Wear Testing Standard Development for Application to High Temperature Gas Cooled Reactor (HTGR) Environment

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UNITED STATES NUCLEAR REGULATORY COMMISSION
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Issues For Assessment

1. Background – NRC and Its Regulatory Role
2. General Information on HTGR Design – Graphite Core Component Functions
3. Some Known Information On Graphite Dust Generation in Pebble Bed Reactor
4. Some Available ASTM Wear Test Methods for Ceramics
5. Need For Consistency and Acceptable Methodology For Extrapolation And Interpolation
6. Uncertainties in Data, Assumptions, and Model
7. Verification and Validation Demonstration Using Round Robin Testing
8. Adoption of Recommended Practice and Use in ASME Codes and Standards Development

Mission of the NRC

The Nuclear Regulatory Commission licenses and regulates the Nation's civilian use of byproduct, source, and special nuclear materials to ensure adequate protection of public health and safety, promote the common defense and security, and protect the environment.

The mission is accomplished through licensing of nuclear facilities which possess, use and dispose nuclear materials; the development and implementation of requirements governing licensed activities; and inspection and enforcement activities to assure compliance with these requirements.

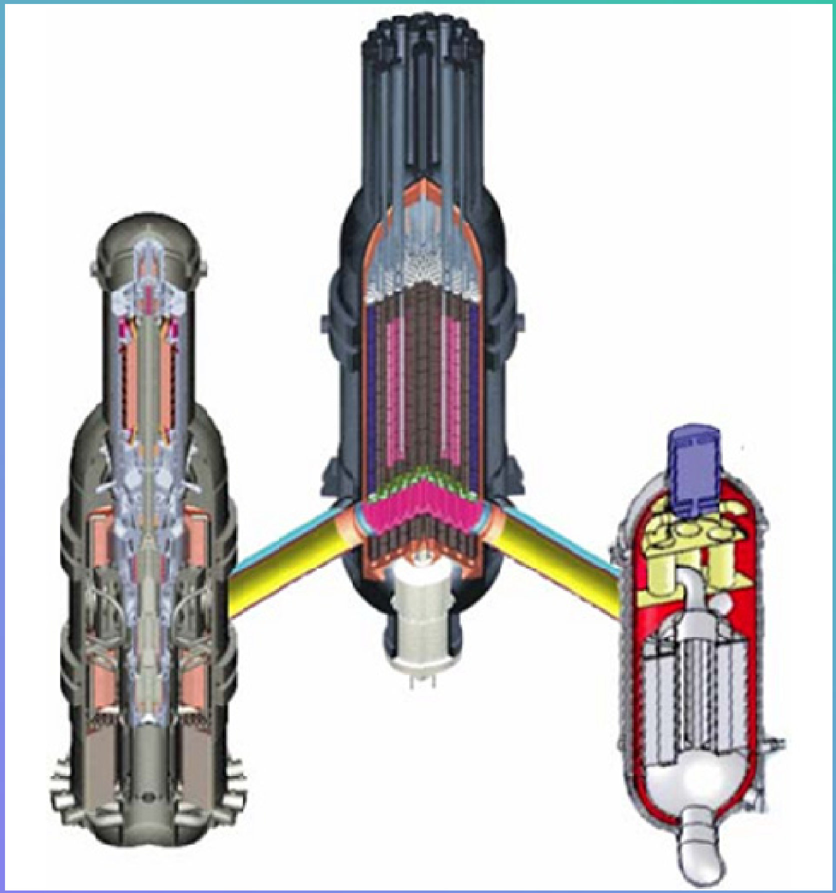
Regulatory Responsibilities

10 CFR Parts 1 -199
Nuclear Regulatory Commission

Staff reviews licensee's
safety analysis report (SAR)
using standard review plan (SRP)

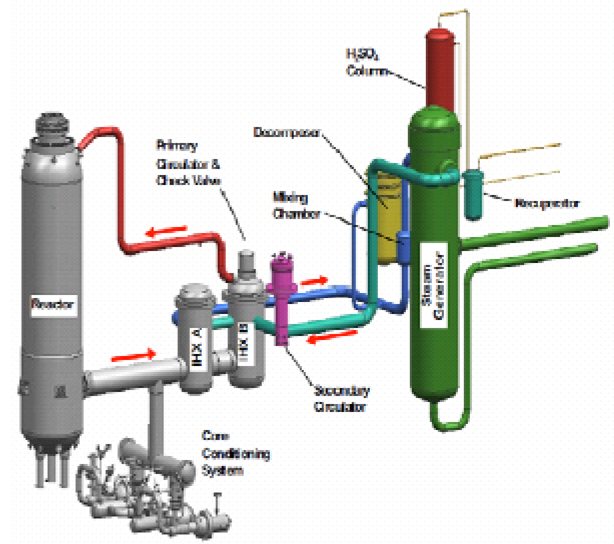
Staff uses guidance documents,
such as regulatory guides (RG),
codes and standards (C&S),
and industry documents,
for guidance on acceptable procedures,
methodology for technical review

