PBMR Design Certification Pre-Application Planning

June 30, 2005

Rockville, MD

Agenda

Time	Topic	Lead by
8:30 am	Opening Remarks	NRC/PBMR (Pty) Ltd.
8:45 am	Pre-Application Planning Overview	PBMR (Pty) Ltd.
9:00 am	PBMR Safety Principles and Design	PBMR (Pty) Ltd.
10:00 am	Proposed Focus Topics for the Review	PBMR (Pty) Ltd.
11:00 am	Break	
11:15 am	Proposed Focus Topics (Cont.)	PBMR (Pty) Ltd.
12:00 am	Policy Issues Related to the PBMR Design Certification Effort	PBMR (Pty) Ltd.
12:15 pm	Lunch	
1:15 pm	Policy Issues (Cont.)	PBMR (Pty) Ltd.
1:45 pm	Administrative Procedures	NRC
2:00 pm	Discussion of Planning Process and Approach; Planning and Review Issues; Next Steps	NRC/PBMR (Pty) Ltd.
3:00 pm	Opportunity for Public Comment	All
3:15 pm	Adjourn	

Pre-Application Planning Overview

Edward Wallace
Sr. General Manager – US Programs

Pre-Application Objectives

- Prepare for completing a Design Certification (DC) application for commercial PBMRs as soon as possible to support U.S. utility long range planning evaluations
- Establish a clear path forward for PBMR / HTGR licensing in the U.S.
- Clarify issues identified in Exelon's pre-application work still relevant to submitting a PBMR DC application
- Identify any new issues that require pre-application work or inclusion in the DC application
- Identify any further development and testing required for PBMR certification in the U.S.

Pre-Application Planning

- **Focus on limited issues unique to PBMR; much more limited than Exelon scope**
- **Rely on industry / generic initiatives where appropriate**
- **Conduct effective resource planning with NRC Staff to avoid start/stop events by either party**
- **Multi-phase DC approach**
  - Scope and Resource Plan — Jun 05 - Sep 05
  - Focused Technical Exchanges — Oct 05 - Dec 06
  - Staff Position Papers — Sep 06 - Jan 07
  - Complete Pre-Application — Jan 07
  - PBMR Prepare DC Submittal — Jan 06 - Mar 07
  - Submit DC Application — 2Q 2007
  - Conduct DC Review / Certification — 2Q 07 – 4Q 11
- **Minimal impact on NRC Staff during pre-application phase**
  - Estimated resources in FY05 for planning ~1 FTE
  - Estimated resources in FY06 for pre-application reviews ~3-5 FTE (less than Exelon review as Owner Issues not part of scope, and RAI base exists to work from on key issues)

Pre-Application Topics

- Selection of Licensing Basis Events
- Safety classification of Structures, Systems and Components (SSCs) and Defense-in-Depth
- Fuel design and qualification
- Applicable codes and standards & materials selection
- Computer code Verification & Validation (V&V)
- Single vs. multi-module certification

Specific Planning Outcomes

- **PBMR and NRC conduct preliminary planning meetings to:**
  - Confirm pre-application scope of individual issues
  - Identify any additional NRC Staff issues for pre-application work
  - Establish review objectives and outcomes for each issue to guide DC application content
  - Establish preliminary schedules for submittals, reviews and position papers
  - Estimate resources based on agreed scope
  - Identify policy issues for Commission consideration

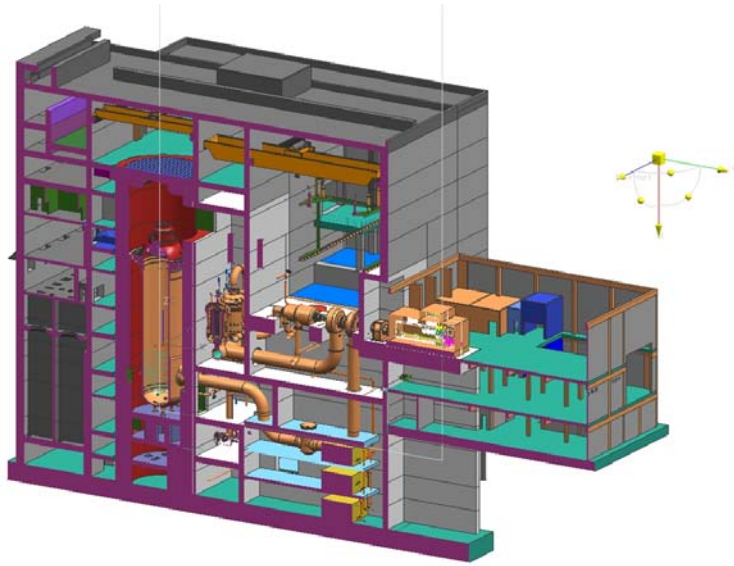
PBMR Safety Principles and Design

Willem Kriel

June 30, 2005

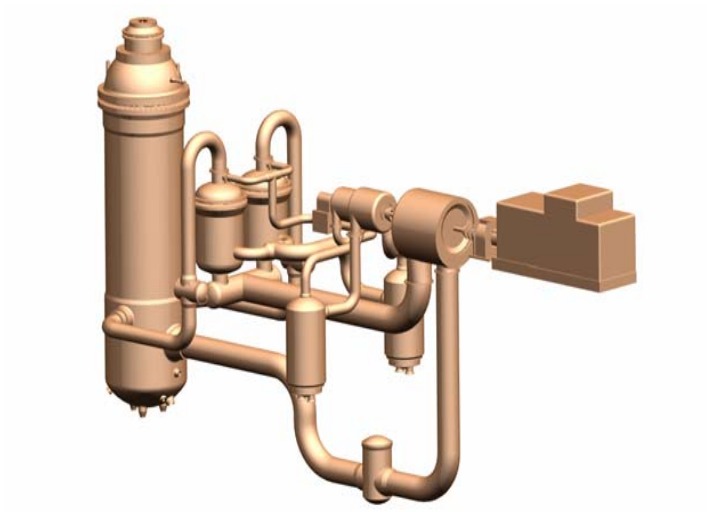
Commercial Plant Specifications

• Power Output per Module	400 MW(th)
• Rated Power per Module	165-175 MW(e)
• Four-pack Plant	660-700 MW(e)
• Module Construction Schedule	24 months (1st)
• Planned Outages	30 days per 6 years
• Fuel Costs & O&M Costs	< 9 mills/kWh
• Availability	>95%
• Overnight Construction Cost	<$1500/kWe (2004 $, 4-pack)
• Emergency Planning Zone	400 m



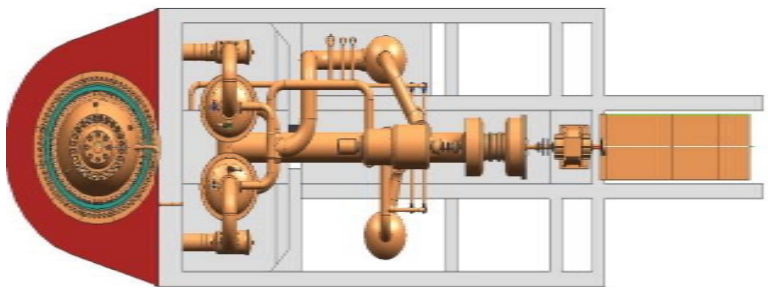
Design Layouts

Main Power System (MPS)

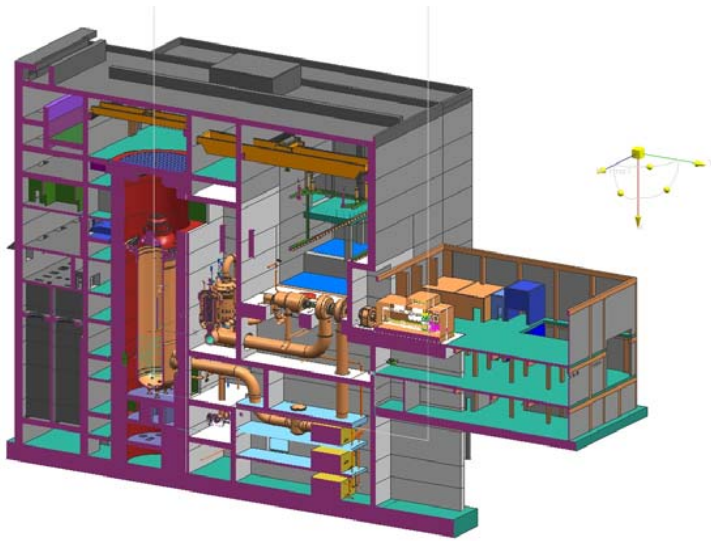


Height total	62.9 m
Height above ground	40.9 m
Depth below ground	22 m
Width	37.0 m
Length	66.1 m
Levels (floors)	11
Material	40 MPa concrete
Seismic acceleration	0.4 g Horizontal
Aircraft crash	< 2.7 ton – no penetration;
	777 – penetration outside barrier; nuclear safety not compromised

