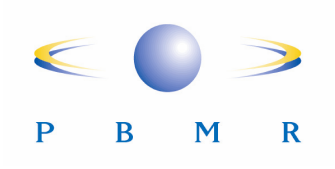


Computer Code, Data and Evaluation Model (EM) Verification & Validation (V&V)

Charles L. Kling

August 22, 2005

Discussion Outline

- Issue Definition & Objective Outcomes
- Overall V&V strategy
- EM V&V approach and status
- Accident Analysis Process
- Software V&V approach and status
- Future V&V planning
- Next steps
- References

Issue Definition

- **Background**
  - NRC analytical tool 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. A final version of the V&V plans … will be available by April 2003*
- **Current Issues**
  - Confirmation of the suite of computer codes/evaluation models (EMs), the associated V&V process and related testing

Issue Focus

- **The PBMR V&V process for EMs has been modified to closely follow NRC DG-1120**
  - e.g., EMDAP including PIRTs for normal operation, DBE, BDBE, etc.
- **Existing test data on TRISO fuel and data from existing/planned test facilities in SA are expected to fully support the safety related V&V process for the NRC in the US.**

Outcome Objectives

- Agreement on PBMR EM development and assessment process
- Agreement on the scope of the V&V computer code/EM suite
- Agreement on scope for the PBMR testing program for computer code/EM V&V
- Agreement on the planned white papers, topical reports, etc. and the DCA specification

Overall V&V Strategy

- The Evaluation Model concept
- V&V approach
- Accident analysis process

The Evaluation Model concept:

Accident Analysis

Calculation/analysis used to demonstrate that *Regulatory Acceptance Criteria* are met for defined licensing basis events.

The Evaluation Model Concept

Evaluation Model

A calculational framework consisting of *one or more Calculation Models* **and specific inputs used to model specific system behaviour under certain conditions.**

The Evaluation Model Concept

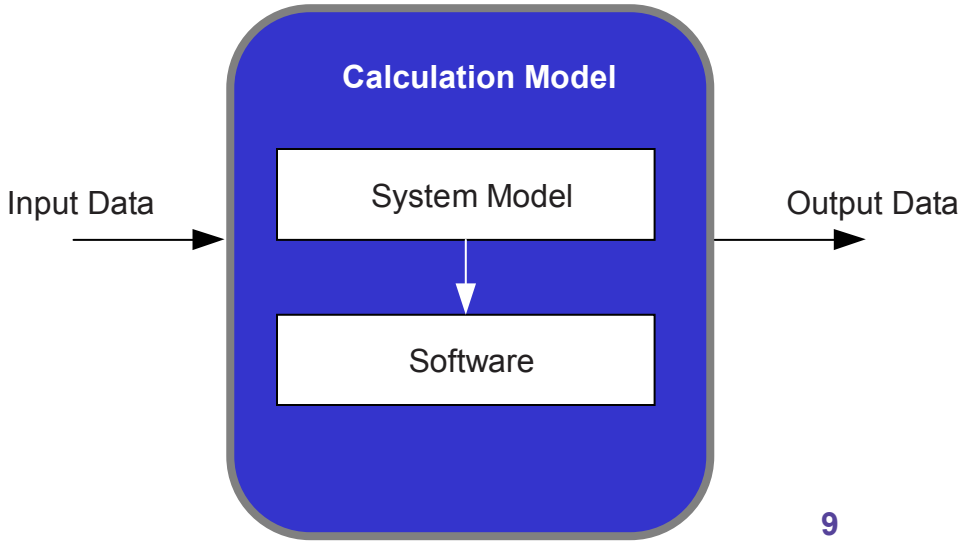
Calculation Model

An analytical quantification of a real system and the ways phenomena occur within that system, used to predict behaviour of the real system under specified conditions.
Where a Software Product is used the Calculation Model is the combination of the *System Model* and *Software*.

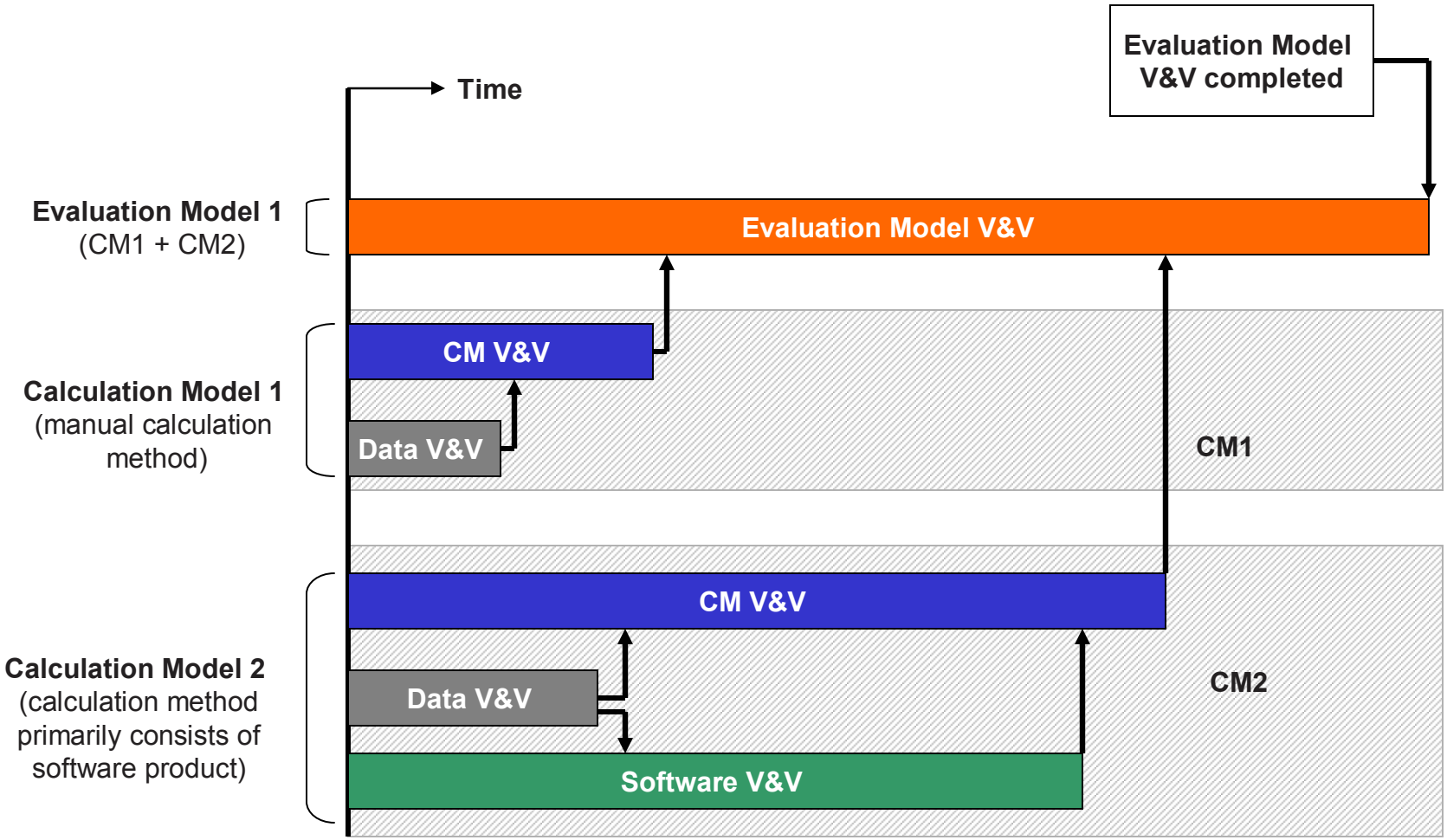
Manual Calculation Model:

