

Safety Evaluation Challenges for NGNP VHTR Materials of Construction and Components



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The contents of this presentation do not necessarily reflect any position of the NRC.

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ABBREVIATIONS

CTE	Coefficient of Thermal Expansion
DID	Defense-In-Depth
ISI	Inservice Inspection
MTR	Material Test Reactor
NGNP	Next Generation Nuclear Plant
Op E	Operating Experience
PRA	Probabilistic Risk Assessment
SSC	Structures, Systems, and Components
VHTR	High Temperature (Gas Cooled) Reactor
V & V	Verification and Validation

Outline

1. **Materials for NNGP VHTR**
2. **Regulatory Review Technical Information Needs**
 - **Design for Performance (Design Margins, Time-Dependent Material Degradation Issues)**
 - **Design for Inspection**
 - **Inservice and Shutdown Inspection, Surveillance**
 - **Degradation Assessment for Continued Operation**
 - **Extrapolation of Data to/From Operational Conditions**
3. **Guidance from Consensus Codes and Standards**
4. **Summary**

NGNP VHTR Metallic Materials

Metal/Alloy Type	Alloys	Components
Low Alloy Steel	SA 508; SA 533B; 2-1/4 Cr, 1 Mo,V; 9Cr, 1Mo,V (Grade 91)	Reactor Pressure Vessel and Piping
Stainless Steel	304; 316; 347	Core Barrel; Duct; Recuperator
High Alloy Material	INCONEL 617; Haynes 230; Incoloy 800H; Hastelloy X and XR; Inconel 740	Core Barrel, Intermediate Heat Exchanger; Piping, Bolting, Control Rods, Turbomachinery

