The Politically Correct Nuclear Energy Plant

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Ford Distinguished Lecture Series

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Politically Incorrect !

- High Cost
- Meltdowns
- Reprocessing (for now)
- Breeder Reactors (for now)
- Proliferation
- Waste that Dissolves in Water
- Big - Small is Beautiful
- Nuclear Energy - But Getting Better

Politically Correct !

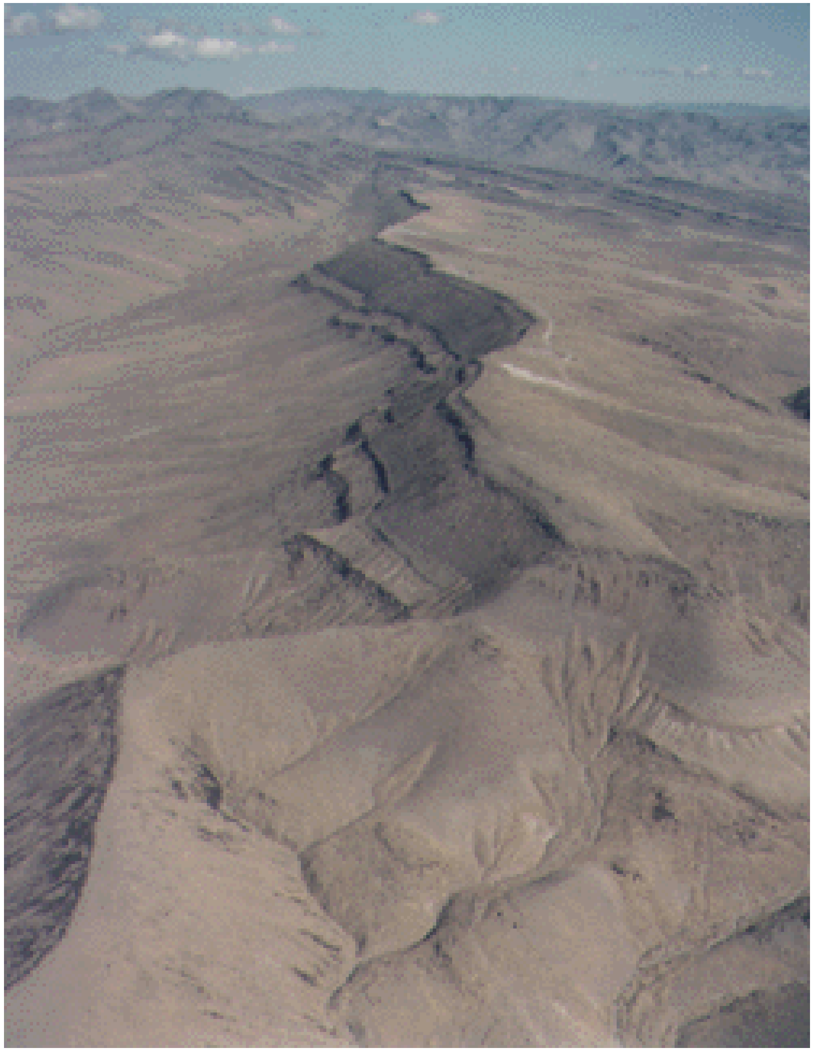
- Natural Safety
- No Meltdowns
- No Reprocessing
- Proliferation Resistant
- Competitive with Natural Gas
- Waste Forms that are Geologically Stable
- Something “New” - no “Baggage”

Common Myths

- Continued Burning of Fossil Fuels is Sustainable - Coal, Oil and Natural Gas
- Natural Gas is a Clean Fuel - relative to what - coal?
- Renewables are “clean and free”...
- Conservation with sacrifice will work
- There is no solution to nuclear waste disposal

Yucca Mountain

Next to the Nevada Nuclear Weapons Test Site



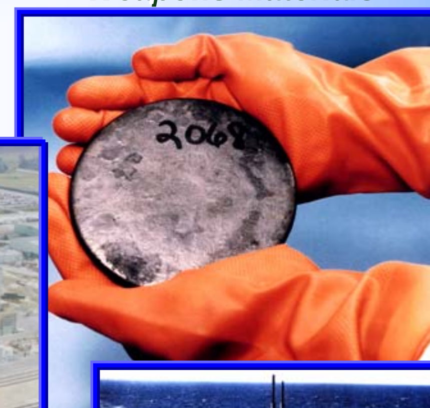
U.S. Department of Energy

High-Level Radioactive Waste Management Program

Our mission is to manage and dispose of the Nation's spent nuclear fuel and high-level radioactive waste. We will provide leadership in developing and implementing strategies that assure public and worker health and safety, protect the environment, merit public confidence, and are economically viable.

Defense Complex Clean-Up

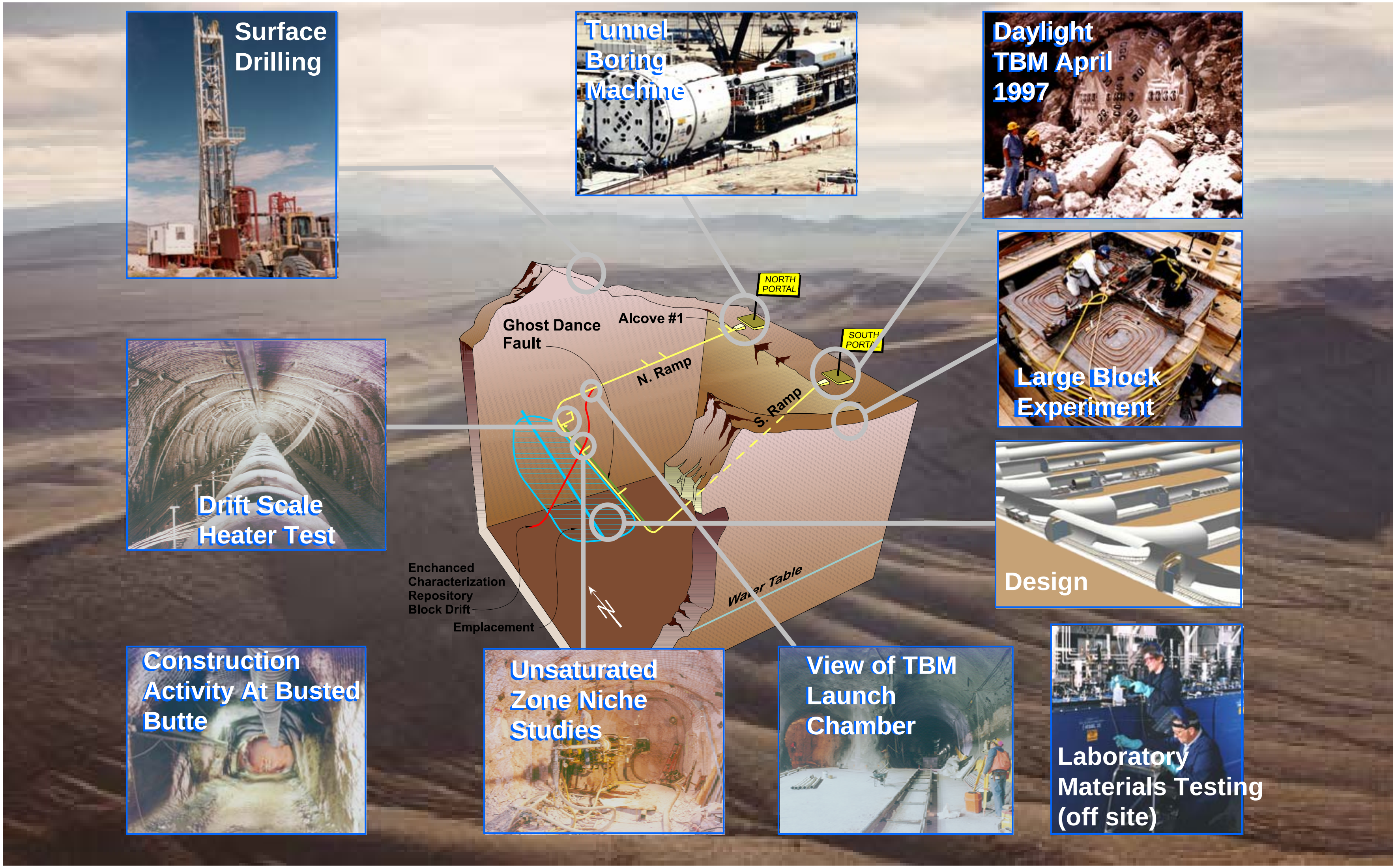
Disposition of Surplus Weapons Materials



Support of Nonproliferation Initiatives, e.g. Disposal of DOE and Foreign Research Reactor Spent Fuel

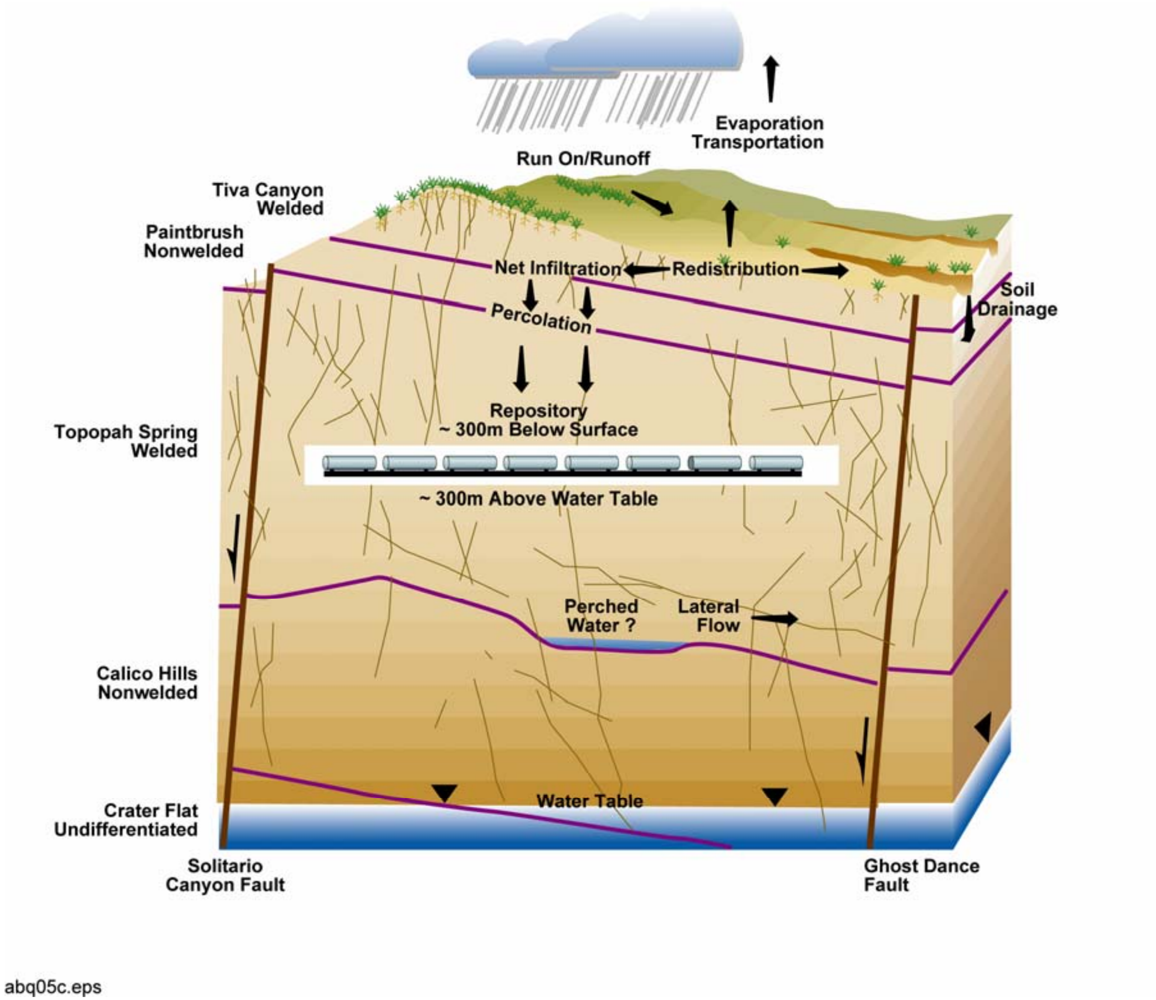
Disposition of Naval Reactor Spent Nuclear Fuel

Viability Assessment "Status Report" Science and Engineering Accomplishments



Viability Assessment:
Total System Performance Assessment (Volume 3)

Water Movement Through the Geologic Formations



Realities

- The California electricity problem is a capacity and transmission problem
- Continued dependence on natural gas for new generation is a bad idea.
- There is no new nuclear energy plant that is competitive at this time.
- De-regulation did not create the competitive market expected
- CO_2 is increasing in the environment.

Examples of Greenhouse Gases Affected by Human Activities

	CO_2	CH_4	N_2O
Pre-industrial concentration	280 ppmv	700 ppbv	275 ppbv
Concentration in 1994	358 ppmv	1720 ppbv	312 ppbv[2]
Rate of concentration change[1]	1.5 ppmv/yr	10 ppbv/yr	0.8 ppbv/yr
Atmospheric lifetime (years)	50-200[a]	12[b]	120

ppmv = part per million volume; ppbv = part per billion volume

[1] The growth rates of CO_2, CH_4 and N_2O are averaged over the decade beginning in 1984.

[2] Estimated from 1992-1993 data.

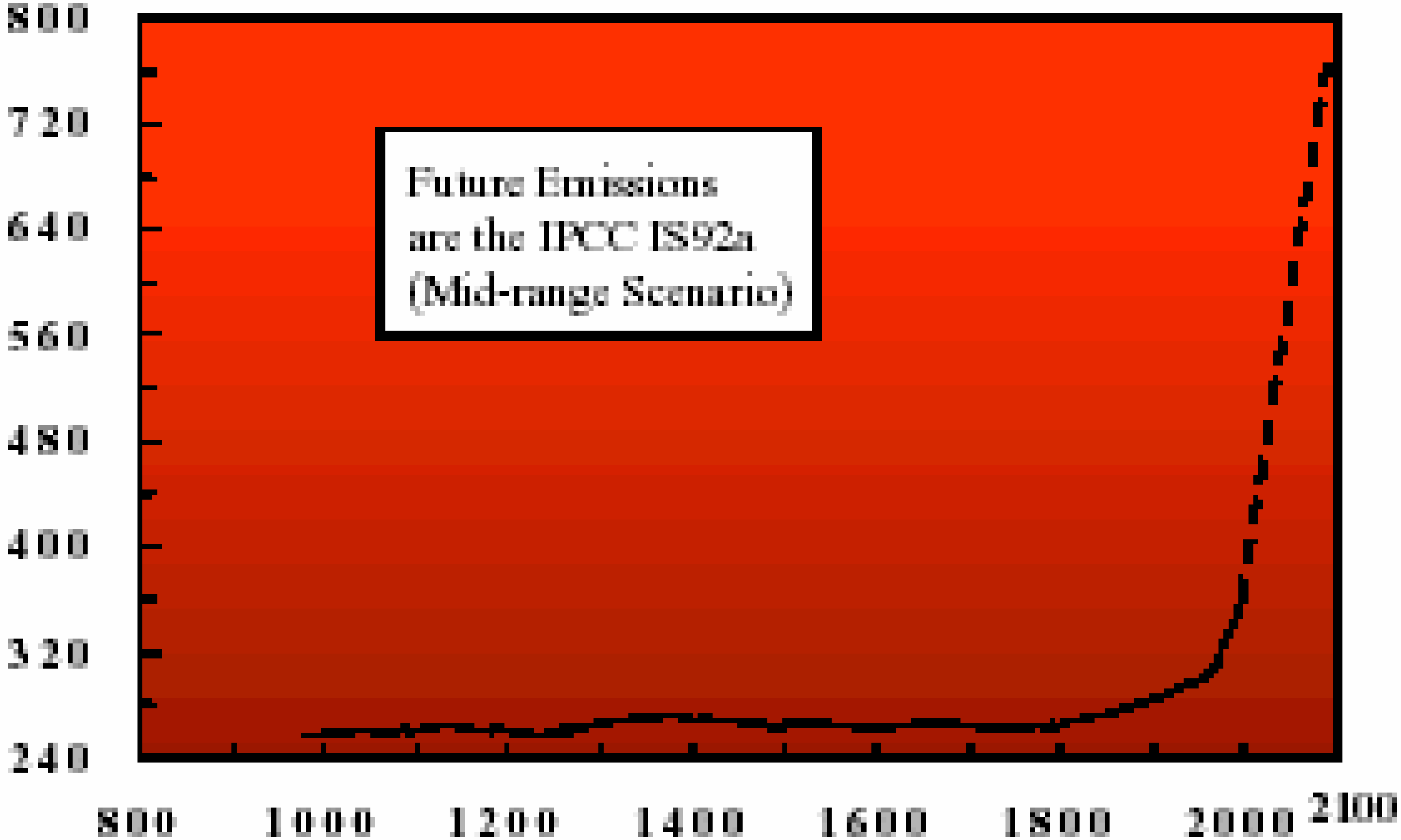
[a] No single lifetime for CO2 can be defined because of the different rates of uptake by different processes.