General Atomics Team Prismatic Reactor FY 2007 NGNP Pre-conceptual Design.

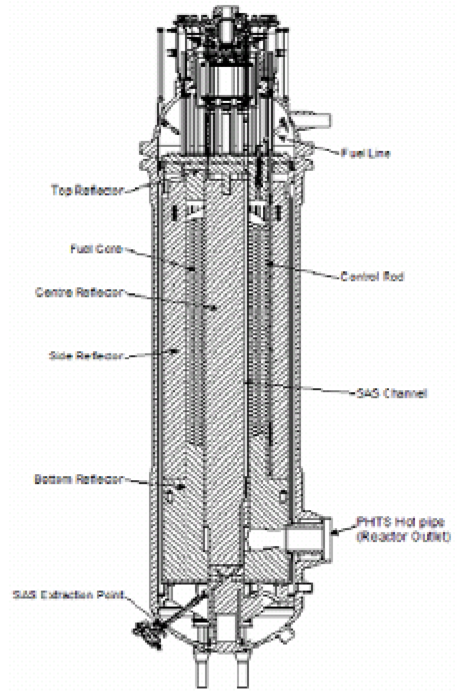


Ref: "Basis for NGNP Reactor Design Down-Selection", INL/EXT-10-19565, August 2010.

WEC/PBMR Team Pebble Bed Reactor FY 2007 NGNP Pre-conceptual Design.



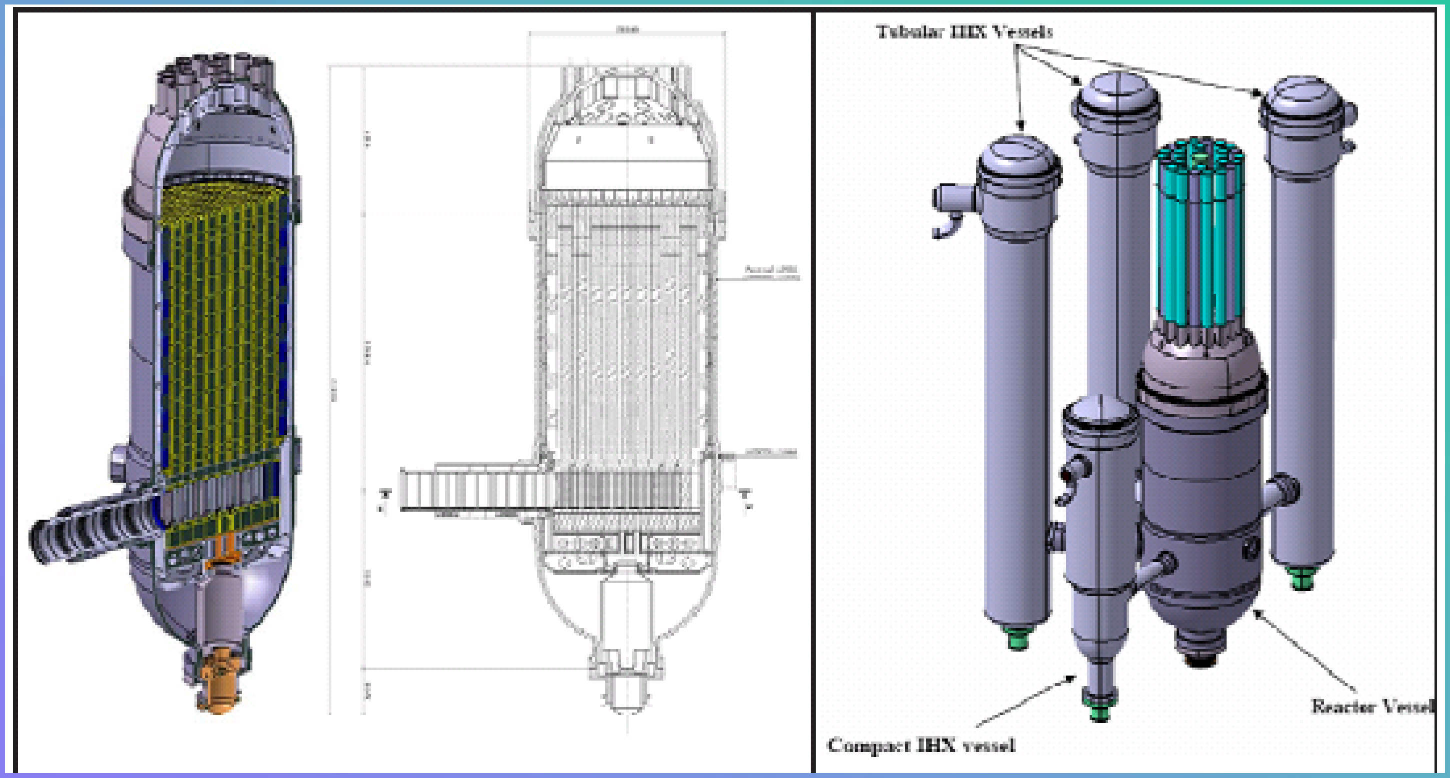
Indirect configuration producing electricity and hydrogen