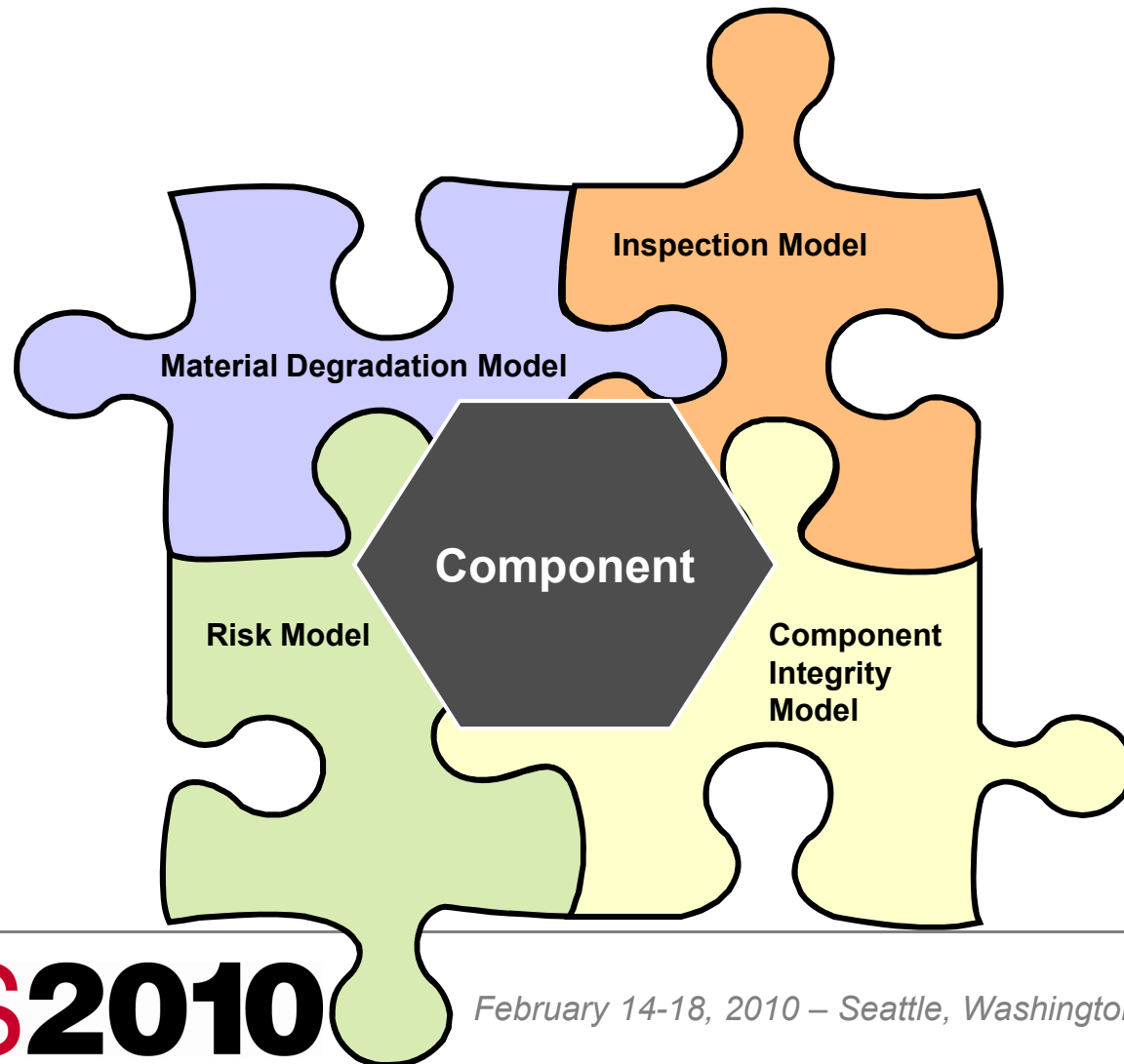
NGNP VHTR Non-metallic Materials

Nonmetallic Material	Components
Insulation Ceramics	Liners for thermal insulation of metallic piping, nozzles, and other components
Insulation Carbon	Core component for thermal insulation adjacent to graphite core
Nuclear Grade Graphite	Moderator and reflector core bricks, other
Ceramic, Carbon-Carbon Composites	Tie rods, anchor, control rods
Concrete	Radiation shield, support structure

Materials-Related Challenges for NGNP VHTR Safety Evaluation

- **Provide acceptable input to risk information and deterministic information in establishing the plant licensing basis**
 - **Involves safety margin and defense-in-depth requirements to adequately accommodate uncertainties and unknowns for NGNP plant designs which have limited operational experience, but utilize inherent characteristics and passive SSCs to reliably achieve safety functions.**
- **Establish an acceptable technical basis for the plant safety analysis**
 - **An acceptable basis from operating experience, experimental data and analysis methods for predicting the performance and behavior of reactor metallic and graphite structures and components within the VHTR pressure boundary system operating environment will need to be established.**