[b] Defined as an adjustment time which takes into account the indirect effects of methane on its own lifetime.

Source: IPCC, 1995

EPA

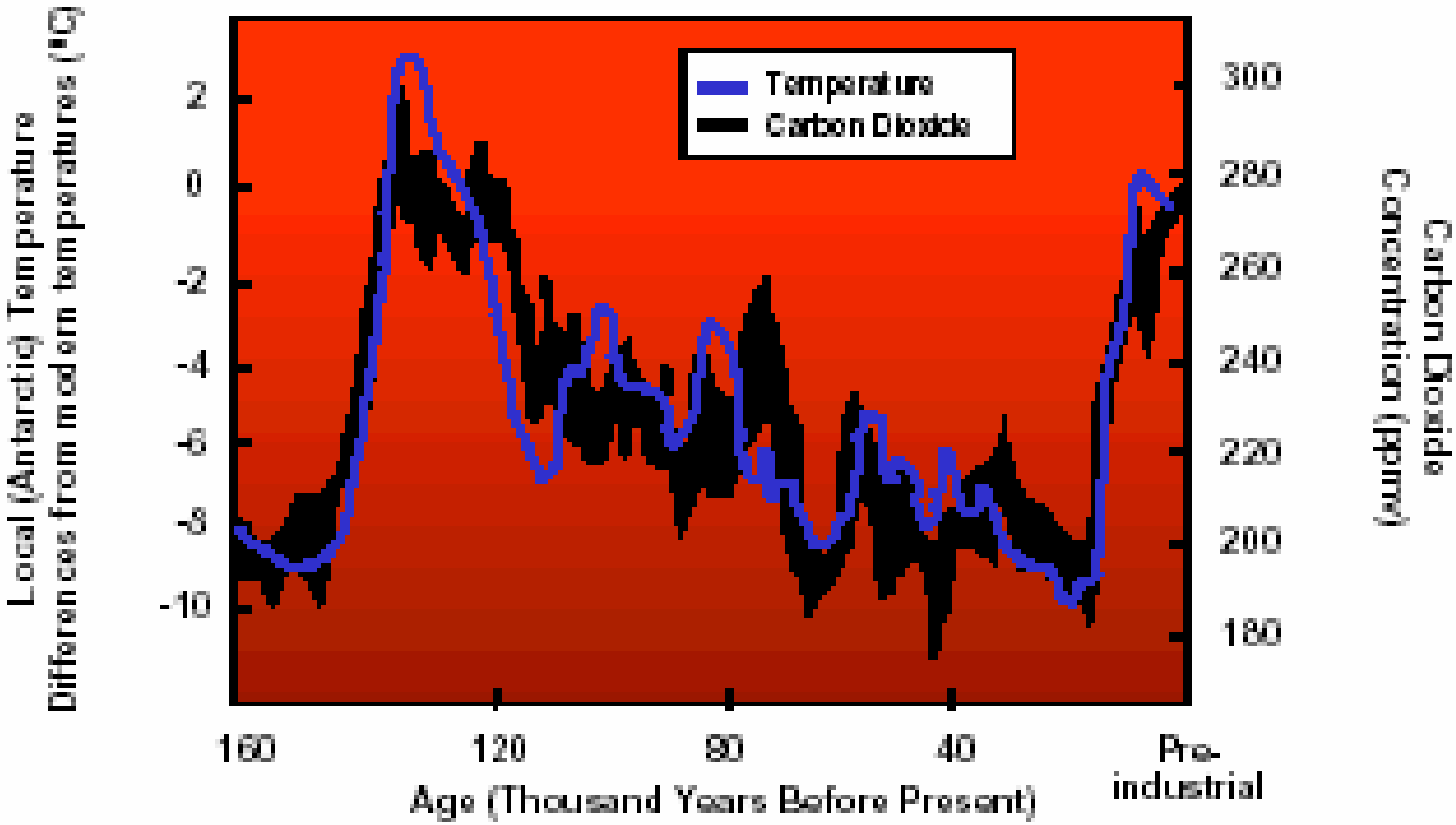
Historical and Projected Future CO_2 Concentrations



Derived from ice-core measurements (Siple and South Pole) and direct observation (Mauna Loa, Hawaii)
Source: Based on IPCC (1995)

EPA

Local Temperature Change and CO_2 Concentrations Over the Past 160,000 Years



Derived from Antarctic ice cores

Source: Based on IPCC (1990)

United States Environmental Protection Agency

Today's Reality

- Nationally - 20 % of electricity comes from existing 104 nuclear plants
- Performance of all nukes improving - fleet capacity factor 90% last year.
- Production Costs Decreasing - not increasing like natural gas
- More of our primary energy demand is being filled by electricity.

What About Transportation ?

- Fuel Cells ?
- Electric Cars ?
- Solar Electric Cars
- Natural Gas ?
- Combo-Cars
- Hydrogen Powered

Where do we get the hydrogen ?

Why Nuclear Energy ? Thought it Was Dead ?

- Too Expensive
- Too Controversial
- No Solution to Nuclear Waste Disposal
- Too Much Financial Risk, But...
- Existing Nuclear Plants Operating Very Well
- But, Generating Companies not Interested in New Nuclear Plants
- Except, this is changing

Tomorrow's Possibilities

- It Depends......

  - On a Product that is:

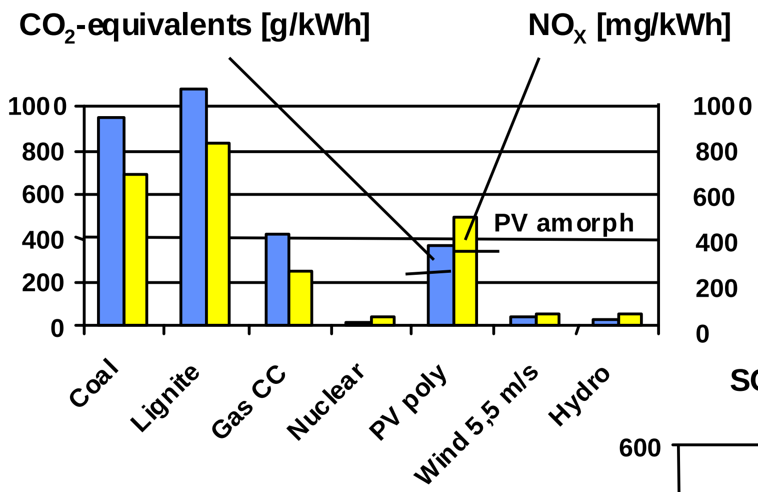
    Cheaper than Natural Gas

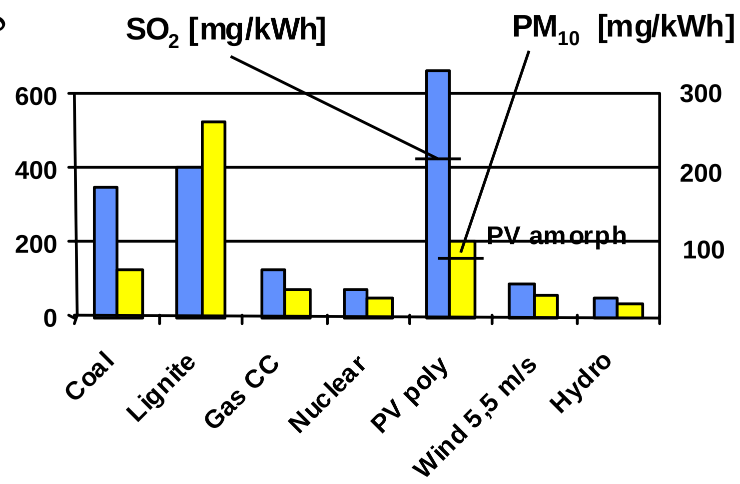
    Cleaner than gas, oil and coal

    Safer than all of the above

    Less environmentally impactful than solar, wind, biomass & hydro

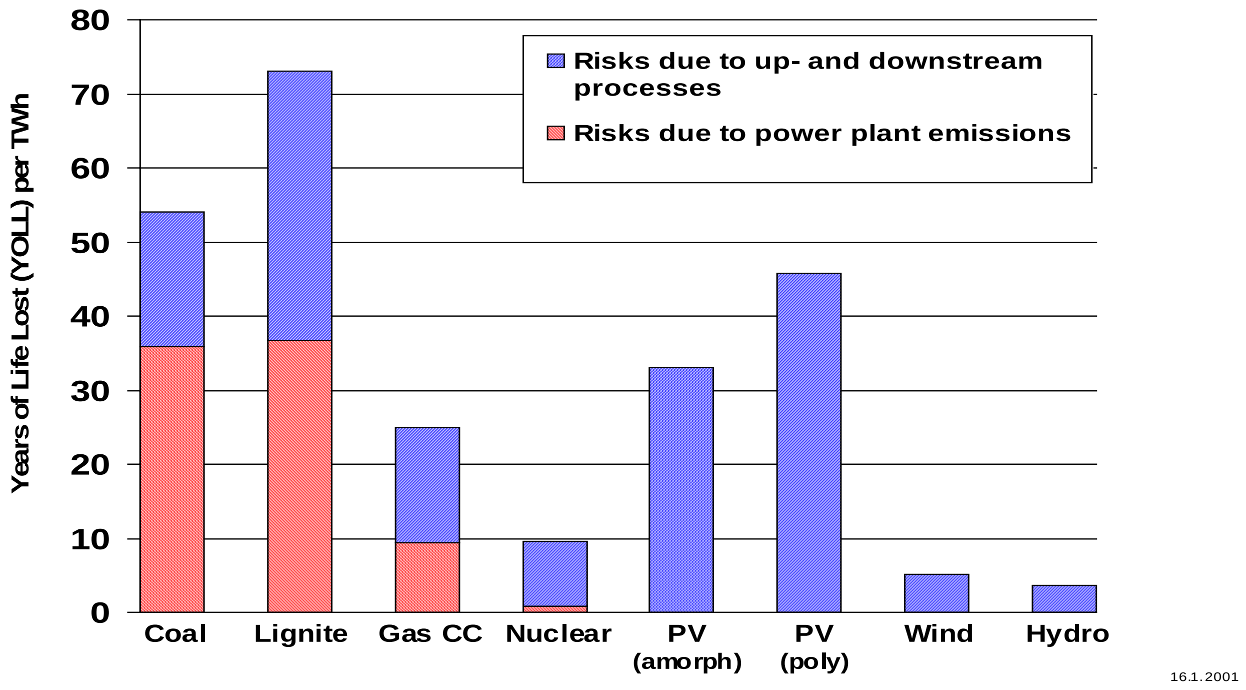
Total Life Cycle Emissions





From "Energy Supply and Sustainable Development: The Need for Nuclear Power", A. Voss, Univ. of Stuttgart.

Health Risk of Energy Systems



From “Energy Supply and Sustainable Development: The Need for Nuclear Power”, A. Voss, Univ. of Stuttgart.

What's the Solution ?

- Develop a Product that:
  1. Can compete with Natural Gas or Coal
  2. Be demonstrably Safe
  3. Has a Waste Form that can be easily disposed
  4. Does not create Proliferation concerns

And.........

- Prove it to the Public, Regulators and Political Leaders

To Do So, One must Change

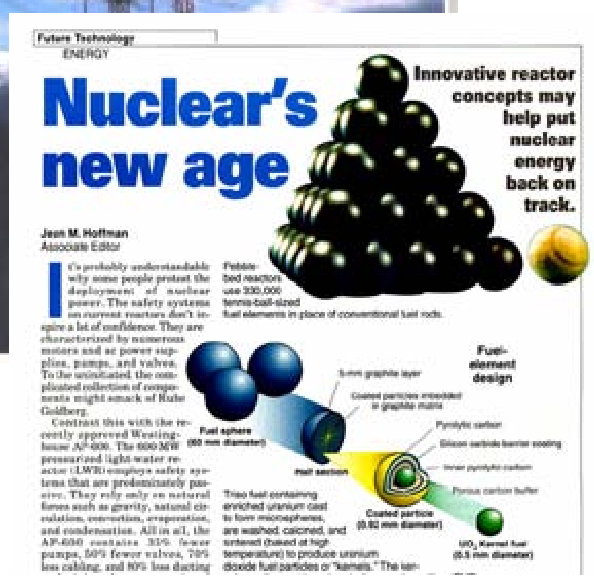
- How we:
  - Design
  - License
  - Build
  - Operate

Nuclear Energy Plants

Is There Such a Thing ?

- Not Yet, but some are working on it.
- South Africa
- China
- Netherlands
- MIT

Not exactly nuclear power houses !



Future Technology
ENERGY

Nuclear's new age

Innovative reactor concepts may help put nuclear energy back on track.

Jean M. Hoffman
Associate Editor

It's probably understandable why some people protest the deployment of nuclear power. The safety systems on current reactors don't inspire a lot of confidence. They are characterized by numerous motors and ac power supplies, pumps, and valves. To the uninitiated, the complicated collection of components might smack of Rube Goldberg.

Contrast this with the recently approved Westinghouse AP-600. The 600-MW pressurized light-water reactor (LWR) employs safety systems that are predominately passive. They rely only on natural forces such as gravity, natural circulation, convection, evaporation, and condensation. All in all, the AP-600 contains 35% fewer pumps, 50% fewer valves, 70% less cabling, and 80% less ducting

Pebble-bed reactors use 330,000 tennis-ball-sized fuel elements in place of conventional fuel rods.

