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PBMR Analytical Codes and Software Controls Overview

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Introduction

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Purpose of the Presentation is to:

- Describe the Software Control functions in PBMR
- Identify the primary analytical codes used for design and analysis of PBMR.
- Discuss specific applications critical to the development of the design and safety case.
- Provide NRC with information to assess their familiarity with the codes used and define long-lead actions to prepare for receipt of the first PBMR application.
- Identify additional information that should be submitted during pre-application to support NRC's preparations for COL review.
- Receive early feedback from NRC on known weaknesses and concerns about the analytical codes and methods that should be addressed in the application.

PBMR Software Control Board

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- Objectives
  - Sanctioning computer program usage
  - Approval of structure, system, component models to be used
  - Establish V&V strategy and obtain sanction from management for implementation
  - Identification of additional software requirements
  - Evaluate changes to procedures related to installation and application of design and safety related software and make recommendations to Quality Management
  - Approval and maintenance of configuration management on software
  - Define and maintain database of training requirements
  - Communicate proposed software changes to management and obtain approval.

PBMR Software Control Scope

- Engineering Analysis
- Reactor Analysis
- Radiation Analysis
- Fuel Performance Analysis
- Risk and Consequence Analysis

Controlled Design Software Status

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- Code Description
- Code Type
- Code Version Control
- Code Uses
- User Certification
- Quality Assurance Requirements

Controlled PBMR Design Model Status

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- **System Model Description**
- **Applicable Code/Version**
- **Model Version Control Measures**
- **Documentation**
  - Input Report
  - IMAN Document Control Number
  - Revision Number
  - Status
- **User Certification**

Software Plan

- **For each analysis the interfaces with data and codes are identified and made visible in the model description or output report;**
- **This ensures that the source of all input data is traceable and that changes in the data can be managed;**
- **The interfaces defined include, for example, input specifications or input values obtained from other analyses.**

Software Control Records

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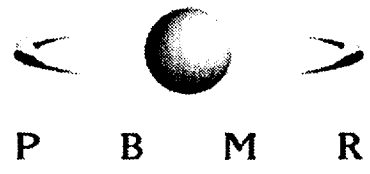
- **Status Control Forms**
  - Discrepancy Reports
  - Change Requests

Conclusions - Software Controls



- Software use is recognized as a critical element of the design process.
- Configuration Management programs exist to manage software uses, users, models and quality requirements.

Principle Analytical Codes in Use

Analytical Code Applications

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- Engineering Analysis
- Reactor Analysis
- Radiation Analysis
- Fuel Performance Analysis
- Risk and Consequence Analysis

Engineering Analysis Code Listing

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- Flownet Nuclear Solver
- Flownet Nuclear
- Fuelnet
- Star-CD
- Fluent
- PFC-3D
- Patran
- Nastran
- ADAMS

Analytical Code Type and Use

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- Engineering Analysis

- Flownet Nuclear Solver

- Thermal Fluid Network Solver - Analysis, design and optimization of thermal fluid networks such as the PBMR Main Power System (MPS) including controls

- Flownet Nuclear

- Thermal Fluid Network Analysis Code - Analysis, design and optimization of thermal fluid networks such as the PBMR MPS including controls

- Fuelnet

– Discrete event simulation code - Analysis of the process flow rates and control strategies used for the Fuel Handling and Storage System of the PBMR

Analytical Code Type and Use (Con't)

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- **Star-CD**
  - General purpose thermo-fluids Navier-Stokes solver, based on finite volume discretisation of the constituent equations - Detail analysis of mass, momentum and energy transfer inflow fields as well as conjugate heat transfer in solids Thermal radiation in gasses and between solid surface is also simulated in discretised domain. Steady and transient modes.

Analytical Codes Type and Use (Con't)

- **Fluent**
  - General purpose thermo-fluids Navier-Stokes solver based on finite volume dicretisation of the constituent equations - Detailed analysis of mass, momentum and energy transfer inflow fields as well as conjugate heat transfer in solids Thermal radiation in gasses and between solid surface is also simulated in discretised domain. Steady and transient modes.
- **PFC-3D**
  - Distinct element modeling code - Distinct element modeling of the movement of fuel and graphite spheres in the reactor. This analysis includes sphere loading and dynamics.

