Some of the Challenges in NGNP HTGR Graphite Component Safety Evaluation

ORNL/NRC Workshop on Graphite Research

Rockville, MD, U.S.A.

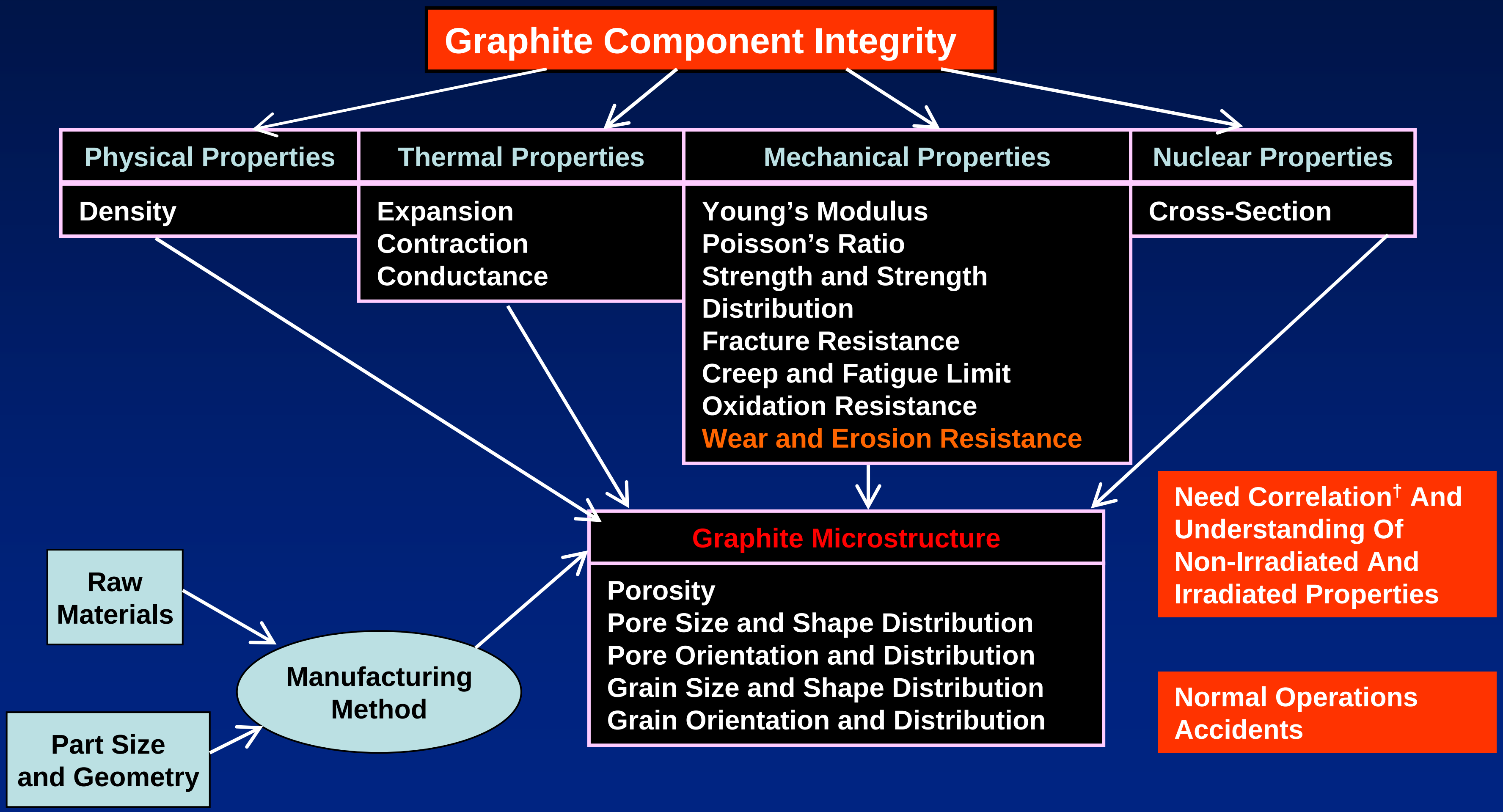
Dr. Makuteswara Srinivasan
Senior Materials Engineer
Office of Nuclear Regulatory Research
March 17, 2009

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

Outline

1. Nuclear Graphite in the NGNP Context
2. Integrating Predictive Models – Input to Regulatory Decision
    a) Graphite Degradation Model
    b) Graphite (Structural) Component Integrity Model
    c) Graphite Inspection Model
    d) Contribution to Risk (Normal, AOO, Accident)
    e) Risk Assessment Model
    f) Integration into Regulatory Decision
3. Challenges in Consensus Codes and Standards
    a) Performance Acceptance Criteria
    b) Inservice Inspection
    c) Surveillance Requirements
4. Summary