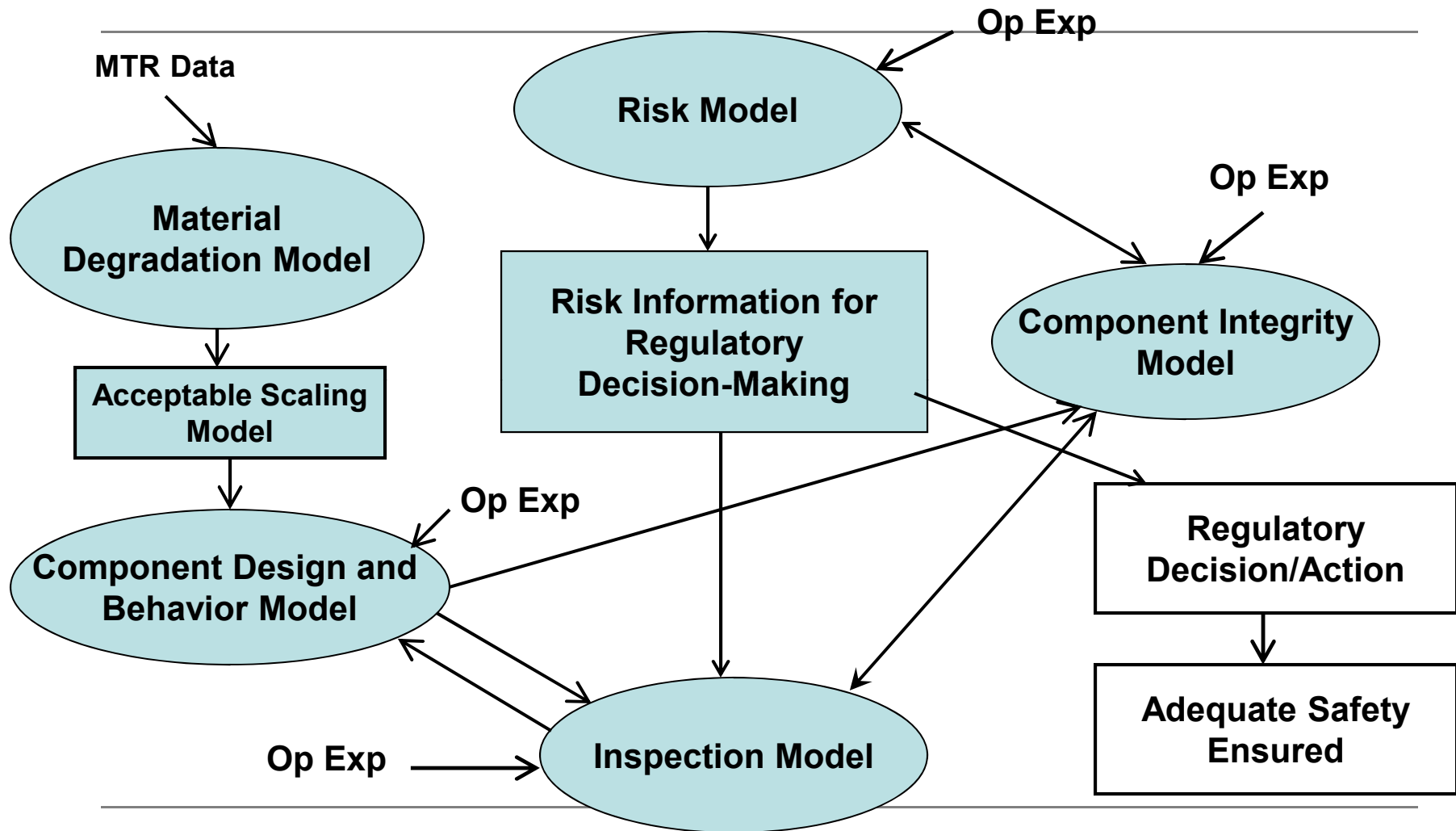
Development PRA Tools for NGNP-Specific Materials And Components



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