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(NR)

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# **Pebble Bed Modular Reactor Project Overview**

***October 10, 2002***

# Purpose of Discussion

- **To familiarize US NRC with the ongoing progress of the PBMR project, and to share PBMR's plans for design certification for consideration in NRC long term planning**

# Agenda

- **PBMR History**
- **Key Strategies**
- **Recent Design Improvements**
- **Plant Summary Description**
- **Design Process**
- **Major Development Testing**
- **Fuel Supply Strategy**
- **Project Status and Milestones**
- **Investors**
- **Strategic Suppliers**
- **Licensing Status**
- **Business Case Summary**
- **Suggested Cooperative Development**

# PBMR History

- **1993** PBMR evaluation in RSA begins based on HTR technology and 3 shaft, direct cycle design
- **1995** Pre-feasibility study
- **1998** Formation of Project Team
- **1999** Start Detailed Feasibility Study
- **1999** Eskom LOI for Demonstration Plant & 10 Modules
- **2000** RSA Cabinet support and Commercial Partners
- **2000** License & EIA submission
- **2001** SAR Rev 1 submitted to NNR
- **2002** Uprate to 400 MWth
- **2002** September Business Case Completed (McKinsey)

# Key Strategies

- **Competitive economics**
- **Strict adherence to standardization**
- **Use of international strategic suppliers**
- **Module repetition on 3-4 months timescale; rapid learning curve**
- **Short construction period**
- **Minimum market disruption**
- **Deployment of distributed generation**
- **Use of simple systems and operations**
- **Minimum required maintenance**
- **Achieve inherent safety**
- **Small emergency planning zone**