Fuel-element design

Fuel sphere (60 mm diameter)

Half section

5-mm graphite layer

Coated particles imbedded in graphite matrix

Pyrolytic carbon

Silicon carbide barrier coating

Inner pyrolytic carbon

Porous carbon buffer

Coated particle (0.92 mm diameter)

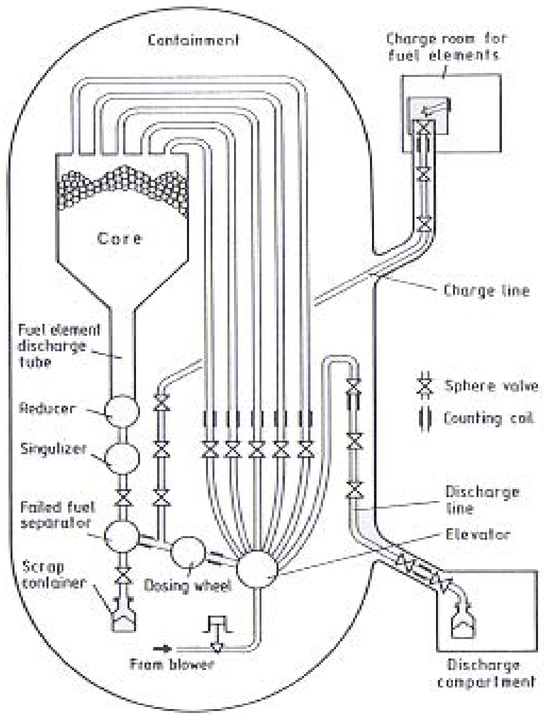
UO_2 Kernel fuel (0.5 mm diameter)

Triso fuel containing enriched uranium cast to form microspheres, are washed, calcined, and sintered (baked at high temperature) to produce uranium dioxide fuel particles or "kernels." The ker-

Modular High Temperature Pebble Bed Reactor

- 110 MWe
- Helium Cooled
- 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
- Process Heat Applications - Hydrogen, water

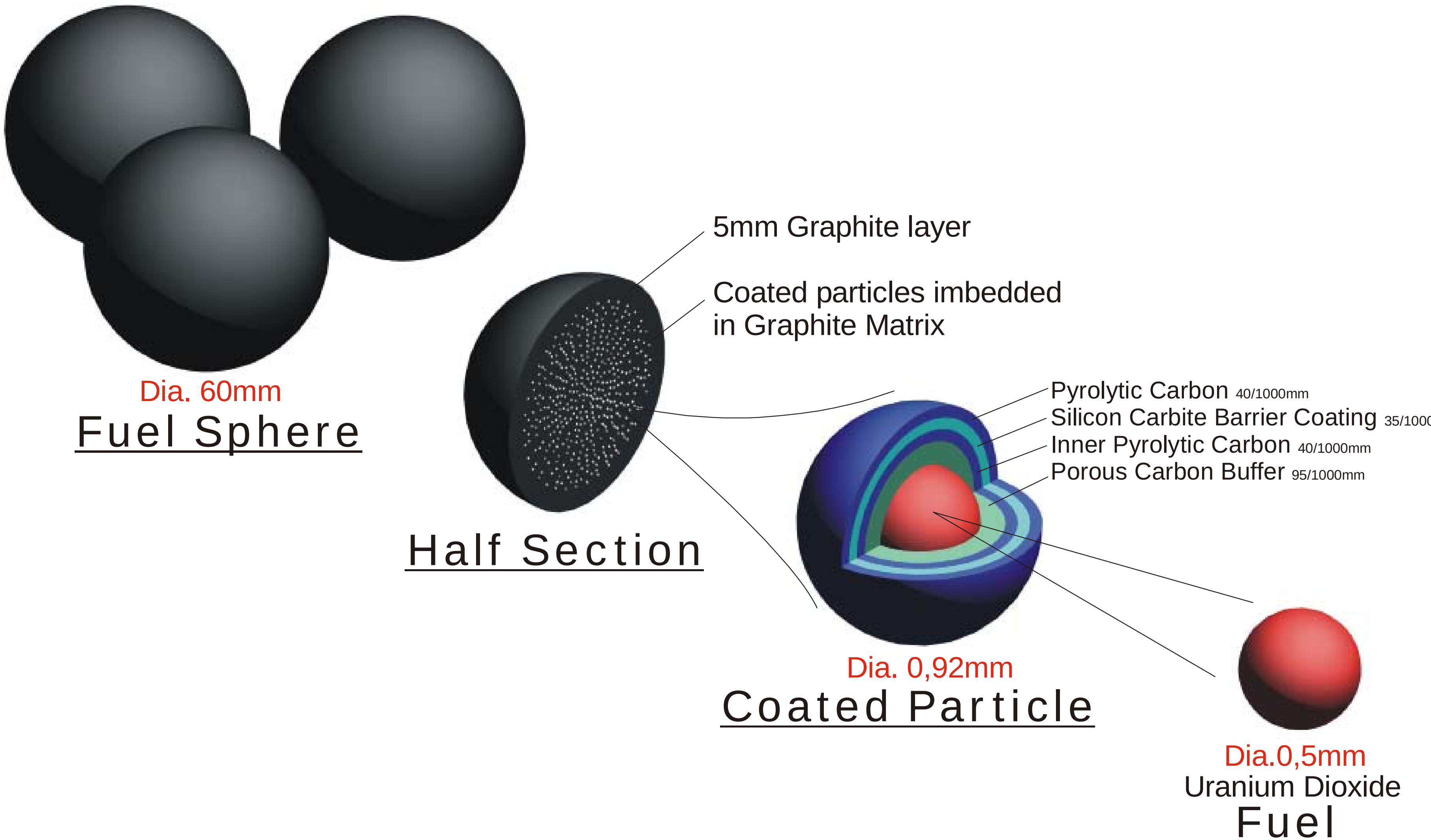
What is a Pebble Bed Reactor ?

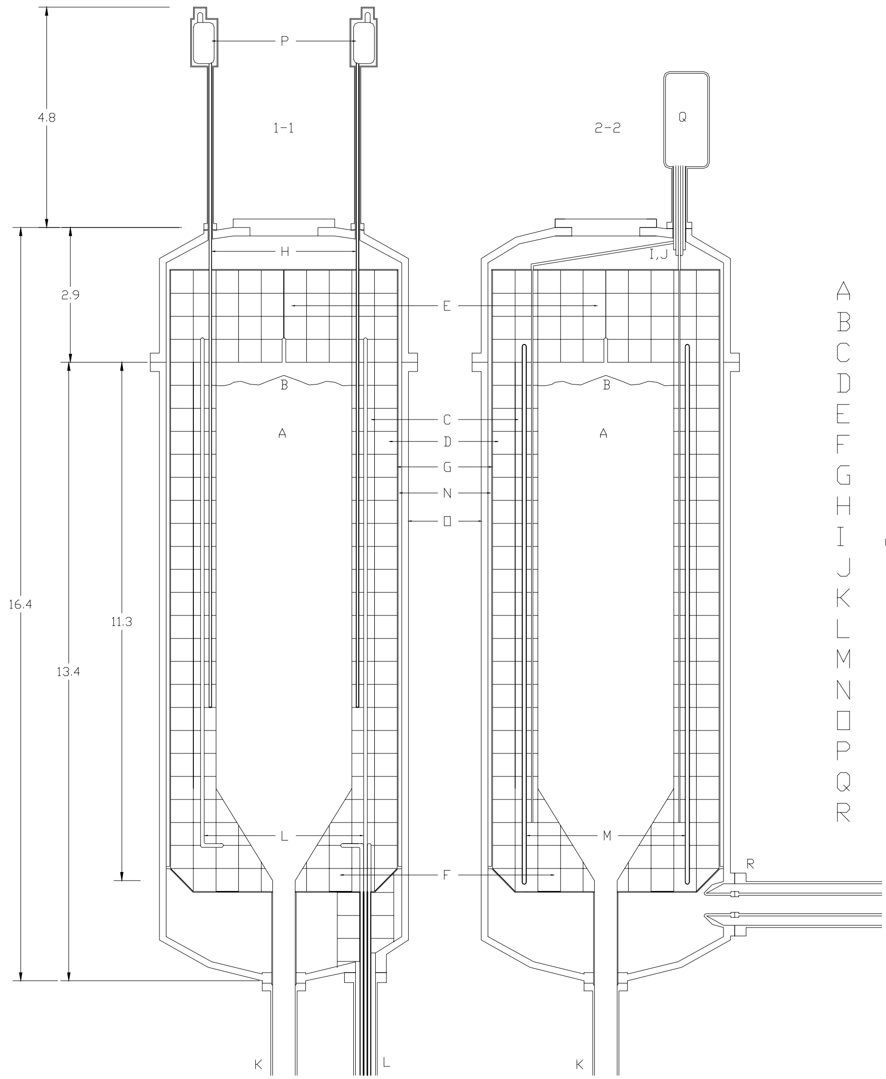


- **360,000 pebbles in core**
- **about 3,000 pebbles handled by FHS each day**
- **about 350 discarded daily**
- **one pebble discharged every 30 seconds**
- **average pebble cycles through core 10 times**
- **Fuel handling most maintenance-intensive part of plant**

FUEL ELEMENT DESIGN FOR PBMR

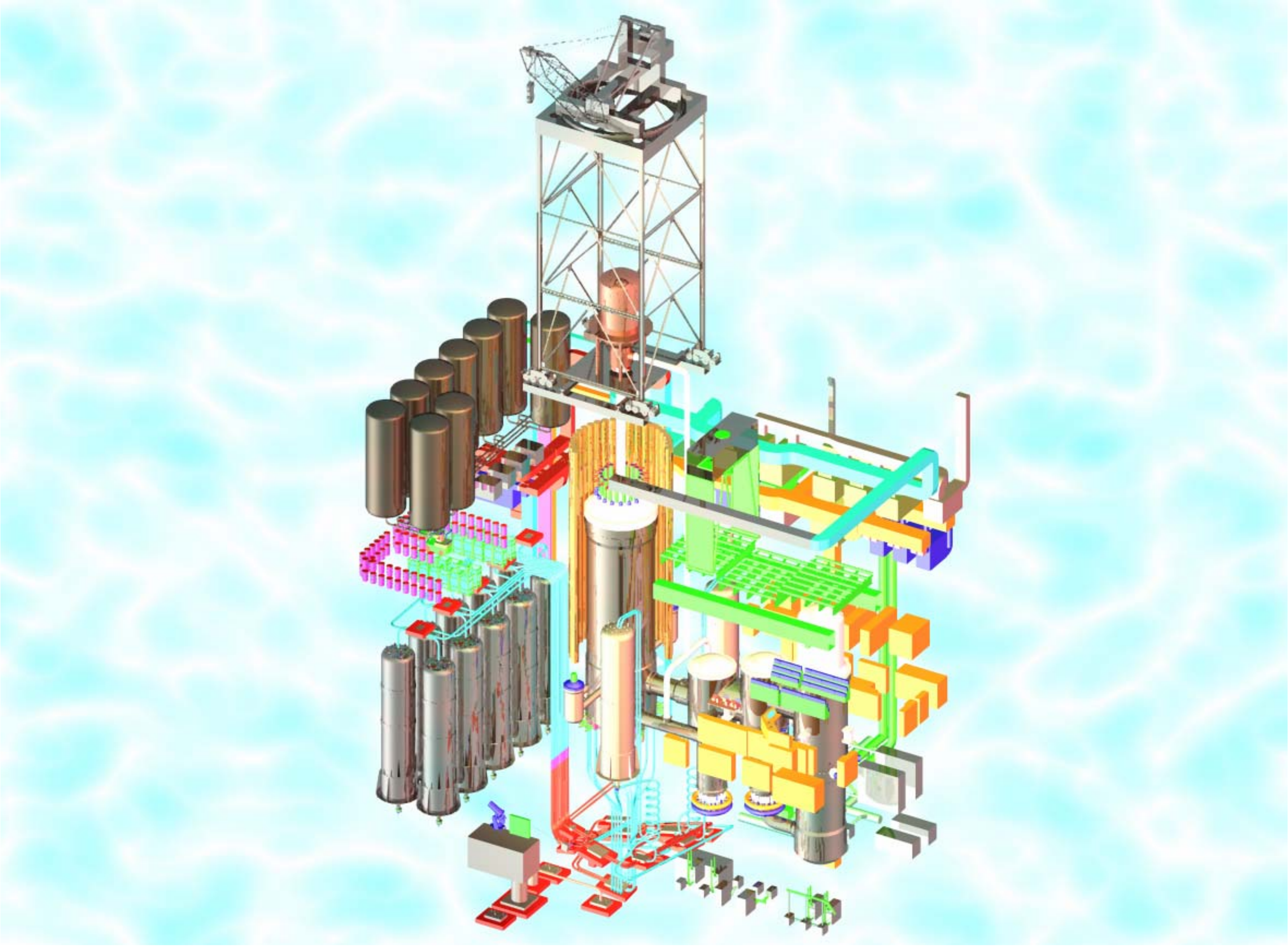
P B M R



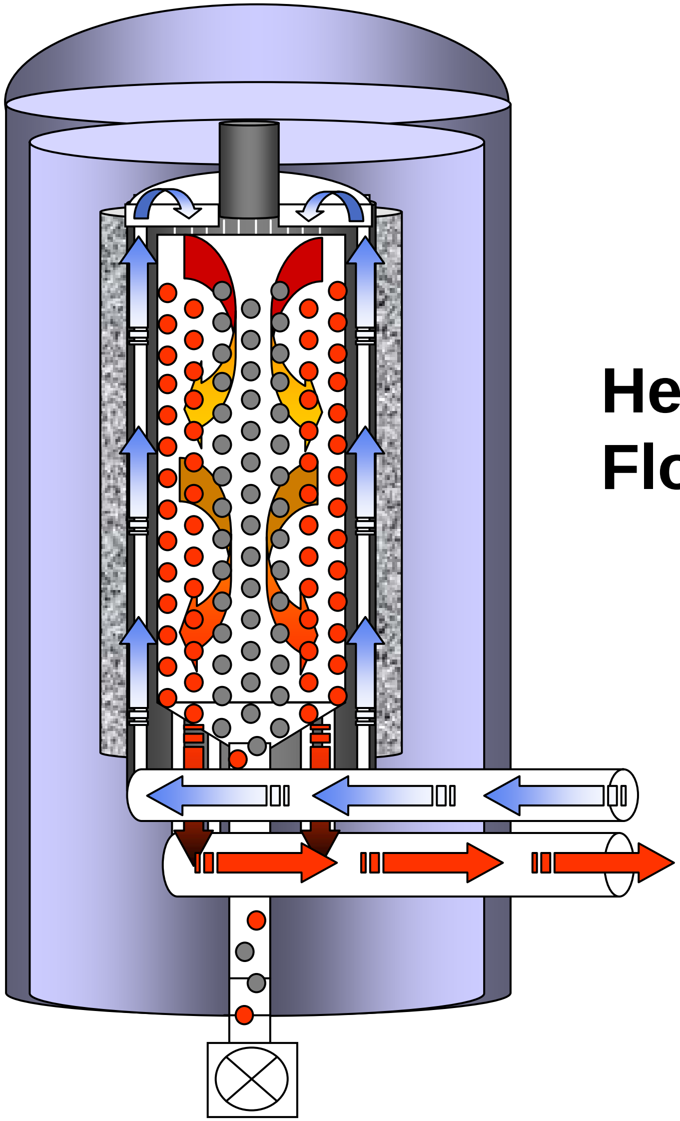


A Pebble Bed Core
B Fuel Drop Points (5)
C Inner Reflector
D Outer Reflector
E Top Reflector
F Bottom Reflector
G Core Barrel
H Control Rod Channels (6)
I Absorber Ball Drop Channels (18)
J Absorber Ball Lift Channel (1)
K Fuel Discharge Tube
L Pebble Fuel Lift Channels (5)
M Coolant Flow Channels (6)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