Graphite Component Integrity



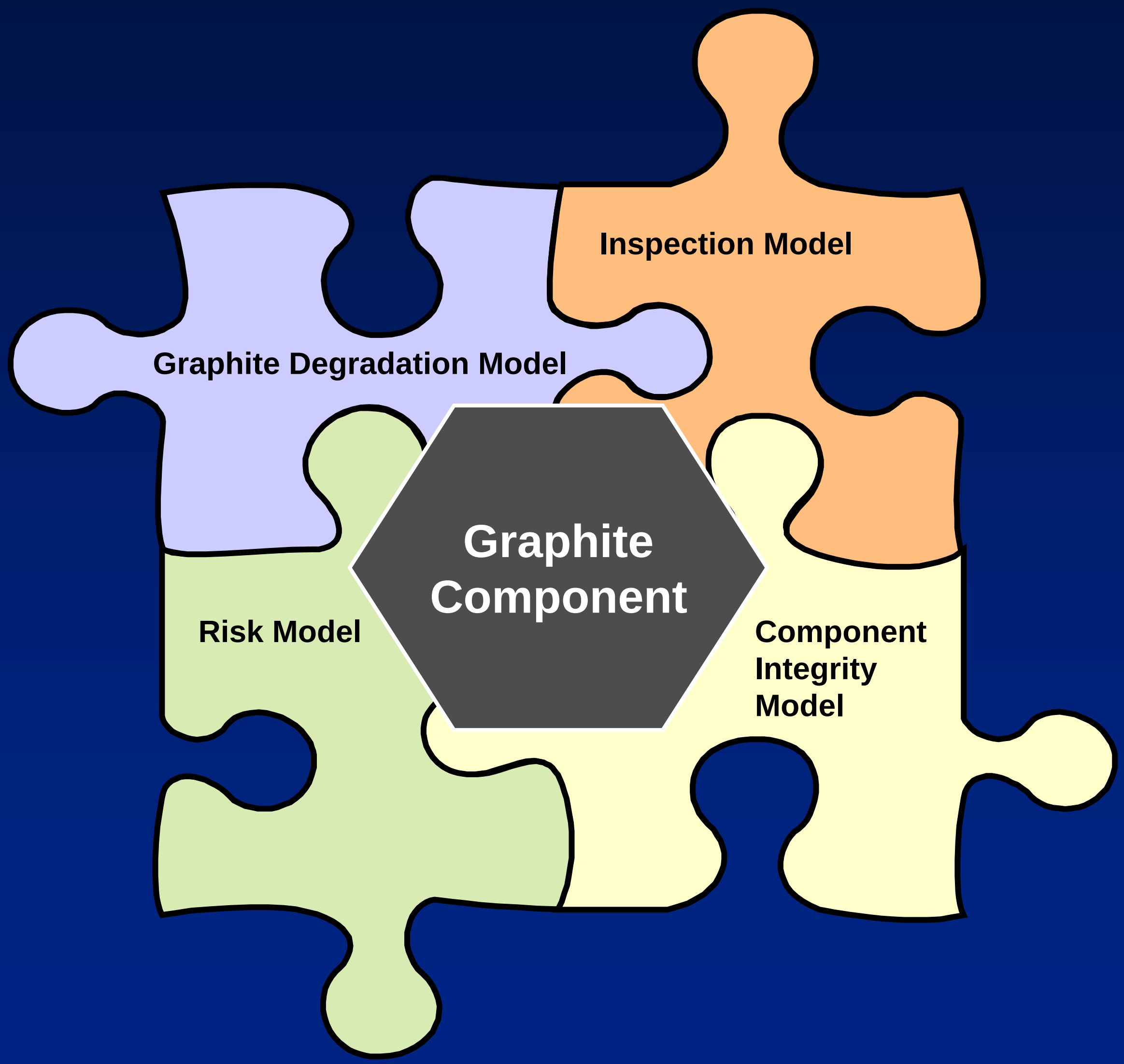
† Correlation does not imply cause;
PIE and analysis may shed light.

