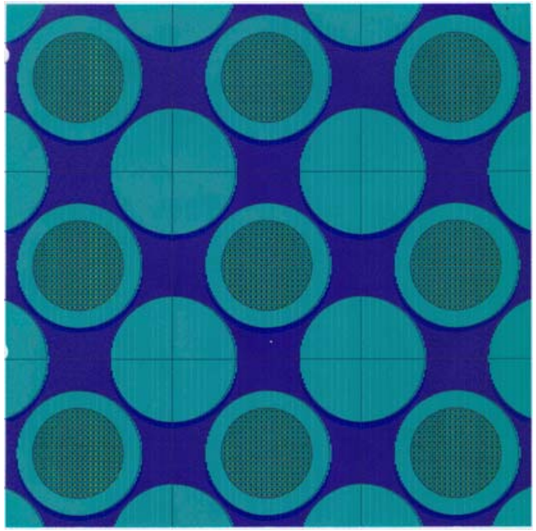
TRISO fuel particle



Core



Fuel sphere



Core lattice

Safety

- LOCA Analysis Complete - *No Meltdown*
- Air Ingress benchmarking with FLUENT CFD code Japanese and German Experiments
- Objectives
  - Conservative analysis show no “flame”
  - Address Chimney effect
  - Address Safety of Fuel < 1600 C
  - Use Fluent for detailed modeling of RV