Equipment Layout

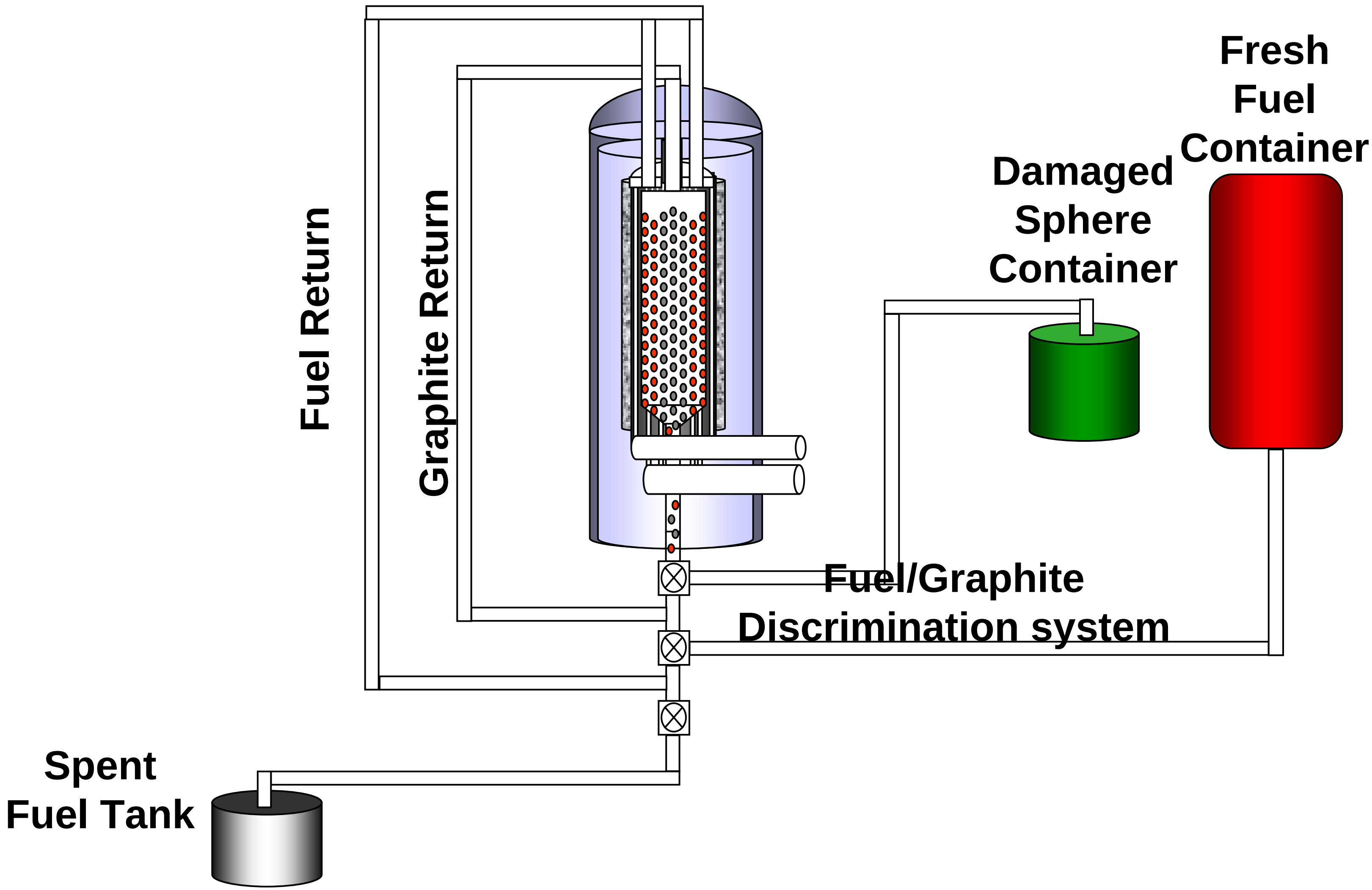


Reactor Unit



Helium Flowpath

Fuel Handling & Storage System



Safety Advantages

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

AVR: Jülich

15 MWe Research Reactor

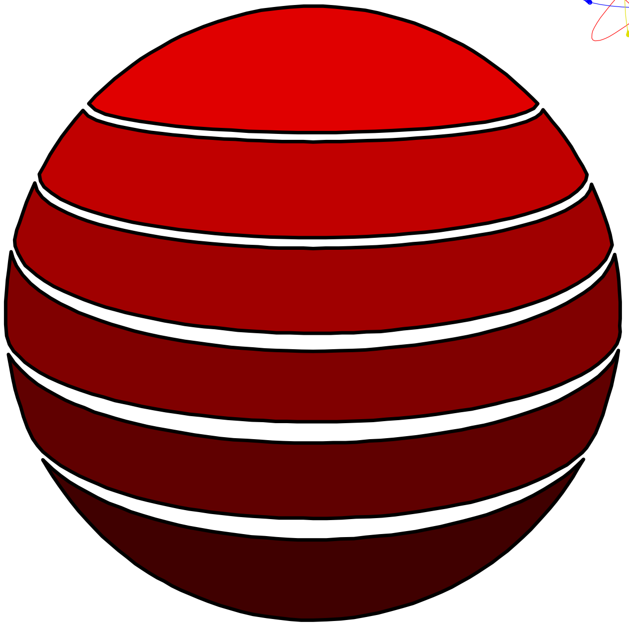
THTR: Hamm-Uentrop

300 Mwe Demonstration Reactor

HTR- 10 China
First Criticality Dec.1, 2000

MIT's Pebble Bed Project

- Similar in Concept to ESKOM
- Developed Independently
- Indirect Gas Cycle
- Costs 3.3 c/kwhr
- High Automation
- License by Test

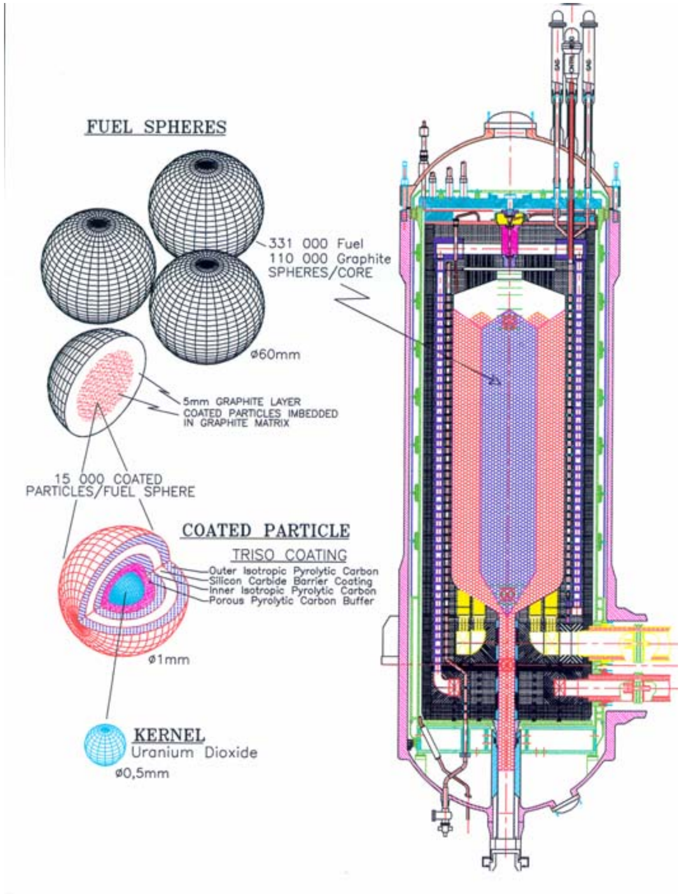


MIT's Project Objective

Develop a conceptual design of a complete nuclear energy plant to show that it can meet the objectives of economy, safety, non-proliferation and waste.

Then **BUILD** one!

Modular Pebble Bed Reactor



Thermal Power	**250 MW**
Core Height	**10.0 m**
Core Diameter	**3.5 m**
Fuel	**UO_2**
Number of Fuel Pebbles	**360,000**
Microspheres/Fuel Pebble	**11,000**
Fuel Pebble Diameter	**60 mm**
Microsphere Diameter	**~ 1mm**
Coolant	**Helium**

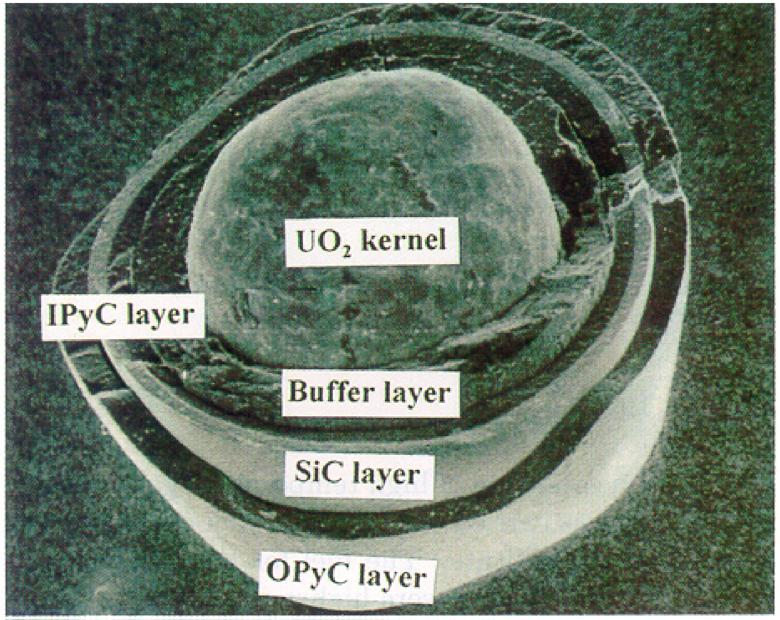
Project Overview

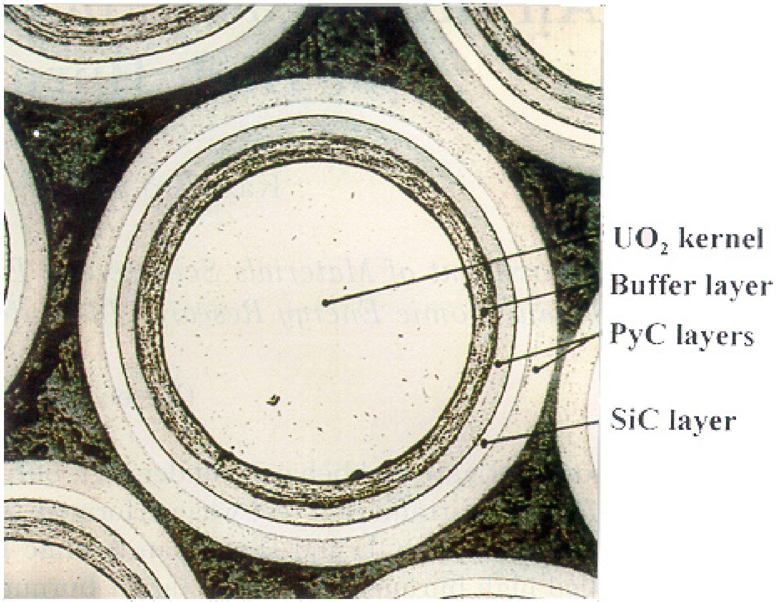
- **Fuel Performance**
- **Fission Product Barrier**
- **Core Physics**
- **Safety**
- **Balance of Plant Design**
- **Modularity Design**
- **Core Power Distribution Monitoring**
- **Modeling of Pebble Flow**
- **Reactor Research/ Demonstration Facility**
- **License by Test**
- **Future Research Needs**

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

Coated TRISO Fuel Particles





IPyC/SiC/OPyC: structural layers as pressure vessel and fission product barrier

Buffer PyC: accommodate fission gases and fuel swelling

From Kazuhiro Sawa, et al., J. of Nucl. Sci. & Tech., 36, No. 9, pp. 782. September 1999

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

- MNCP Modeling Process Being Developed
- Tested Against HTR-10 Benchmark
- Being Tested Against ASTRA Tests with South African Fuel and Annular Core
- VSOP Verification and Validation Effort Beginning

Nonproliferation

Pebble-bed reactors are highly proliferation resistant:

- small amount of uranium (9 g/ball)
- high discharge burnup (100 MWd/kg)
- TRISO fuel is difficult to reprocess
- small amount of excess reactivity limits number of special production balls

Diversion of 8 kg Pu requires:

- 260,000 spent fuel balls – 2.6 yrs
- 790,000 first-pass fuel balls – 7.5
- ~15,000 'special' balls – 3

Spent Fuel

Pu238	5.5%
Pu239	24.1
Pu240	25.8
Pu241	12.6
Pu242	32.0

First Pass

Pu238	~0 %
Pu239	64.3
Pu240	29.3
Pu241	5.6
Pu242	0.8

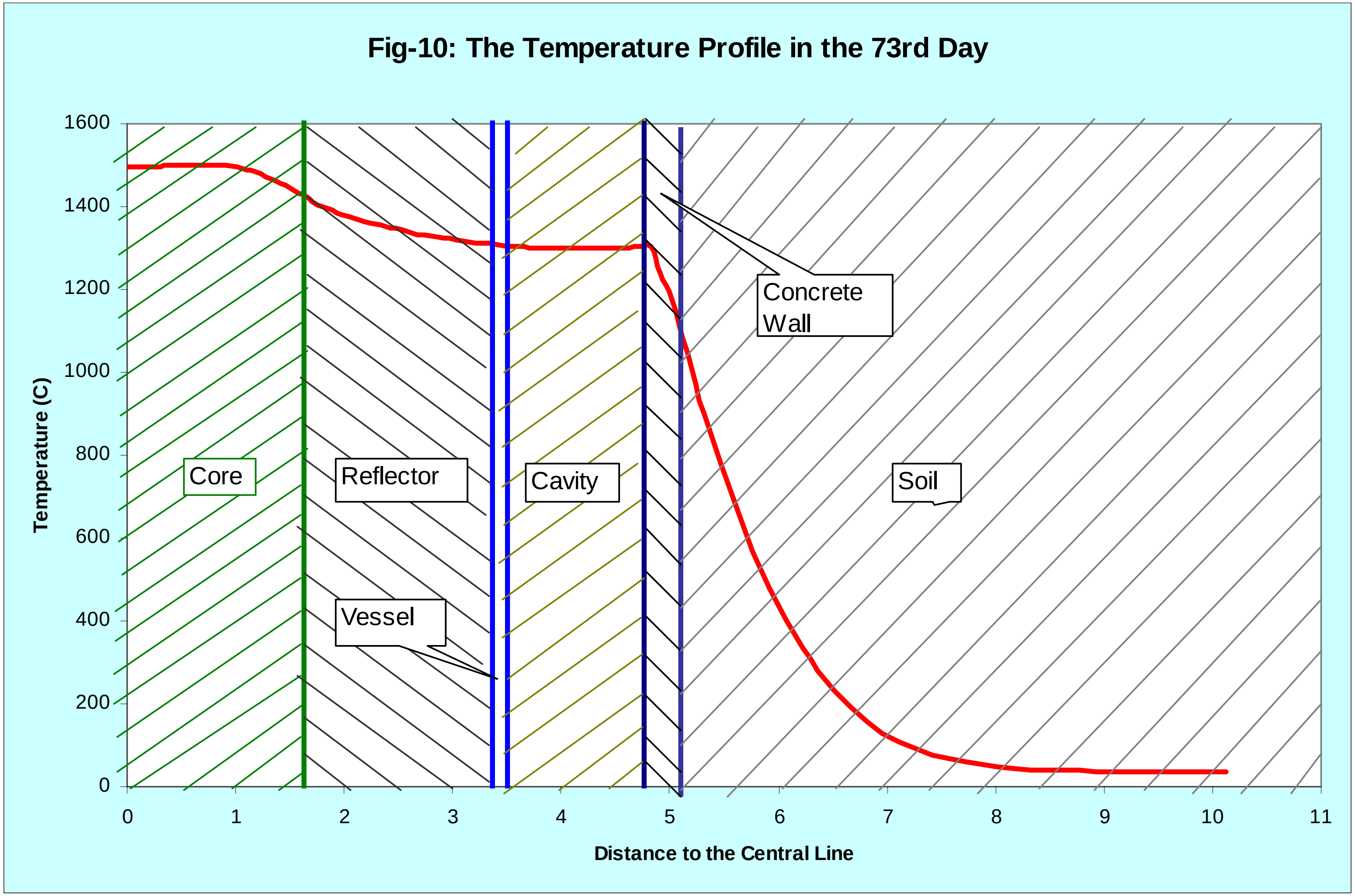
Proliferation Conclusions

- At high burnups not useful or even practical to reprocess for weapons however crude.
- Extraction at lower burnups requires a huge number of pebbles to be diverted which can be detected due to limited access to pebbles and “closed” nature of system with reasonable IAEA detection systems in place.

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

Temperature Profile



Air Ingress Analysis Preliminary Conclusions

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 often feared “graphite fire” can be excluded because of the temperature distribution and the low vapor pressure of the vaporized materials.