Analytical Code Type and Use (Cont)

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- **Patran**
  - Finite element pre/post processor - Pre and post processor for the Nastran and Dytran finite element codes.
- **Nastran**
  - Finite element analysis software - Finite element code used for analysis of the mechanical structures of the PBMR
- **ADAMS**
  - Explicit dynamics analysis code- Explicit dynamics analysis code for the modeling of the PBMR structures.

Reactor Analysis Code Listing

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Reactor Analysis

- VSOP
  - Code system for the numerical simulation of the physics of thermal reactors. It is used for processing cross sections, to set up the reactor and fuel element, evaluate repeated neutron spectra, calculate neutron diffusion in 2- or 3-D, fuel burnup, fuel shuffling, reactor control, thermal hydraulics and fuel cycle costs. The thermal-hydraulics in steady state and quasi-steady state is restricted to HTRs in two spatial dimensions.

Reactor Analysis Code Listing

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- VSOP suite of codes consisting of:
  - Interface with nuclear libraries: ENDF/B-IV, -V, and JEF-I
  - GAM-I
  - THERMOS
  - ZUT-DGL
  - CITATION
  - THERMIX
  - FEVER
  - KPD
  - DATA2
  - BIRGIT
  - TRIGIT
  - FIRZIT
  - Life

Reactor Analysis Code Listing

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- Reactor Analysis (Continued)
  - TINTE
  - RZ-KIND
  - ZIRCUS

Analytical Codes Type and Use

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- **ZUT-DGL**
  - Sub-code for calculating the resonance integrals for given concentrations of Th-232 and/or U-238. This is done in a specific fuel assembly and for different temperatures of the respective absorber materials.
- **DATA2**
  - Prepares fuel element input data from its geometric design
  - Atom densities are homogeneously distributed for the many different batches in the reactor

Analytical Codes Type and Use

- **BIRGIT (r-z), TRIGIT (x,y,z), and FIRZIT (ϕ,r,z)**
  - Provides the geometric design in 2-D,and/or 3-D of the reactor
  - Generates both VSOP layers and CITATION compositions
  - Material data is provided in the geometrically defined positions
  - Batches, layers, and spectrum zones are formed
  - Average atom densities are calculated to form broad group cross-sections

Analytical Codes Type and Use

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- **GAM-I**
  - Epithermal library - 68 group structure within the energy range 10 MeV to 0.414 eV
- **THERMOS**
  - Thermal library - 30 group structure within the energy range 10^{-5} eV to 2.05 eV
- **CITATION**
  - Perform 2- or 3-D diffusion calculations
- **FEVER**
  - Burnup and fuel shuffling is covered by a further development of this code

Analytical Codes Type and Use

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- **LIFE**
  - Employs the full irradiation history of each fuel batch for decay heat evaluation
- **KPD**
  - Performs fuel cycle cost analysis at every step of fuel management
- **THERMIX**
  - Perform 2-D T-H, both steady-state and quasi-steady state
  - Temperatures in fuel and moderator regions are used in the spectrum zones for neutronic evaluation

Analytical Codes Type and Use

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- **TINTE**

  - Code for time-dependent and temperature excursions.

  Calculation of control rod ejection, reactivity and associated temperature excursions due to a fast control rod withdrawal, criticality effects due to pebble bed compaction under seismic loading, dynamic short term analysis.

- **RZ-KINDT, ZIRKUS**

  - Possibly to be used to benchmark VSOP and TINTE

Radiation Analysis Code Listing

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- Radiation Analysis
  - MCNP
  - SCALE 4.4
  - FISPACT/EASY97
  - SPATRA
  - ORIGEN-JUEL-II
  - MCBEND

Analytical Codes Type and Use

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- **MCNP**

  - MCNP is a general purpose, continuous-energy, generalized geometry, time dependent, coupled neutron-photon-electron Monte-Carlo transport code.

  Gamma and neutron shielding, ex-core criticality, neutron and gamma transport calculations (core)

- **SCALE 4.4**

  - Modular code package to perform criticality, shielding and heat transfer analysis using well established functional modules.