MPS Top View with Citadel

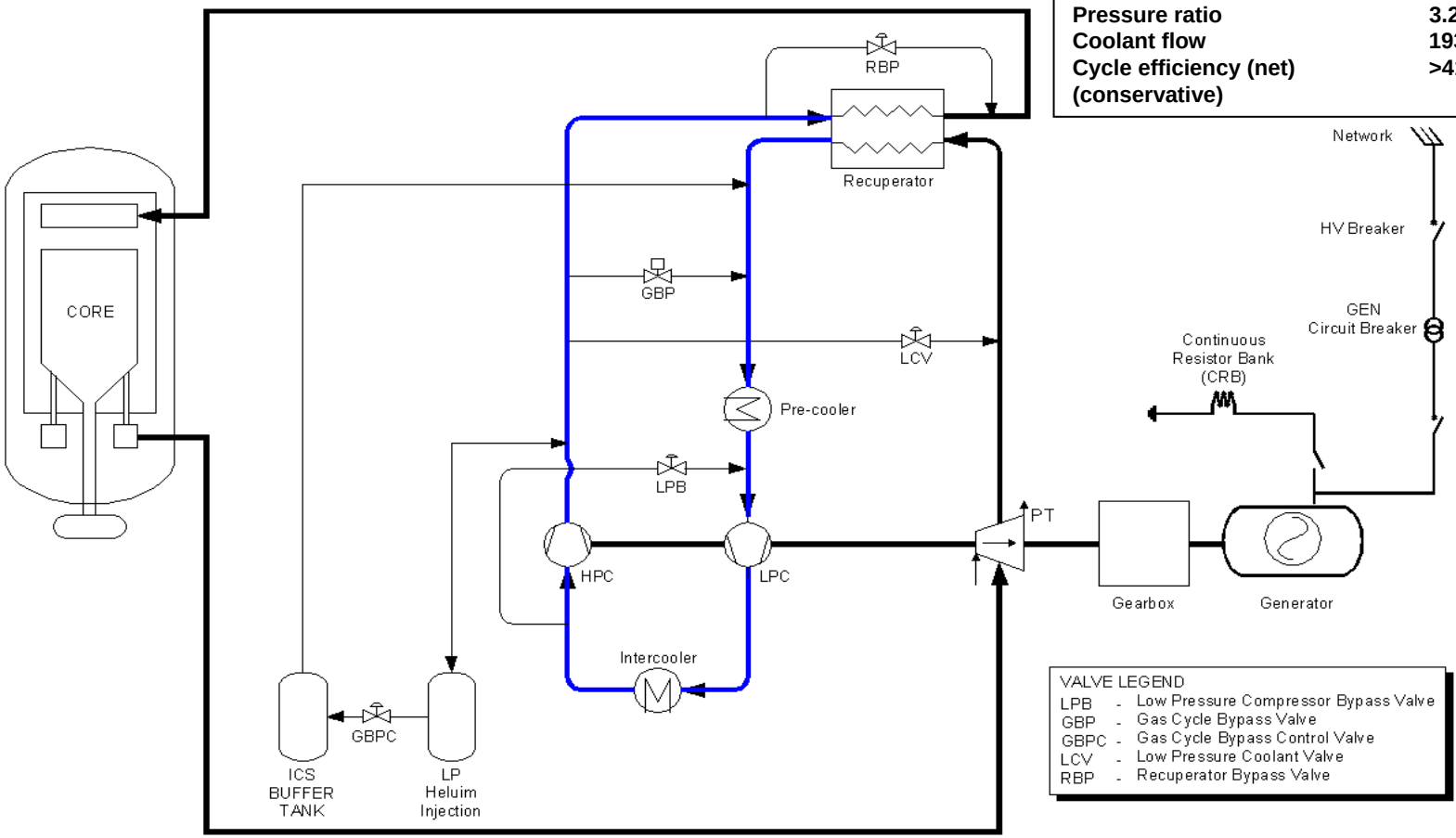


Demonstration Plant Cutaway

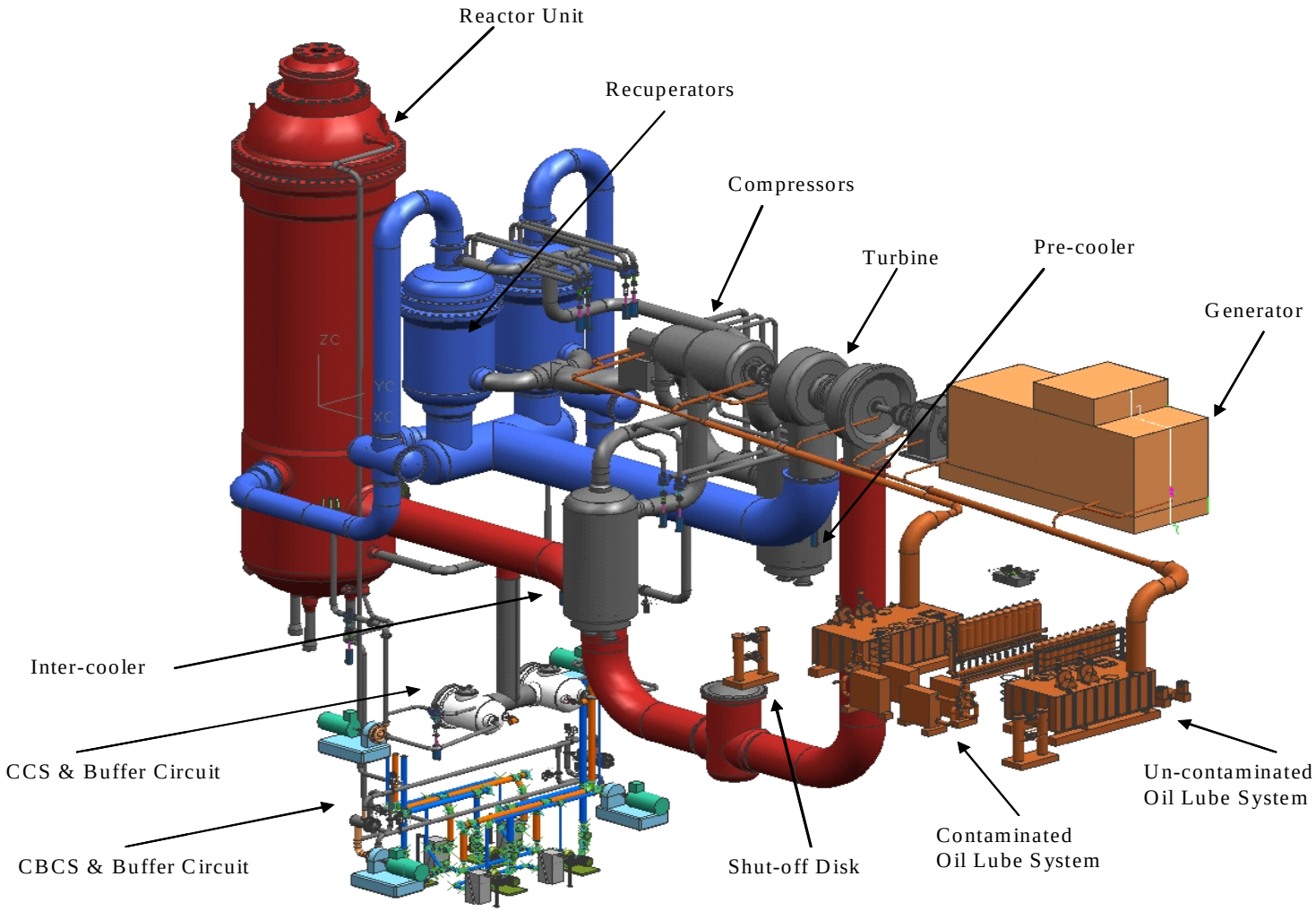


Direct Brayton Cycle

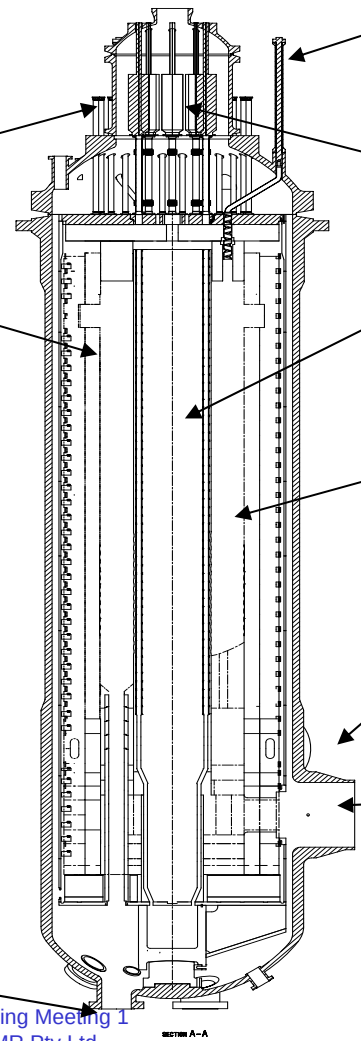
Power Output (Demo)	**400 MWth**
	>165 MWe
Coolant pressure	**9 MPa**
Coolant temperatures	**900°C outlet**
	503°C inlet
Pressure ratio	**3.2**
Coolant flow	**193 kg/sec**
Cycle efficiency (net) (conservative)	**>41%**



Main Power System



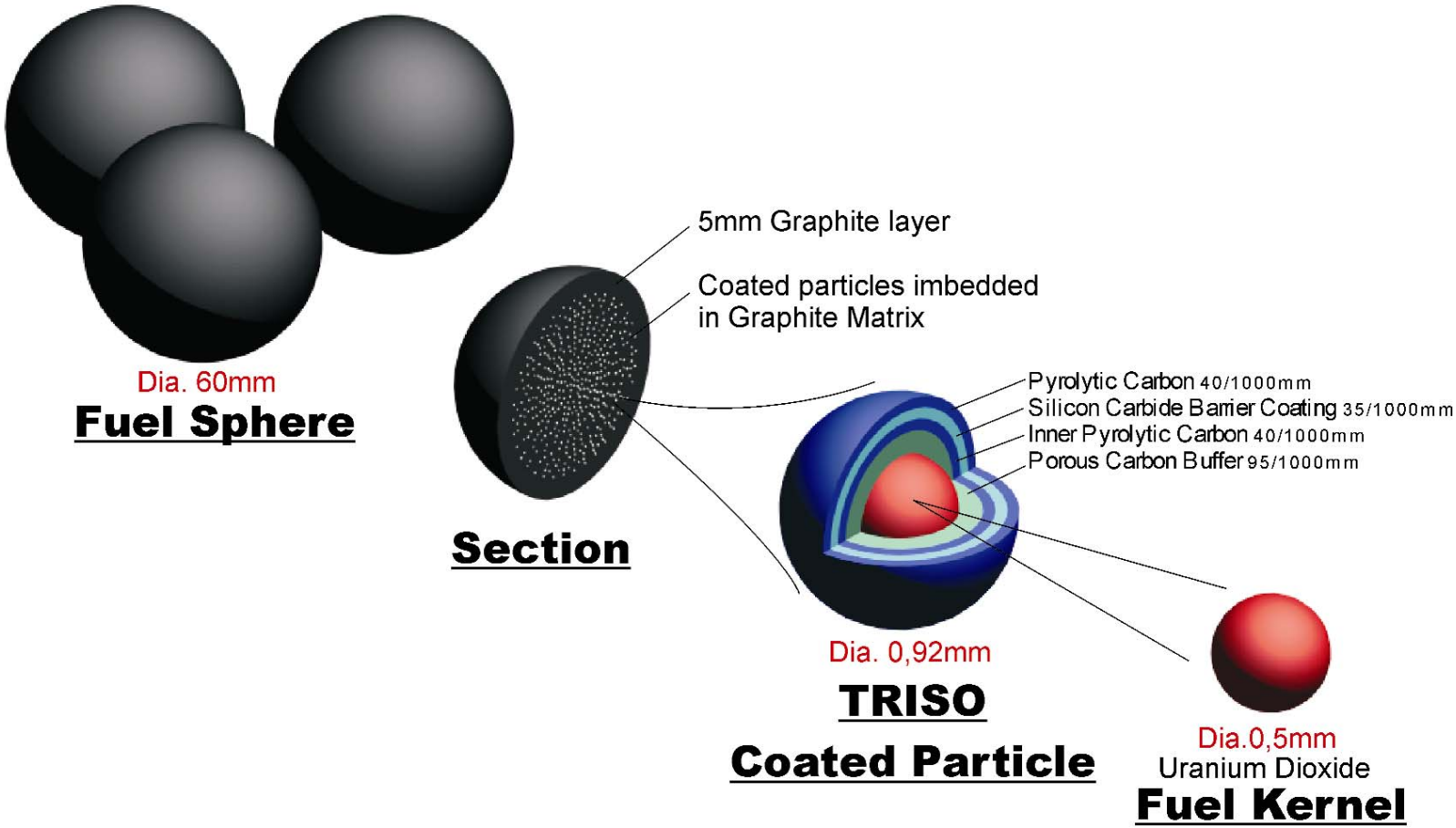
Reactor Unit Vessel Assembly



SPECIFICATION

Total height RPV	30 m
Inside dia. RPV	6.2 m
Coolant	Helium
Max. helium pressure	9 MPa
Normal Ops. temp. of RPV	300°C
RPV vessel material	SA 508/533
RPV mass assembled	~1700 t
RPV vessel mass	1000 t (lid included)