Waste Disposal Conclusions

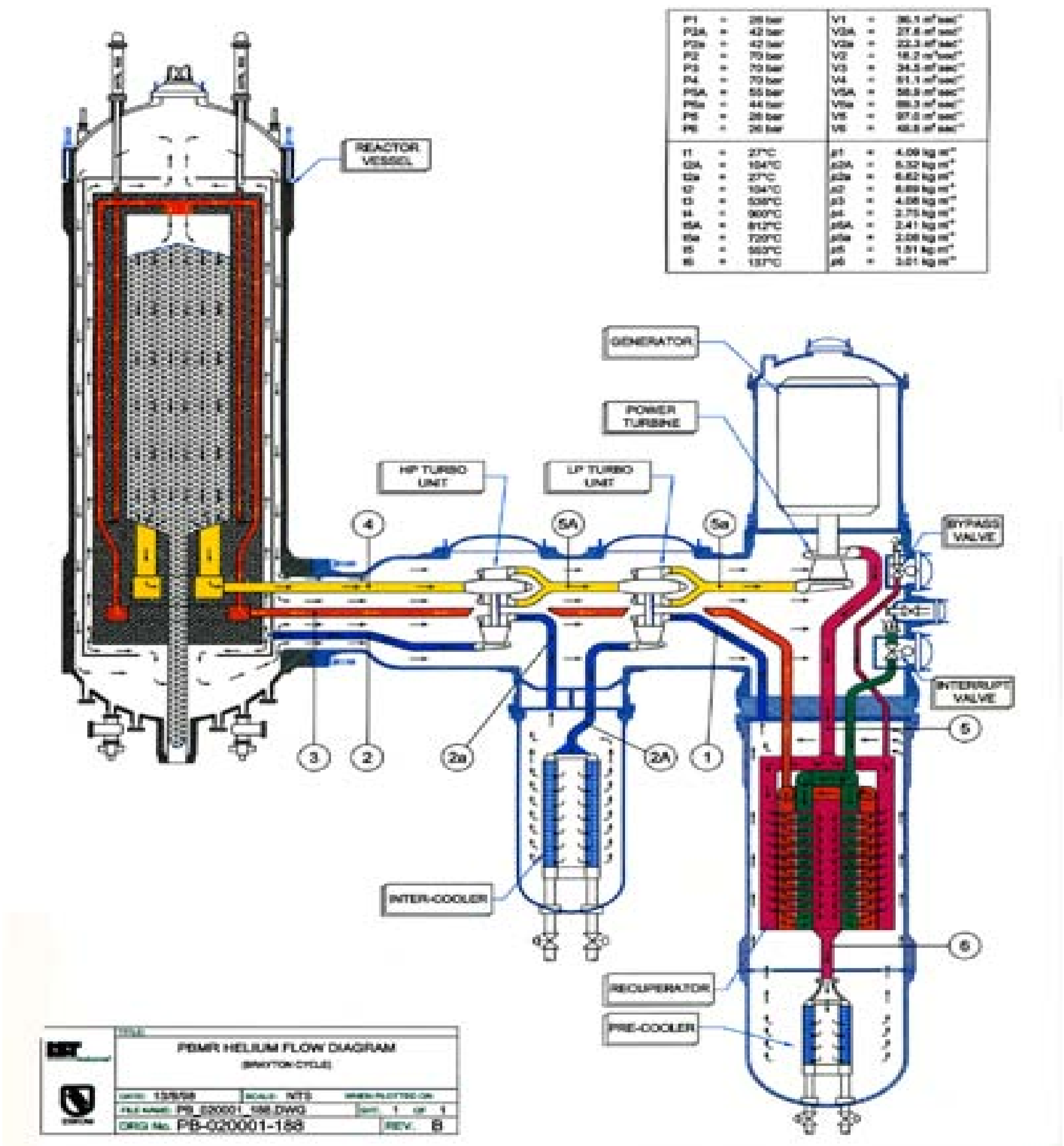
- Per kilowatt hour generated, the space taken in a repository is less than spent fuel from light water reactors.
- Number of shipments to waste disposal site 10 times higher using standard containers.
- Graphite spent fuel waste form ideal for direct disposal without costly overpack to prevent dissolution or corrosion.
- Silicon Carbide may be an reffective retardant to migration of fission products and actinides.

Pebble Bed Reactor Designs

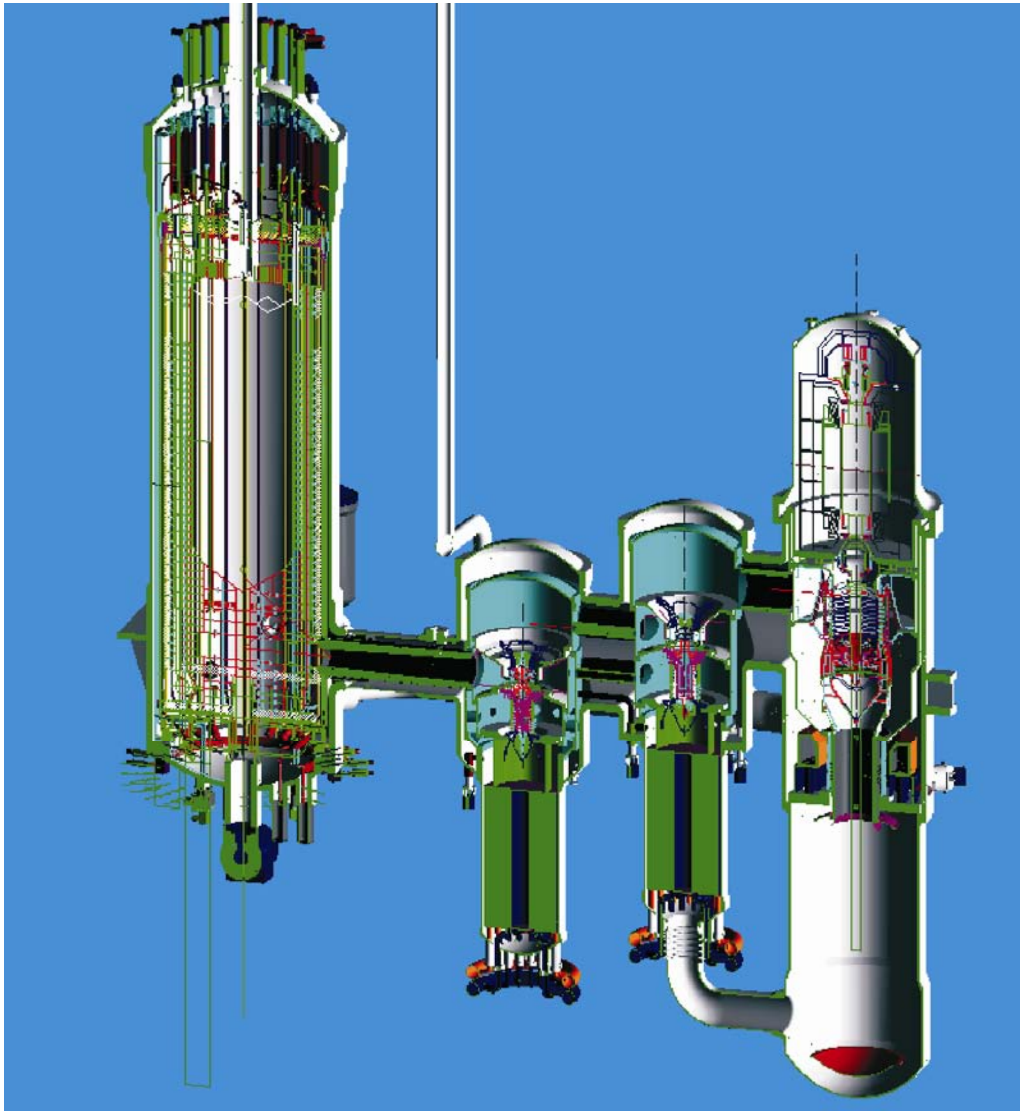
- PBMR (ESKOM) South African
  - Direct Cycle
  - Two Large Vessels
- MIT/INEEL Design
  - Indirect Cycle - Intermediate He/He HX
  - Modular Components - site assembly

PBMR Helium Flow Diagram

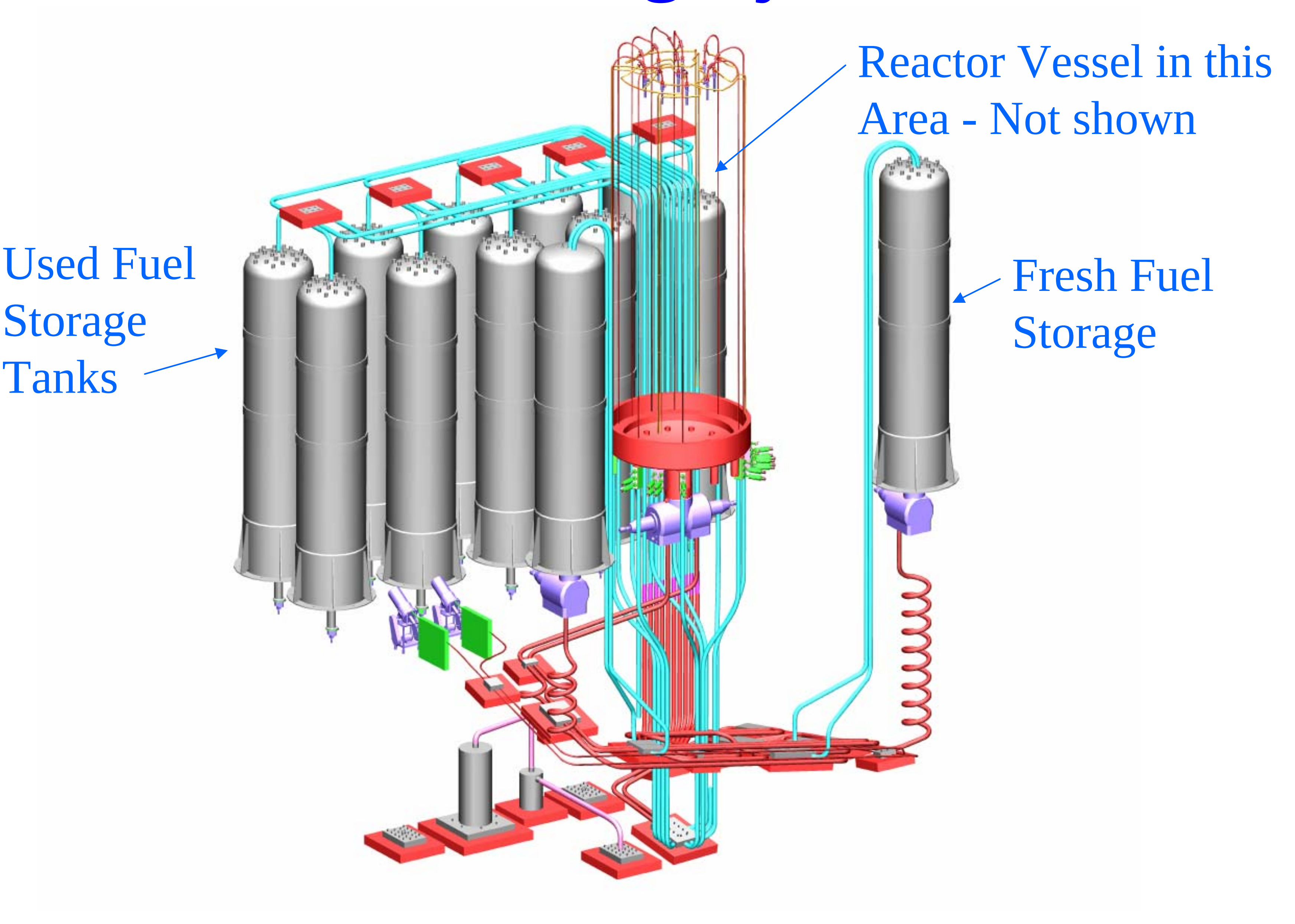
Direct
Cycle



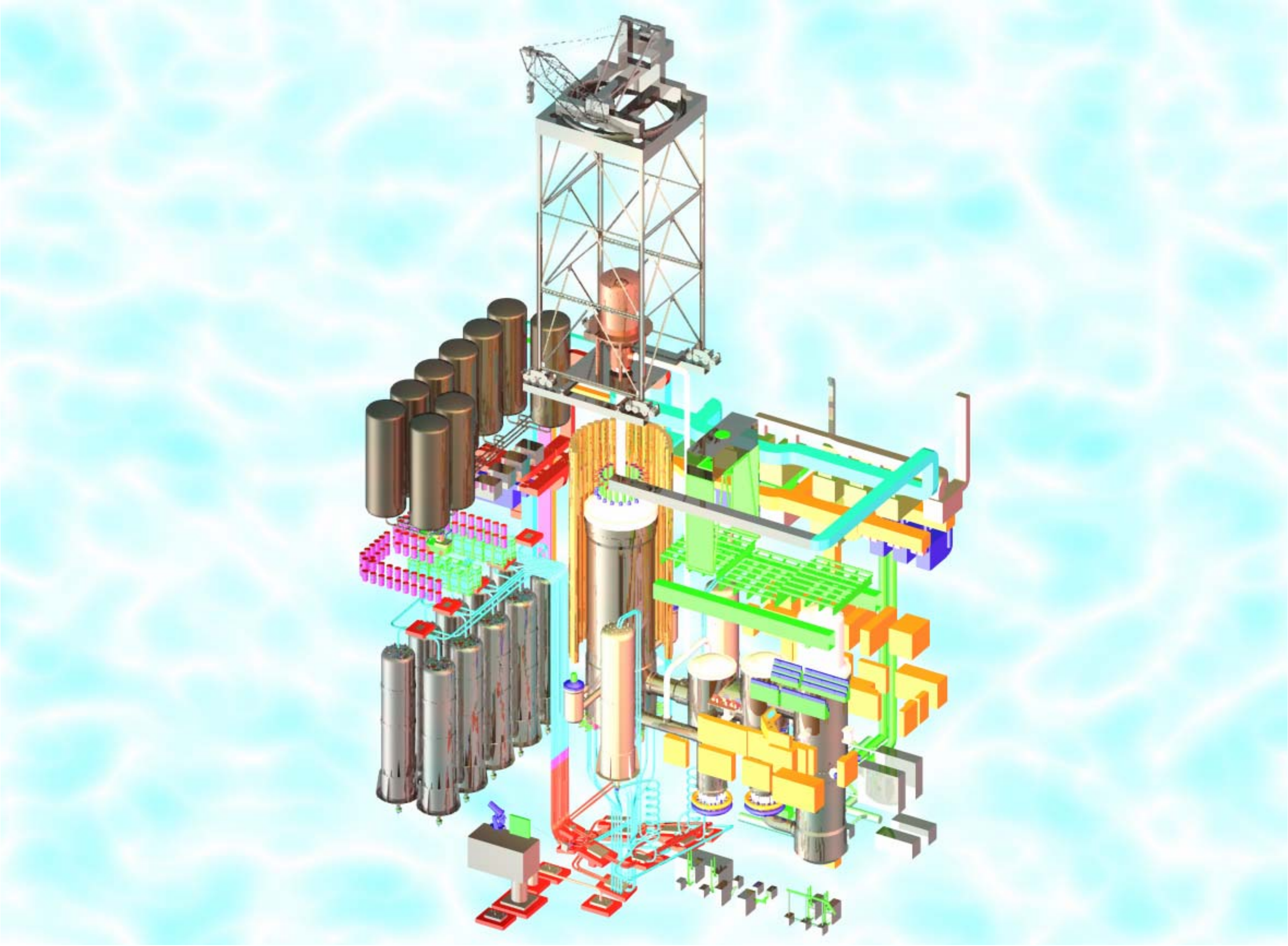
MPS Cutaway



Fuel Handling System



Equipment Layout



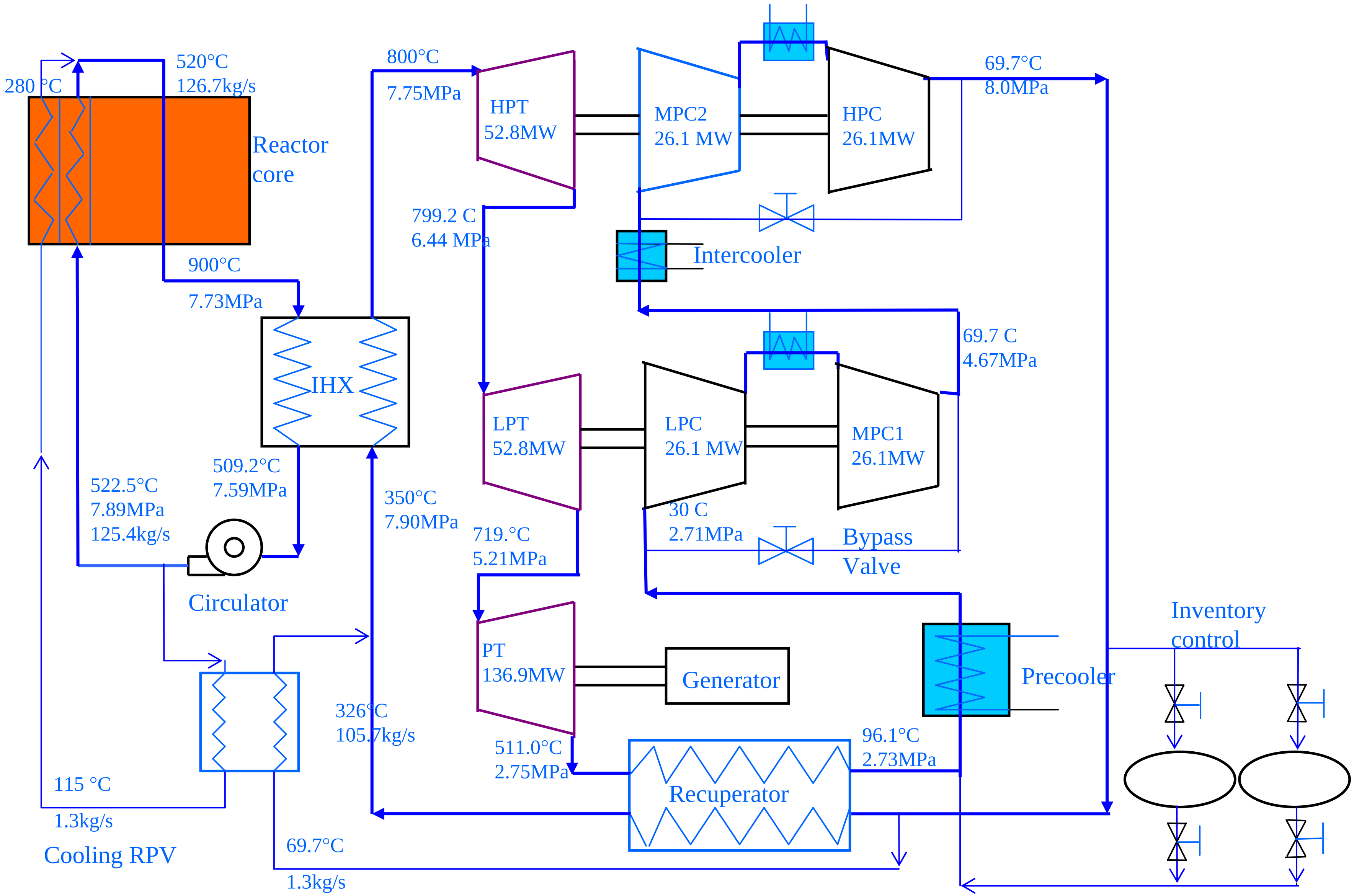
MIT MPBR Specifications

Thermal Power	250 MW - 115 Mwe
Target Thermal Efficiency	45 %
Core Height	10.0 m
Core Diameter	3.5 m
Pressure Vessel Height	16 m
Pressure Vessel Radius	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	$450^{o}C/850^{o}C$
Helium pressure	80 bar
Mean Power Density	3.54 MW/m^3
Number of Control Rods	6