Massachusetts Institute of Technology
Department of Nuclear Engineering

Advanced Reactor Technology Pebble Bed Project

Figure 1: The Figure of the Model

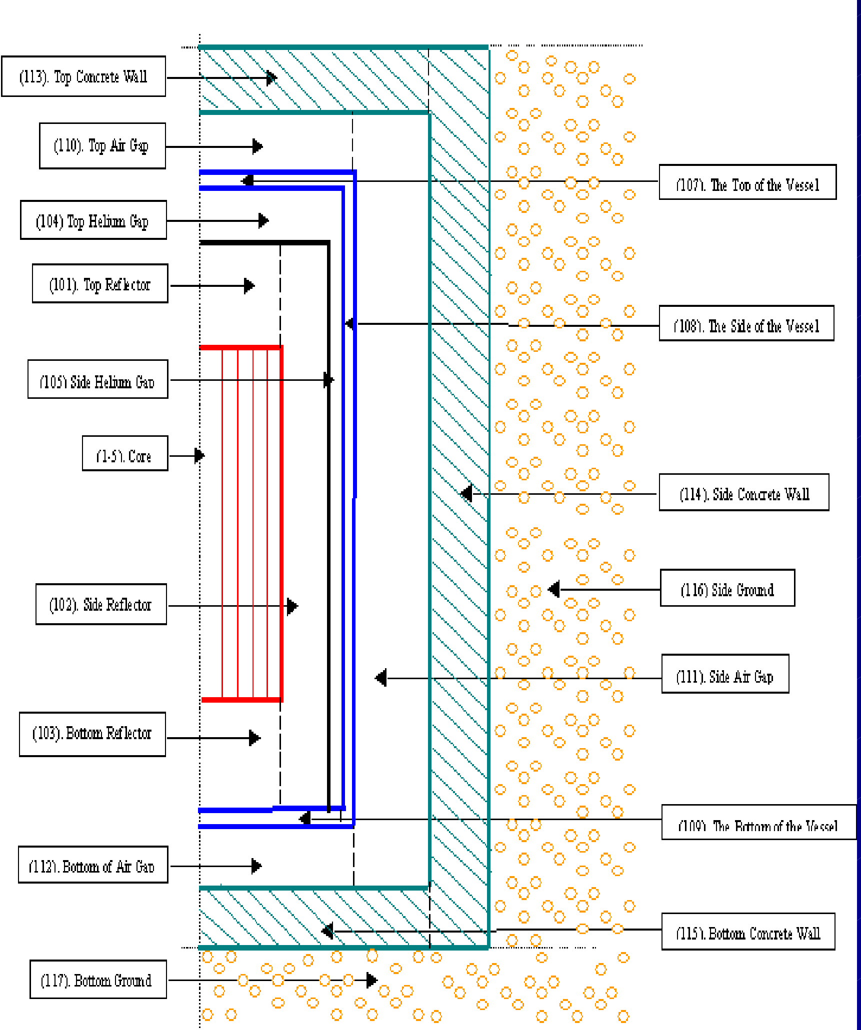
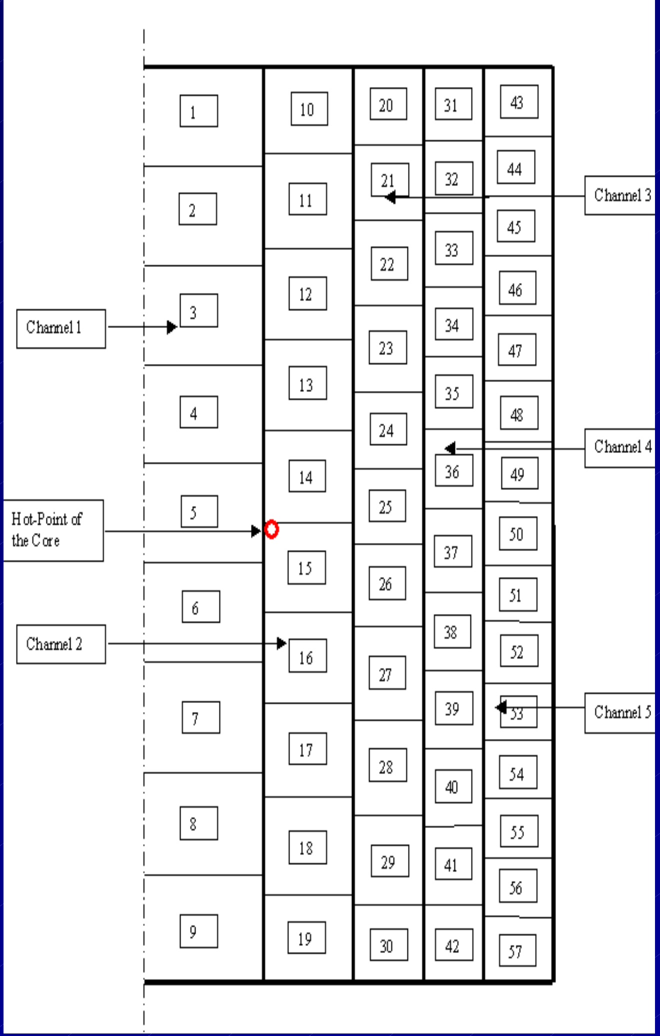
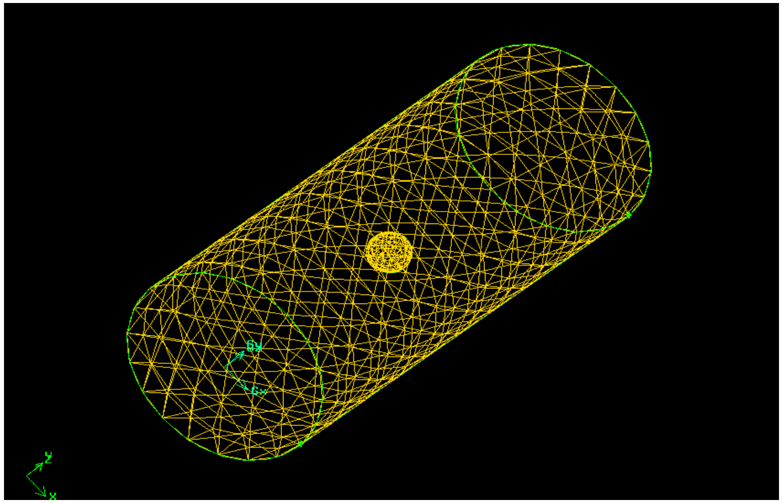
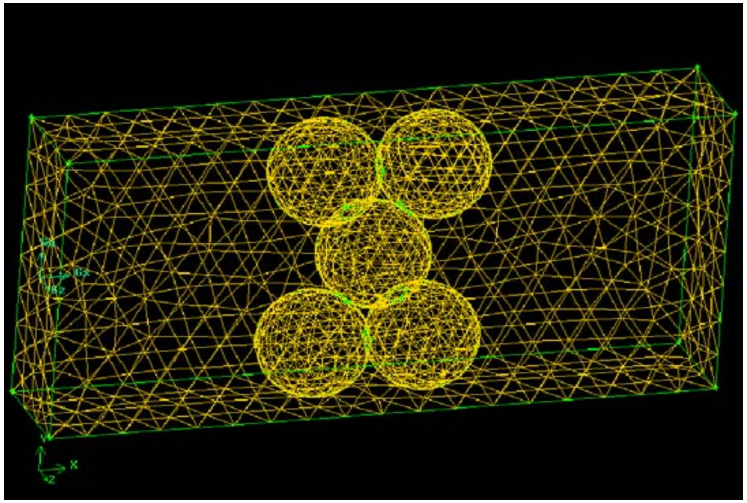