x + y = z

or



Integrating the V&V Processes



Evaluation Models for PBMR Safety Analysis

Evaluation Model	Short Description	# Calc Models	Calculation Models Used
Pre-break	Calculates the expected pre-break conditions, just before a break in the Helium pressure boundary occurs. The time phase for this EM ends when such a break occurs. It does not include any of the phenomena that might occur during a pressure boundary break or later.	19	• VSOP99 PBMR400DP3 Reactor model • VSOP/CITATION 3D Model – RCS • VSOP/CITATION 3D Model – RSS • VSOP/CITATION 3D Model – RCS + RSS • MCNP 400MW PBMR Core & core structures model • SCALE Fuel Depletion Sources, Inventories and decay heat model • FLOWNEX MPS Model • CFD dust behaviour in MPS model • NOBLEG gaseous FP release model • FIPREX/GETTTER Metallic FP Release (normal geometry) model • RADAX PCU, FHSS, CCS, HICS, CBCS FP plate-out and dust distribution models • H3 Production model • C14 Production model • Turbine blade erosion productions model • Activation of erosion products model
Reactor cavity activation	Calculates the activation of Ar40 to Ar41 in the reactor cavity	2	• MCNP Reactor cavity interface radiation source model • Ar-41 Building release model
Heat removal transients	Calculates the transient reactor temperatures for forced cooling and loss of forced cooling scenarios.	2	• TINTE PBMR400DP3 Reactor model • FLOWNEX MPS Model
Reactivity transients	Calculates the transient reactor response for reactivity transient scenarios.	3	• VSOP99 PBMR400DP3 Reactor seismic model • TINTE PBMR400DP3 Reactor model • TINTE PBMR400DP3 Reactor seismic model
Air Ingress	Calculates the rate of air ingress for pipe break scenarios.	1 (+1 later)	• CFD Model for reactor air ingress • TINTE corrosion model – later

Evaluation Models for PBMR Safety Analysis

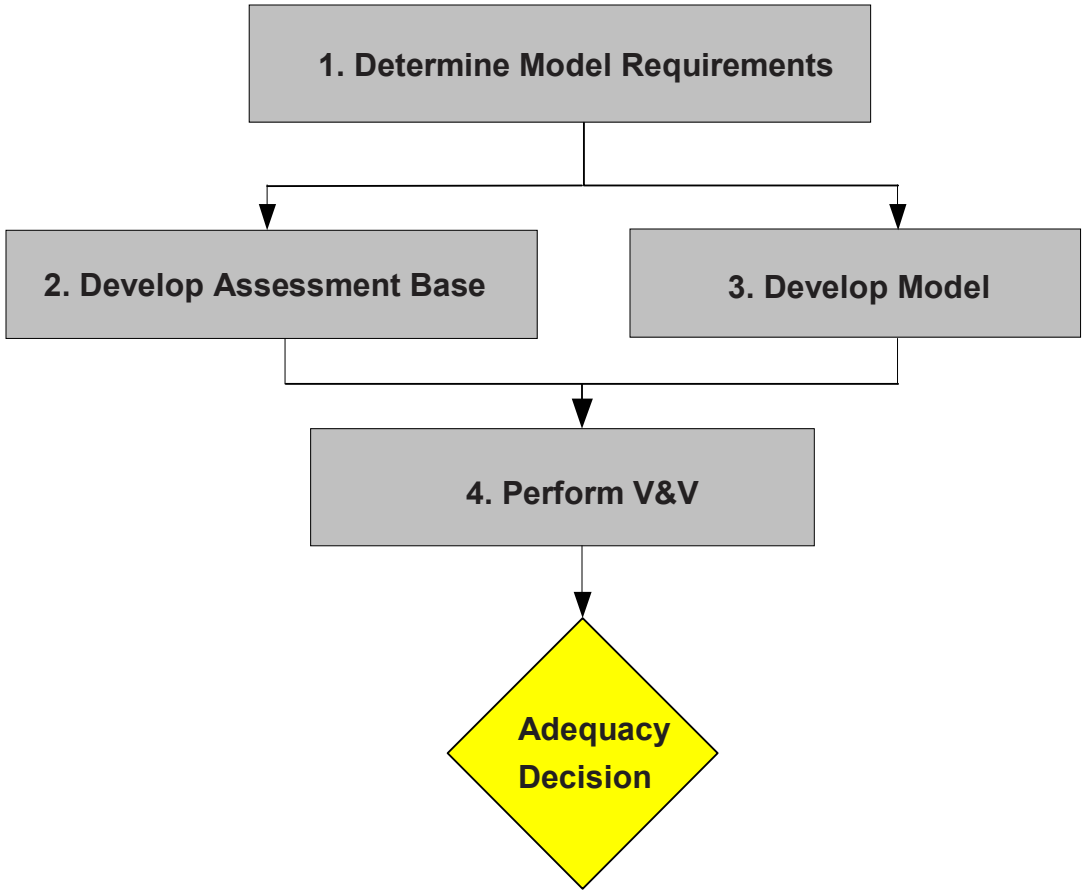
Evaluation Model	Short Description	# Calc Models	Calculation Models Used
Normal operation release	Calculates the release of activity during normal operation as a result of Helium Pressure Boundary leakage.	4	• AMBER Worker dose airborne activity from normal releases • AMBER Worker eDCF normal operations model • FLOWNEX MPS model • Waste characterization model
Atmospheric dispersion	Calculates the atmospheric dispersion and public dose	2	• PC-COSYMA Atmospheric dispersion model • ADMS Atmospheric Dispersion model
Initial Release	Release of activity already present in the circuit at the time of a break.	1	• FLOWNEX MPS Model
Initial Release worker dose	Calculates worker dose due to initial release.	1	• AMBER Worker eDCF initial release model
Delayed release worker dose	Calculates worker dose due to delayed release.	1	• AMBER Worker eDCF Delayed release model
Delayed release	Calculates the delayed release of fission products due to core heat-up for scenarios where there is a loss of forced cooling.	7	• VSOP99 PBMR400DP3 Reactor seismic model • TINTE PBMR400DP3 Reactor model • TINTE PBMR400DP3 Reactor seismic model • FIPREX/GETTTER Metallic FP Release (normal geometry) model • FIPREX/GETTTER Metallic FP Release (core compaction) model • Reactor unit retention model • Building retention model

Evaluation Model V&V Approach

- Justify by one or more means that the calculation model integration passing outputs from one calculation model as inputs to the next calculation model is legitimate.
- Especially where the modeling of different effects is separated into more than one calculation model.
- If feedback effects or interdependencies exist the validity of separating them may well be jeopardized. In this case appropriate alternative models, experiments or plant data will need to be acquired to assess validity.

Evaluation Model V&V Approach

The EM development and V&V process applied at PBMR is based on NRC DG-1120.