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

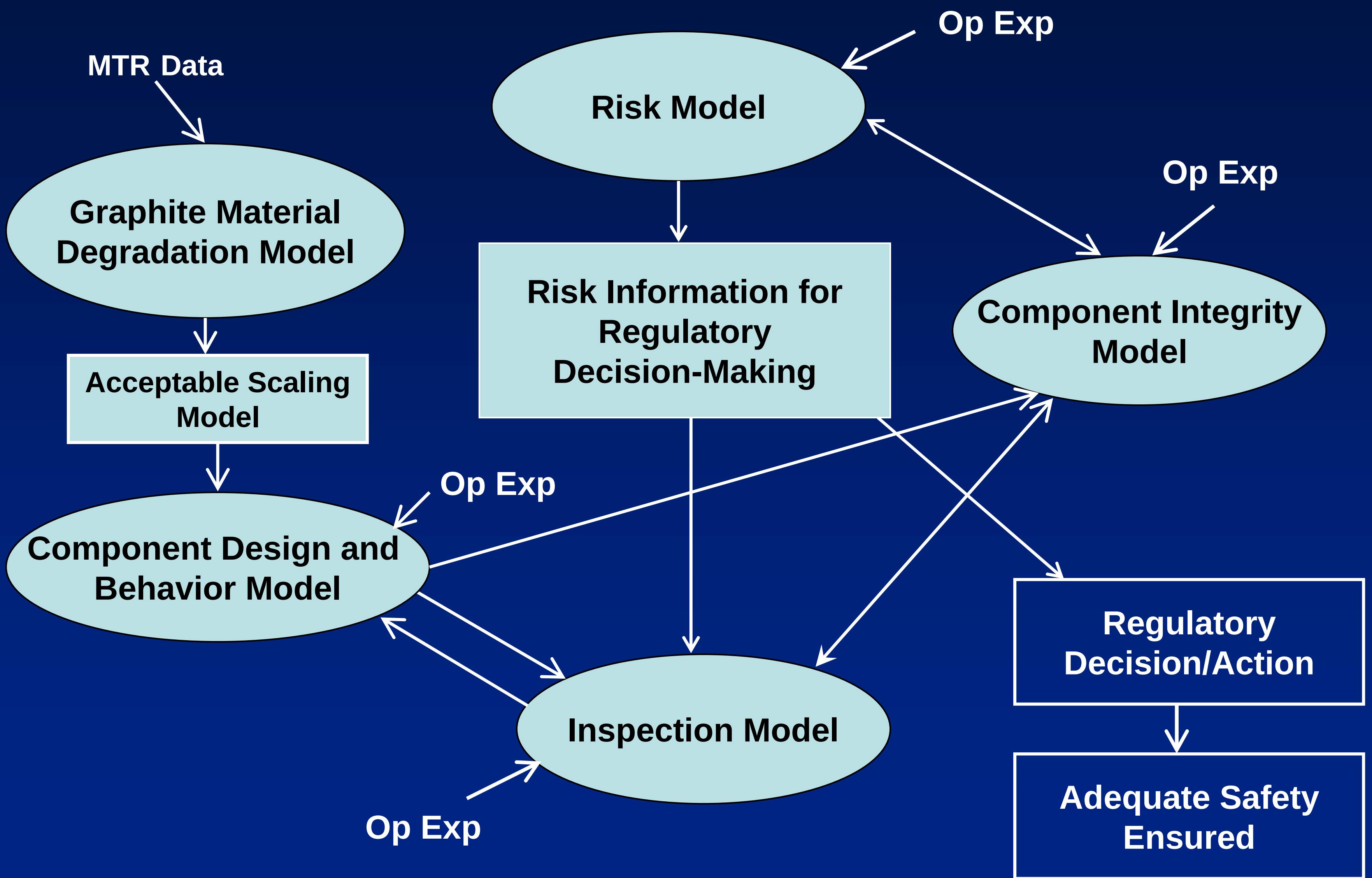
Materials-Related Challenges for NGNP HTGR Safety Evaluation

- 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 graphite structures and components within the HTGR pressure boundary system operating environment will need to be established.