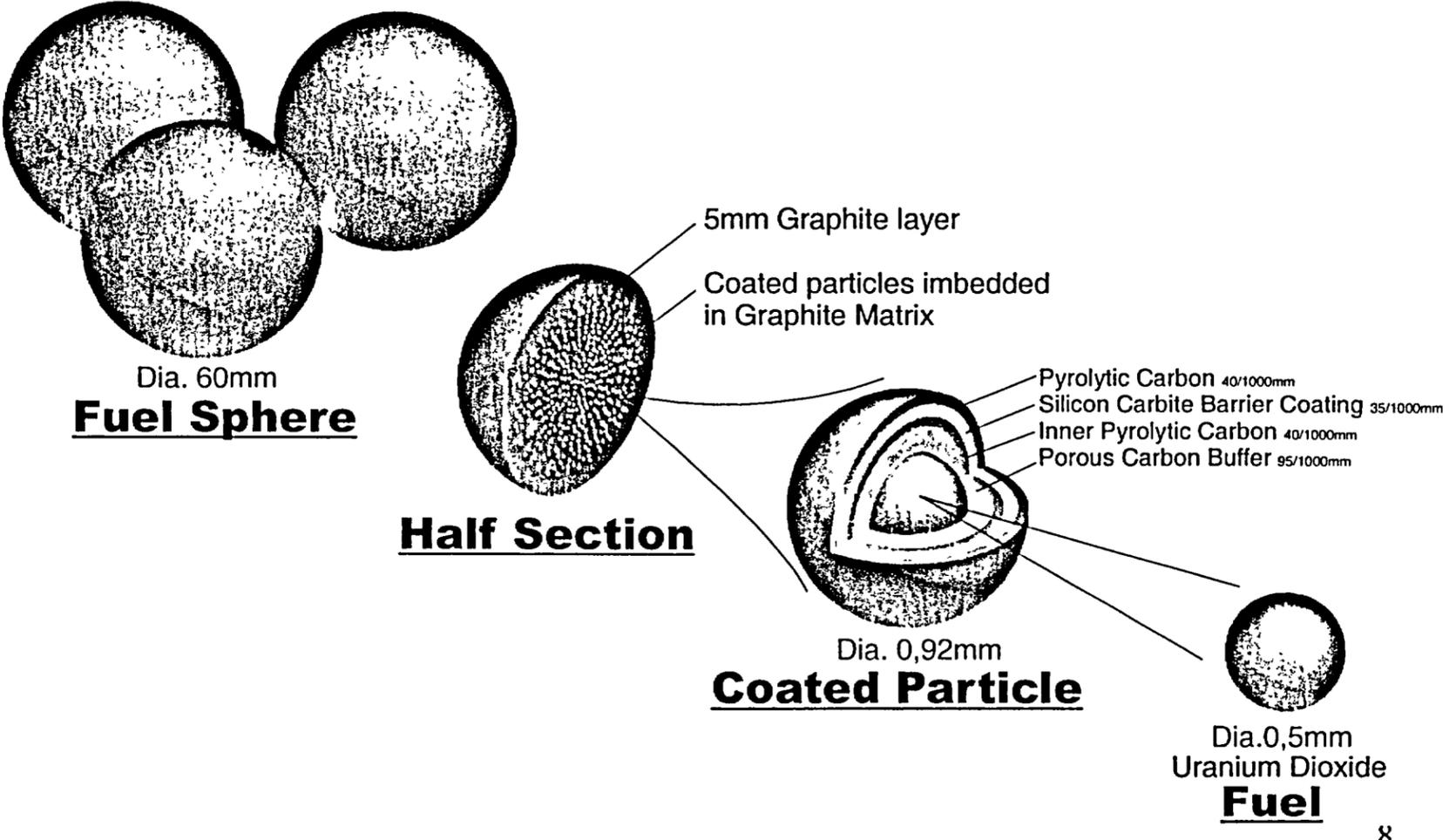
# Recent Design Improvements

- **Uprate to 400 MWth (165 MWe)**
- **Fixed Central Graphite Reflector rather than Dynamic Reflector**
- **Three refueling exit paths/chutes together with a simplified and more maintainable Fuel Handling System**
- **Dry gas seal between turbine and generation**
- **Conventional oil thrust and catcher bearing on generator rather than magnetic bearings**
- **Preliminary multi-module (8-pack) general arrangement design**
- **Revised core structure design with stainless steel core barrel and carbon fiber composite restraints**

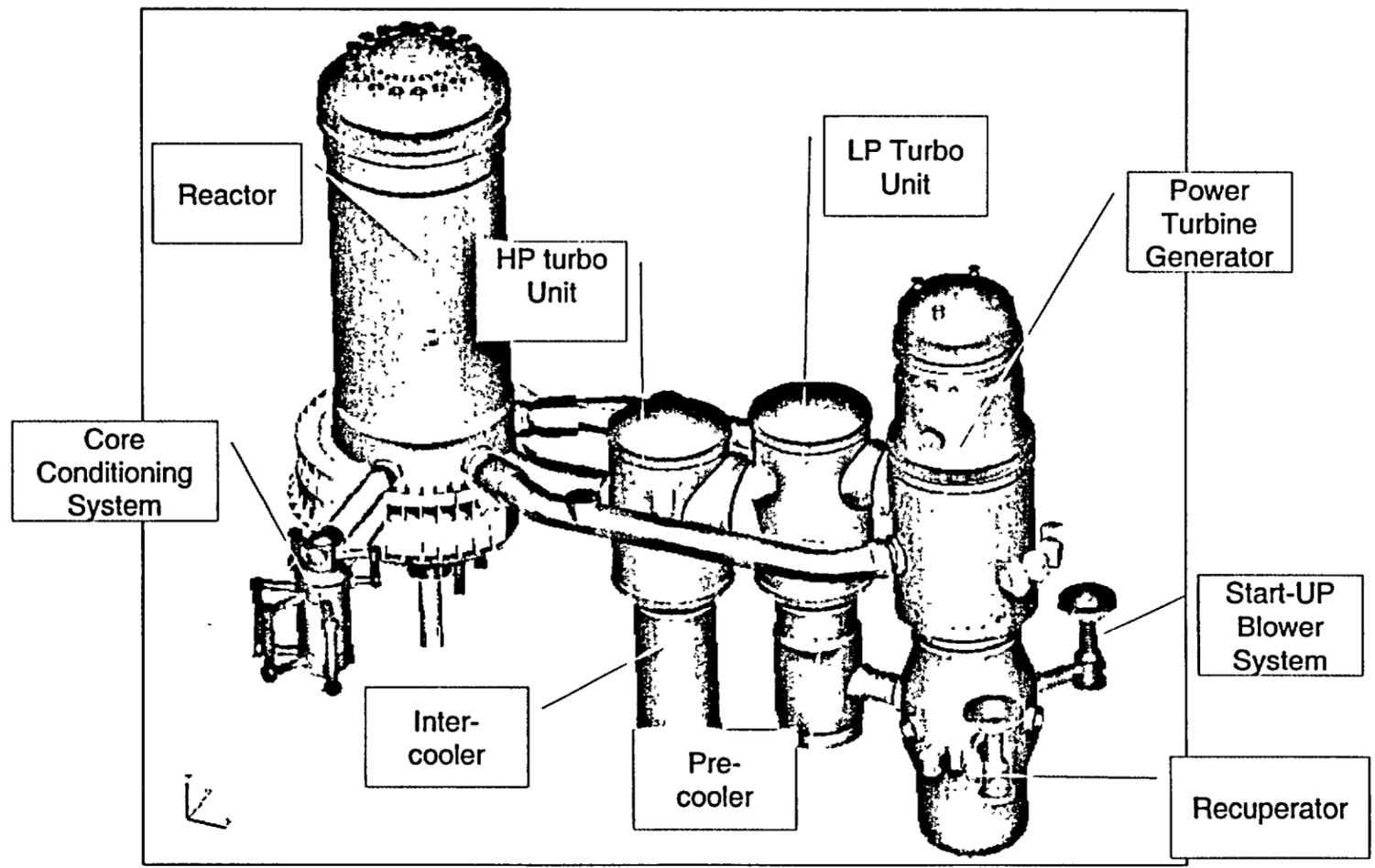
# Plant Target Specification

- **Rated Power per Module** 165 MW(e)
- **Eight-pack Plant** 1280-1320 MW(e)
- **Continuous Stable Power Range** 40-100%
- **Load Rejection w/o Trip** 100%
- **Construction Schedule (nominal)** 24 months (first module)
- **Short and Infrequent Outages** 30 days per 6 years
- **Seismic** 0.4g
- **Overnight Construction Cost** \$1000-1200/kWe
- **Fuel Costs** \$4.1/MWh
- **O&M Costs** \$5/MWh
- **Emergency Planning Zone** <400 m
- **Availability** >95%