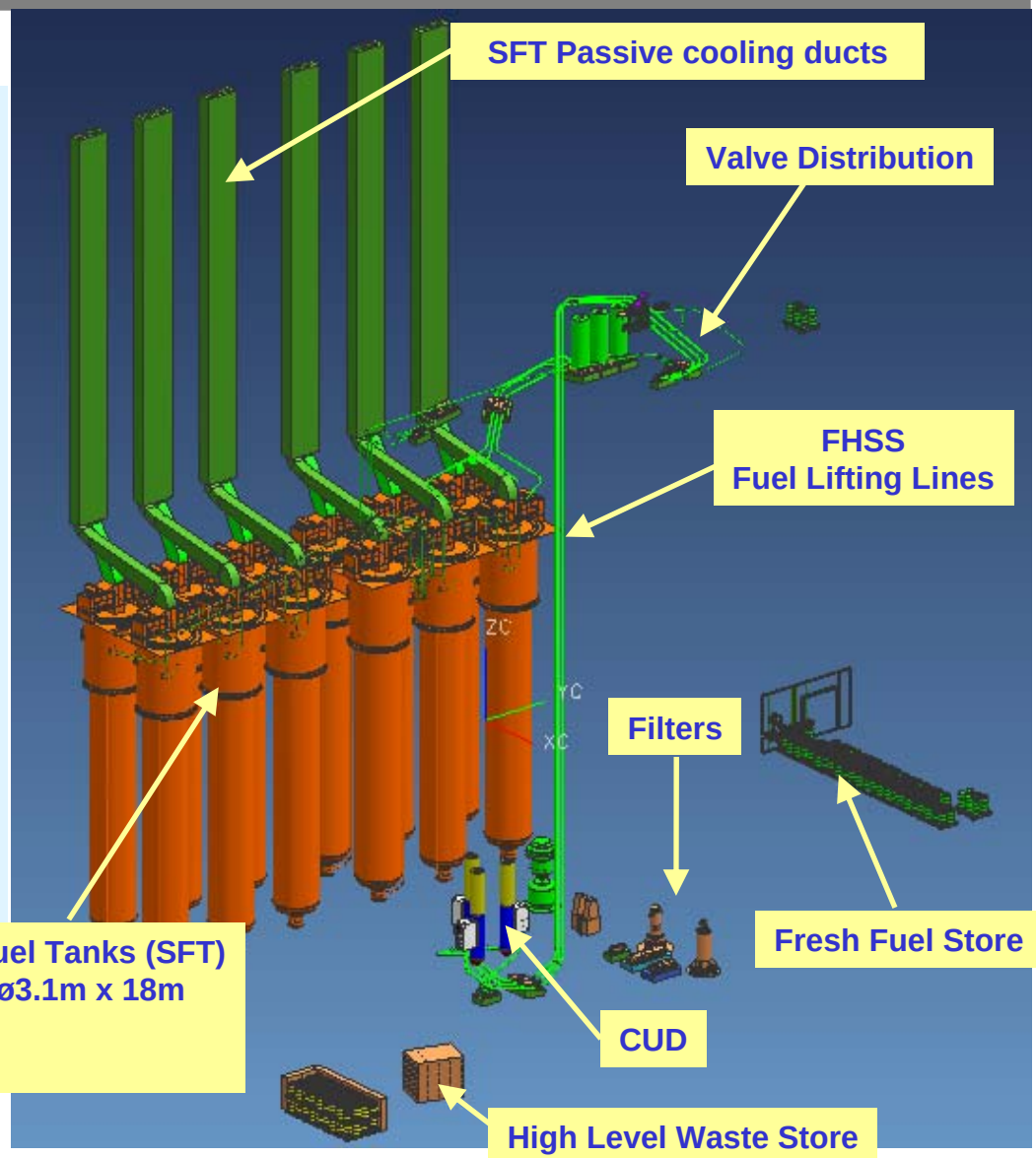
Fuel Design



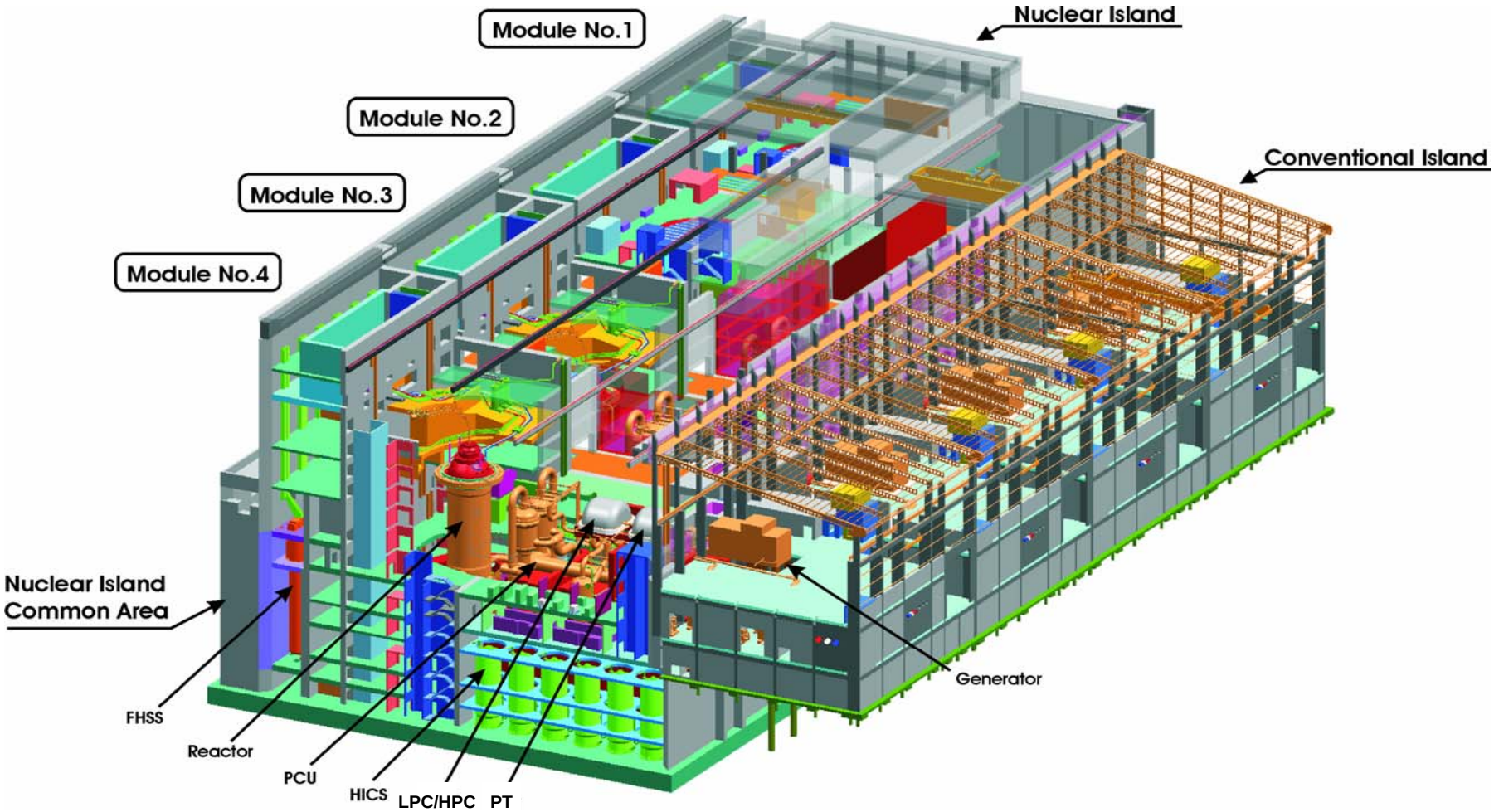
Fuel Handling & Storage System

SPECIFICATION

Medium	Helium
Daily sphere circulation rate	2900
Daily operating time	12 hours
Number of fuel passes through core	6
Operating pressure	1 – 9 MPa
Operating temperature	20 - 260ºC
Fuel spheres in core	451555
Fuel sphere feeding points	3
Core defueling points	3
Fresh fuel storage capacity	70 canisters
Fresh fuel canister capacity	1000 spheres
Spent fuel storage capacity spheres	6 000 000
Number of spent fuel tanks (modular installation as req)	10
Spent fuel period	80 yrs.



Multi-Module Plant



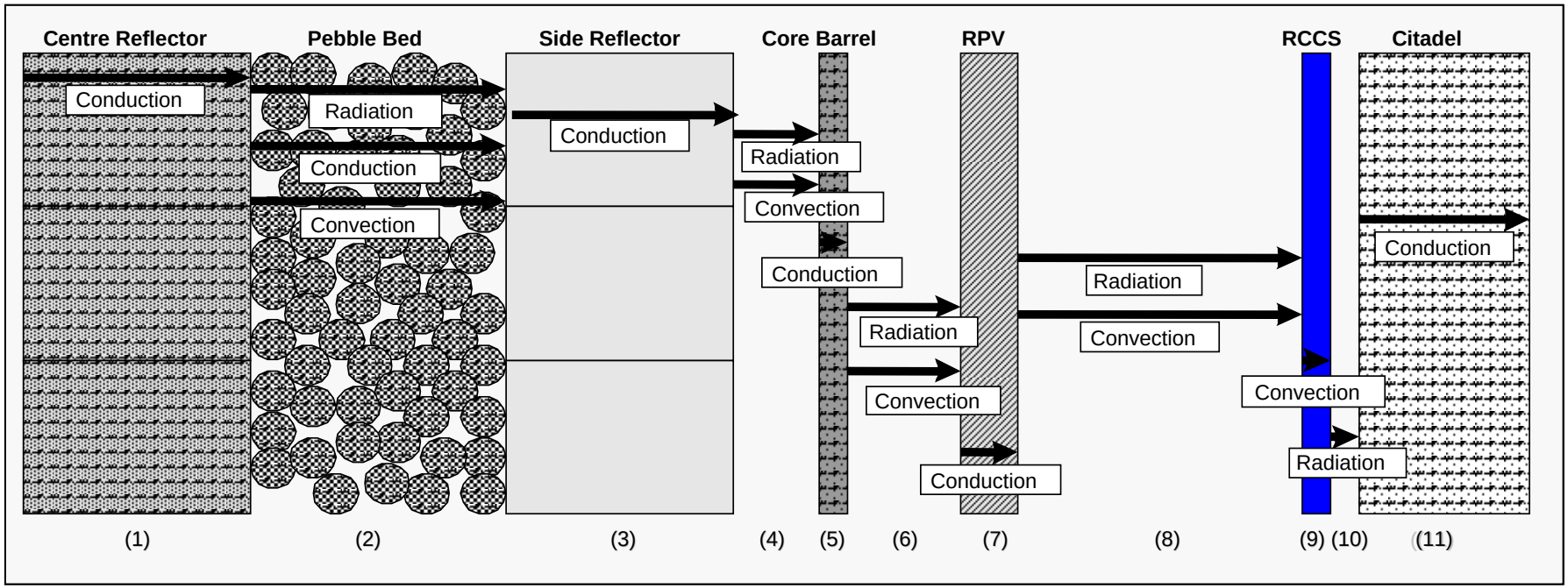
Important PBMR Paradigm Shifts

- **The safety of the PBMR core is not dependent on the presence of the helium coolant.**
- **The fuel, helium coolant, and graphite moderator are chemically compatible under all conditions.**
- **The response times of the reactor are very large (days as opposed to seconds or minutes).**
  - Early insertion of control rods or small absorber spheres is not required.
  - No startup of active cooling systems are required.
  - Early (e.g., < 24 hours) operator actions provide substantial defense-in-depth.
- **There is no inherent mechanism for runaway reactivity excursions or power excursions.**
- **The fuel has large temperature margins.**

Basic Safety Design Principles

- **Assuring primary radionuclide retention within ceramic coated fuel particles**
- **Additional margin provided by the primary pressure boundary and module building**
- **Fuel radionuclide retention achieved by:**
  - Control of core heat removal
    - *Large core heat capacity*
    - *Large temperature margins*
    - *Passive heat removal to cavity*
  - Control of heat generation
    - *Limited excess reactivity*
    - *Strong negative temperature coefficient*
  - Control of chemical attack
    - *Large RPV penetrations located below core level to limit air ingress (diving bell principle)*
    - *Limited water volumes in low pressure interfacing systems*