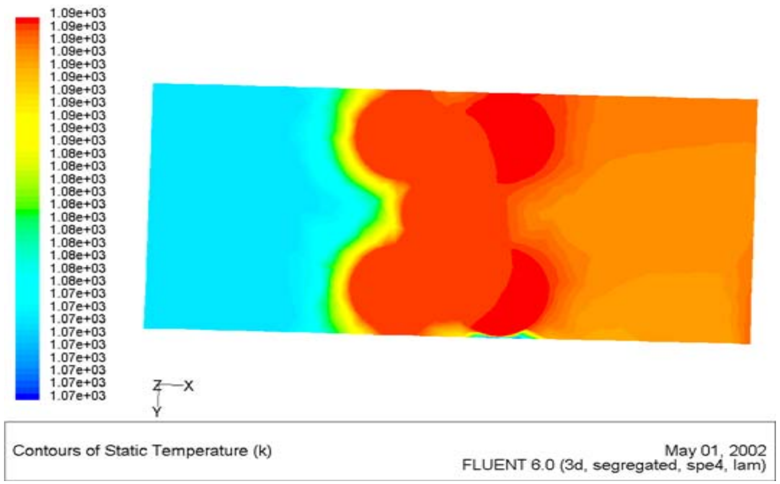
Fig-2: The Geometry of the Core



Verify the Chemical Model (FLUENT 6.0)

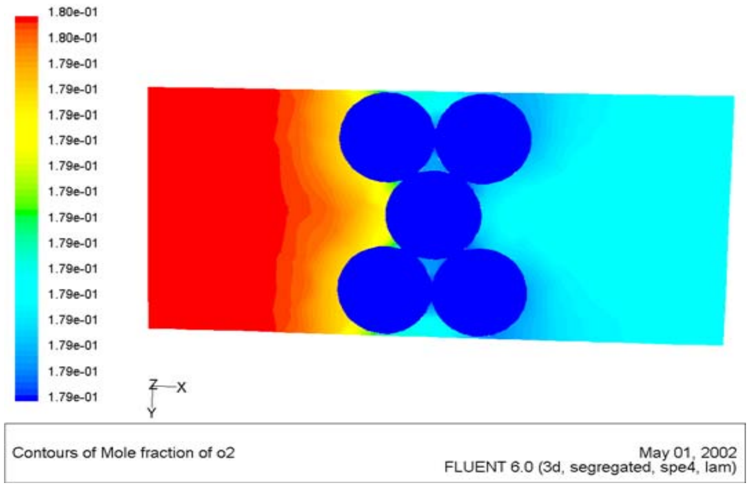






Contours of Static Temperature (k)