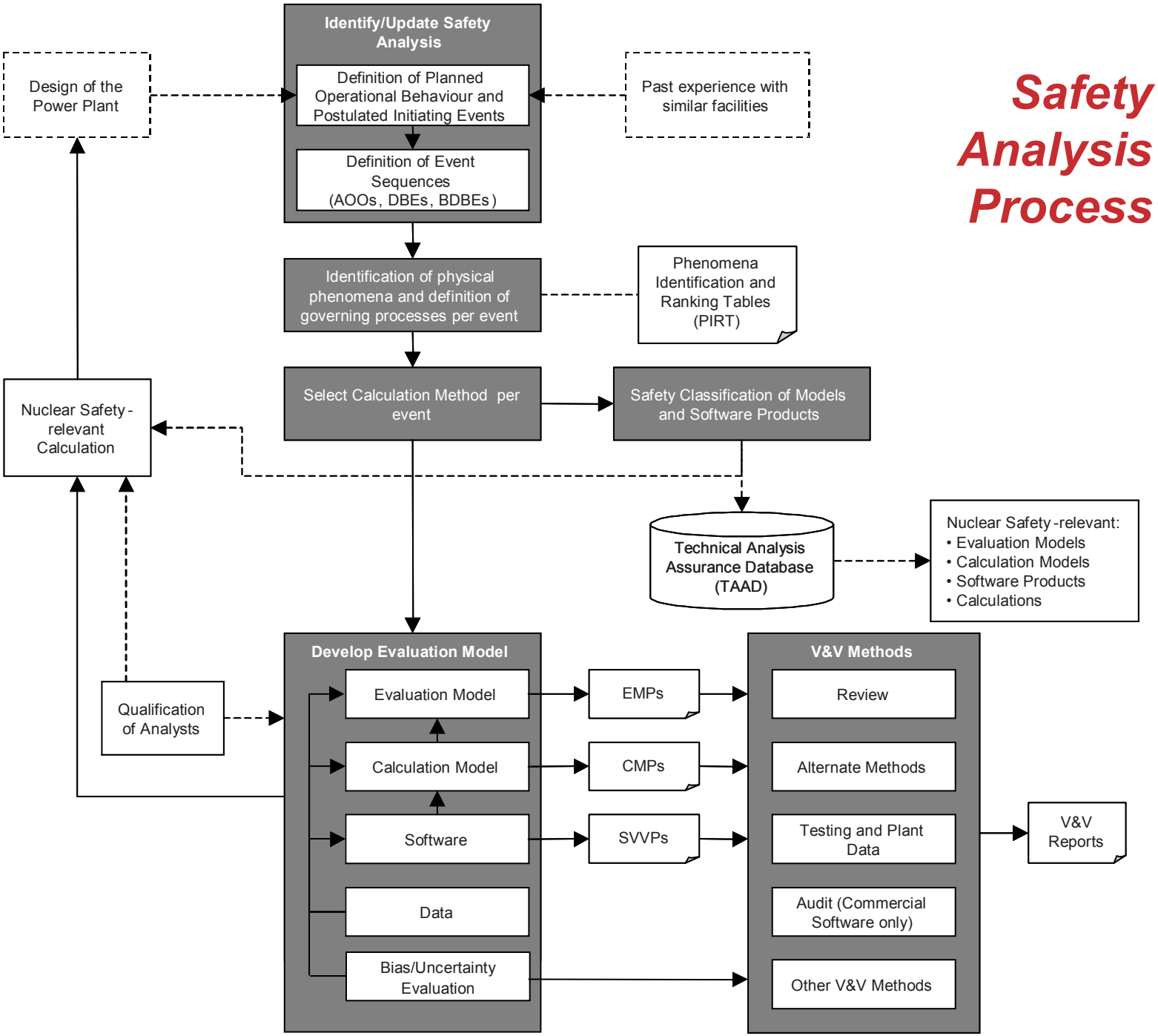


Evaluation Model V&V Status

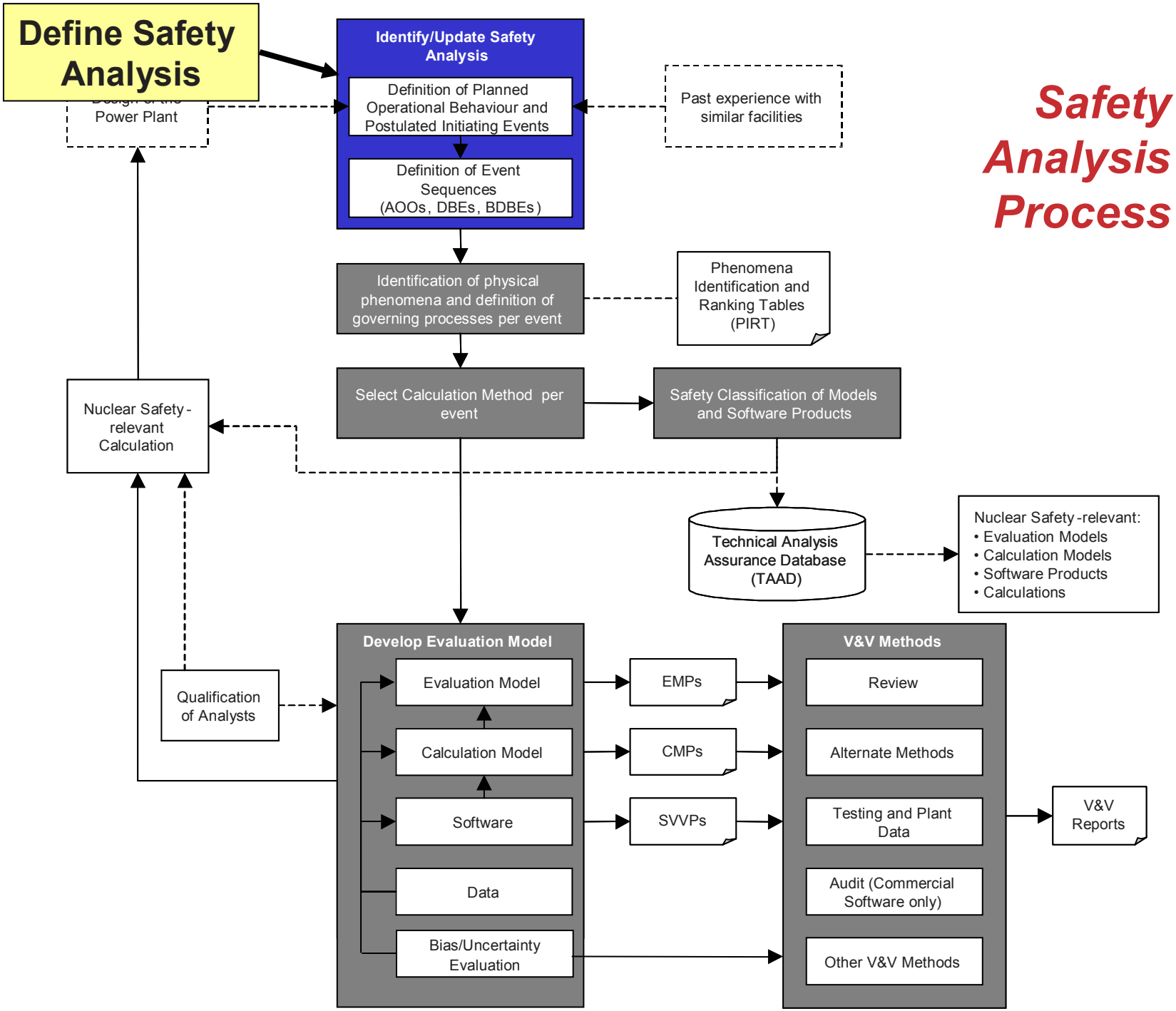
- PBMR plans to complete all evaluation model V&V planning by submission of the construction and installation safety case in March 2006.