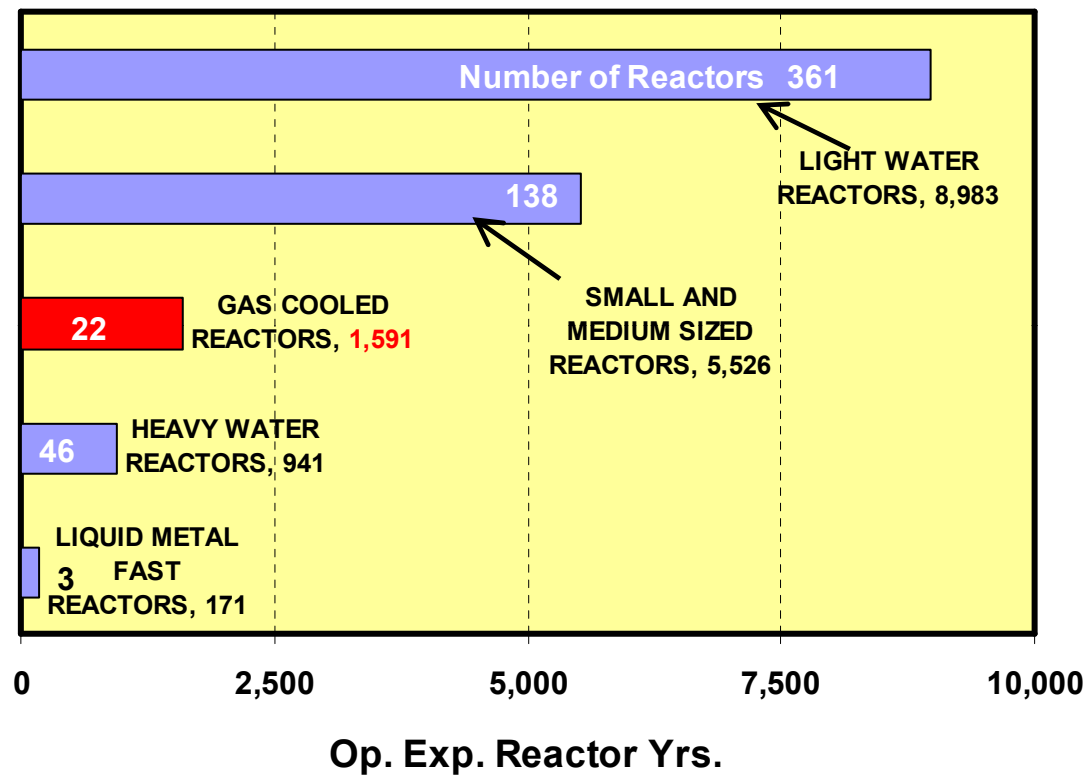
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Influence of Material Behavior on Risk Assessment