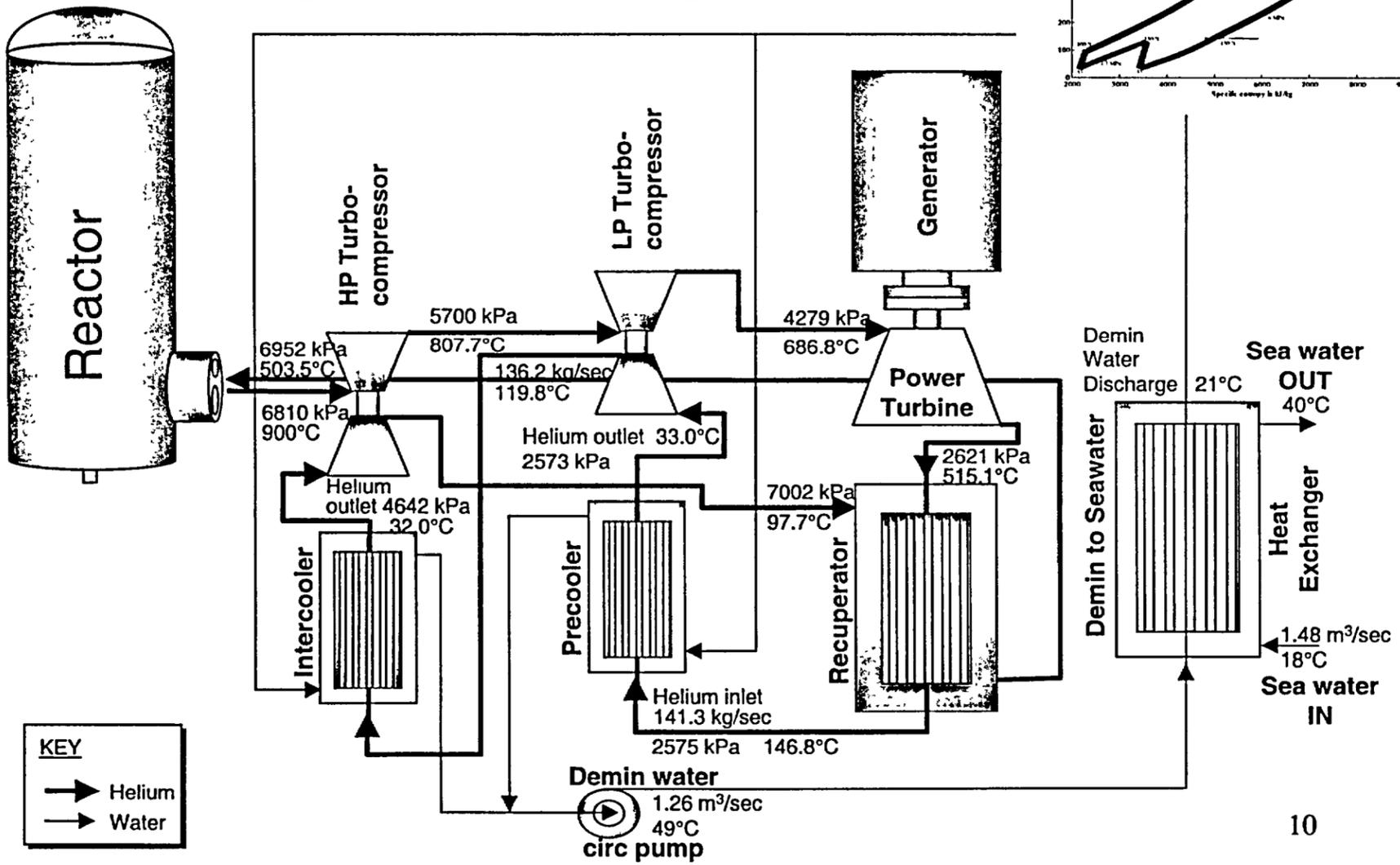
# Fuel Element Design for PBMR



# Main Power Systems

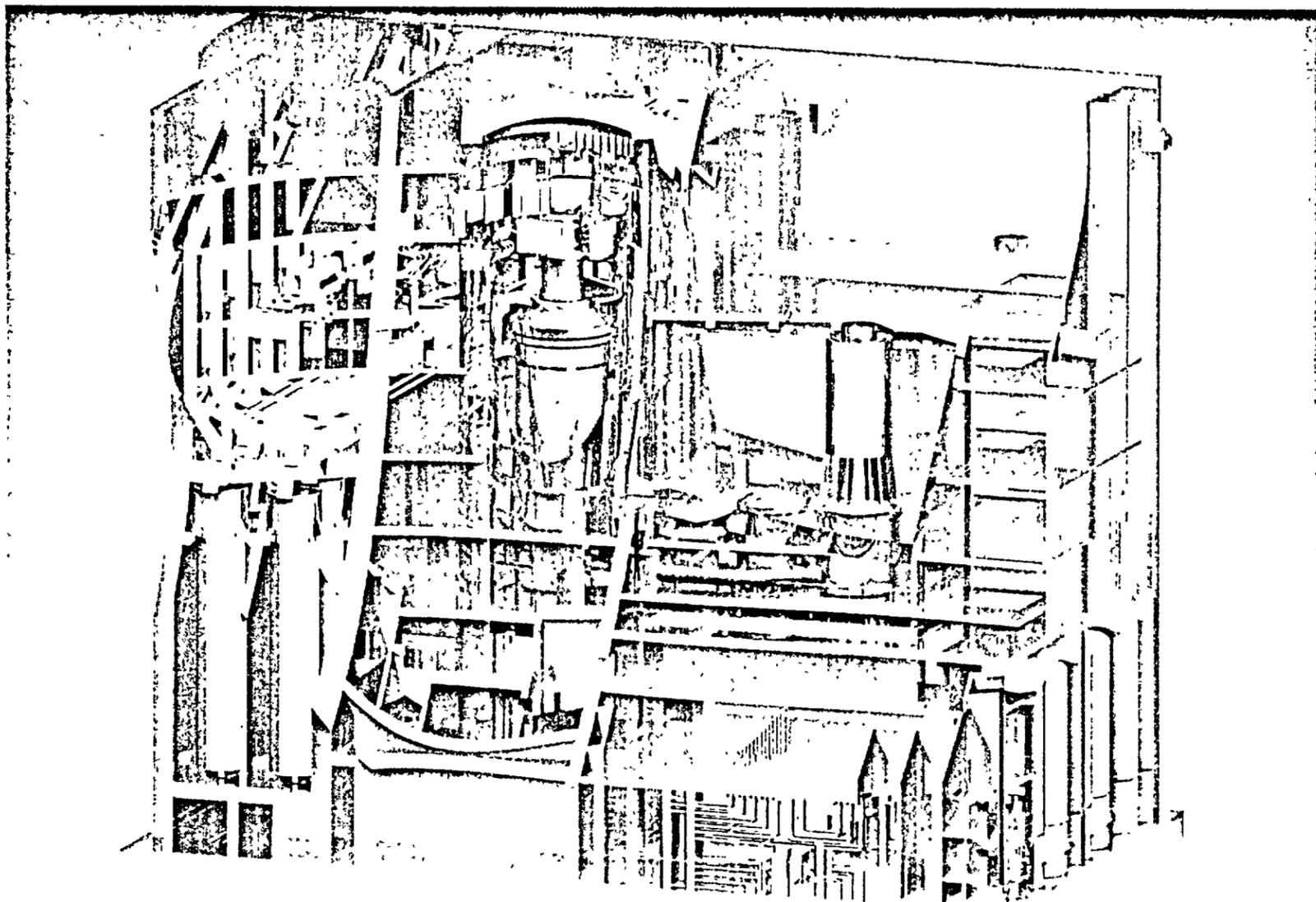