- No feedback effects have been identified yet, thus the calculation model integration is justifiable in this fashion for the current licensing stage requirements.

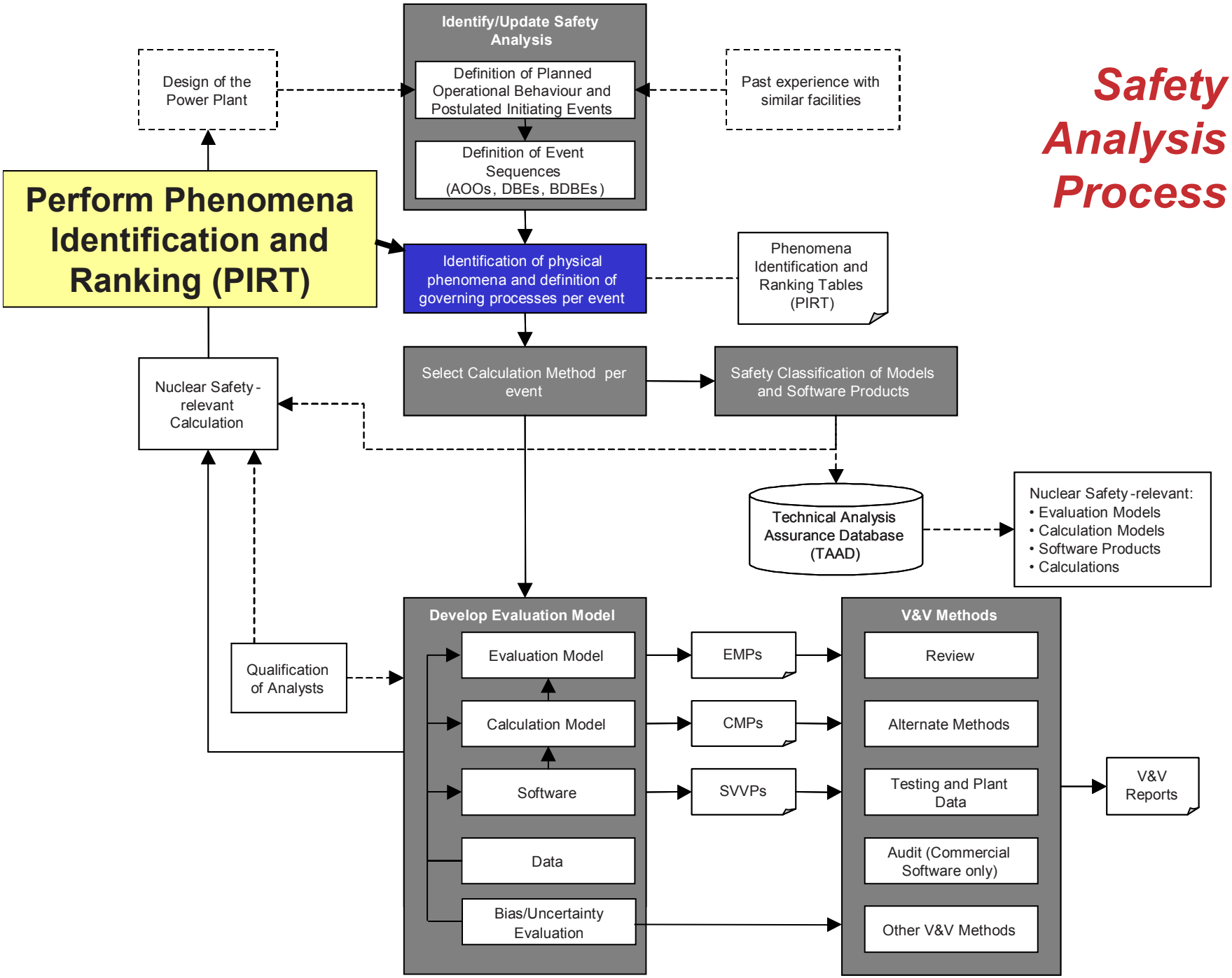
Safety Analysis Process



Safety Analysis Process



Safety Analysis Process



PBMR PIRT Development

- **PBMR has developed the following 13 PIRT tables:**
  - DLOFC, Delayed Release <10mm, unisolated break in PB
  - DLOFC, Delayed Release ≥10mm, unisolated break in PB
  - DLOFC, Delayed Release ≥16mm, unisolated break in HX
  - DLOFC, Initial Release <10mm, unisolated break in PB
  - DLOFC, Initial Release ≥10mm, unisolated break in PB
  - DLOFC, Initial Release ≥16mm, unisolated break in HX
  - Pressurized Loss of Forced Cooling
  - Air Ingress/Graphite Corrosion following break in He PB
  - Pre-break conditions, excluding PCU
  - Pre-break conditions, PCU
  - Atmospheric Dispersion of Radioactive Material
  - Reactor Cavity Activation
  - Citadel Building Retention