World Nuclear Energy Generation

Cumulative Operating Experience of World Nuclear Power Reactors

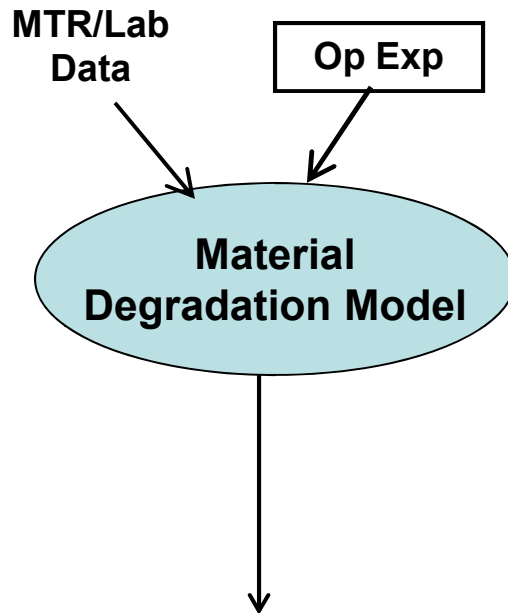


Ref: "Global Development of Advanced Nuclear Power Plants and Related Activities", IAEA, September 2006.

Some Examples of Types of Material Property Degradation/Failure Phenomena

- **Corrosion – Several Types (General, Flow-Accelerated, Pitting, Crevice, other)**
- **Mechanical Fatigue (Vibrations, Ratcheting, Other)**
- **Thermal Fatigue**
- **Irradiation-Assisted Stress Corrosion Cracking (IASCC)**
- **Primary Water Stress Corrosion Cracking (PWSCC)**
- **Creep, including delayed or slow crack growth**
- **Creep Fatigue**
- **Thermal Conductivity**
- **Mechanical Strength**
- **Fracture Toughness**
- **Environmental Effects, Such As Oxidation**
- **Other**

Evaluation of the Risk-Informed PRA for NGNP VHTR Components



Specific to Each Degradation

Material Aging Effects – CTE, Creep, Thermal Conductivity, Dimensions, Elastic Modulus, Fracture Toughness, and Strength.

$F(\text{time } (t), \text{ time at temperature } (t_T), \text{ fluence } (\phi), \text{ temperature } (T), \text{ and atmosphere})$

Issues: Generic degradation mechanism – however, extent of degradation may be component and environment (material, stress, temperature, atmosphere) specific

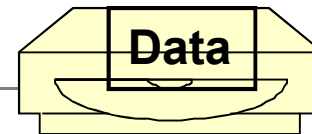
Unknowns (changes in environment)

Output: Change in Property as a $f(\text{time})$

Degradation rate – highly variable (includes modeled and not-modeled variables)