Designed for Passive Heat Removal



Graphite

Graphite
Helium
Nuclear Fuel

Graphite

Helium

Stainless Steel

Helium

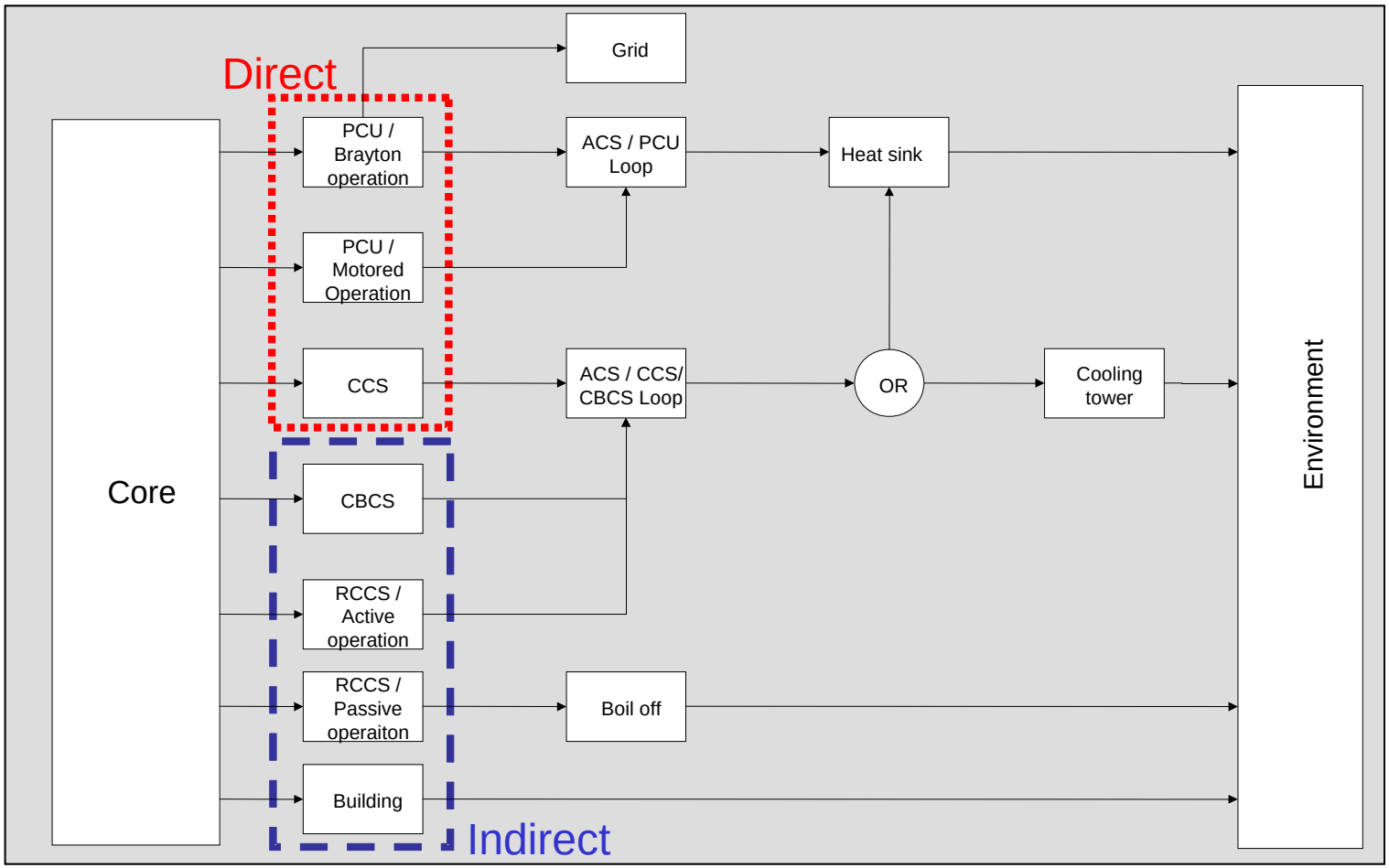
Carbon Steel

Air

Air
Stainless Steel
Pipes & H_2O

Concrete

Core Heat Removal Options



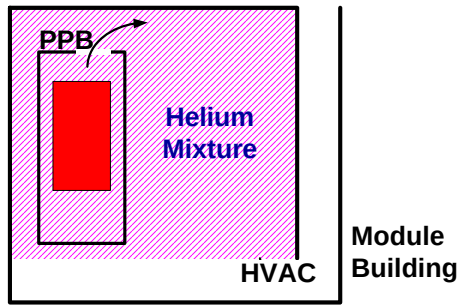
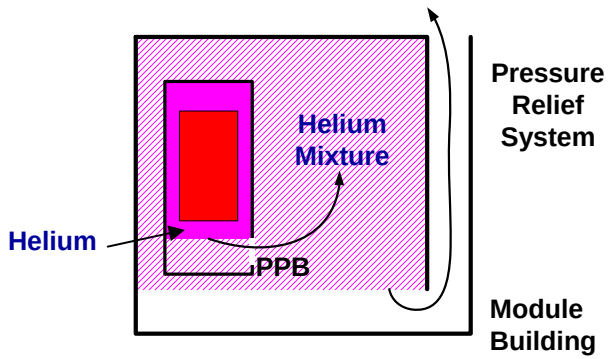
Heat Generation Controlled by Intrinsic Properties

- **AVR pebble bed reactor in Germany demonstrated that its strong negative temperature coefficient shuts the reactor down from full power.**
  - No control rod or reserve shutdown material insertion required
  - Reactor remained subcritical for >20hrs and thereafter power generated was acceptably small to limit fuel and reactor temperatures

- **HTR-10 pebble bed reactor in China demonstrated the same fundamental behavior. (*ref. 2004 IAEA conference*)**

- **PBMR analysis for a depressurized loss of forced cooling without control rod or SAS reactor trip predicts the time available before recriticality is ~80 hours.**

Design Limits Air Ingress Potential

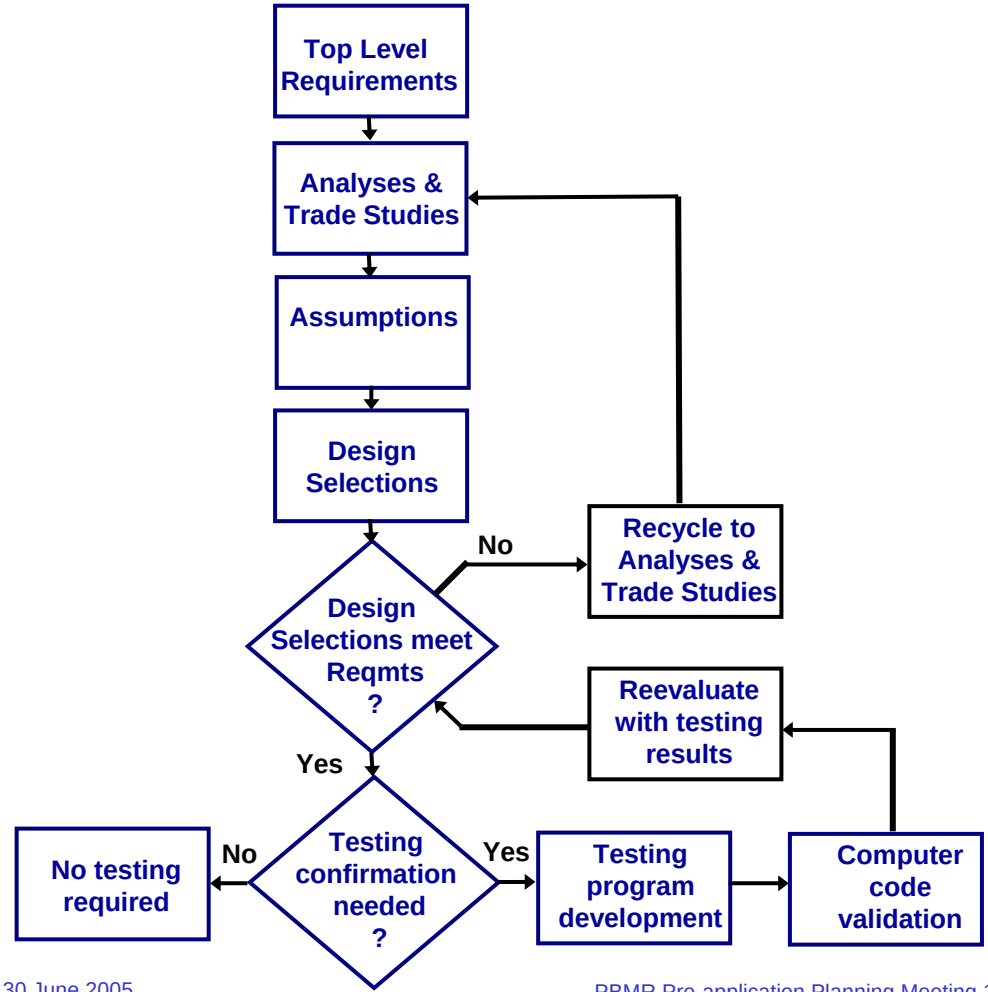
Location	Primary Helium Flow Path
Top Leaks	 No large penetrations at top of RV
Bottom Leaks & Breaks	 Diving bell principle

Development & Test Philosophy

- Base the PBMR on the technology demonstrated on the AVR, THTR, and other early gas reactors where sufficient successful experience exists
- Utilize materials, components and processes that have a proven nuclear industry track record or proven industrial record to the maximum extent
- Conduct research and development to address technology applications new to the PBMR nuclear applications or where PBMR conditions go beyond existing industry experience data
- Develop test facilities that are capable of additional confirmatory benchmarking of PBMR Pty analytical codes for the PBMR design conditions

Role of Testing in Safety Design Approach

Design Approach



Design and Test Integration

- Top Level Regulatory Criteria
- Selection and Evaluation of LBEs
- Selection and Evaluation of SSC's for their intended application and their required reliability
- Assumptions with regard to systems response, material properties, computer code validation, etc.
- Confirmatory testing of design selections performing safety functions, e.g., fuel & graphite
- Validation of computer codes used in LBE evaluation

Development & Test Program

- **Important component of the U.S. Design Certification effort**
- **Based on extensive technology transfer of the prior German designs and operating experience**
- **Comprehensive program to confirm engineering parameters demonstrated**
  - Large scale test facilities
  - Substantial amount of testing completed or ongoing
  - International effort committed to the future of gas reactors
- **PBMR also supports the development of advanced gas reactor codes and standards under ANS, ASME, IAEA and other nuclear standards committees.**

Development & Test Program Elements

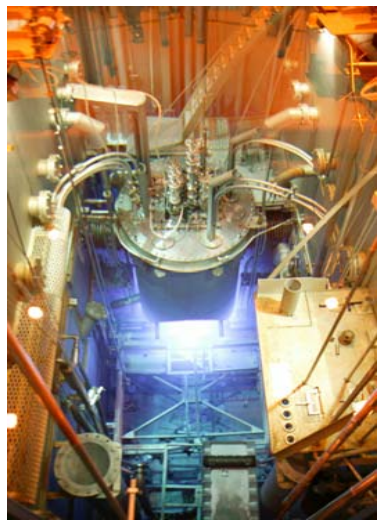
- **Basic Development (Completed)**
  - Part and full scale testing of systems and components for PBMR conditions to confirm the design approach
- **Fuel and Materials Irradiation Test Program (Ongoing)**
  - Add confirmatory data on the performance of PBMR fuel under normal operating and accident conditions
- **Component Development Testing (Ongoing)**
  - Full scale testing of components to confirm performance, reliability and maintenance capabilities
- **Validation Test Programs (Ongoing)**
  - Part scale test programs to validate design assumptions and safety codes
- **Advanced R&D Programs**
  - Focus on improvements in basic plant capabilities and upgrading of design to full VHTR conditions

Development & Test Program Status

Facility	Test Objectives	Status
Fuel Laboratory (Pre-production Fuel)	Add confirmatory data on fuel performance under normal and accident conditions	Graphite testing – 2006-07 Coated particle testing – 2005-07 Pebble testing – 2006-08
Pilot Fuel Plant	Production scale facility to verify manufactured fuel is of requisite quality and performance	Building refurbishment underway Operational – 2008
PBMR MicroModel	Benchmark codes for control simulation and T-H performance	Testing complete
Helium Test Facility	Full scale testing of components to confirm performance, reliability and maintenance capabilities	Construction underway Operational – 2006
Heat Transfer Test Facility	Determine heat transfer properties of packed graphite pebble beds with heat generation under various cooling conditions	Detailed design complete Procurement underway Operational – 2006
NACOK Facility (Germany)	Investigate oxidation (corrosion) of hot graphite cores during air ingress events	Testing complete