Development of NGNP- Specific PRA Tools for Graphite Components

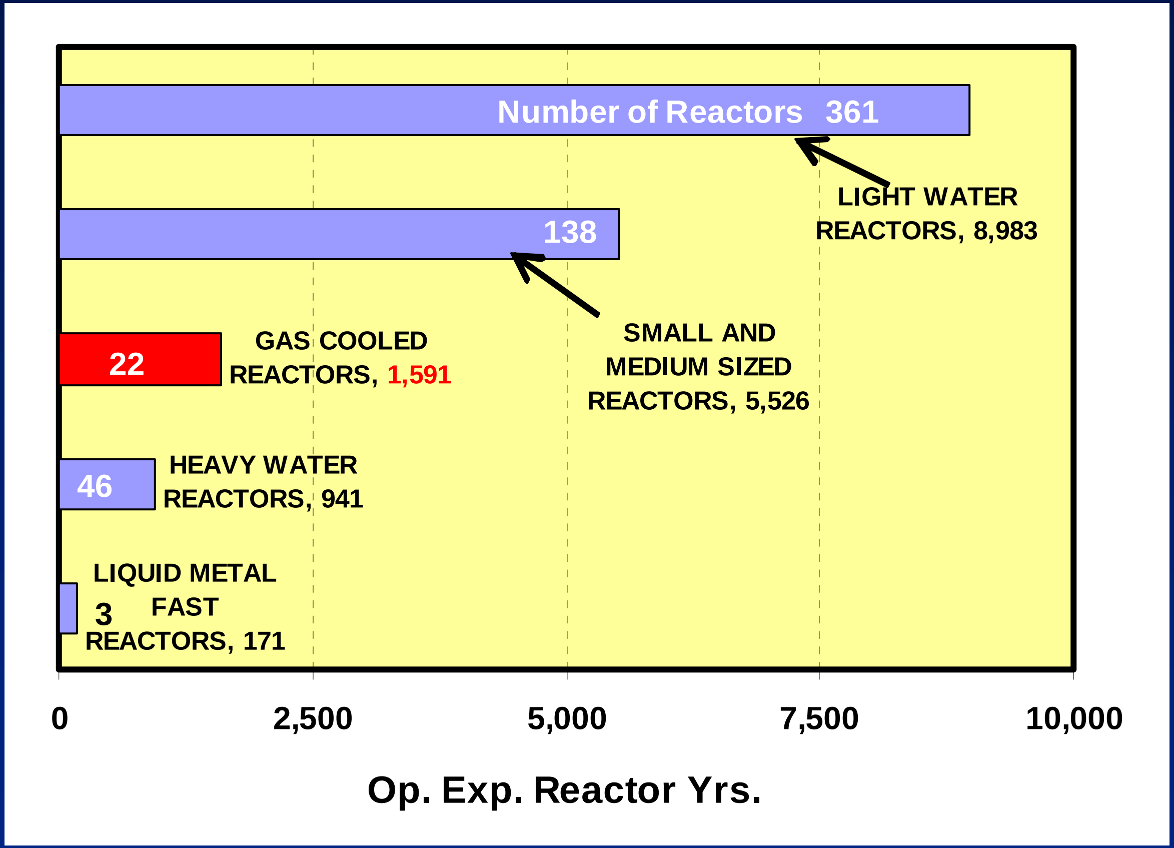


Influence of Graphite Behavior on Risk Assessment



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.

Evaluation of the Risk-Informed PRA for Graphite Components

MTR Data

Op Exp

Material Degradation Model

Specific to Each Degradation

Graphite Aging Effects – CTE, Creep, Thermal Conductivity, Dimensions, Elastic Modulus, and Strength.

F(time (t), time at temperature t_T), fluence (ϕ), temperature (T), and atmosphere)

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

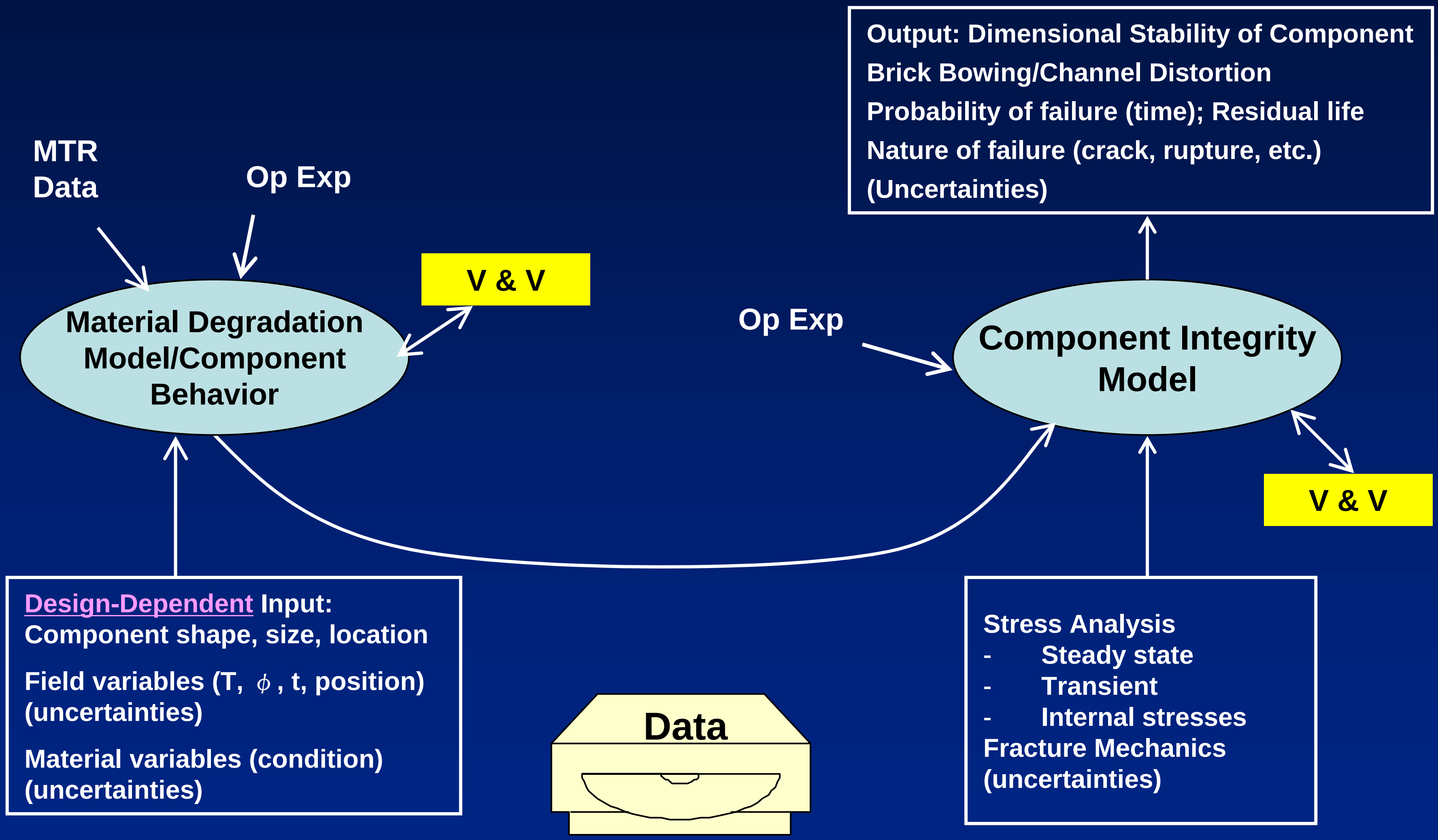
Unknowns (changes in environment)