Considers and Quantifies Uncertainties

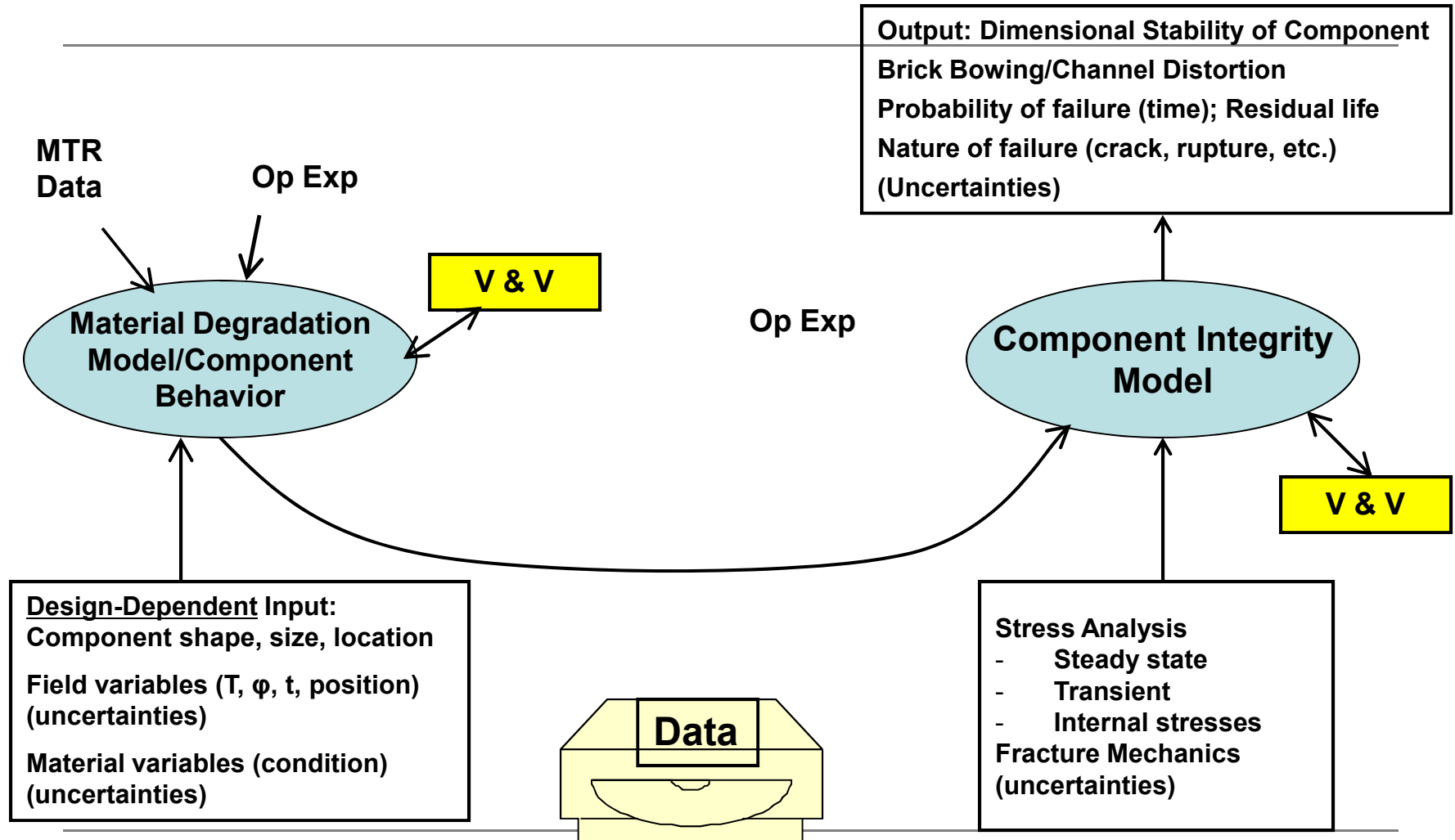
Degree of Needed Conservatism



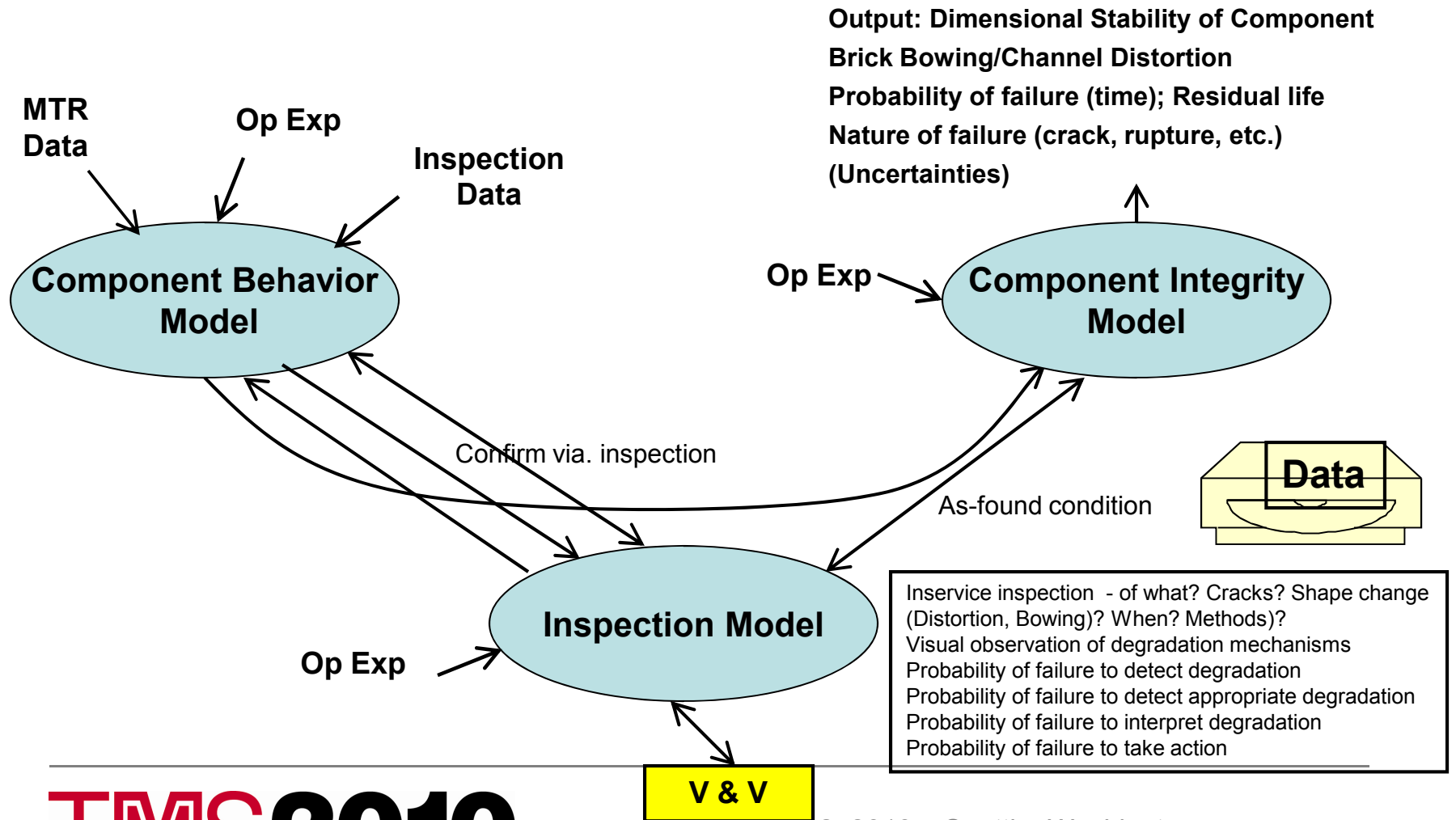