DLOFC = Depressurized Loss of Forced Cooling

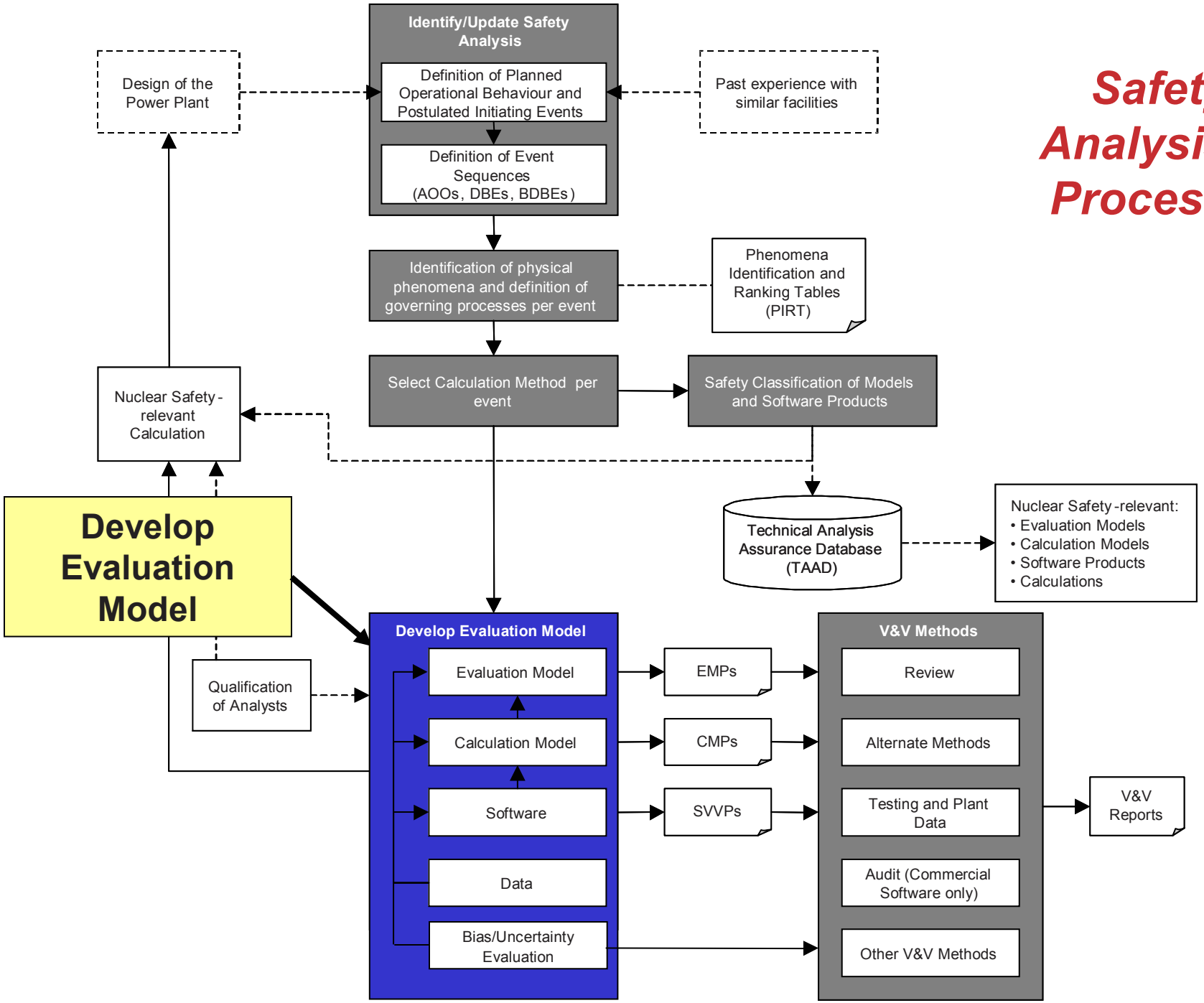
VHTR PIRT Comparisons

- **NRC TRISO PIRT**
  - Component (not event) oriented
  - Many phenomena covered by correlations (i.e., are not modeled in detail by PBMR)

- **INL VHTR PIRT**
  - High Pressure Conduction Cooling (HPCC)
  - Low Pressure Conduction Cooling (LPCC)
  - Load change full power to reduced power