# PBMR Thermal Cycle Power Conversion Unit



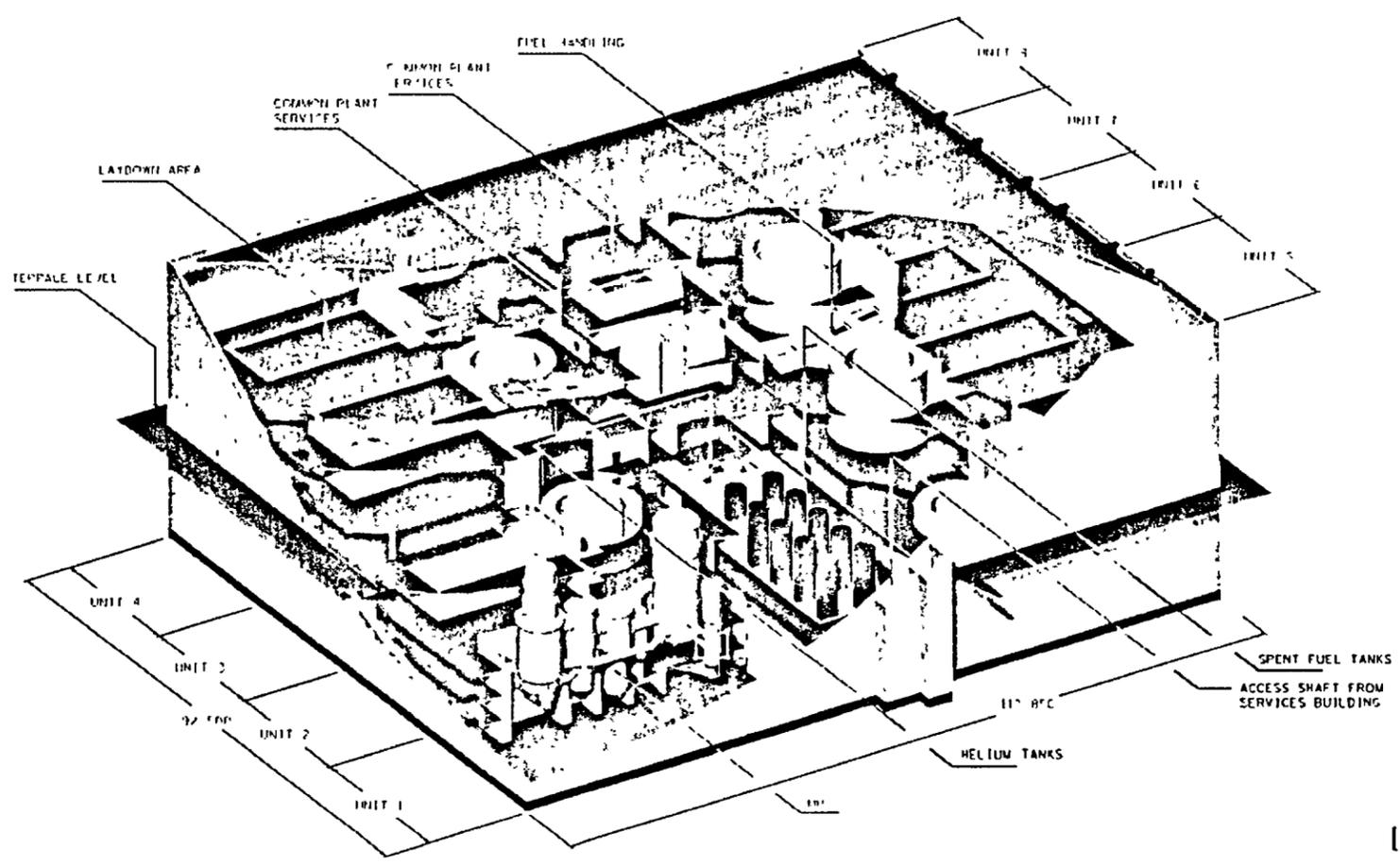