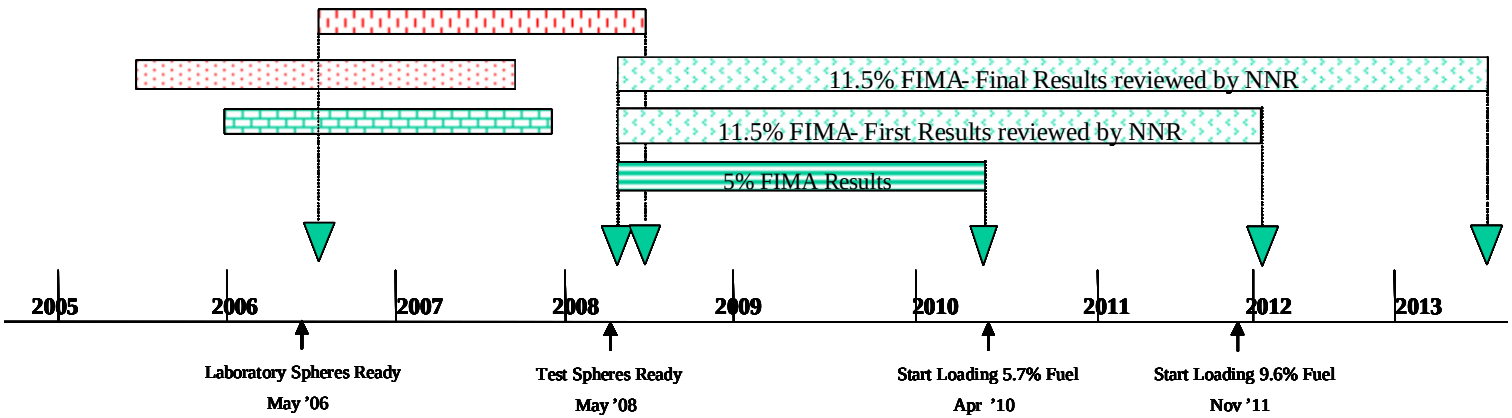
Fuel Development Program

- **Fuel Manufacturing Development Program**
  - Manufacturing Process Understanding
  - Quality Control Program Development
  - Small-scale Coating
  - Sphere Fabrication
  - Pre-production Fuel
- **Fuel Irradiation Test Program**
  - Graphite Properties
  - Coated Particle Characterization
  - Pre-production Fuel Irradiation
  - Production Fuel Irradiation

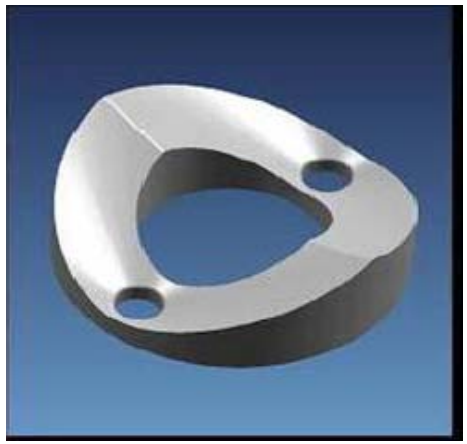


Fuel Irradiation Testing Program

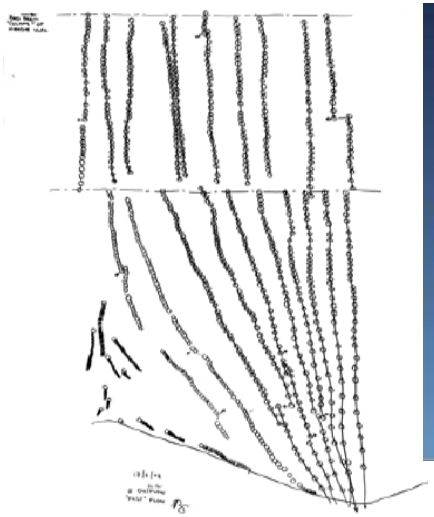
Allow Reactor Burnup to 5% FIMA	Allow Normal operation of Reactor with Equilibrium Core
4 x FE 5% FIMA Burnup PIE + Heating Mar '08 - Sep '10	12 x FE 11.5% FIMA PIE + Heating Mar '08– Jul 2013 (1st results reviewed by NNR Feb'11)
Graphite Samples Qualification	
4 x FE 10% FIMA Burnup Pre-production Irradiation (May'06- July '08)	
Coated Particle Characterisation	

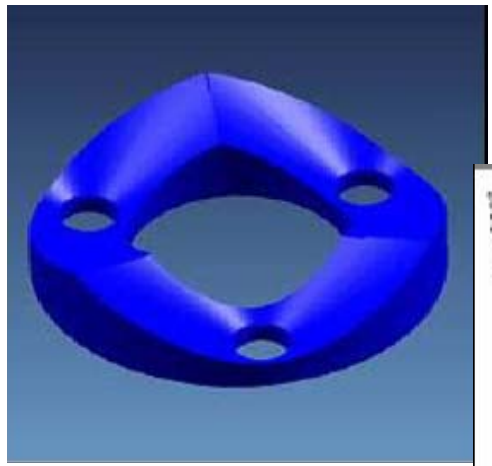


Fuel Spheres: Sphere flow tests 2&3 Outlet Core Base

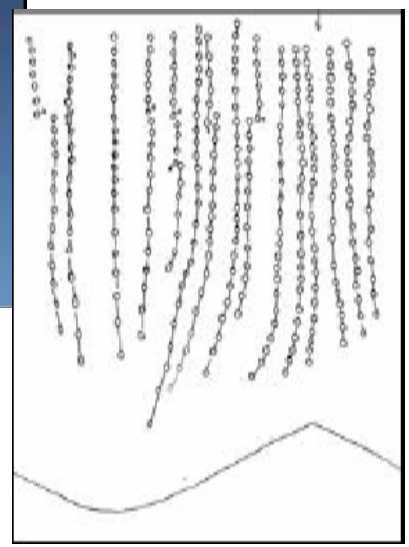


2 Outlet Core Base

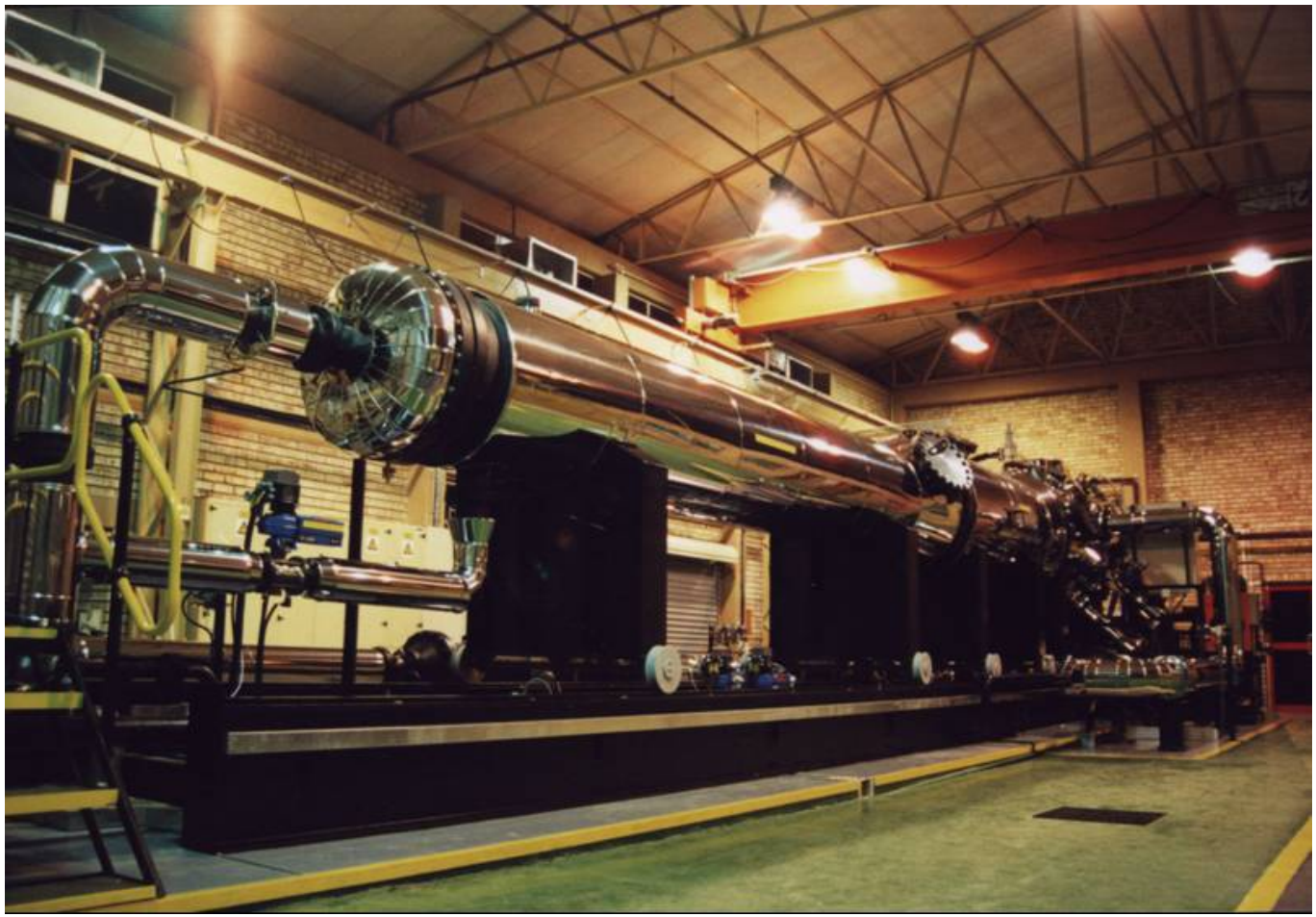




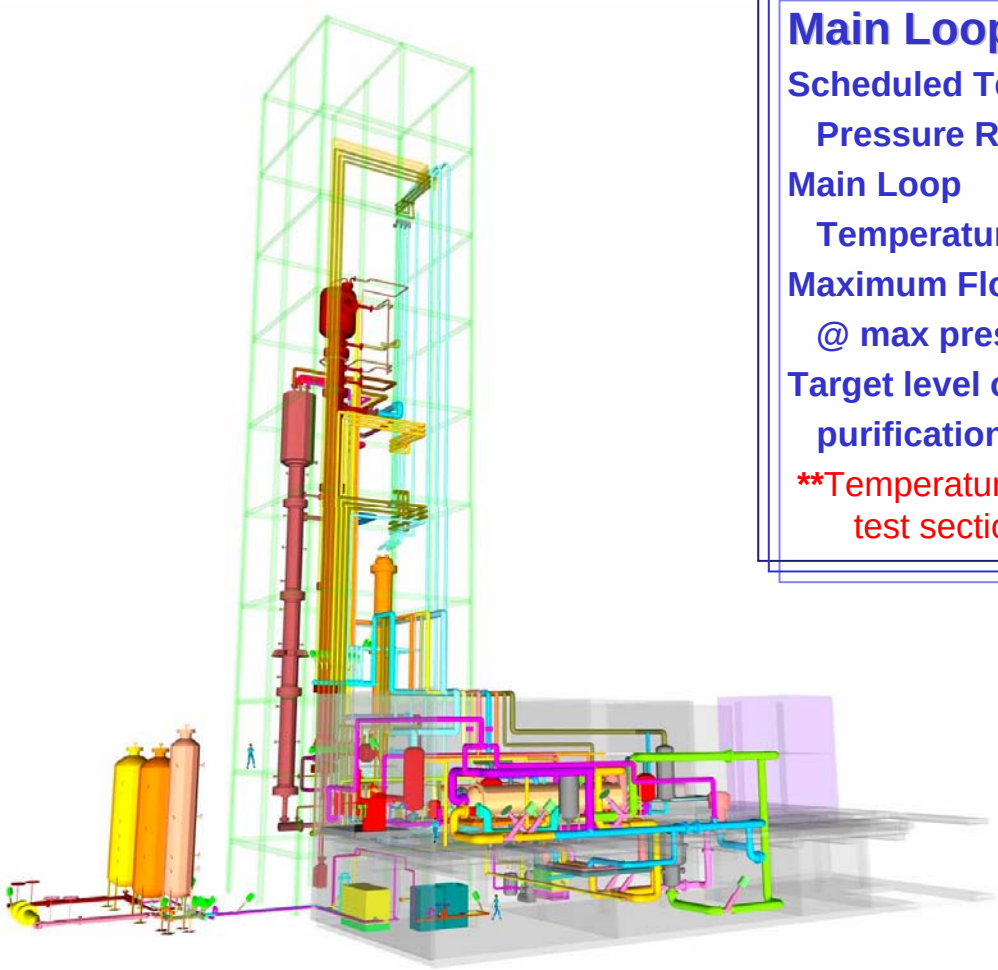
3 Outlet Core Base



PBMR MicroModel



Helium Test Facility



Main Loop Characteristics

Scheduled Test	
Pressure Range	3.2MPa to 9.5MPa
Main Loop	
Temperature Range	up to 660°C**
Maximum Flow	
@ max pressure	2.47kg/s @ 9.5MPa
Target level of	
purification	>99.997% pure Helium