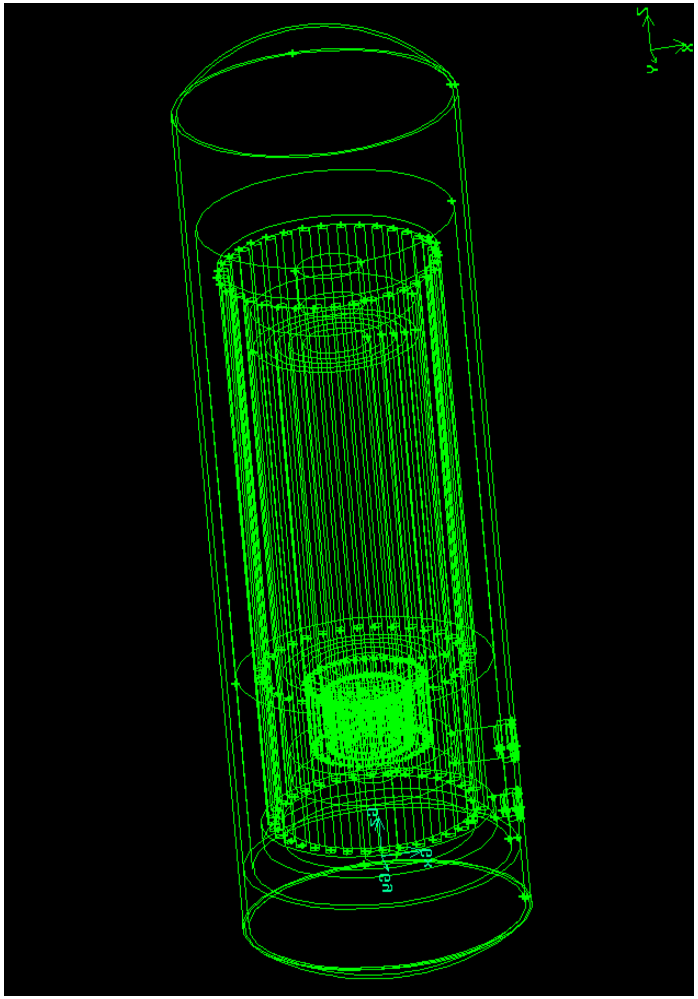
May 01, 2002
FLUENT 6.0 (3d, segregated, spe4, lam)



Contours of Mole fraction of o2

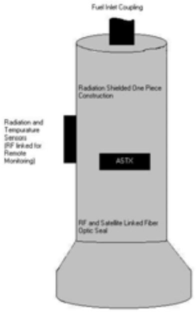
May 01, 2002
FLUENT 6.0 (3d, segregated, spe4, lam)