Features of Current Design

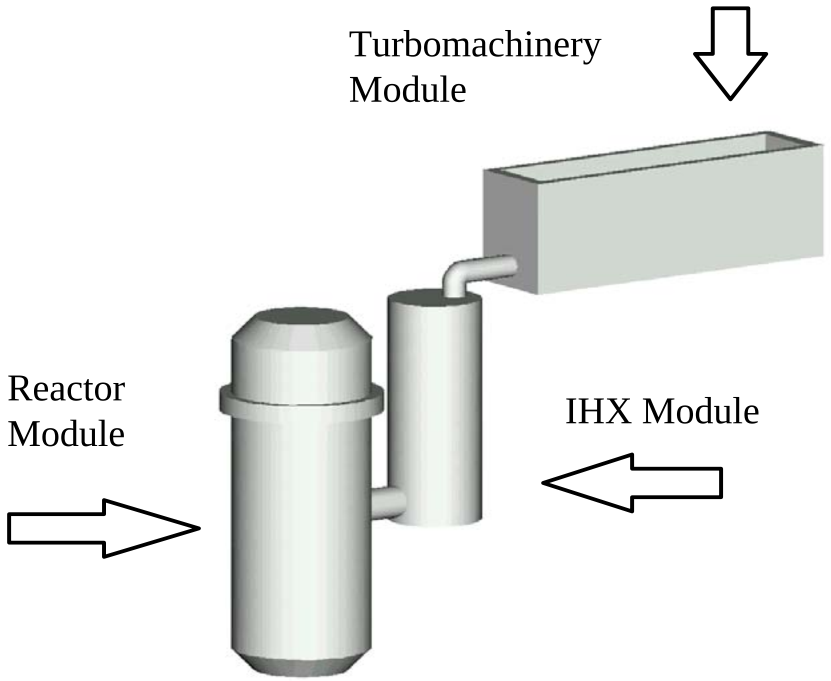
Thermal Power	250 MW
Gross Electrical Power	132.5 MW
Net Electrical Power	120.3 MW
Plant Net Efficiency	48.1% (Not take into account cooling IHX and HPT. if considering, it is believed > 45%)
Helium Mass flowrate	126.7 kg/s
Core Outlet/Inlet T	900°C/520°C
Cycle pressure ratio	2.96
Power conversion unit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

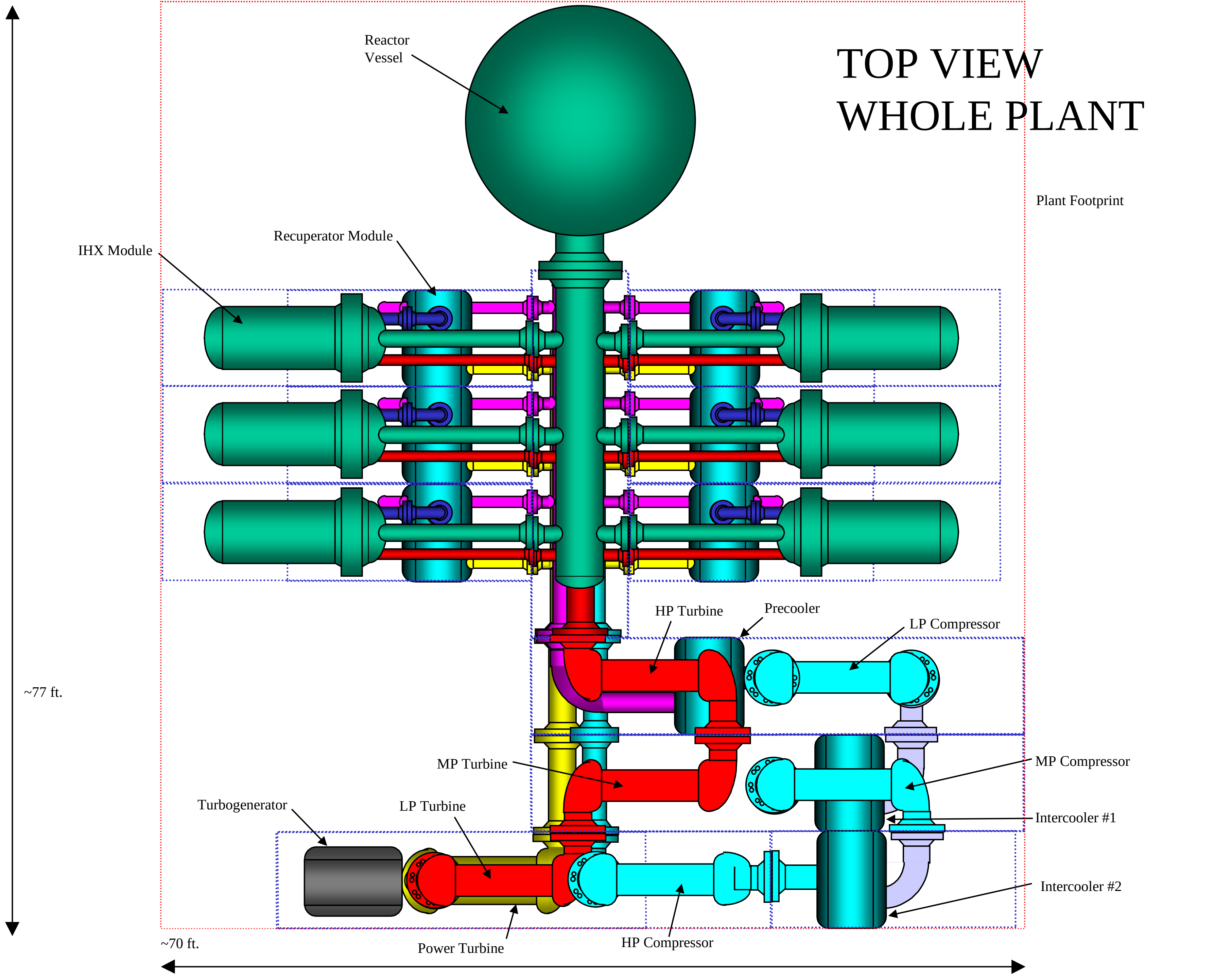
Current Design Schematic



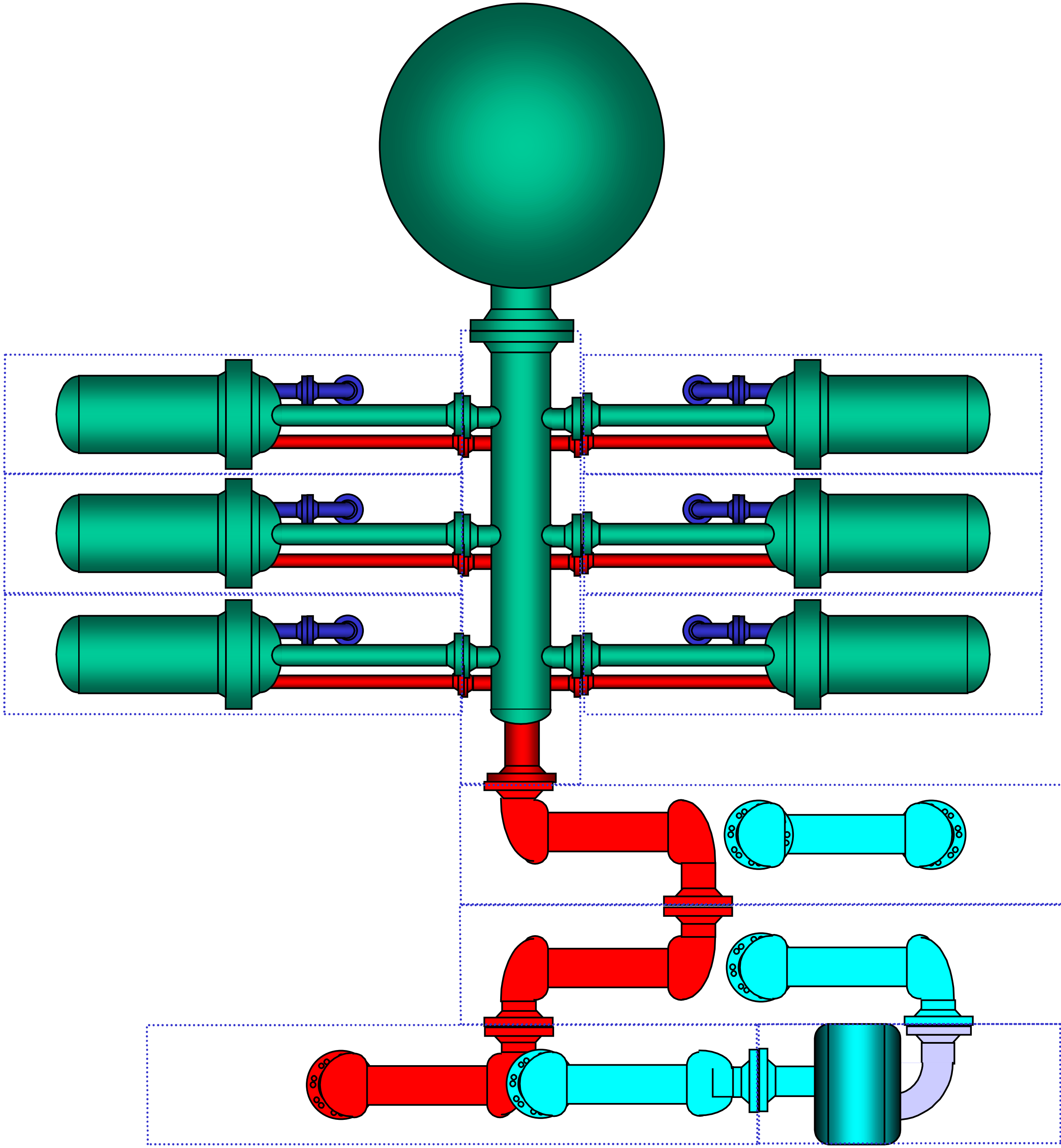
MIT Design for Pebble Bed

Conceptual Design Layout



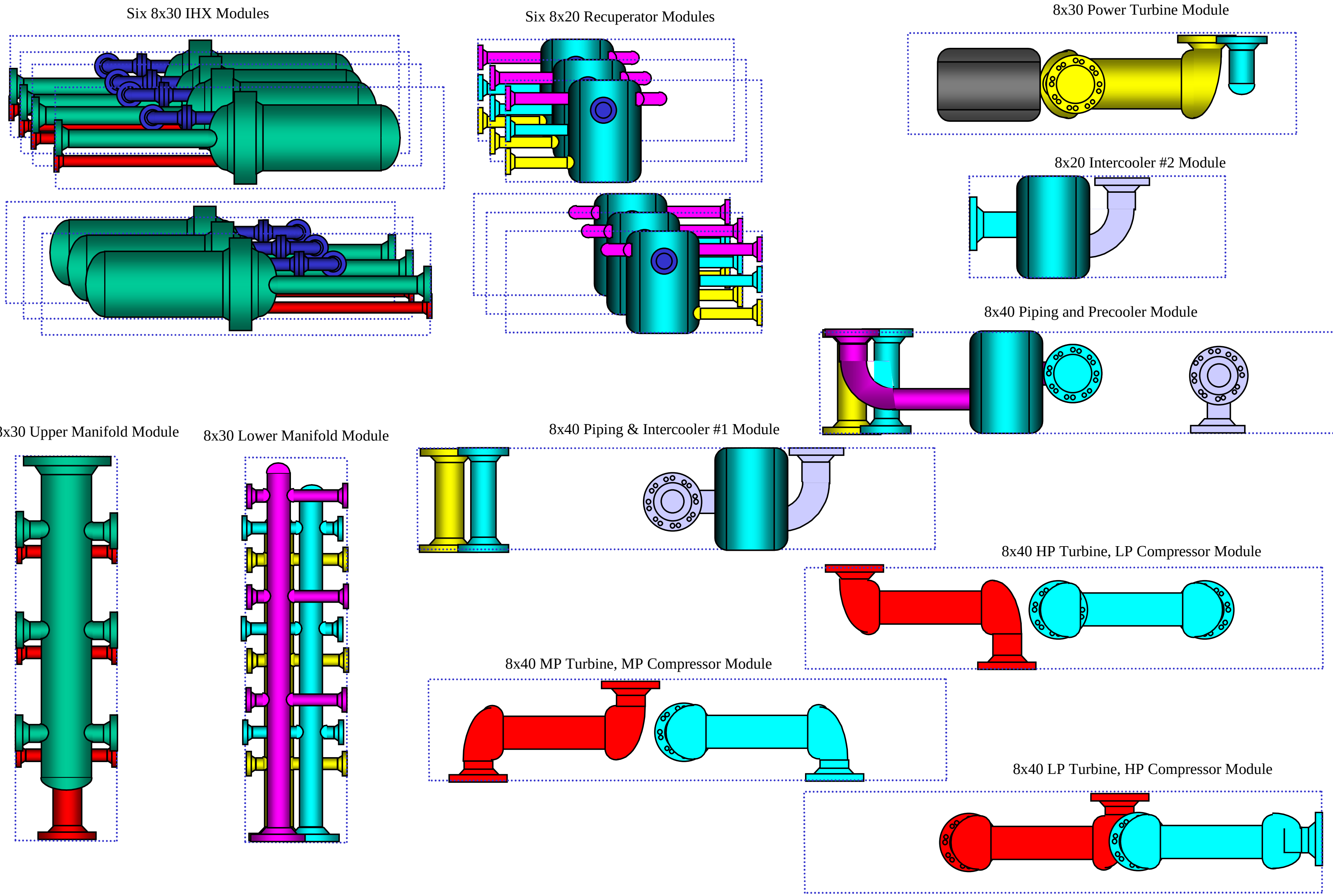


TOP VIEW
WHOLE PLANT
Reactor Vessel
Plant Footprint
Recuperator Module
IHX Module
~77 ft.
HP Turbine
Precooler
LP Compressor
MP Turbine
MP Compressor
Turbogenerator
LP Turbine
Intercooler #1
Intercooler #2
~70 ft.
Power Turbine
HP Compressor