**Temperatures up to 1100C are generated within test sections

Helium Test Facility

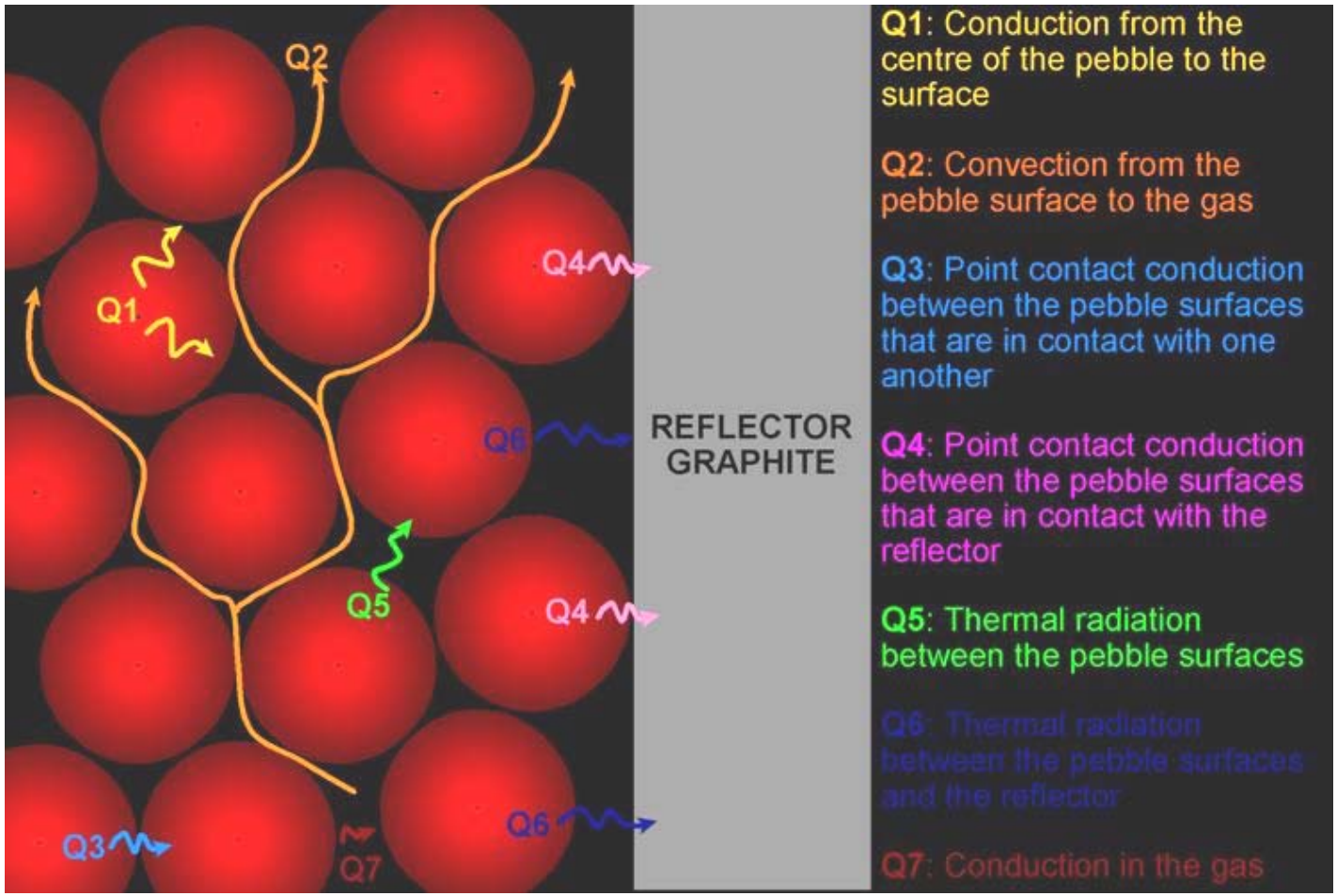
December 2004 – Pouring of concrete base

February 2005 – FHS valve block installation

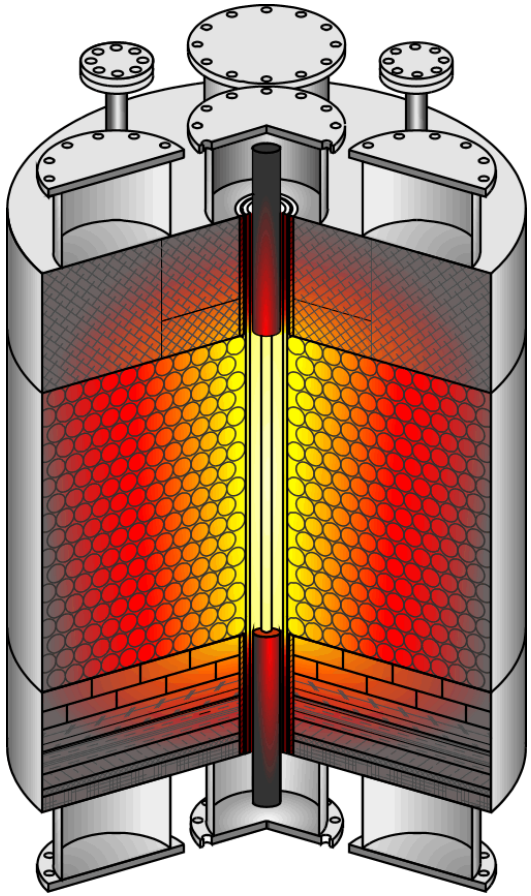
March 2005 – Level 2 preparations

May 2005 – High bay structural steel

Pebble Bed Heat Transfer Validation



Heat Transfer Test Facility



- The complexity and the strong interaction of the heat transfer phenomena in the pebble bed, requires a test facility to perform separate effects tests and also integrated tests to quantify the complex heat transfer phenomena in pebble cores.
- Modern Computational Fluid Dynamics (CFD) codes provide previously unavailable capability for design simulation when supported by appropriate verification testing

The NACOK Facility

- The NACOK experiments are primarily for validation and verification purposes of codes used for air ingress analyses.
- These are detailed experiments to quantify and subsequently model the effect of air ingress on the rate of localized corrosion of the graphite reactor components.
- The developed modelling capability is essential for the prediction of the effect of air ingress on the current and future PBMR designs.
- This work will be used to validate TINTE and PBMR CFD codes.

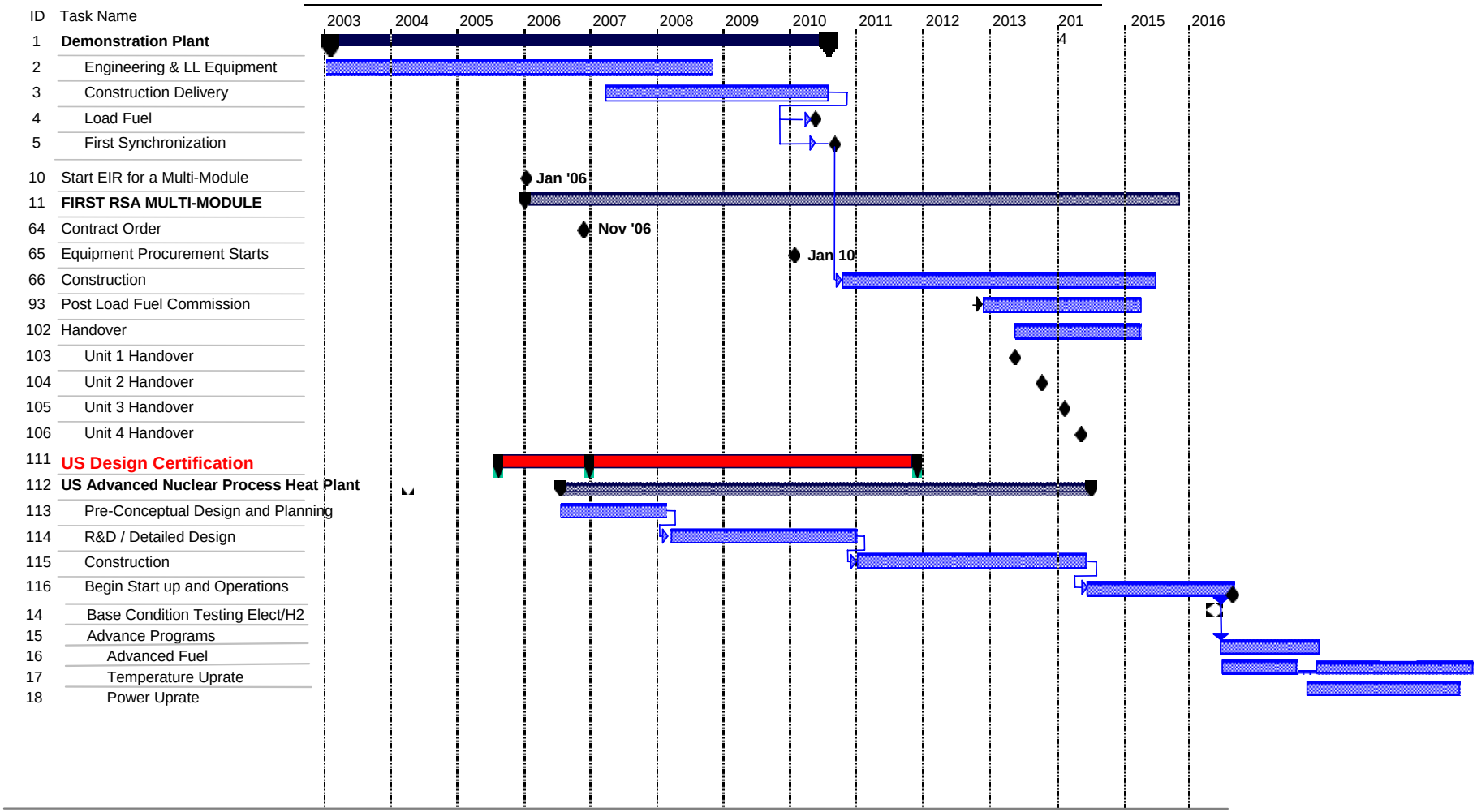
Program Status

- Koeberg site on Western Cape selected for South African PBMR Demonstration Power Plant
- Safety Analysis Report in preparation; to be submitted to National Nuclear Regulator (NNR) in 1Q06
- Demonstration Power Plant construction scheduled to start April 2007 with fuel load in 2010
- Equipment procurement for the first commercial multi-module plant in South Africa expected in 2010; startup of first module in 2013
- U.S. design certification of the commercial multi-module plant to be completed by 2011

Design Maturity

- Based on successful German pebble bed experience of AVR and THTR from 1967 to 1989
- Evolution of direct helium Brayton cycle starting with Eskom evaluations in 1993
- Over 3.2 million manhours of engineering to date with 700 equivalent full-time staff (including major subcontractors) working at this time
- Over 12,000 documents, including detailed P&IDs and an integrated 3D plant model
- Detailed Bill of Materials with over 20,000 line items and vendor quotes on all key engineered equipment

Integrated Program Plan



Proposed Focus Topics for Pre-Application Review

June 30, 2005

Selection of Licensing Basis Events

Dr. Fred A. Silady

June 30, 2005

Issue Definition

- **Background**
  - Licensing Basis Event determination for non-LWRs is not well established in current regulatory practice or requirements.
  - The use of PRA to better understand plant design and performance in normal, abnormal, design basis and beyond design basis events is an essential element of modern safety assessments and encouraged by NRC Policy.