Output: Change in Property as a f(time)
Degradation rate – highly variable (includes modeled and not-modeled variables)

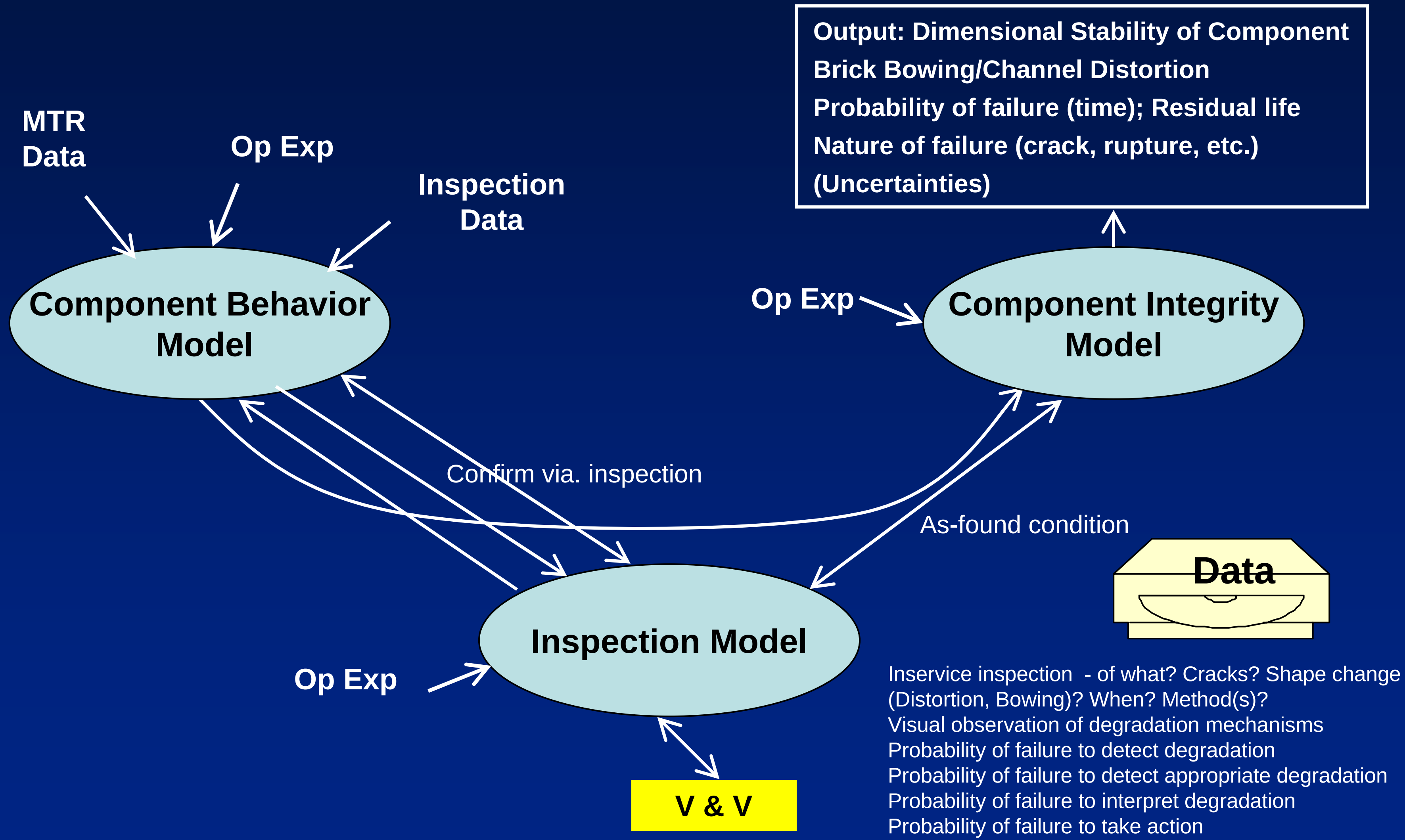
Considers and Quantifies Uncertainties

Data

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

Op Exp; Component Failure Effects

Output: HTGR Risk Measure

- adequate heat removal;
- reactivity control; and
- confinement of radioactivity