- **ANL VHTR CSAU/PIRT**
  - Focused on DCC,PCC and Load Change

Safety Analysis Process

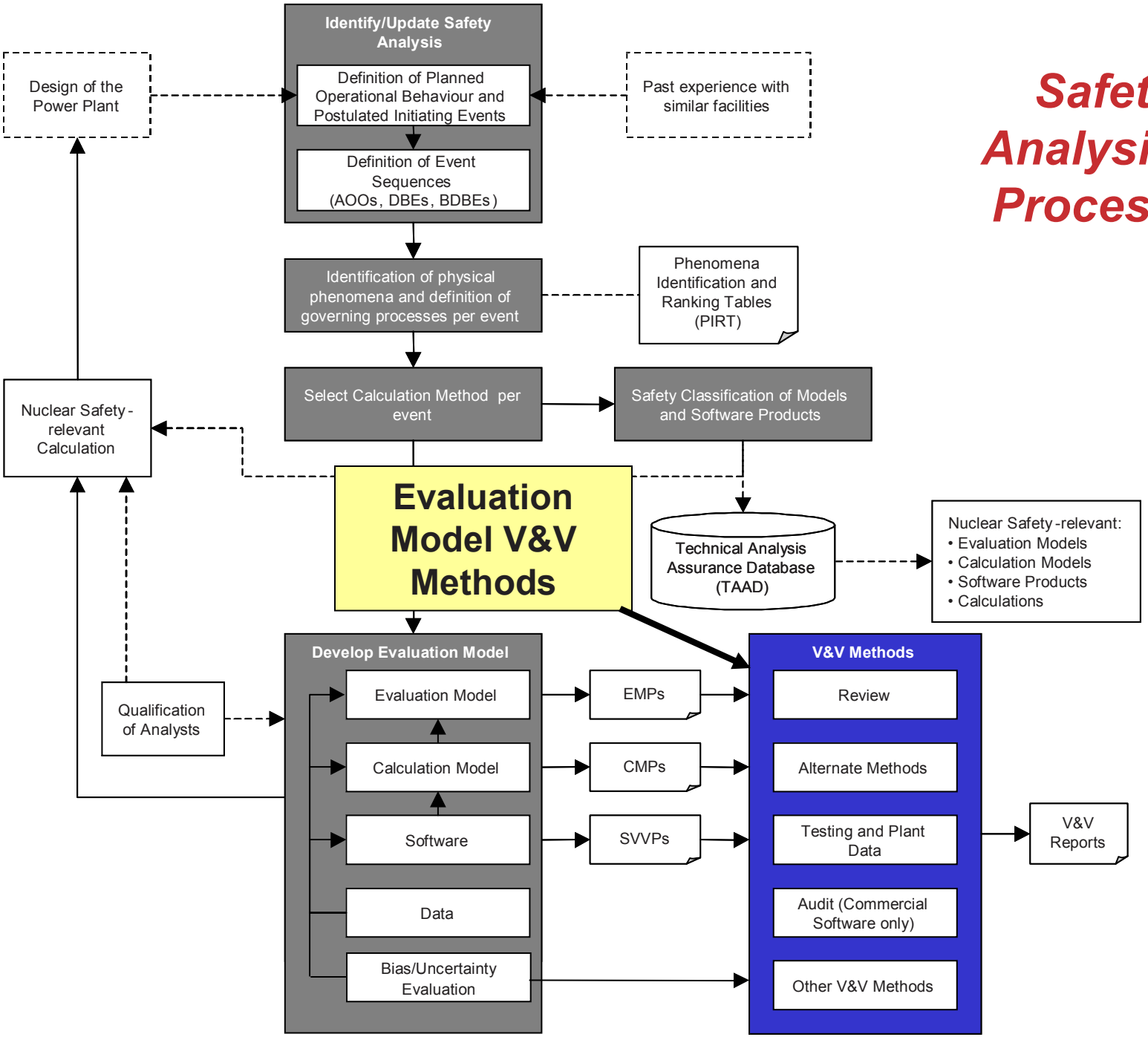


V&V Plans

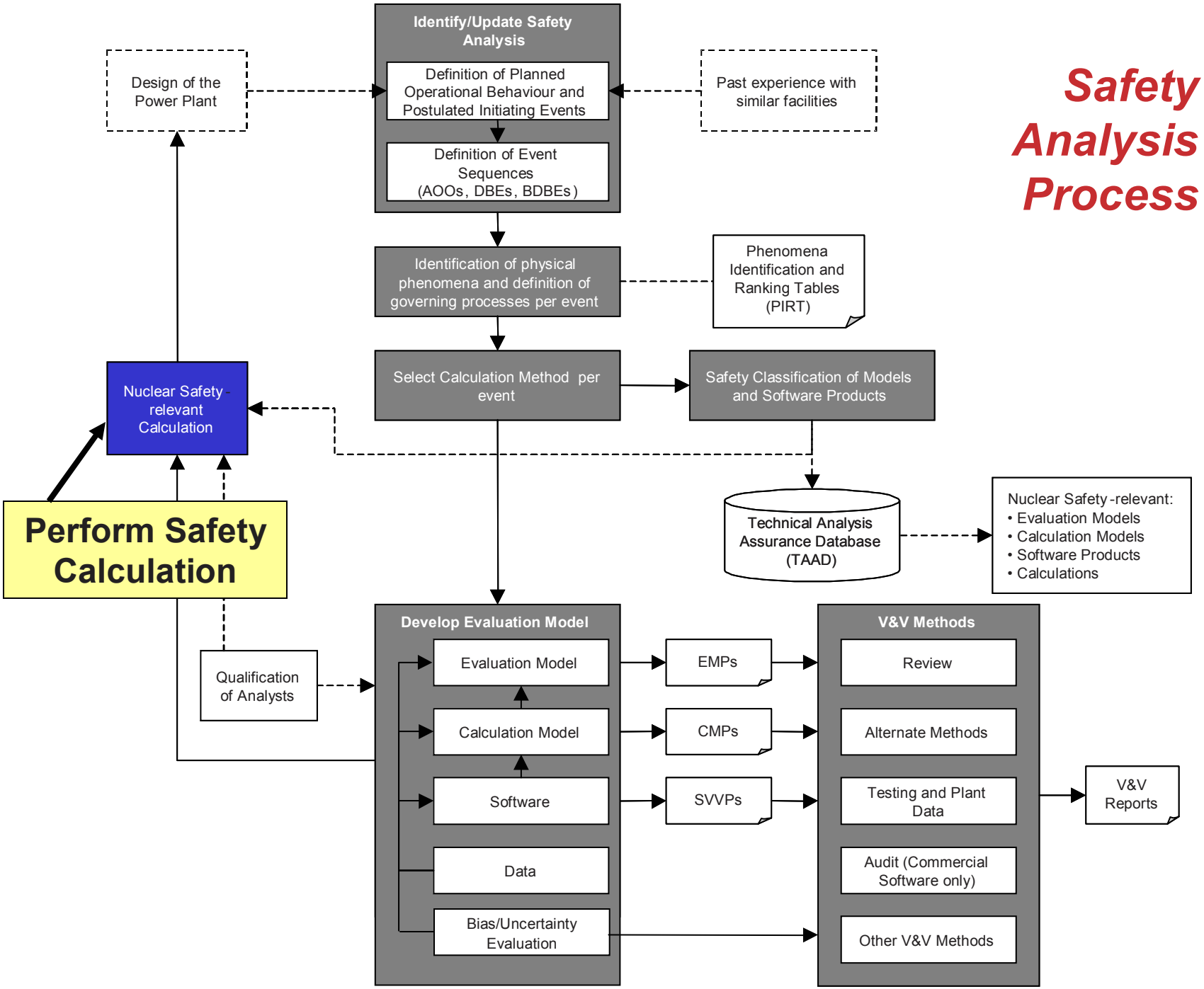
- Evaluation Model Plans (EMPs), Calculation Model Plans (CMPs) and Software V&V Plans (SVVP) identify all V&V activities

- Planning for current and future V&V activities (for future licensing stage requirements)