# PBMR Single Module

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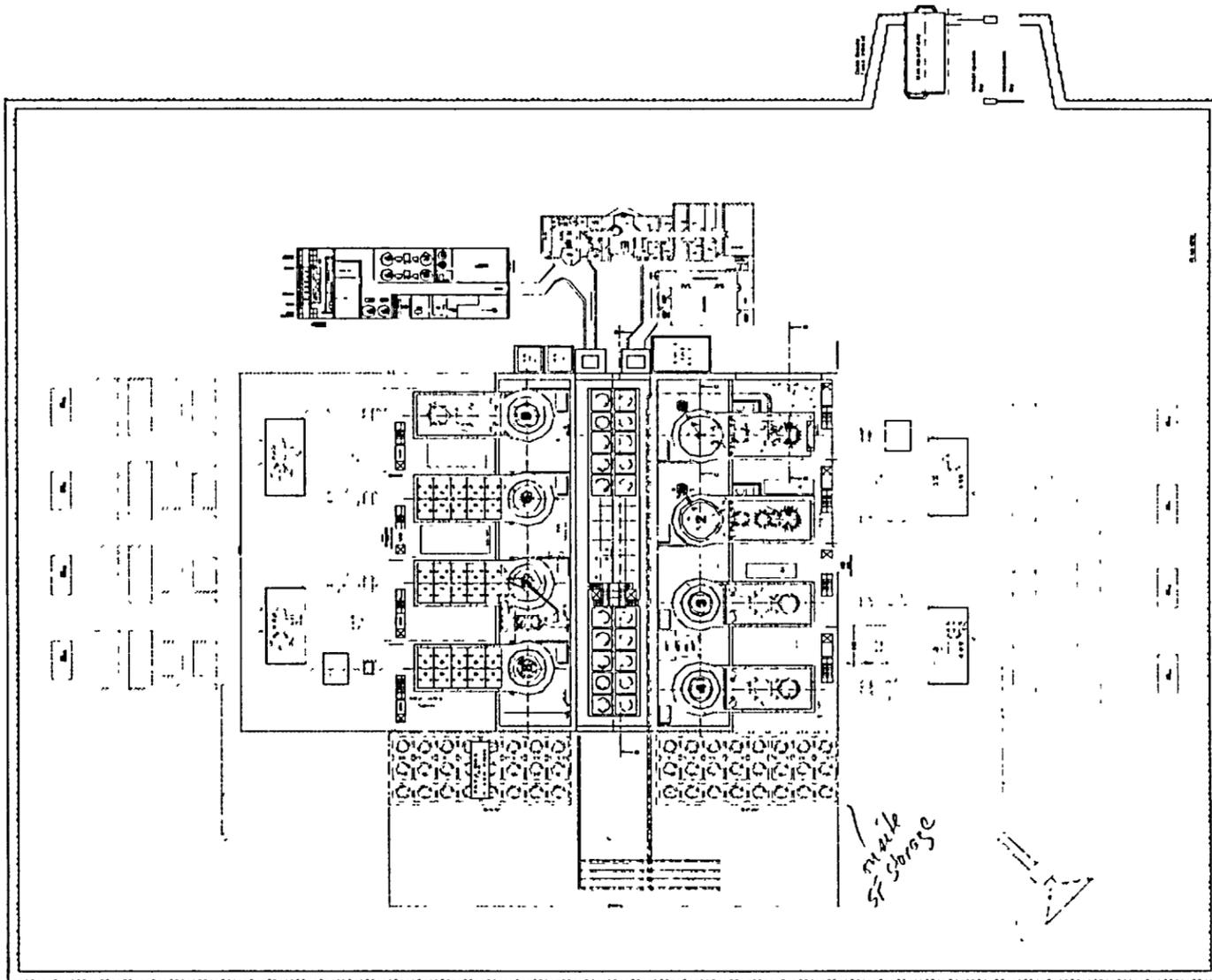
# PBMR Multi Module