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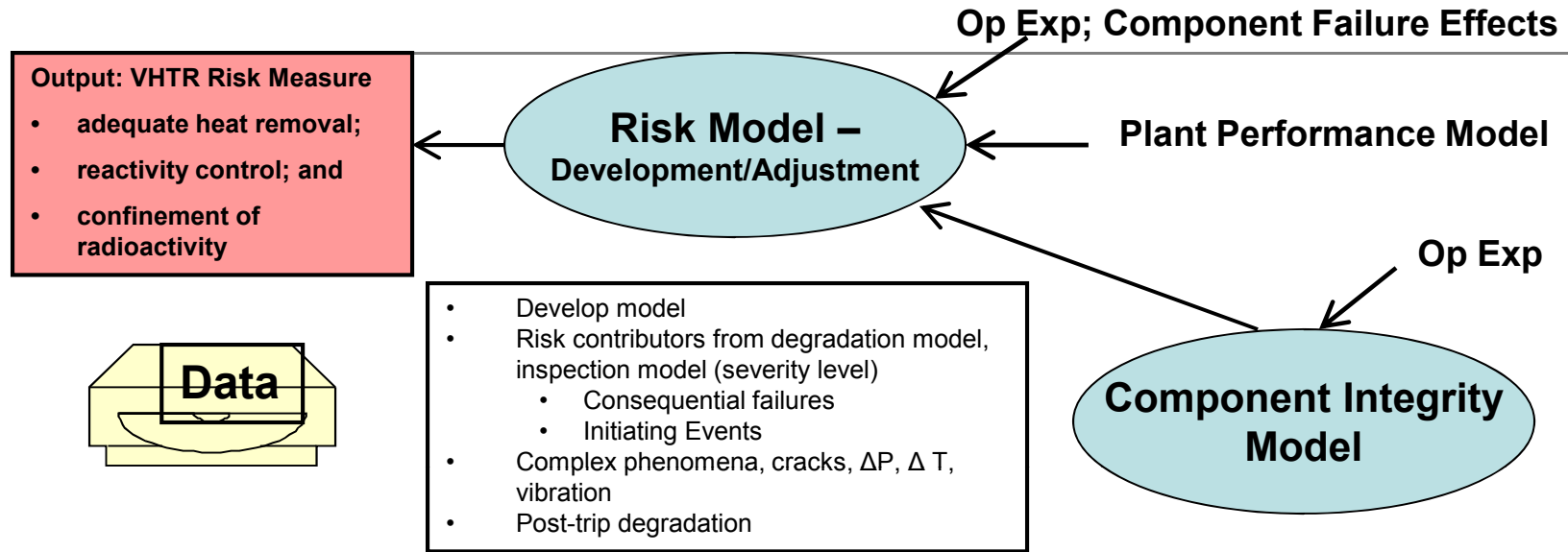
Analysis of Graphite Component Degradation for Risk-Informed PRA