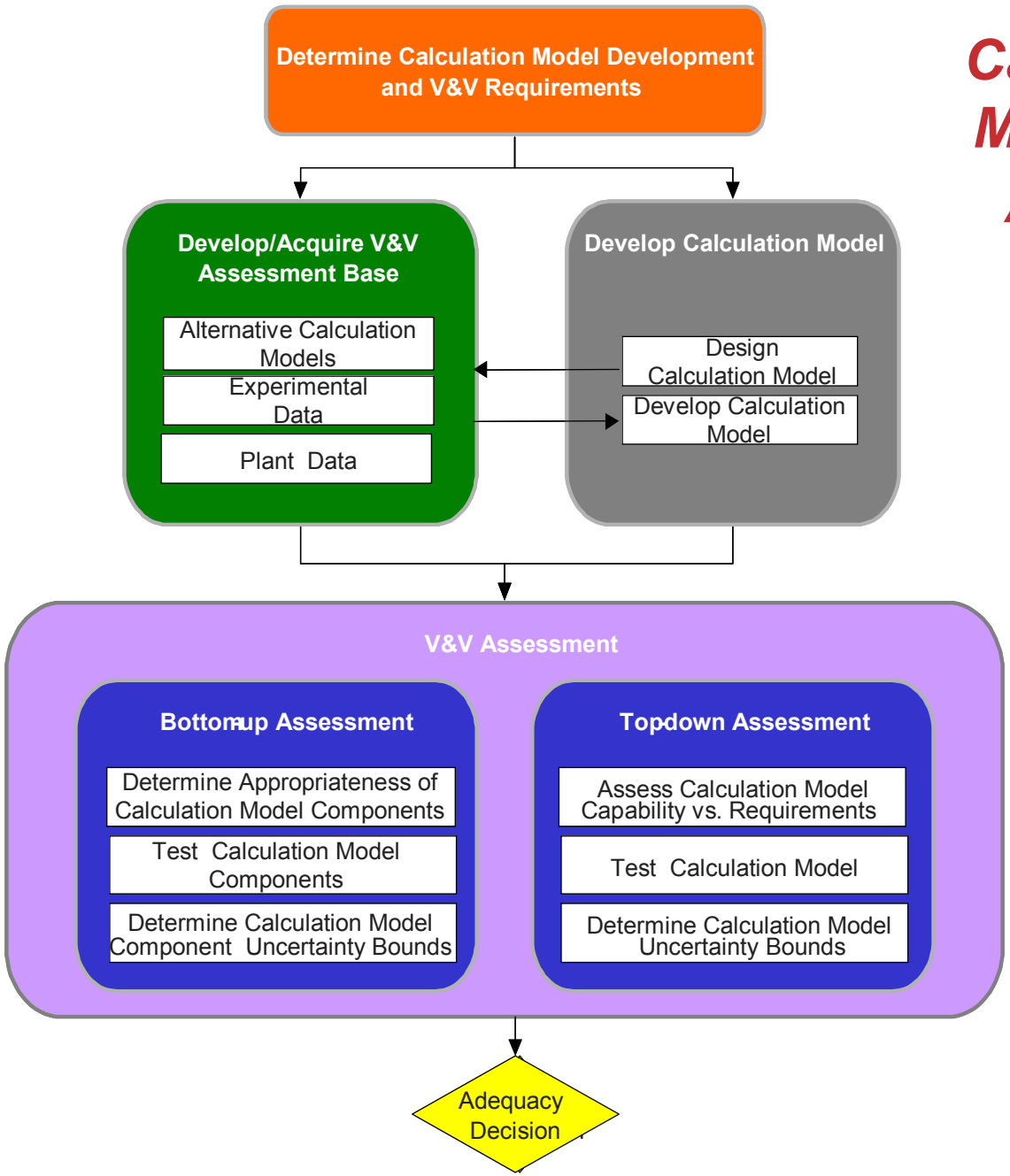
Safety Analysis Process



Safety Analysis Process



Calculation Model V&V Approach



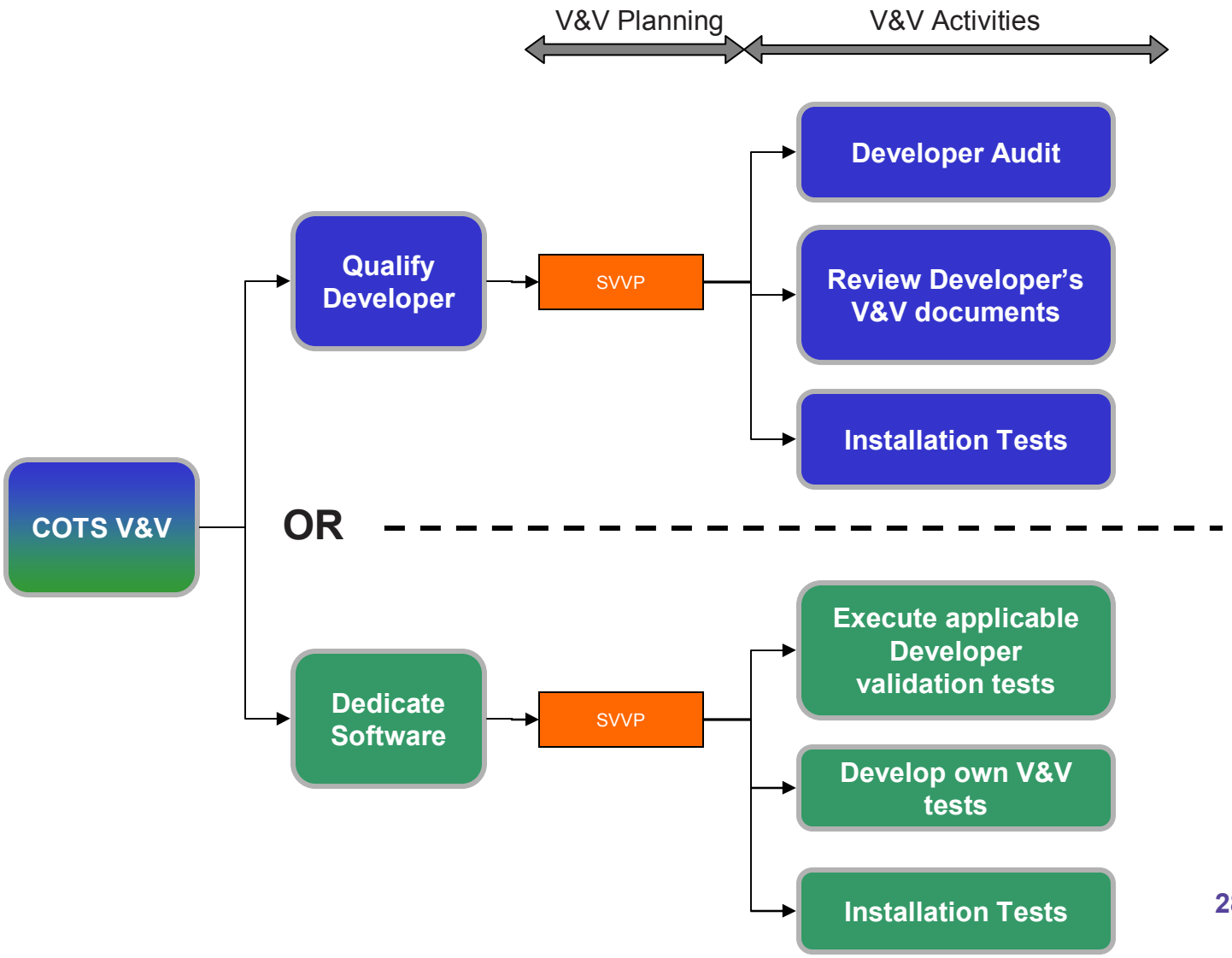
Calculation Model V&V Status

- **PBMR plans to complete all calculation model V&V planning by submission of the construction and installation safety case in March 2006.**
- **Alternative thermo-hydraulic cycle analysis comparisons have been performed.**
- **Alternative neutronic & thermo-hydraulic reactor analysis benchmarking in CRP-5**
- **Comparisons with Pebble Bed Micro-model Test Facility**
- **Pebble Bed Heat Transfer Test Facility detail design complete:**
  - High Pressure Test Unit (separate effects facility) operating by June 2006
  - High Temperature Test Unit (integral effects) operating by Dec 2006
- **Plate-out Test Facility basic design complete, should be operating by Dec 2006.**

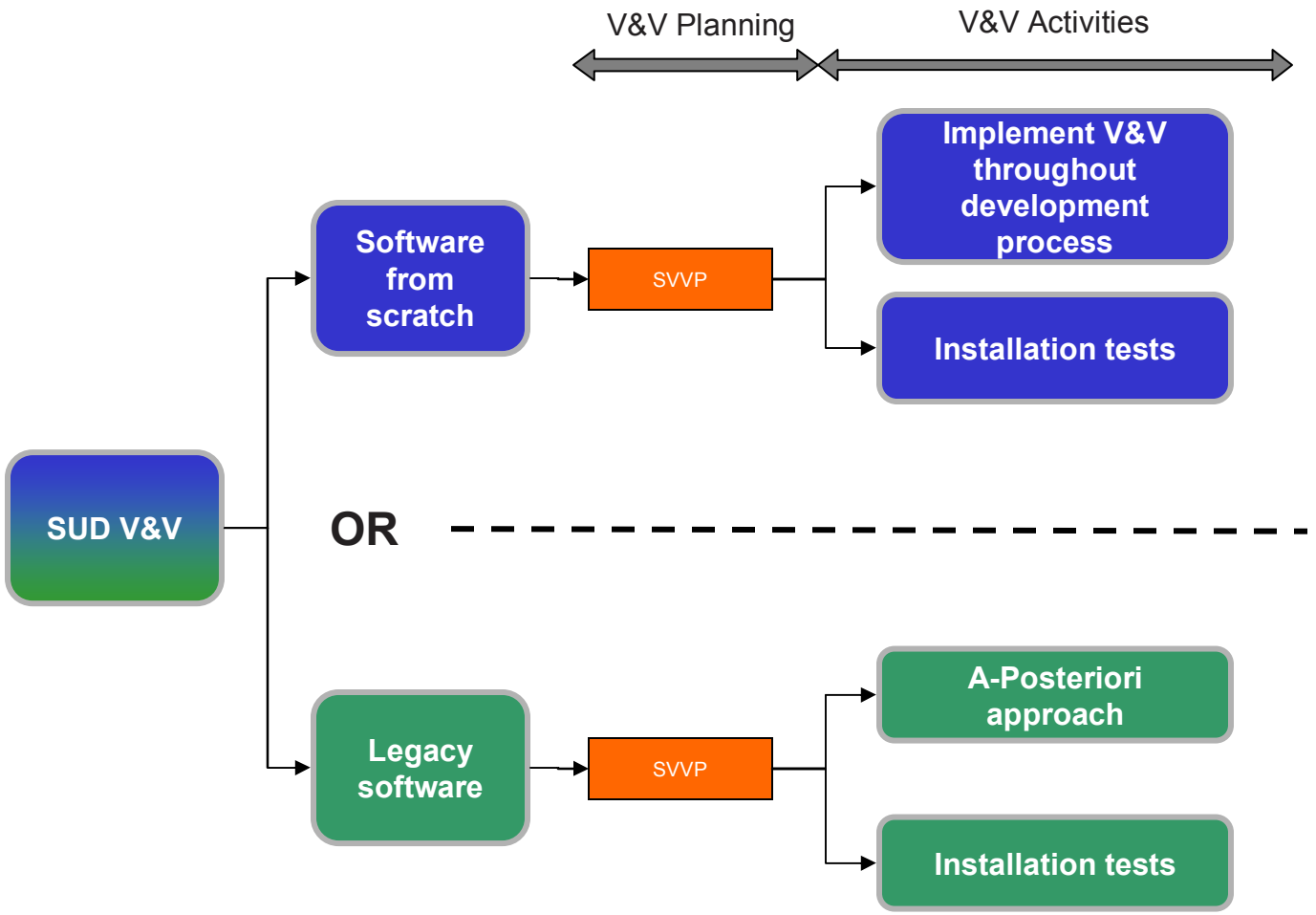
Software V&V Approach

- **Different V&V approaches for the following types of software:**
  - Commercial-Off-The-Shelf (COTS)
  - Software Under Development (SUD)
    - *Legacy*
    - *Software developed from scratch*