PLANT MODULE SHIPPING BREAKDOWN

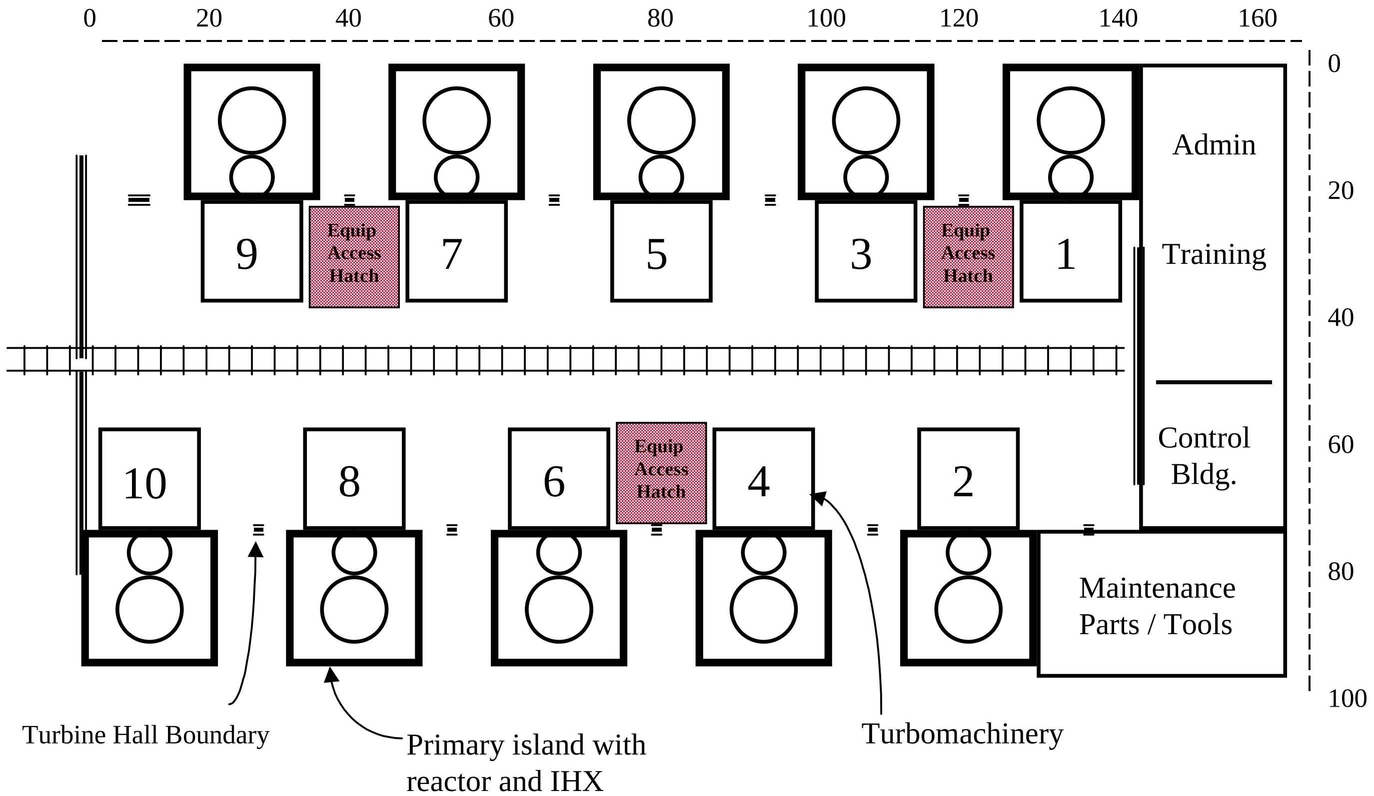
Total Modules Needed For Plant Assembly (21): Nine 8x30 Modules, Five 8x40 Modules, Seven 8x20 Modules



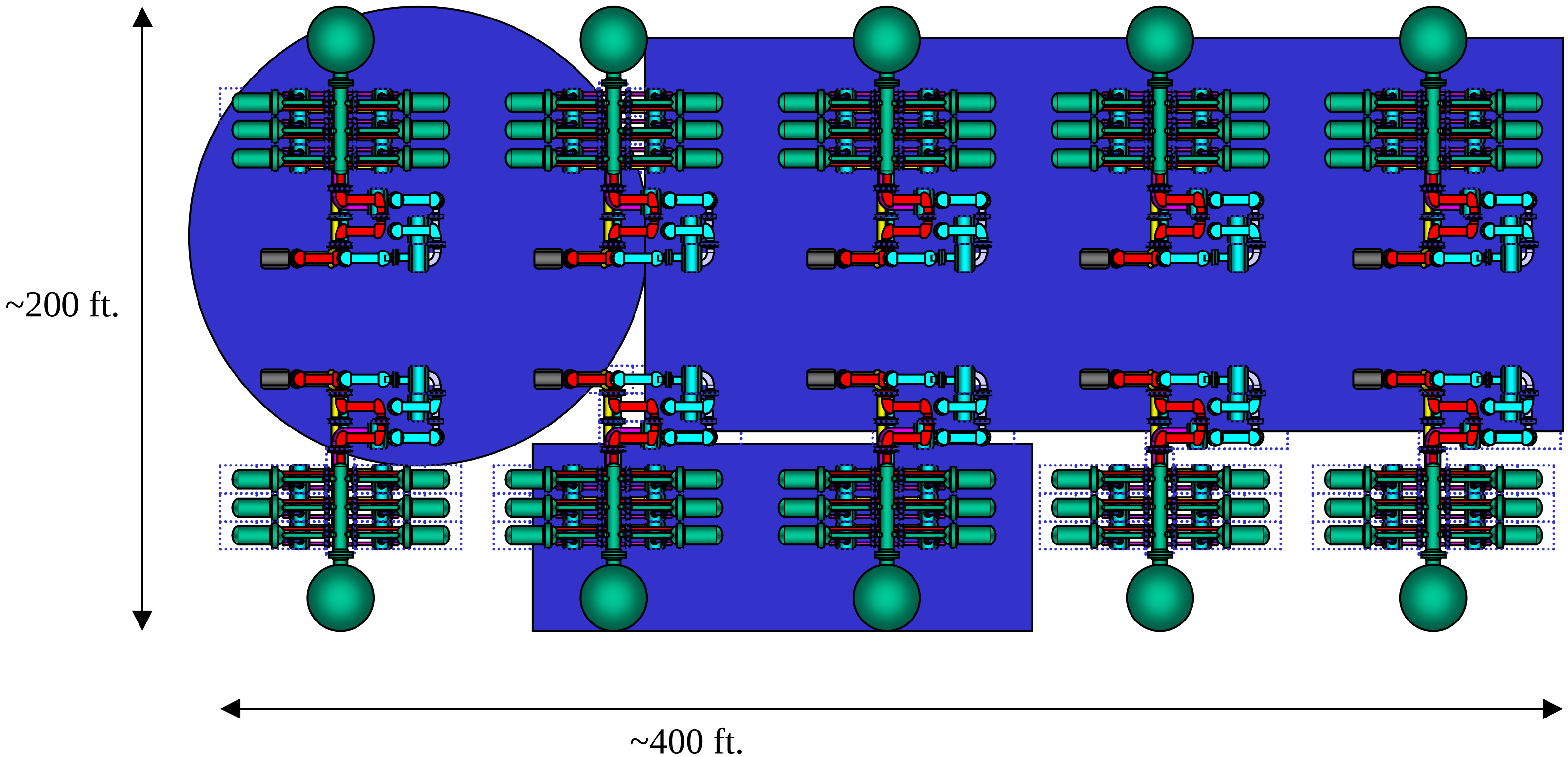
For 1150 MW Electric Power Station

Ten-Unit MPBR Plant Layout (Top View)

(distances in meters)



AP1000 Footprint Vs. MPBR-1GW



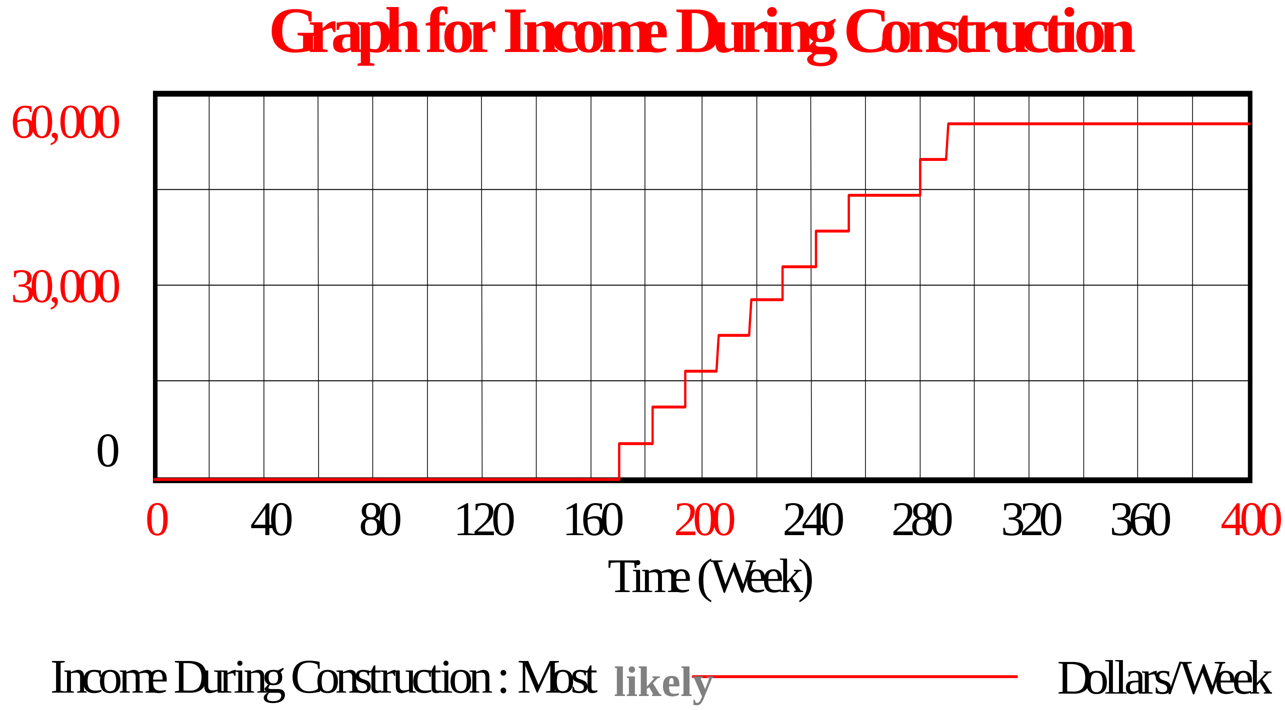
Competitive With Gas ?

• Natural Gas	3.4 Cents/kwhr
• AP 600	3.6 Cents/kwhr
• ALWR	3.8 Cents/kwhr
• MPBR	3.3 Cents/kwhr

Relative Cost Comparison (assumes no increase in natural gas prices) based on 1992 study

ESKOM's estimate is 1.6 to 1.8 cents/kwhr (bus bar)

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

Key Technical Challenges

- Materials (metals and graphite)
- Code Compliance
- Helium Turbine and Compressor Designs
- Demonstration of Fuel Performance
- US Infrastructure Knowledge Base
- Regulatory System

Opportunities

- **Major New Source of Electric Generation**
- **Competitive with natural Gas**
- **Markets in US and worldwide including China.**
- **Introduce new way of manufacturing plants**
- **Build Demo plant in Idaho - $ 350 Million**
- **US Utilities will buy if competitive.**
- **Desalinization Market**
- **Process Heat Market**
- **Hydrogen Generation Market**
- **Restore US Leadership**

The Inevitability of Nuclear Energy

- Environmentalists will realize the important contribution that nuclear energy can make to a clean environment.
- The price of fossil fuels will continue to increase
- Politicians will realize that ideas matter, especially bad ones and begin to think about consequences not expediency
- We need a new nuclear technology that is politically correct.

Common Questions ?

- What about the Safety of Existing Plants ?
- What about Uranium Supply ?
- How much power could/should come from Nuclear energy ?
- When will Fusion be available ?
- Is spent fuel waste or a resource ?

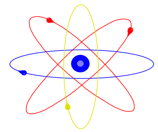
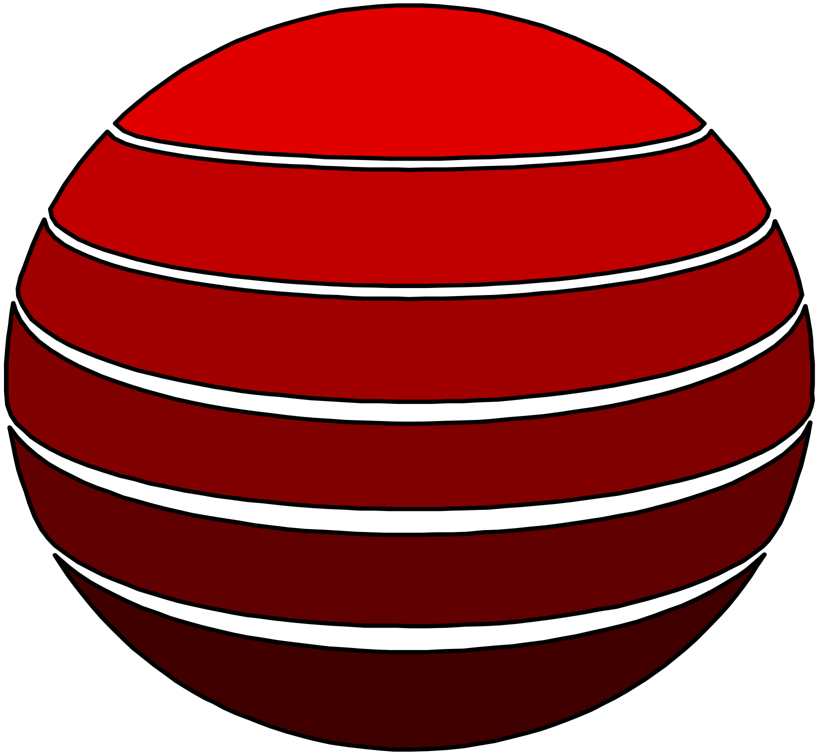
A “New” Question

- Can Nuclear Plants withstand a direct hit of a 767 jet with a plane load of people and fuel ?
- Can it deal with other Terrorist Threats?

  - Insider

  - Outsider

  - General Plant Security

Exelon - MIT/INEEL Projects

Exelon

- Commercial
- Direct Cycle
- German Technology
- Not Modular
- German Fuel
- NRC site specific application (exemptions)
- Repair Components

MIT/INEEL

- Private/Government
- Indirect Cycle
- US advanced Technology
- Truly modular
- US fuel design (U/Th/Pu)
- NRC Certification using License by Test
- Replace Components

MPBR PLANT CAPITAL COST ESTIMATE
(MILLIONS OF JAN. 1992 DOLLAR WITH CONTINGENCY)

Account No.	Account Description	Cost Estimate
20	LAND & LAND RIGHTS	2.5
21	STRUCTURES & IMPROVEMENTS	192
22	REACTOR PLANT EQUIPMENT	628
23	TURBINE PLANT EQUIPMENT	316
24	ELECTRIC PLANT EQUIPMENT	64
25	MISCELLANEOUS PLANT EQUIPMENT	48
26	HEAT REJECT. SYSTEM	25
	TOTAL DIRECT COSTS	1,275
91	CONSTRUCTION SERVICE	111
92	HOME OFFICE ENGR. & SERVICE	63
93	FIELD OFFICE SUPV. & SERVICE	54
94	OWNER'S COST	147
	TOTAL INDIRECT COST	375
TOTAL BASE CONSTRUCTION COST		1,650
CONTINGENCY (M$)		396
TOTAL OVERNIGHT COST		2,046
UNIT CAPITAL COST ($/KWe)		1,860
AFUDC (M$)		250
TOTAL CAPITAL COST		**2296**
FIXED CHARGE RATE		9.47%
LEVELIZED CAPITAL COST (M$/YEAR)		217

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

O&M Cost

- Simpler design and more compact
- Least number of systems and components
- Small staff size: 150 personnel
- $31.5 million per year
- Maintenance strategy - Replace not Repair
- Utilize Process Heat Applications for Off-peak - Hydrogen/Water

Sequence of Pebble Bed Demonstration

- China HTR 10 - December 2000
- ESKOM PBMR - Start Construction 2002
- MIT/INEEL - Congressional Approval to Build 2003 Reactor Research Facility
- 2005 ESKOM plant starts up.
- 2008 MIT/INEEL Plant Starts Up.