  Gamma shielding (QAD), ex-core criticality (KENO), source term (ORIGEN-S), core model (MORSE).

Analytical Codes Type and Use

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- **FISPACT/EASY97**

  - The European Activation System (EASY)/FISPACT is a complete tool for the calculation of activation in materials exposed to neutrons.
  Neutron activation calculations of steel structures, concrete, graphite, etc. close to the reactor

- **. SPATRA**

  - Fission product distribution throughout the primary system.
  Calculate fission product distribution throughout the primary system.
  Plate-out of certain fission products such as Ag-110m.

Analytical Codes Type and Use

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- **ORIGEN-JUEL-II**

  - Code for calculating source terms.

  Source term calculations in the core, decay heat calculations and fission product calculations.

- **MCBEND**

  - A Monte-Carlo code for general radiation transport calculations.

  Calculate neutron, gamma-ray and charged particle transport in sub-critical systems, design of transport casks and, shields and to predict nuclear instrument responses and dose rates.

Fuel Performance Code Listing

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- **Fuel Performance Analysis**
  - PANAMA
  - FRESCO
  - STRESS3
  - STAPLE

Analytical Codes Type and Use

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- **PANAMA**

  - Thin shell pressure vessel code.

  Calculation of failed particle fraction in PBMR fuel elements as a result of internal gas pressure in coated particles and weakening if the SiC layer due to thermal dissociation resulting in pressure vessel failure.

- **FRESCO**

  - Fission product diffusion code.

  Calculation of fractional release of fission products from single PBMR fuel element during upset event temperature transients.

Analytical Codes Type and Use

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- **STRESS3**

  - Thick shell pressure vessel code.

  Calculation of failed particle fraction in PBMR fuel as a result of internal gas pressure in coated particles and induced stress in the SiC layer.

- **STAPLE**

  - Statistical variation code based on the Stress3 model.

  Calculation of coated particle failure statistics using variational procedures for coated particle properties.

Risk / Consequences Codes Type and Use

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- **Risk and Consequence Analysis**

  - PC COSYMA
  - RISK SPECTRUM
  - LUDEP

Analytical Codes Type and Use

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- **PC COSYMA**

  - Safety Assessment

  Used to assess health, environmental and economic impact of radiological releases.

- **RISK SPECTRUM**

  - Safety Assessment

  Used in reliability and safety analysis.

- **LUDEP**

  - Safety Assessment

  Used to calculate doses from intake of radio-nuclides to regions of the respiratory tract and other body organs.

Conclusions - Analytical Codes

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Engineering Codes	**Developed for PBMR type** reactors	**Key Safety Code**
Flownet Nuclear Solver	X	
Flownet Nuclear	X	
Fuelnet	X	
Star-CD		X
Fluent		
PFC-3D		
Nastran		
ADAMS		X
TINTE	X	X
RZ-KINDT	X	
ZIRKUS	X	
VSOP	X	X

Conclusions - Analytical Codes

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Reactor Codes	Developed for PBMR type reactors	Key Safety Code
Interface with nuclear libraries:		
ENDF/B-IV, -V, and JEF-I	X	
GAM-I	X	
THERMOS	X	
ZUT-DGL	X	
CITATION	X	
THERMIX	X	
FEVER	X	
KPD	X	
DATA2	X	
BIRGIT	X	
TRIGIT	X	
FIRZIT	X	
LIFE	X	

Conclusions - Analytical Codes

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Radiation Analysis	Developed for PBMR type reactors	Key Safety Code
MCNP		X
SCALE 4.4		
FISPACT/EASY97		
SPATRA	X	X
ORIGEN-JUEL-II	X	X
MCBEND		

Conclusions - Analytical Codes

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Fuel Analysis	**Developed for PBMR type reactors**	**Key Safety Code**
PANAMA	X	X
FRESCO	X	X
STRESS3	X	
STAPLE	X	
Risk and Consequence Analysis		
PC COSYMA		X
RISK SPECTRUM		X
LUDEP		X

Outcome Objectives

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- NRC introduced to analytical code types and uses
- NRC to identify specific list of codes and models that are needed from PBMR to become familiar with and be ready for submittal of application