Risk Model – Development/Adjustment

Plant Performance Model

Op Exp

Data

- Develop model
- Risk contributors from degradation model, inspection model (severity level)
  - Consequential failures
  - Initiating Events
- Complex phenomena, cracks, ΔP, Δ T, vibration
- Post-trip degradation

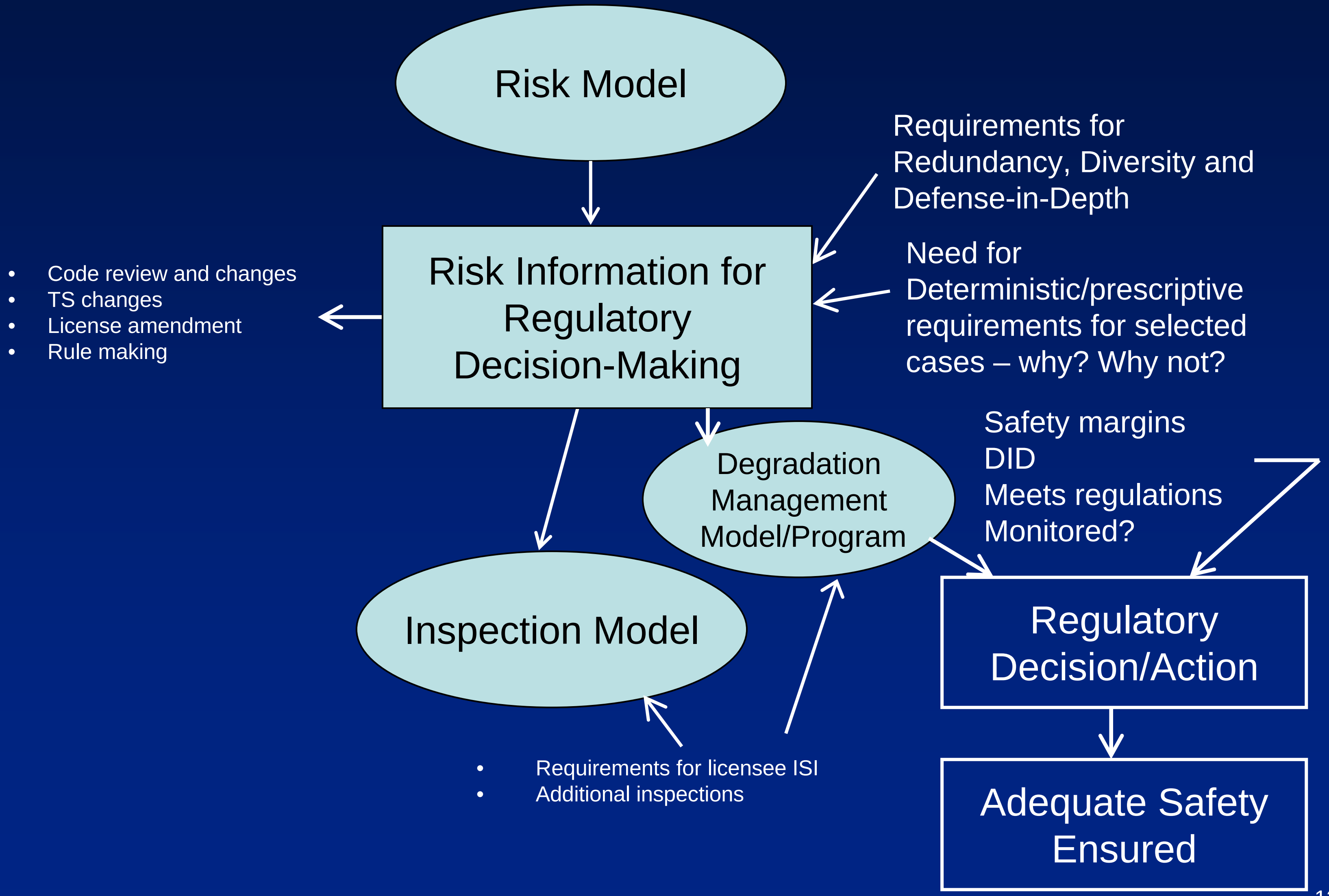
Component Integrity Model

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.