CUT AWAY ISOMETRIC OF PBMR MULTI MODULE CONCEPT



# Multi-Module Layout

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# Key Safety Characteristics

- The safety of the reactor is not dependant on the presence of the coolant (cooling or criticality).
- In no accident scenario is the early insertion of control rods required (early means in the first few days).
- There is no meaningful limit on transient power levels – only long term power level.
- The principal barrier to radioactive release is fuel integrity; a conventional containment is not required technically.
- Emergency Planning Zone (EPZ) less than 400 m



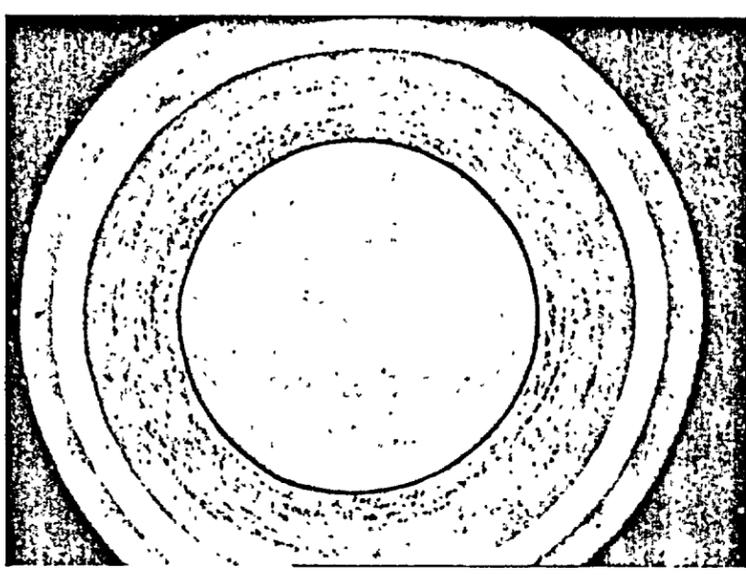
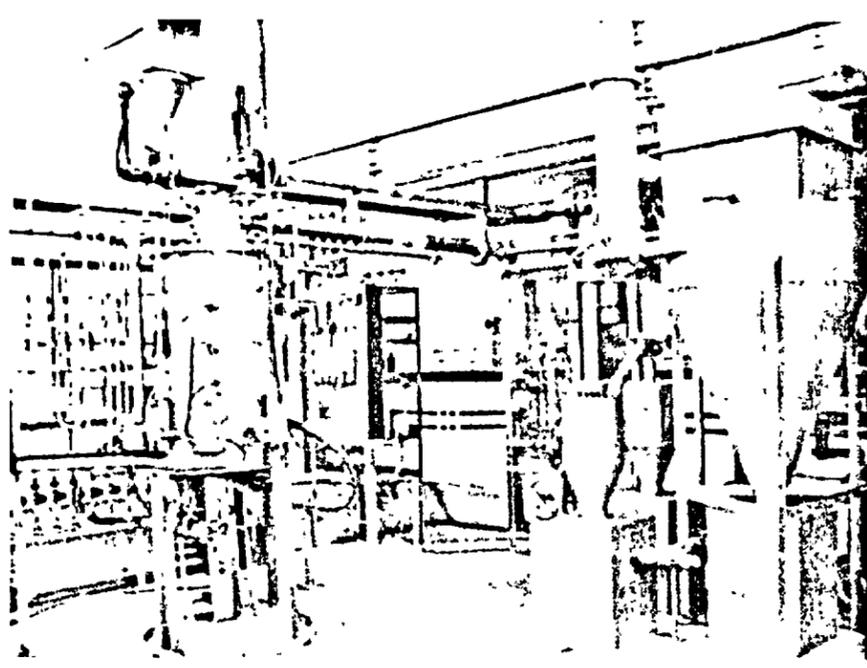
# Major Development Testing (Ongoing and Planned) Cont'd