Highlights of Plan to Build

- Site - Idaho National Engineering Lab (maybe)
- "Reactor Research Facility"
- University Lead Consortium
- Need Serious Conceptual Design and Economic Analysis
- Congressional Champions
- Get Funding to Start from Congress this Year

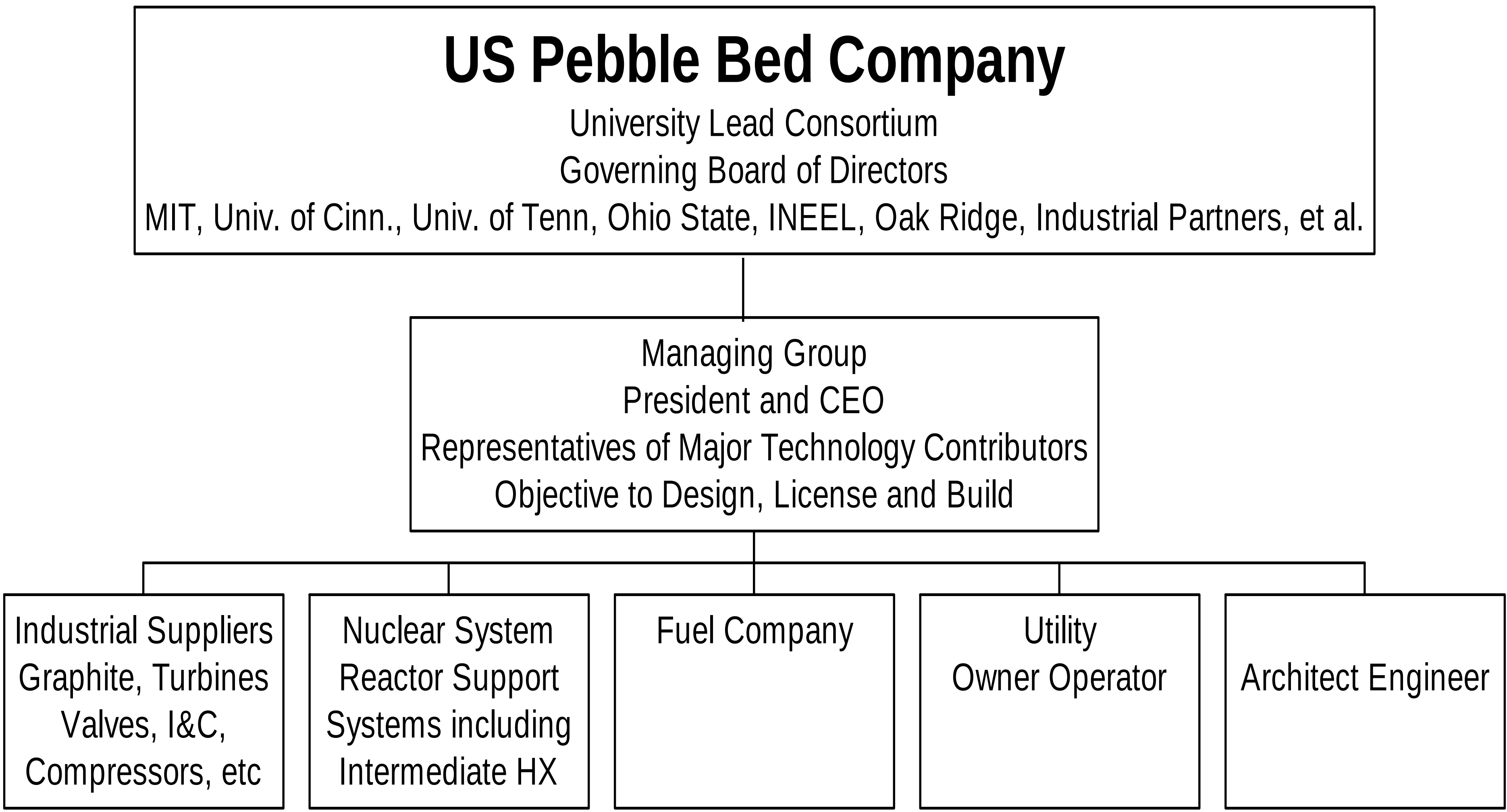
Reactor Research Facility
Full Scale

- **"License by Test" as DOE facility**
- **Work With NRC to develop risk informed licensing basis in design - South Africa**
- **Once tested, design is "certified" for construction and operation.**
- **Use to test - process heat applications, fuels, and components**

Why a Reactor Research Facility ?

- To "Demonstrate" Safety
- To improve on current designs
- To develop improved fuels (thorium, Pu, etc)
- Component Design Enhancements
- Answer remaining questions
- To Allow for Quicker NRC Certification

Modular Pebble Bed Reactor Organization Chart



License By Test

- Build a research/demonstration plant
  - -reactor research facility
- Perform identified critical tests
- If successful, certify design for construction.

Risk Based Approach

- Establish Public Health and Safety Goal
- Demonstrate by a combination of deterministic and probabilistic techniques that safety goal is met.
- Using risk based techniques identify accident scenarios, critical systems and components that need to be tested as a functional system.

Cost and Schedule

- Cost to design, license & build ~ $ 400 M over 7 Years.
- Will have Containment for Research and tests to prove one is NOT needed.
- 50/50 Private/Government Support
- Need US Congress to Agree.

Cost Estimate for First MPBR Plant

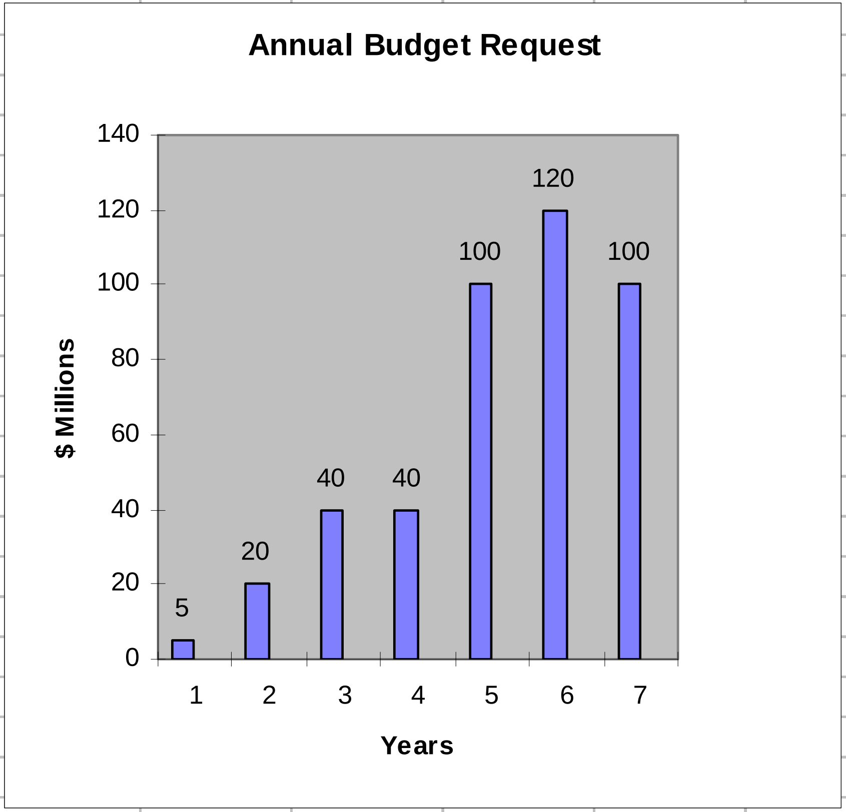
Adjustments Made to MIT Cost Estimate for 10 Units

Estimate Category	Original Estimate	Scaled to 2500 MWTH	New Estimate
21 Structures & Improvements	129.5	180.01	24.53
22 Reactor Plant Equipment	448	622.72	88.75
23 Turbine Plant Equipment	231.3	321.51	41.53
24 Electrical Plant Equipment	43.3	60.19	7.74
25 Misc. Plant Equipment	32.7	45.45	5.66
26 Heat Rejection System	18.1	25.16	3.04
Total Direct Costs	**902.9**	**1255.03**	**171.25**
91 Construction Services	113.7	113.70	20.64
92 Engineering & Home office	106	106.00	24.92
93 Field Services	49.3	49.30	9.3
94 Owner's Cost	160.8	160.80	27.45
Total Indirect Costs	**429.8**	**429.80**	**82.31**
Total Direct and Indirect Costs	**1332.7**	**1684.83**	**253.56**
Contingency (25%)	**333.2**	**421.2**	**63.4**
Total Capital Cost	**1665.9**	**2106.0**	**317.0**
Engineering & Licensing Development Costs			**100**
Total Costs to Build the MPBR			**417.0**

For single unit

Annual Budget Cost Estimates
For Modular Pebble Bed Reactor
Generation IV

Year	Budget Request
1	5
2	20
3	40
4	40
5	100
6	120
7	100
Total	**425**



International Application

- Design Certified & Inspected by IAEA
- International "License"
- Build to Standard
- International Training
- Fuel Support
- No Special Skills Required to Operate

Opportunities

- **Major New Source of Electric Generation**
- **Competitive with natural Gas**
- **Markets in US and worldwide including China.**
- **Introduce new way of manufacturing plants**
- **Build Demo plant in Idaho - $ 350 Million**
- **US Utilities will buy if competitive.**
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Summary

- **Pebble Power** Appears to Meet Economic, Safety and Electricity Needs for Next Generation of Nuclear Energy Plants
- Exelon Investing in South African Project with Desire to Commercialize in US by 2006
- **MIT Project aimed at longer term development with focus on innovation in design, modularity, license by test, using a full scale reactor research facility to explore different fuel cycles, process heat applications, and advanced control system design, helium gas turbines and other components.**

Exelon Interests

- Own rights to 12.5% of “PBMR Pty. Ltd.”
  - Other Investors: ESKOM (40%), IDC (25%), BNFL (22 1/2%)

- A Potential Source of Low Cost Power
  - Exelon’s “Core Competencies”:
    - Operation of Nuclear Power Plants
    - Wholesale trading of Electricity

- Viewed as ‘Merchant Nuclear Power’ – no rate base!

Risks

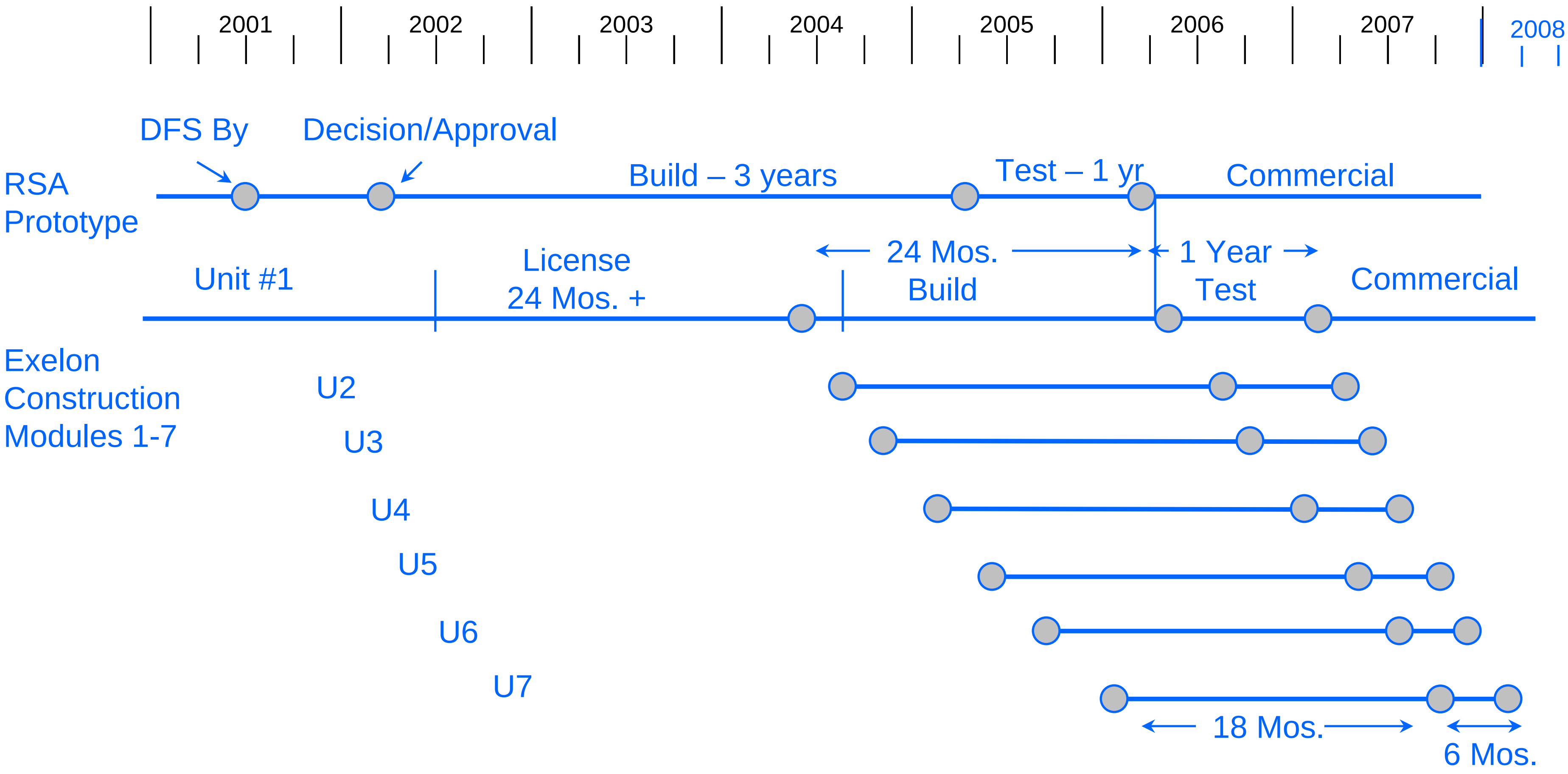
Technical - PTG (magnetic bearings, vertical orientation, high temperature helium environment)
Fuel manufacturing and testing
Several other 'FOAK' systems (none of which are 'nuclear') (compressors, fuel burn up measurement, recuperator)

Regulatory- RSA processes
New processes for ESP, COL, DC
Small modular gas reactors not envisioned in the current US regulations

Schedule- Final design, fuel plant and plant licenses, construction, testing, regulatory approvals

Consortium – Numerous competing interests and agendas will need to be reconciled among the partners and their governments (RSA, UK, USA; Eskom/PBMRPty, BNFL/Westinghouse, etc.)

Overall Schedule/Exelon Desired Schedule



Etc, Etc

PBMR - What's Different?

- **Safety Envelope HUGE**

  low power density, excess reactivity, hi S/D margin, long thermal time constants

- **Simple, Standard design**

  NO feedwater, ECCS, Recirc pumps, EDG's; small EPZ,
  30 total systems, 2 CRT's per unit IS the control room; CCGT staffing and nuclear fuel economics, reasonable incremental capital investment, short time to Mwe, modern design and configuration control by reactor vendor

- **Merchant Nuclear Power aimed at a deregulated environment**

  No rate base; flexibility, size, speed all matter

- **NO direct Government funding**

  Unproven ESP, COL, DC processes; extensive lab work required; considering offset for initial Government fees

- **Full scale demonstration unit to be built in South Africa**

  Aim to fully demonstrate unit's safety and other capabilities, satisfy NRC 'ITAAC'

Technology Bottlenecks

- Fuel Performance
- Balance of Plant Design - Components
- Graphite
- Containment vs. Confinement
- Air Ingress/Water Ingress
- Regulatory Infrastructure

Regulatory Bottlenecks

- 10 CFR Part 50 Written for Light Water Reactors not high temperature gas plants
- Little knowledge of pebble bed reactors or HTGRs - codes, safety standards, etc.
- Fuel testing
- Resolution of Containment issue
- Independent Safety Analysis Capability

Economic Impact of Resolution of Bottlenecks

- Depends on whose money
- Private investment would be large depending on scenario for licensing for first of a kind.
- Expectations to resolve 5 years.
- Impact on licensing depends on strategy.
- Payback depends on number of units and manufacturing infrastructure.

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Conclusions

- Basic Technology Proven
- Specific Designs Need to Be Demonstrated
- Fuel is a key issue
- NRC licensing new technology difficult
- Political support exists
- No Meltdown Core a real plus
- Which Strategy Can Bring the Plant to Market Fastest is an Open Question.
- **Pebble Bed Reactors Can Be Licensed in US**