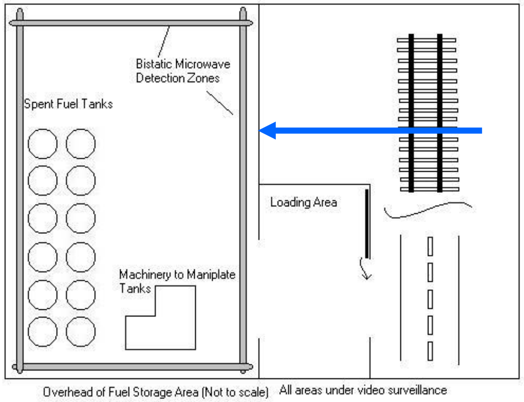
The Detailed Model in Progress



Extrinsic Safeguards System for Pebble Bed Reactors

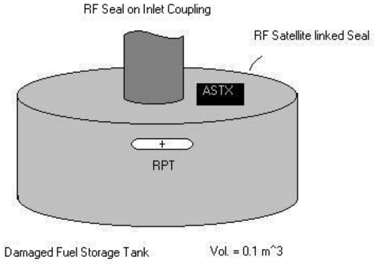
Waste Package

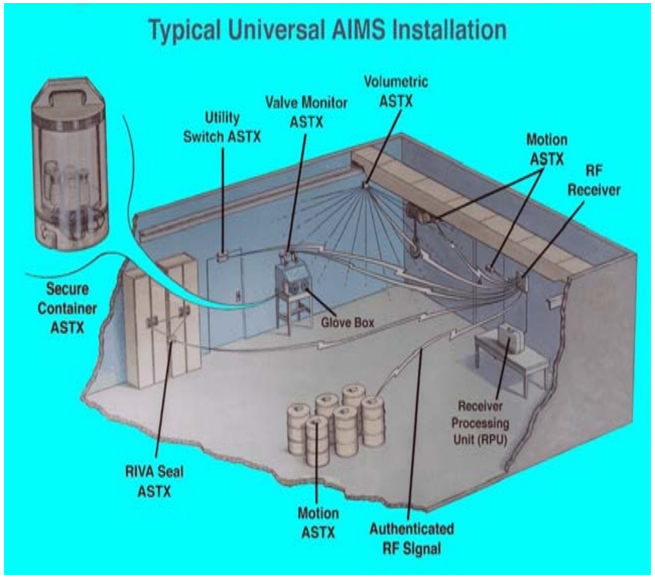




Fresh Fuel Room

Scrap Waste Can





Typical Waste Storage Room

Video Demo

19.mpg

20.mpg

21.mpg

22.mpg

23.mpg

MIT's Project Innovations

- Advanced Fuels
- Totally modular - build in a factory and assemble at the site
- Replace components instead of repair
- Indirect Cycle for Hydrogen Generation for fuel cells & transportation
- Advanced computer automation
- Demonstration of safety tests

Collaborative Research Areas

- Air Ingress
- Accident Performance of TRISO Fuel
- Water Ingress
- Burnup Measurements
- Power Distribution Measurements
- Graphite Lifetime
- Defueling Systems
- Verification of Computer Codes - VSOP, Tinte
- Xenon Effects
- Modeling of Pebble Flow
- Mixing in Lower Reflector

Research Areas Continued

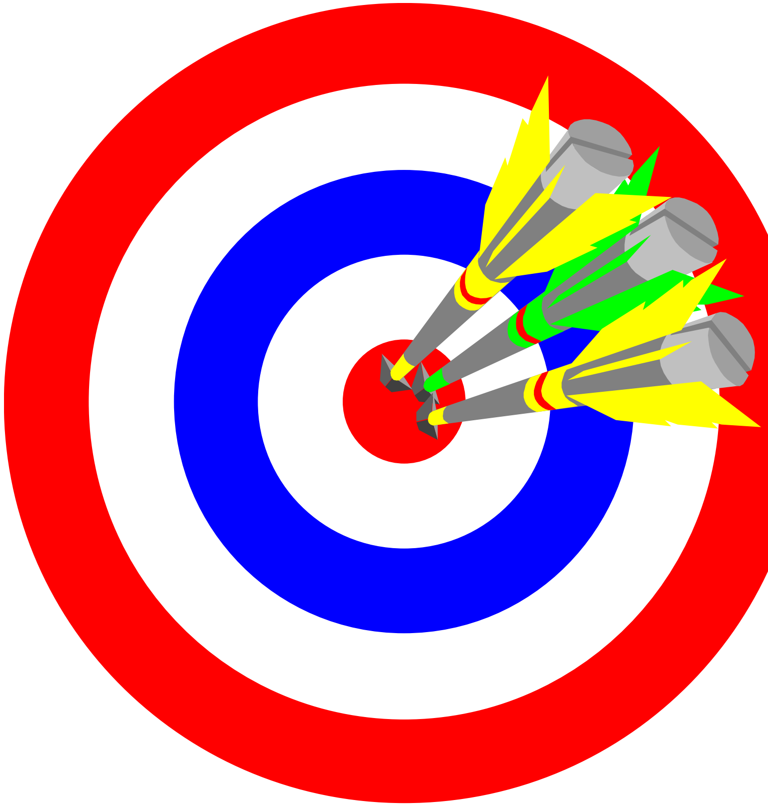
- Containment
- Terrorist Impacts
- Burning Potential
- Advanced I&C - Computer Control
- Safeguards
- International Standards
- Materials - ASME

- Blowdown Impacts
- Release Models
- Break Spectrum
- Water Ingress
- Seismic Impacts
- Post Accident Recovery
- “License By Test”

MIT Projects on Advanced Reactors Technology

Coolant	Near Term	Long Term
Core Design Options		
Water	High Burnup	Thorium Fuel
	Annular Fuel	Pressure Tube
		IRIS
Gas	Pebble Bed Reactor	Modular Fast Gas-Cooled-Gas Turbine
Lead		Actinide Burning Reactor
Turbine Cycle Options		
Helium	Indirect Cycle	High Temperature for H_2 Production
CO_2		Super Critical CO_2

Summary



- Nuclear Energy is coming back
- Global Environmental Issues are worrisome
- Plenty of research challenges in NGNP and Generation IV
- It is a good time to be a nuclear engineer !