COTS V&V Approach



SUD V&V Approach



Software V&V Status

- Commercial-Off-The-Shelf (COTS)
- Legacy Software Under Development
- Software developed from scratch

COTS Software V&V Status

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
MSC.Marc	Finite Element software for structural analysis	Qualified Developer • Developer audit • 17 installation tests	• Installation tests complete • MSC audit completed • Dedication program to be initiated • V&V completion December 2005
MSC.Nastran	Finite Element software for structural analysis	Qualified Developer • Developer audit • 70 installation tests	• Installation report complete • MSC audit completed • V&V completion October 2005

COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
PFC3D	For analyzing pebble bed flow, porosity and forces	Dedication • Installation tests • 6 validation tests	• Installation report complete • Validation testing complete • V&V completed
SASSI	For earthquake induced seismic analysis	Dedication • Installation tests • 10 validation tests	• Installation report complete • Validation testing complete • V&V completed

COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
RiskSpectrum	Fault and event tree analysis for PRA	Qualified Developer • Review developer V&V documents • 1 Installation test	• V&V completed
PC Cosyma	Calculates dose and risk to public, using dispersion modeling	Dedication • 1 validation tests	• V&V completed
LUDEP	Calculates worker dose due to inhalation	Dedication • 4 validation tests	• V&V completed

COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
Fispact/ EASY	Calculates induced radioactivity of PCU and surroundings by neutrons from core	Dedication • 74 installation tests • Validation tests V&V of FISPACT-97	• V&V completed
Microshield	Calculates external dose rates to workers and shielding requirements	Dedication • Review developer V&V documents • 2 Installation tests	• V&V completed
Fluent	CFD code for calculating fluid flow and heat transfer	Dedication	• V&V completed

COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
MCNP	Calculates radiation shielding and criticality	Qualified Developer	• V&V completed
AMBER	Calculates the migration and fate of contaminants in a system.	Dedication	• V&V completed
ADMS	Calculates the potential radiological dose to the public from a nuclear plant accident	Dedication	• V&V completed
Origen-Scale	Calculates time-dependent isotopic inventories in irradiated nuclear reactor fuel	Qualified Developer	• V&V completed

Legacy Software V&V Status

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
VSOP99	Suite of interlinked codes calculating reactor operational history and quasi-steady state reactor core neutronic analysis	Posteriori V&V Joint effort between PBMR and FZJ	• SVVP complete • Posteriori V&V baseline established by Nov '05 • Re-engineering of development products to be carried out from 2006
Radax	Determines fission product concentration and dust distribution throughout the MPS	Posteriori V&V Joint effort between PBMR and Westinghouse Reaktor (GmbH)	• SVVP completed by Dec '05

Legacy Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
TINTE	Simulates transient behaviour of the reactor core	Posteriori V&V Joint effort between PBMR and FZJ	• SVVP complete • Posteriori V&V baseline established by Nov '05 • Re-engineering of development products to be carried out from 2006
GETTER	Calculates the time dependent release of long-lived metallic fission products from the spheres	Posteriori V&V	• SVVP completed by Dec '05
NobleG	Calculates the steady state release of noble gases (Kr, Xe) and the halogens (Br, I) from the fuel spheres	Posteriori V&V	• Phase 1 completed (initial validation and theory verification, SVVP, Baseline V&V Status Report, and V&V Measures Test Plan)

Developed Software V&V Status

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
FIPREX	Pre- and post processor for GETTER input and output	Development V&V	• Verification completed by Dec '05 • Validation completed by Dec '06
Flownex	An implicit thermal-fluid network analysis code used for the analysis of temperatures, pressures and mass flows	Development V&V	• V&V completed

Future V&V planning

- Evaluation Model V&V
- Calculation Model V&V
- Data V&V

Evaluation Model V&V

The V&V approach: to justify that the software product integration is legitimate (especially where the modeling of different effects is separated into one or more software products)

- **This will be determined by a line-by-line review of the evaluation model.**
- **If feedback effects are found, a comprehensive V&V effort is required against an assessment base.**
- **No feedback effects have yet been identified, thus the model integration is justifiable using this approach for the current licensing stage requirements.**

Calculation Model V&V

The V&V approach: a comprehensive V&V effort using an appropriate assessment base

- **Performing a bottom-up assessment of the Calculation Model components**
- **Performing a top-down assessment of the integrated Calculation Model**
- **All of the Calculation Model Plans (CMPs) will be completed during Design Certification.**

Data V&V

The data used in Calculation Models (System Models), Calculations and Software Products (embedded data) shall be strictly controlled and under change management.

- Each item of data shall have a clearly defined origin in documentation, technical databases, or its source shall be clearly identified.
- All un-validated data shall be identified as an outstanding item.
- Data V&V activities shall be planned in the V&V register and managed to completion.

Exelon RAIs

Area of Review	Timing	Pre-application Work Item(s)
Analytical Codes and Software Control		
PANAMA		PANAMA has been replaced by spreadsheet calculations.
RAIs 5.1.1-5.1.5	1	
FRESCO		FRESCO has been replaced by GETTER.
RAIs 5.1.6, 5.1.7	1	
PANAMA and FRESCO		
RAIs 5.1.8, 5.1.9	1	
RAIs 5.2.1-5.2.3	2	
General Issues		
RAIs 5.2.4-5.2.8	2	

Exelon RAIs

Area of Review	Timing	Pre-application Work Item(s)
Core Design and Heat Removal		
RAIs 6.2.1*-6.2.6*, 6.2.8*, 6.2.10*, 6.2.19*, 6.2.20*, 6.2.22*-6.2.26*, 6.2.28*-6.2.32*, 6.2.37*, 6.2.55	2	
PBMR Operational Modes and States		
RAI 7.1.2	1	
RAI 7.2.1	2	

General Steps of Work

- Identify documentation required by the NRC for pre-licensing review of computer code/EM V&V methodology
- Compare PIRTs generated by PBMR with other VHTR PIRTs (when they become available)
- Document relationship of PBMR testing program to the computer code/EM V&V process
- Workshop(s)
- RAI's from NRC
- RAI Response Workshop and draft DCA spec for topic
- Revised Final Papers and DCA specification
- NRC closure documentation

Background References

- "Summary of Pre-application Presentations Regarding the Pebble Bed Modular Reactor (PBMR)," Exelon letter from K. F. Burton to U.S. Nuclear Regulatory Commission, Project No. 713, dated October 30, 2001.
- "Response to NRC Letter dated September 26, 2001 Regarding the Pebble Bed Modular Reactor Technical Information Availability," Exelon letter from K. F. Burton to U.S. Nuclear Regulatory Commission, Project No. 713, dated November 15, 2001.
- "Request for Additional Information (RAI) on Analytical Codes and Software Control; Core Design and Heat Removal and; Operational Modes and States for the Pebble Bed Modular Reactor (PBMR)," NRC letter from F. Eltawila to K. Borton, May 31, 2002.