Annular Pebble Bed Reactor

Ref: "Basis for NGNP Reactor Design Down-Selection", INL/EXT-10-19565, August 2010.

AREVA Team Prismatic Reactor
FY 2007 NGNP Pre-conceptual Design



Ref: "Basis for NGNP Reactor Design Down-Selection", INL/EXT-10-19565, August 2010.

Carbonaceous Dust

Potential Sources:

a) Friction and abrasion of moving fuel spheres, consisting of partially graphitized carbon – pebble bed reactor

b) Frication and abrasion between fuel spheres and graphite core components - pebble bed reactor

c) Coolant flow-induced localized vibration and erosion on graphite core components - pebble bed reactor and prismatic reactor

Technical Issues:

1. Carrier of fission products – adsorbs tritium (hydrogen), iodine, strontium, and cesium.
2. Material and equipment degradation from dust abrasion and deposition.
3. Unknown, potential change in coolant heat transfer.
4. Potentially can react with moisture to produce hydrogen – reducing effects on metal components. Technical details unknown – reaction thermodynamics and required concentration range

Estimated Dust Quantity

- Estimates have been made for previous HTRs
  - AVR (15 MWe, 21 year operation): 60-100 kg
  - THTR (300 MWe, 16 month operation): ~25 kg
  - 400 MW PBMR estimate (based on AVR data)
    - 15 kg/y
    - 43 kg/y
    - 100 kg/y
- HTR-Module
  - ~ 23 kg/y
- 500 MWt pebble bed NGNP (Westinghouse)
  - 48 kg/y
- Contrast with, e.g., Peach Bottom (~4 kg)

Ref: "Dust Generation and Transport", Paul Humrickhouse, VHTR R&D FY11 Technical Review Meeting, April 26-28, 2011,Albuquerque, New Mexico.

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Case For ASTM Standard For Friction And Wear Test For HTGR Application

1. Friction and wear of carbon and graphite materials under HTGR environment is unlike other commercial application
2. Non-standard tests conducted thus far have yielded varying and inconclusive results, which are hard to interpret and apply
3. An ASTM standard for testing will provide consistency and advance technical understanding
4. An ASTM test standard would establish peer-reviewed and approved test protocol, which can be endorsed by international regulatory bodies

HTGR Friction and Wear

- An excellent source is the Idaho National laboratory Webpage on Graphite Dust Issues Resolution - https://secure.inl.gov/dust2010/default.aspx
- Dust Production Mechanisms:
  - Adhesive wear – bonding and tearing (pulling) apart (dominant for pebble wear)
  - Abrasive wear – shear between hard and soft surfaces
  - Fatigue wear – repeated contact
  - Corrosive wear – chemical reaction

HTGR Friction and Wear – Contd..

The adhesive wear volume is given by:

$$V = K_{ad} \frac{N}{H} L,$$

where,

K_{ad} = wear coefficient for adhesive wear;

L = sliding length;

N/H = “real” contact area;

N = normal force; and,

H = hardness.