- **Helium Test Loop** **IST @ NECSA**
  - Systems
  - Components
  - Special Tools
  - Graphite Erosion
- **Fuel Qualification and Testing** **@ NESCA,**
  - Pre-Irradiation **Russia,**
  - In-Reactor **SAFARI (RSA)**
  - Post-Irradiation
- **Materials Testing**
  - Graphite Irradiation Life
  - Carbon Fiber Composite Irradiation Life

# Fuel Supply Strategy

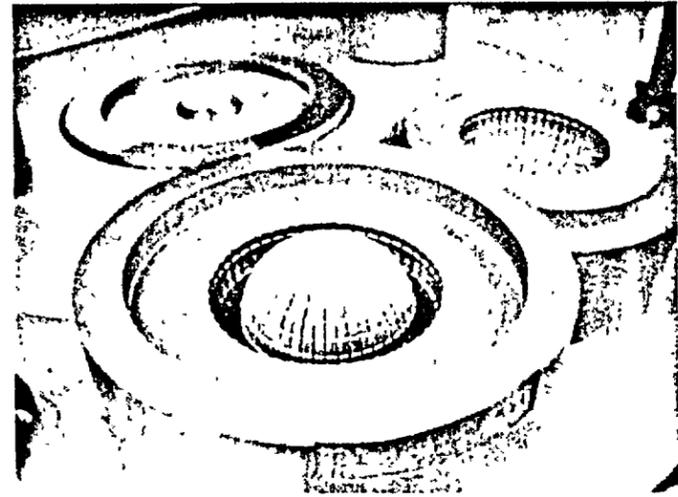
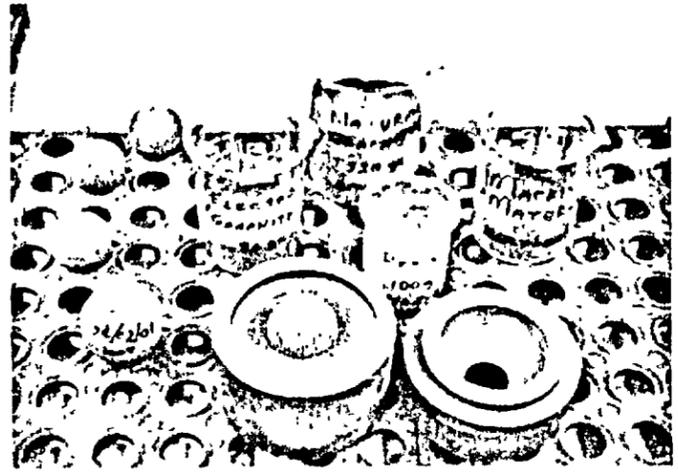
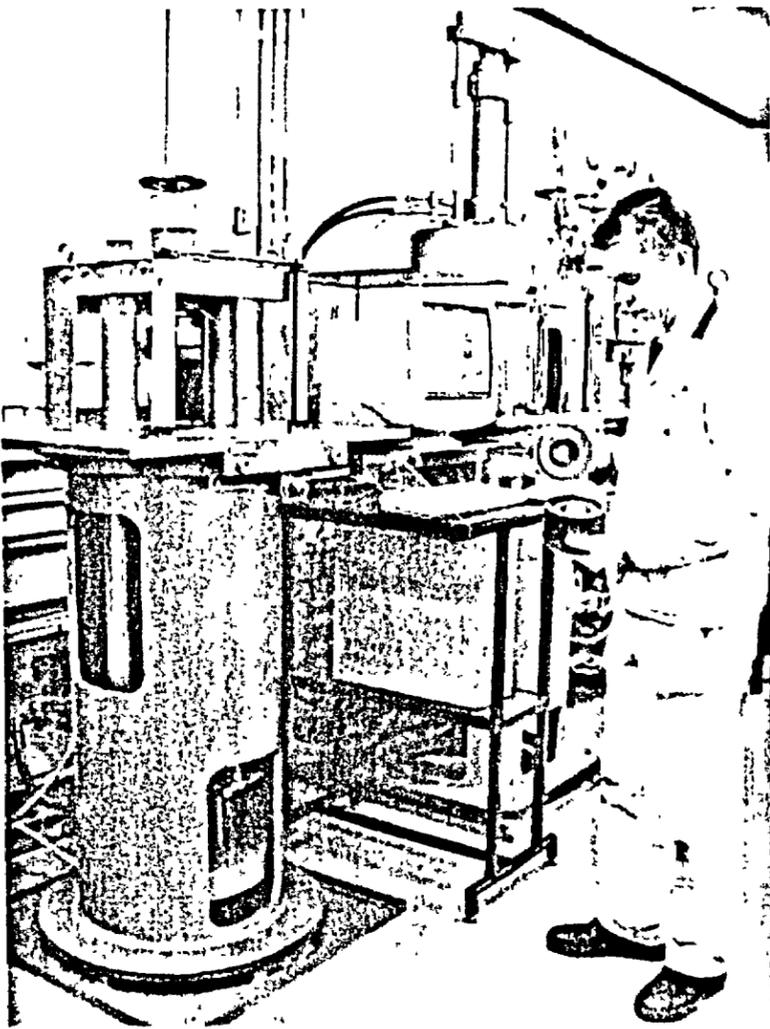
- **Fuel Design**
  - Based on German Pebble Bed Reactor using equivalence approach (fuel specification, starting material, critical processes, and quality control)
  - Perform confirmatory tests to prove fuel within German envelope
- **Fuel Fabrication Technology**
  - NFI for particle fabrication
  - NUKEM for pebble fabrication
- **Fuel Fabrication**
  - Pilot Plant for PBMR Demonstration plant fuel and possibly first PBMR commercial plant fuel
  - Commercial Plant once sufficient orders obtained