Role of Graphite Inspection in Component Integrity Evaluation for Risk-Informed PRA



Analysis of Risk-Informed PRA Using Component Performance Assessment Model

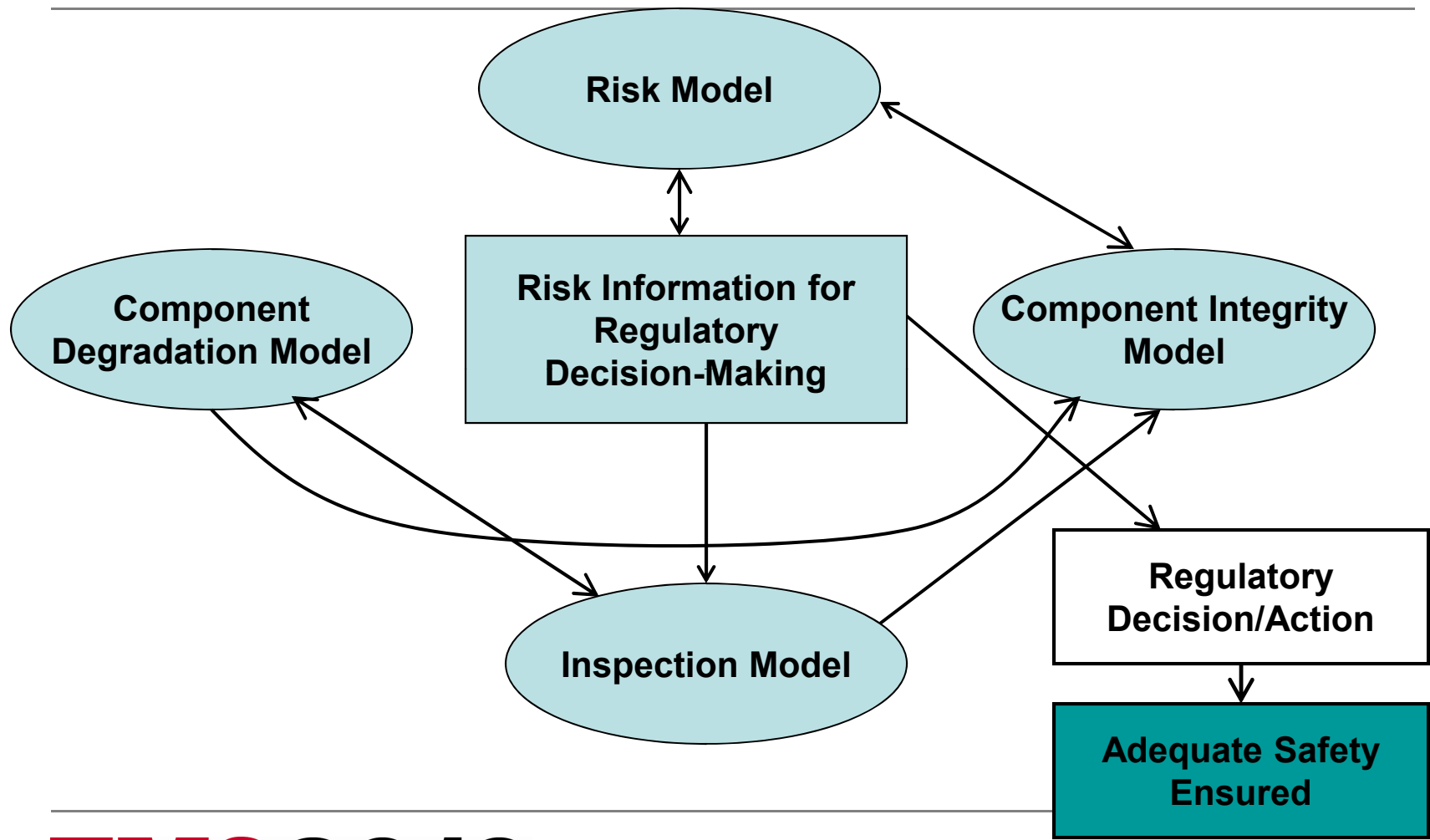


Notes: The applicability and the sufficiency of the component integrity model (and the whole core model) for normal operation, transients, and other analyzed postulated accidents for assessing the risk measure needs to be established.

Caution: (1) When initial risk measure is very low there may be a tendency to ignore potential model weaknesses (incompleteness).

(2) Robustness of results is dependent on the quality, quantity, and confidence in the information supplied. A major element that influences the robustness of the results is the adequacy of inspections and the confirmation from inspection data.

Evaluation of the Risk-Informed PRA For NGNP VHTR Components and Regulatory Decision/Action



Materials-Related Challenges For the Safety Evaluation of NGNP VHTR

- **Develop NRC staff expertise, technical tools, and data to support an effective and efficient independent safety evaluation of the NGNP VHTR components.**
 - **Materials performance analysis codes**
 - **Structural and component integrity analysis codes**
 - **Surveillance requirements and inspection codes**
 - **Tools to evaluate the efficacy of component degradation management programs**
- **Establish VHTR material-specific regulatory positions, guidance documents, or standard review plans for the NRC staff to conduct an effective and efficient design safety review of components.**
- **Establish VHTR material-specific NRC staff regulatory positions, guidance documents, or standard review plans on staff review of in-service inspection and surveillance plans and techniques.**

Summary

- **Independently verified and validated predictive analytical models and codes for NGNP material properties are needed for the NRC staff evaluation of the design of NGNP VHTR components.**
- **Independently verified and validated predictive codes are needed for the NRC staff evaluation of NGNP VHTR component integrity.**
- **Independently verified and validated inspection codes and standards are needed for the NRC staff evaluation of NGNP component degradation during service. Need to develop technical bases for guidance on in-service inspection and shutdown inspections.**
- **The NRC staff needs technical information on model and data uncertainties, and their overall effect (sensitivity) on failure probability predictions.**
- **The NRC staff needs to communicate to risk analysts the importance of properly considering material/component degradation model and data uncertainties in risk evaluation models for risk informed regulatory decisions.**