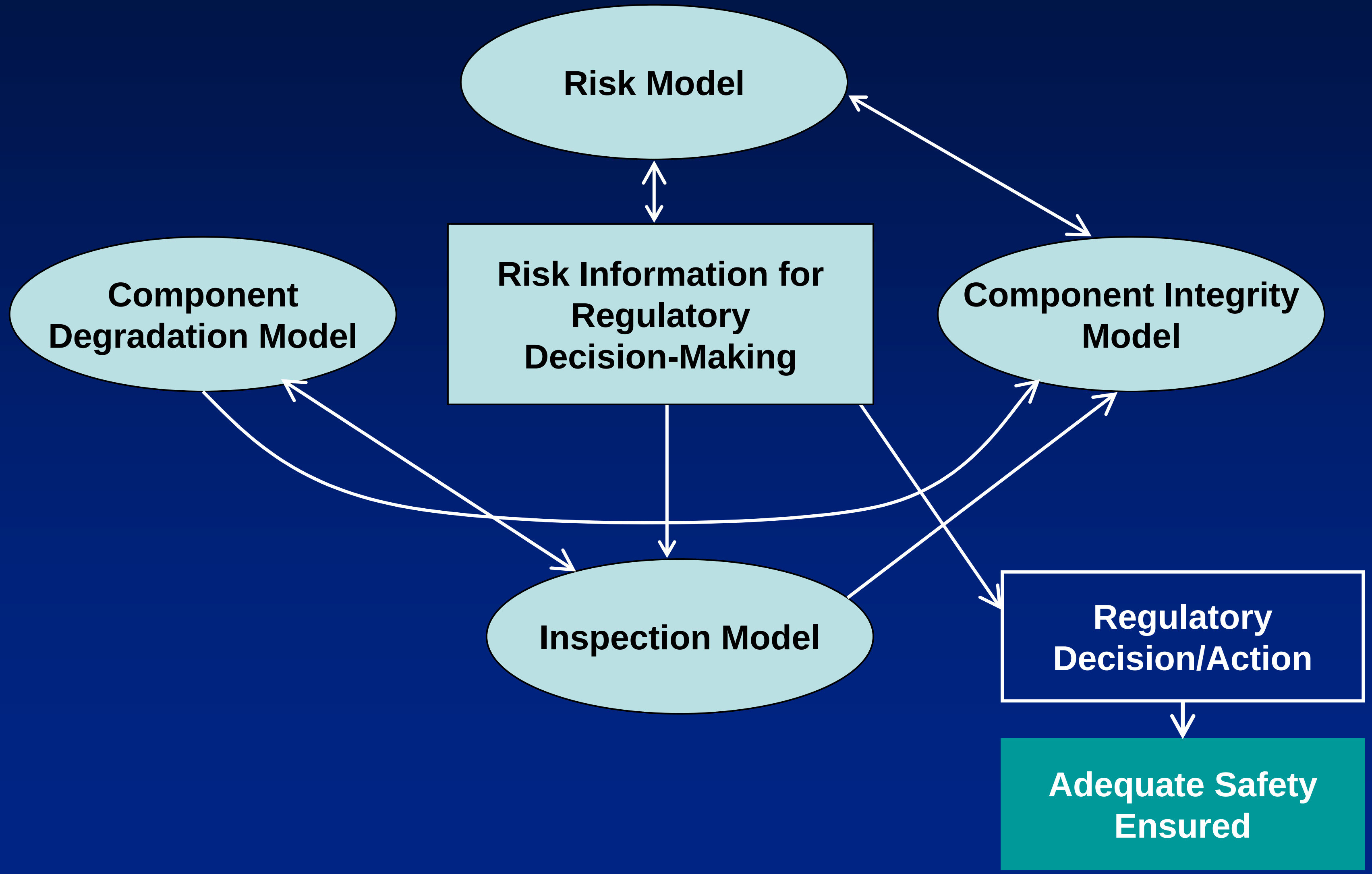
Caution: (1) When initial risk measure is very low there may be a tendency to ignore potential model weaknesses (incompleteness).

(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.

Integrating Risk-Informed PRA Into Regulatory Decision



Evaluation of the Risk-Informed PRA for Graphite Components and Regulatory Decision/Action



Materials-Related Challenges for NRC Staff's Safety Evaluation of NGNP HTGR

- Develop NRC staff expertise, technical tools, and data to support an effective and efficient independent safety evaluation of the NGNP HTGR graphite 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 HTGR graphite-specific regulatory positions, guidance documents, or standard review plans for the NRC staff to conduct an effective and efficient design safety review of HTGR graphite components.
- Establish HTGR graphite-specific NRC staff regulatory positions, guidance documents, or standard review plans on staff review of in-service inspection and surveillance plans and techniques.

Basic Technical Issues for NGNP HTGR Graphite Component Safety Evaluation

Issues Regarding Graphite Component Safety Requirement:

Early Operation Years: Reactor operation with a cracked graphite component is not allowed.