# Fuel Particle Coater Laboratory



# Fuel Sphere Laboratory

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# Fuel Qualification and Testing Program

- Establish rigorous quality control of fabrication process and fuel product
- Early fuel compacts and pebbles from NFI to be tested in Russia
- Early fuel compacts from NFI to be tested in South Africa SAFARI reactor
- Pilot Plant fuel pebbles to be tested in SAFARI reactor
- Commercial plant pebbles to be tested in Russia and/or the SAFARI reactor
- Post Irradiation Examinations (PIE) to be conducted on all tests
- Long term fuel development and irradiation program to be conducted in SAFARI reactor

# Current Full Time Staffing Resources

<b>TOTAL</b>	<b>465</b>
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**Total Manhours to date ~1,500,000**  
**Total costs to date ~\$100M**

# Investors

- **Eskom**
    - South African government-owned electric utility
  - **Industrial Development Corporation (IDC)**
    - South African government-owned investment bank
  - **British Nuclear Fuels Ltd (BNFL)**
    - British government-owned nuclear reactor, fuel and services supplier
  - **Exelon\***
    - US electric and gas utility
  - **Future Investors**
- \* **Announced that it will not be an investor beyond current feasibility phase but remains a potential customer**

# Strategic Suppliers

- MHI (Japan)
- NFI(Japan)/Nukem(Germany)
- SGL (Germany)
- Ingersoll Rand (US)
- IST (RSA)
- Westinghouse (US)
- Ensa (Spain)
- Sargent & Lundy (US)
- Murray & Roberts (RSA)

**Turbo-Machinery**  
**Fuel Technology**  
**Graphite**  
**Recuperator**  
**Nuclear Auxiliaries**  
**Instrumentation**  
**Pressure Boundary**  
**Architect Engineer**  
**EPCM**

# South Africa Licensing Status

- Agreed licensing process and stages *4 stages*
- Agreed scope of submittals and schedule
- Agreed list of key licensing issues; strategy to address these in process
- Formal questions from NNR on SAR Rev 1 issued July 31, 2002
- Environmental Impact Assessment (EIA) Record of Decision (RoD) expected in November 2002
- NNR review of SAR Rev 1 scheduled for completion on October 31, 2002; public participation will follow RoD
- Government approval of project after positive RoD and acceptable Business Case (expected by end of 2002)
- Site preparation license expected at end of March 2003

*1 site work  
2 constr.  
3 load fuel  
4 commercial*

# US Licensing Status

- **NRC agreement on proposed approach**
- **Phase 1 of the Regulatory Guidance Review completed**
- **Fuel Test and Qualifications program progressed**
- **US Licenseability Assessment completed**
- **Pre-application activities documented**
- **Ready for reactivation by PBMR**
- **Multiple Module Reactor Issues responded to by NRC**
- **Start of Design Certification planned for 2006;  
completion after startup of the Demonstration reactor**

# Summary of Business Case

- Effort led by McKinsey & Company, with input from all four investors and PBMR Pty (8 month effort)
- High Impact Teams established for critical area input

<u>Area</u>	<u>Lead</u>
– Construction Cost and Schedule	Exelon/Murray & Roberts/Stone & Webster
– Fuel Plant and Fuel Cost	BNFL
– Capital Cost Reduction	Sargent & Lundy
– First of a Kind Engineering	Sargent & Lundy
– Turbo-Machinery	PBMR/MHI
– Legal and Commercial	PBMR
– Organization Assessment and Transition	PBMR

# PBMR Business Case (Cont'd)

- **Detailed Project Plan based on Work Breakdown Structure**
  - Demonstration Plant
  - Commercial 8-Pack
  - Fuel Pilot Plant
  - Commercial Fuel Plant
  - PBMR First of a Kind Design
  - PBMR Pty Infrastructure Development
- **Detailed Cost Estimate for Above Six Activities**
- **Risk Assessment using probabilistic techniques Performed on Both Schedules and Costs**
- **Focused on 14 key worldwide markets, including U.S., Japan, U.K., RSA, Korea and China** *(all current nuclear programs)*

# **Suggested Development Efforts in Cooperation with US NRC**

- **Follow through on the cooperative fuel testing program proposed by Exelon for PBMR licensing in the U.S.**
- **High Temperature Gas Reactors would benefit from NRC approval of Code Cases N-201 and N-499.**
- **As part of the pre-application review, PBMR will define, and review with the NRC, the proposed testing program, including that on the South African demonstration plant.**