Factors Affecting Wear Rate and Material Loss

1. Normal Contact Force
2. Temperature
3. Surface Condition of Contact Materials
4. Atmosphere (Chemical Reaction)
5. Neutron Damage to the Surface

A List of Selected Past Work

1. H. Zaidi, F. Robert, D. Paulmier, “Influence of adsorbed gases on the surface energy of graphite:consequences on the friction behaviour, Thin Solid Films 264, 46-51 (1995).
2. Luo, X., Yu, S., Sheng, X, “The friction behaviors of nuclear graphite at different temperatures”. Tribology 24 (5), 402–405 (2004).
3. L. Xiaowei, Y. Suyuan, S. Xuanyu, and H. Shuyan, “Temperature effect on IG-11 graphite wear performance, Nuclear Engineering and Design 235, 2261–2274 (2005).
4. O.M. Stansfield, “Friction and wear of graphite in dry helium at 25, 400, and 800 C”, Nuclear Applications, Vol.6, 313-320 (1969).

Summary of Past Experience

1. "Preliminary Pebble Bed Reactor Core Dust Production Literature Review", Joshua Cogliati, Abderra Ougouag and Javier Ortensi. https://secure.inl.gov/dust2010/docs/documents/dust_report.pdf.
2. "Dust Generation and Transport", Paul Humrickhouse, VHTR R&D FY11 Technical Review Meeting, April 26-28, 2011,Albuquerque, New Mexico.

- High data variation – three orders of magnitude difference in friction coefficient
- Inconsistency in materials
- Temperature-dependency trends are inconsistent
- Suggests either high uncertainty in wear coefficients or application to materials and temperatures that are not representative
- Mechanistic models presently under-predict generation

Pebble Ball-to-Ball Friction and Wear Experiment

Potentially ball mill can be used to study and standardize testing

- Convenient to use with matrix (A3-carbon) pebble fuel balls
- Inner liner could be core graphite material or material of the fuel handling system
- Inlet and outlet could be provided for (externally heated) helium coolant
- Inner graphite liner could also be heated using resistance heating
- Wear volume easy to measure for individual balls and estimate average
- Wear volume of the liner may also be readily measurable
- Wear particle characterization (size distribution, x-ray line profile) possible to provide information on potential wear mechanism
- Dynamic wear, perhaps simulating pebble movement in pebble bed reactor
- Wear coefficient can not be determined.

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Select ASTM Wear and Friction Testing Standards

1. C808-75 (Reapproved 2010) e1 - Standard Guide for Reporting Friction and Wear Test Results of Manufactured Carbon and Graphite Bearing and Seal Materials
2. G77-05 (Reapproved 2010) - Standard Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test
3. G99-05 (Reapproved 2010) - Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus
4. G117-02 (Reapproved 2007) - Standard Guide for Calculating and Reporting Measures of Precision Using Data from Interlaboratory Wear or Erosion Tests
5. G118-02 (Reapproved 2007) - Standard Guide for Recommended Format of Wear Test Data Suitable for Databases

Select ASTM Wear and Friction Testing Standards – Contd.

6. G133-05 (Reapproved 2010) - Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear
7. G163-10 - Standard Guide for Digital Data Acquisition in Wear and Friction Measurements
8. G206-11 - Standard Guide for Measuring the Wear Volumes of Piston Ring Segments Run against Flat Coupons in Reciprocating Wear Tests
9. G115-10 - Standard Guide for Measuring and Reporting Friction Coefficient
10. G98 – 02 (Reapproved 2009) - Standard Test Method for Galling Resistance of Materials

Considerations for Next Step

- Conduct research to assess existing ASTM methods for adaptation to NGNP VHTR data needs.
- Select a method or develop a new wear and friction test for HTGR graphite and fuel pebbles.
- Demonstrate proof-of-concept
- Compare and interpret data for consistency and conformance, including quantification of potential uncertainties
- Conduct round-robin to inform bias, reproducibility, and accuracy in test standard
- Publish draft standard for review and ballot

List of Abbreviations

Abbreviation	Stands For
AVR	Arbeitsgemeinschaft Versuchsreaktor
C&S	Codes and Standards
CFR	Code of Federal Regulations
HTGR	High Temperature Gas Cooled Reactor
HTR	High Temperature Reactor
NGNP	Next Generation Nuclear Plant
PBMR	Pebble Bed Modular Reactor
RG	Regulatory Guide
SAR	Safety Analysis Report
SRP	Standard Review Plan
THTR	Thorium High Temperature Reactor
VHTR	Very High Temperature Reactor
WEC	Westinghouse Electric Company