Mid-Life Operation Years: Reactor operation with cracked graphite component may be allowed, depending upon the safety significance of the observed cracking and assurance of negligible degradation on further reactor operation. Additional ISI may be warranted.

Component Replacement Criteria:

Needs development.

COLE-BAKER A., REED J., Measurement of AGR graphite fuel brick shrinkage and channel distortion, in Management of Ageing Processes in Graphite Reactor Cores, ed.Neighbour, G., Royal Society of Chemistry, London(2007), 201-208.

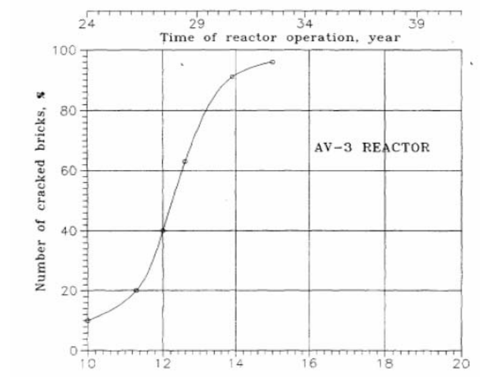
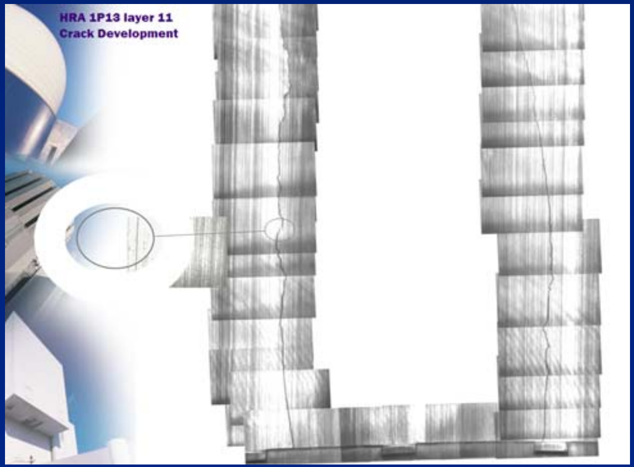


Figure 3. The cracking of reactor bricks during AV-3 operation.

P.A. PLATONOV, O.K. CHUGUNOV, V.N. MANEVSKY, V.I. KARPUKM, “Radiation damage and life-time evaluation of RBMK graphite stack”, in Proceedings of a specialists meeting held in Bath, United Kingdom, 24-27 September 1995, INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA-TECDOC-901, pp:79 -89.



Basic Technical Issues for NGNP HTGR Graphite Component Safety Evaluation

1. Component Failure Criteria – Graded on Safety Significance
   a) Probability of failure estimates, extrapolated from small population irradiation data.
   b) If cracking of a graphite component is allowed (in some areas).
      i. Maximum number of allowable cracks and the nature of cracking.
      ii. Cracking characterization, and procedures to assess its safety significance and its effect on risk measures.
   c) Cracking will not be allowed in critical areas such as fuel and control rod bricks, coolant channel areas, and core support columns.

Basic Technical Issues for NGNP HTGR Graphite Component Safety Evaluation

2. Component Performance Criteria
   a) Maximum allowable permanent deformation (brick bowing and channel distortion) in critical areas
3. Component Inspection Criteria
   a) Design-for-inspection of critical areas
   b) Sizing of flaws and flaw evaluation and procedures to assess their safety significance and their effect on risk measures
   c) Methods to measure and categorize component deformation, and procedures to assess its safety significance and its effect on risk measures
4. Surveillance Requirements Including Coupons, Core Sampling (Trepanning), Core Restraint Monitoring, Core Support Monitoring, and Testing Protocols
5. Acceptance/Replacement Criteria For Flawed Graphite Component In Service
6. Graphite Component Degradation Management Program and Procedure to Assess Its Efficacy

Summary

1. **Independently verified and validated predictive analytical models and codes for NGNP graphite properties are needed for the NRC staff evaluation of the design of NGNP HTGR graphite components.**
2. **Independently verified and validated predictive codes are needed for the NRC staff evaluation of NGNP HTGR graphite component integrity.**
3. **Independently verified and validated inspection codes and standards are needed for the NRC staff evaluation of NGNP HTGR graphite component degradation during service.**
4. **The NRC staff needs technical information on model and data uncertainties, and their overall effect (sensitivity) on failure probability predictions.**
5. **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.**

ABBREVIATIONS

AOO	Anticipated Operational Occurrence
CTE	Coefficient of Thermal Expansion
DID	Defense-In-Depth
HTGR	High Temperature Gas Cooled Reactor
ISI	Inservice Inspection
MTR	Material Test Reactor
NGNP	Next Generation Nuclear Plant
Op E	Operating Experience
ORNL	Oak Ridge National Laboratory
PIE	Post-Irradiation Examination
PRA	Probabilistic Risk Assessment
TS	Technical Specifications
V & V	Verification and Validation