- **Issue**
  - Establish the mechanisms and approaches to determining Licensing Basis Events for the PBMR design using a combination of probabilistic and deterministic methods

Issue Focus

- **Issues with LBE selection include**
  - Use of PRA risk insights to select a comprehensive set of risk-informed event sequences
  - Extent of inclusion of multiple and common cause failures
  - Extent of inclusion of events affecting more than one reactor module
  - Extent of inclusion of external events and shutdown events
  - Extent of inclusion of a role for defense-in-depth
  - Best means to account for uncertainties in frequency and consequences
  - Events to use for operational limits, events for design, events for emergency planning, and events for meeting safety goals
  - Rare events that are sufficiently low in frequency that they need not be considered
  - Best means to harmonize PBMR process with the Staff's technology neutral framework development

Issue Focus

- **LBEs include:**
  - Anticipated Operational Occurrences (AOOs) used as basis for operational limits, such as tech specs, and to show compliance with normal operational offsite dose criteria
  - Design Basis Events (DBEs) used as basis for design, such as equipment classification, and to show conservative compliance with limiting offsite dose criteria
  - Beyond Design Basis Events (BDBEs) used as basis for rare event analysis to show compliance with limiting offsite dose criteria and for establishing actions for events that exceed EPA Protective Action Guidelines (PAGs)

- **LBEs are collectively evaluated to show compliance with Quantitative Health Objectives (QHOs) of Safety Goals.**

Outcome Objectives

- **Agreement on selection method:**
  - Use of PRA to select a comprehensive set of event sequences
    - *Inclusion of multiple and common cause failures*
    - *Treatment of events affecting more than one reactor module*
    - *Inclusion of external events and shutdown events*
    - *Inclusion of statistically-combined uncertainties in frequencies and consequences*
    - *Highlight defense-in-depth by explicitly considering all SSCs capable of performing a safety function*
  - Based on the mean frequencies of event sequences per plant year
  - Event sequences < TBD/plant year need not be considered

- **Understanding of the role of defense-in-depth in LBE selection**

- **Understanding how the PBMR process will align with the Staff's technology-neutral licensing framework initiative**

References

- **Exelon pre-application interactions**
  - Exelon letter dated March 15, 2002, “Revision of Exelon Generation Company’s Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States,” Section 4.
  - Exelon presentation to ACRS, “Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States,” October 2001.

- **DOE submittal to NRC, “Preliminary Safety Information Document for the Standard MHTGR,” Volume 1, Section 3, August 1992, Amend 11.**

Safety Classification of Structures, Systems, and Components (SSCs) and Defense-in-Depth

Dr. Fred A. Silady

June 30, 2005

Issue Definition

- **Background**
  - Implementation of SSC safety classification has evolved for LWRs over several decades.
  - The development of SSC safety classification methodology for non-LWRs with a unique set of DBE challenges has not been established.
  - Advanced gas reactors contain inherent features and passive safety-related SSC that have no reliance on AC power or other conventional means of assuring public safety.

- **Issue**
  - Establish the approach for determining the safety classification and special treatment for the PBMR SSCs relied on or providing added safety margins during LBEs.

Issue Focus

- **Issues with SSC safety classification include:**
  - Events leading to classification of equipment
  - Events for which the safety-related SSCs are sufficient for prevention or mitigation
  - Selection of which SSCs are classified as safety-related
  - Special treatment alternatives for safety-related SSCs
  - Role of SSCs that provide safety margins and defense-in-depth
  - Treatment needed for SSCs not classified as safety-related
  - Best means to harmonize the PBMR process with the Staff's technology-neutral licensing framework

Issue Focus

- **Safety Classification**
  - means to focus regulatory attention and resources on a subset of the plant's SSCs to provide added assurance that required safety functions are accomplished for offsite public protection

- **SSCs classified as safety-related**
  - proposed by applicant and shown to provide sufficient mitigation to meet dose criteria during DBEs and to provide sufficient prevention of high-dose BDBEs
  - receive special treatment during design, manufacturing / construction, operation, and maintenance

- **SSCs classified as non safety-related**
  - may also perform functions that provide safety margins and defense-in-depth, in addition to other functions needed for the owner
  - are also within the regulator's purview and receive limited special treatment as needed for performance assurance, availability, and operational requirements

Outcome Objectives

- **Understanding of what is meant by safety classification**
- **Identification of the process by which SSCs are classified as safety-related and their special treatment**
- **Understanding of the role of defense-in-depth in safety classification for non-LWR designs**
- **Understanding of the kinds of limited treatment to be applied to non safety-related SSCs**
- **Understanding how the PBMR process will align with the Staff's technology-neutral licensing framework initiative**

References

- **Exelon pre-application interactions**
  - Exelon letter dated March 15, 2002, “Revision of Exelon Generation Company’s Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States,” Section 5.
  - Exelon presentation to ACRS, “Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States,” October 2001.

- **DOE submittal to NRC, “Preliminary Safety Information Document for the Standard MHTGR,” Volume 1, Section 3, August 1992, Amend 11.**

Fuel Design and Qualification

Stanley E. Ritterbusch

June 30, 2005

Issue Definition

- **Background**
  - Integrity of PBMR fuel particles is a critical characteristic of PBMR.
  - German TRISO fuel design selected as the reference design
    - *Proven experience 1967 - 1989 at German AVR and THTR facilities*
  - German manufacturing process adopted for PBMR fuel plant
  - New tests expected to confirm current performance envelope
  - Computer code and monitoring limits being developed to demonstrate that fuel behavior will be within performance envelope

- **Issue**
  - Demonstrate adequacy of the fuel qualification program by confirming:
    - *Fuel performance envelope*
    - *Methods for showing conformance with that envelope*
    - *Methods for showing equivalence in German vs. PBMR fuel manufacturing*

Issue Focus

- ***Extent*** **of tests with regard to confirming the performance envelope**
- ***Means*** **of showing compliance with the performance envelope over time**
- ***Extent*** **of documentation on equivalence of PBMR and German fuel manufacturing**

Outcome Objectives

- Identification of scope of the fuel qualification test program
- Agreement on methods and monitoring to confirm that fuel design complies with the performance envelope
- Understanding of the scope of documentation

References

- **Exelon pre-application interactions**
  - Exelon letter dated March 18, 2002, "Document Supporting the March 28, 2002, Pre-Application Meeting Regarding the PBMR"
    - *Transmitted slides for March 28, 2002 meeting on "Pebble Bed Modular Reactor Fuel Qualification Program"*
  - Exelon letter dated May 24, 2002, "Submittal of the Pebble Bed Modular Reactor Pty. Document No. 010520-425, Revision 2, 'Pebble Bed Modular Reactor Nuclear Fuel'"
  - NRC letter dated June 27, 2002, "Request for Additional Information (RAI) on Pebble Bed Modular Reactor (PBMR) Nuclear Fuel; Fuel Fabrication Quality Control Measures and Performance Monitoring Plans; and PBMR Fuel Qualification Test Program"

Codes and Standards Selection

Willem Kriel, PBMR

June 30, 2005

Issue Definition

- **Background**
  - The PBMR design makes extensive use of a large body of well understood LWR codes.
    - *As the safety case philosophy for PBMR differs from that of LWRs, existing rules for the choice of design codes, standards, regulations, and guidelines are not directly applicable.*
    - *Correlation with the safety classification effort is needed for the choice of the most appropriate codes and standards.*
  - In some cases new codes and standards specific to HTGRs are needed.
  - The PBMR design will also include Code Cases not previously approved by the NRC.
  - International codes and standards have been utilized successfully in gas reactor applications.

- **Issue**
  - Confirmation of the acceptability of the unique suite of Codes and Standards that will be used or developed for PBMR reactor design

Issue Focus

- **Applicability of current LWR mechanical codes**
  - PBMR has been designed extensively to operate within the envelope defined by existing LWR materials and Code limits.
  - Code Cases covering excursions from allowable limits have been identified.
  - There are no applicable In-service Inspection rules for modular HTGRs
- **Graphite**
  - There is no approved design code for the design of ceramic core structures. PBMR makes use of internal design requirements based on the draft KTA3232.
- **Civil and Structural**
  - PBMR utilizes a combination of local and international construction codes.
- **Instrumentation & Control**
  - Post event monitoring will deviate from selected standards due to PBMR specific requirements and/or constraints.
- **Safety and Quality Classification**
  - Quality group designations of LWR components are not directly applicable to PBMR.

Proposed Design Codes and Standards

- **Mechanical**
  - ASME III: NB, NC, ND, NF, NG
    - *with Code Cases N-499-2 and N-201-4*
  - ASME B31.1 & ASME B31.3
  - ASME VIII Div 1
  - ASME VIII Div 2

- **Instrumentation & Control**
  - Class 1E (i.e., IEEE 603 and its reference standards)
  - Post-Event Monitoring: Reg. Guide 1.97 and IEEE 497 with exceptions

Proposed Design Codes and Standards

- **Graphite**
  - Core Structure Ceramics is designed according to internal requirements based on the draft rule KTA3232 modified for PBMR application.

- **Civil – Basis for South African Design**
  - The applicable design codes and standards are South African National Standards (SANS).
    - *SANS 1200 Series, Standard Specifications for Civil Engineering Construction*

Proposed Design Codes and Standards

- **Structural:**
  - Reinforced concrete:
    - ACI 349, 'Code Requirements for Nuclear Safety Related Concrete Structures'
    - ACI 318, 'Building Code Requirements for Structural Concrete'
  - Structural Steel:
    - ANSI/AISC N690, 'Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities'
  - Loading Code:
    - ASCE 7-8, 'Minimum Design Loads for Buildings and Other Structures'
    - To reflect local conditions, the following loading code is used:
    - SANS 10160, 'South African Standard, Code of Practice for The General Procedures and Loadings to be Adopted in the Design of Buildings'
  - Seismic Design Guidance:
    - ASCE 498 and appropriate Reg. Guides.
  - Specifications:
    - SANS 10120 Series, Standard Specifications for Civil Engineering Construction adjusted to include for ACI Manual of Concrete Practice and ANSI N690

Proposed Design Codes and Standards

- **In-service Testing**
  - ASME OM Code for the Operation and Maintenance of Nuclear Power Plants
- **Fire Protection**
  - Guidance from NFPA
- **Quality Management System**
  - ASME NQA-1; ISO 9001-2000

Codes and Standards in Development

- **In-service Inspection**
  - ASME Section XI – A new Division 2 for modular HTGRs is in preparation.

- **Graphite**
  - ASME Section III – A new design code for graphite core support structures is in preparation.
  - ASTM – carbon-based materials and testing standards

Outcome Objectives

- Understanding of PBMR's use of NRC accepted conventional LWR codes and standards where applicable
- Understanding of PBMR's use of other codes, code cases, and standards and the level of justification documentation required
- Confirmation of approach toward development of HTGR specific codes and standards where needed

References

- **Exelon pre-application interactions**
  - Exelon letter dated July 22, 2002, “Submittal of Pebble Bed Modular Reactor US Pre-application Review Activities Summary”, included Area 6, Codes and Standards

Materials Selection

High Temperature Materials Metallic and Graphite

Willem Kriel, PBMR

June 30, 2005

Philosophy

- **PBMR structures, systems and component material selection shall (in order of preference):**
  - use materials within the limits of a code or standard that the NRC has accepted, or
  - use materials within the limits of a code or standard that has been accepted by a standards body but the NRC has not yet accepted, or
  - use materials that are not incorporated in a code at this time and design from first principles with appropriate supporting qualification programs.

Issue Definition

- **Background**
  - PBMR makes extensive use of materials that conform with codes and standards found acceptable by the NRC in prior applications.
  - PBMR utilizes several materials that, while known to the NRC, are used outside limits previously accepted.
  - In select cases, PBMR uses materials that the NRC has not reviewed.
- **Issue**
  - Demonstrate adequacy of materials selection program by confirming:
    - *Materials selection and operating environment process*
    - *Materials qualification process*

Issue Focus

- **Agreement is required on a suitable process for material selection and qualification.**
- **This issue can be subdivided as follows:**
  - Metallic materials
  - Carbon-based and ceramic materials
- **Processes to be addressed:**
  - Process for material selection, including consideration of operating environment and its effect on the performance of the material, and
  - Process to determine material qualification requirements.
    - *Focus on materials with required performance that falls outside existing codes and standards*
    - *Particular emphasis on confirming adequacy of performance of materials designed to first principles.*

Outcome Objectives

- **Agreement on the PBMR approach to materials selection and qualification**
- **Understanding of acceptance criteria for material qualification programs**
- **Tied closely to the *Outcome Objectives* for the Codes and Standards focus topic**

References

- **Exelon pre-application interactions**
  - Exelon letter dated July 22, 2002, “Submittal of Pebble Bed Modular Reactor US Pre-application Review Activities Summary”, included Area 7, High Temperature Material

Computer Code Verification & Validation (V&V)

Charles L. Kling

June 30, 2004

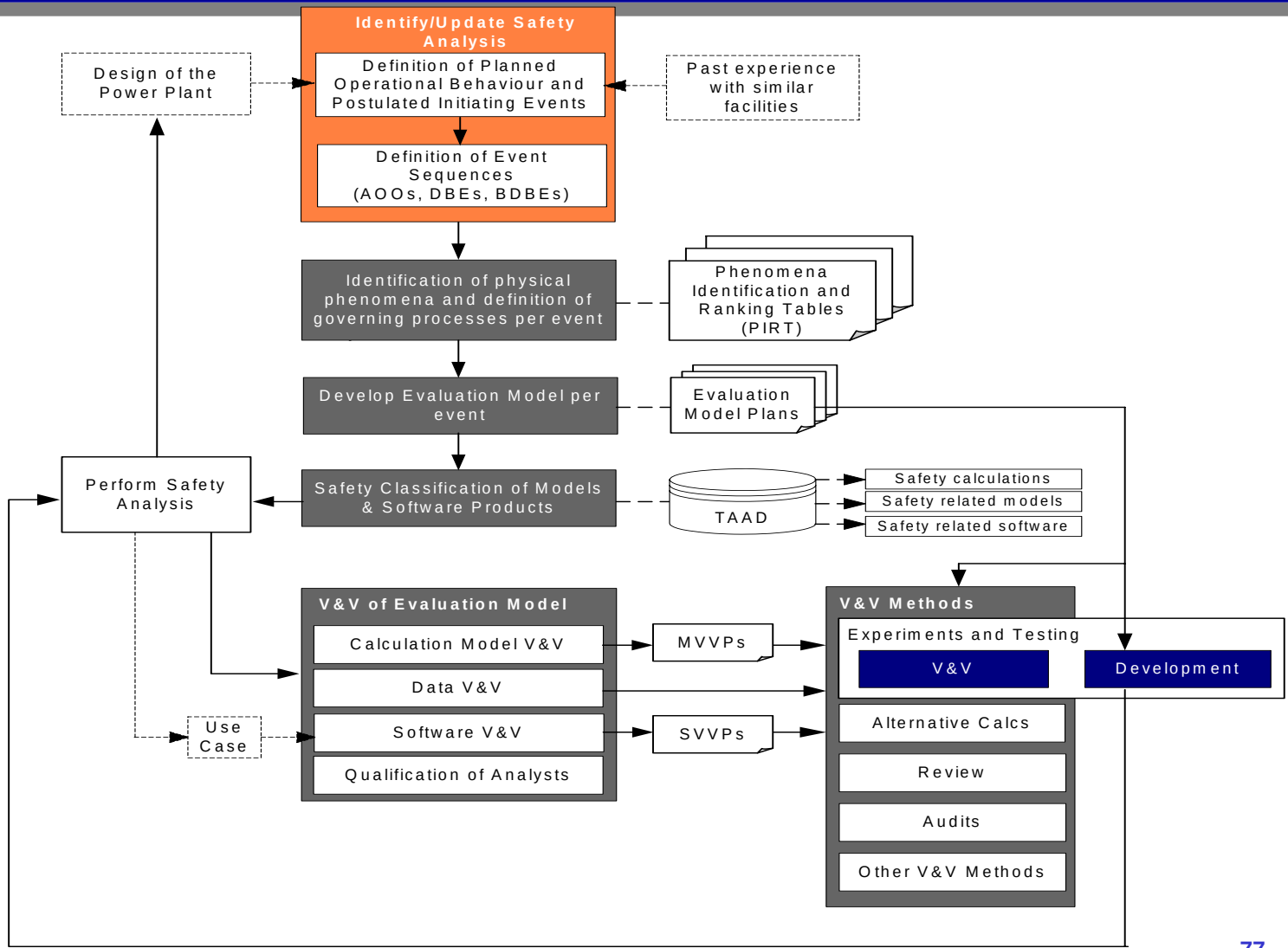
Issue Definition

- **Background**
  - NRC Code V&V issue as of 11/2001:
    - *How will analytical tools used to assess plant response to accident conditions be validated?*
  - Exelon/PBMR response:
    - *Near term : V&V of various computer codes is to be done in stages; the initial strategy and plans will be available by mid-2002.*
    - *Long Term: Computer code V & V activities will be ongoing over the next four years.*
- **Issue**
  - Confirmation of the suite of V&V computer codes, the associated V&V process, and related testing

Issue Focus

- **The PBMR V&V process for safety related computer codes has been modified to closely follow NRC DG-1120**
  - e.g., EMDAP including PIRTs for normal operation, design basis events, severe accidents, etc.
- **Existing test data on TRISO fuel and data from existing/planned test facilities in SA are expected to fully support the safety related computer code V&V process for the NRC in the U.S.**

PBMR V&V Process



V&V Computer Codes

NAME	DESCRIPTION
ENGINEERING	
FLOWNEX	Thermal-Fluid network analysis
FLUENT	CFD analysis of fluid flow and heat transfer
REACTOR	
ORIGEN-SCALE	Fuel depletion / decay heat
TINTE	Transient behavior of reactor core
VSOP	Reactor core neutronics suite
RISK	
PC COSYMA	Radiological dose and risk to the public

V&V Computer Codes

NAME	DESCRIPTION
RADIATION	
AMBER	Contaminant migration in a system
FIPREX	Fission product release from fuel spheres
FISPACT/ EASY97	Neutron induced radioactivity from core
GETTER	Release of long-lived metallic fission products
MCNP	Radiation shielding and criticality
MICRO-SHIELD	Shielding requirements / external dose rates
NOBLEG	Fuel sphere Noble Gas / Halogen release
RADAX4	Fission products in wall materials and fluid

Outcome Objectives

- **Agreement on the scope of the V&V computer code suite**
- **Understanding of PBMR Evaluation Model Development and Assessment Process**
- **Agreement of scope for the PBMR testing program for computer code V&V**

References

- **Exelon pre-application interactions**
  - Exelon letter dated October 30, 2001, “Summary of Pre-application Presentations Regarding the Pebble Bed Modular Reactor (PBMR)”
  - Exelon letter dated November 15, 2001, “Response to NRC Letter dated September 26, 2001 Regarding the Pebble Bed Modular Reactor Technical Information Availability”

Single vs. Multi-Module Certification

Edward M. Burns

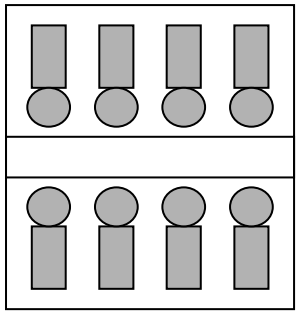
June 30, 2005

Issue Definition

- **Background**
  - PBMR's standard design can be implemented in various module configurations. It would require considerable NRC and industry resources to certify different combinations that could be of interest to owners.
  - Proposed revisions to the Price Anderson Act recognize that small, modular reactors present a different circumstance than large LWR designs.
  - The issue for PBMR is how best to address the Part 52 requirements for an applicant seeking certification of a truly modular design.

- **Issue**
  - Determine whether it is feasible to obtain a Design Certification on a single PBMR reactor module and have that certification apply to any subsequent combination of modules

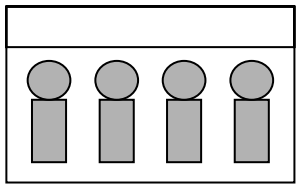
Plant Configurations



8-pack configuration

8 x 165 MWe

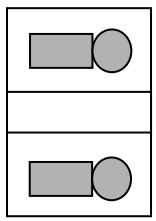
Total output 1320 MWe



4-pack configuration

4 x 165 MWe

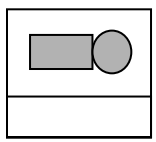
Total output 660 MWe



2-pack configuration

2 x 165 MWe

Total output 330 MWe



Standalone configuration

1 x 165 MWe

Total output 165 MWe

Issue Focus

- **Issues with Multi-Module certification include**
  - Establishment of a basic module configuration for the design that allows for variations in, or sharing of, common systems
  - Determination of the extent to which safety analyses must include events affecting more than one reactor module
  - Specification of boundary conditions between modules such that safety considerations may be developed at the module level
  - Specification of interface requirements between reactor modules
    - *Level of detail*
    - *Balance between DC and COL applications*
  - Identification of restrictions which may be necessary during the construction and startup of a given module to ensure the safe operation of any module already operating

Outcome Objectives

- **Agreement on approach**
  - The fundamental safety case is based on a single module.
  - Interface requirements are specified for systems that are wholly or partially outside the scope of the PBMR basic module that assure that module safety is maintained.
  - Shared systems, common cause failures, and systems interactions are verified during COL review.
- **Understanding on level of detail needed to describe the various options for the configuration of the design, including variations in, or sharing of, common systems**

Background References

- **10 CFR 52.47(b)(3) – Application for certification of a modular design**

Policy Issues Related to the PBMR Design Certification Effort

Edward G. Wallace

June 30, 2005

Issue Definition

- **Background**
  - Several ongoing NRC regulatory initiatives requiring Commission policy direction have implications for PBMR design certification:
    - *Technology-neutral, performance-based licensing framework*
    - *Increased use of risk methods in NRC requirements and guidance*
    - *Establishment of a standardized approach to PRA quality*
    - *Enhanced physical security requirements post-9/11*
    - *Part 52 rulemaking*
  - Industry codes and standards committees are developing new/revised standards directed at gas reactors.

- **Issue:**
  - Need to establish a common understanding of the impacts of these ongoing efforts on PBMR's design certification activities.

Issue Focus

- **Establishing a method for determining applicability at an early stage**
- **Understanding non-LWR implications of new generic requirements**
- **Securing adequate access to necessary information to complete the design (e.g., revised DBT, etc.)**

Outcome Objectives

- **Understanding of scope and criteria for implementation of new issues/programs determined applicable to PBMR**
- **Ensuring access to security and other requirements to complete the PBMR design**

Administrative Procedures

June 30, 2005

Administrative Procedures

- **Format and level-of-detail needed for PBMR issue documentation**
  - Topical reports
  - White papers
  - Reference materials
- **NRC requests for additional information (RAIs)**
- **Documentation form of Staff positions**
- **Project correspondence**
- **Proprietary information**
- **Electronic filings / submission**
- **Payment processes**

Lessons Learned from Other Pre-Application Reviews

June 30, 2005

Lessons Learned

- **NRC insights from prior Part 52 pre-applicants and applicants**
  - Testing requirements
  - International design
  - Operational experience

- **Discuss as agenda topic for next planning meeting**

Next Steps

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Next Steps

- Planning process confirmation of steps
- Planning and review issues confirmation
- Objectives for next meeting
- Target date for next meeting