PBMR Fuel Overview

Design, Manufacturing, Quality Control & Qualification

Attachment 3-b

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Meeting Purpose:

- Overview of PBMR Fuel Technical Issues & Exchange of Information in Pre-Licensing discussion to facilitate:
  - Enhanced understanding of PBMR technology
  - Identification of resources and tool requirements
  - Identification of gaps and long lead items
  - Identification of potential opportunities for NRC involvement in fuel qualification process
  - Formulation of policy issues

AGENDA

1. Background and Context
2. Fuel Design & Specification
3. Fuel Equivalence Plan
4. Schematic Overview of Manufacturing Process & Quality Control
5. Fuel Qualification & Testing
6. Core Condition Monitoring
7. Pebble Flow Testing
8. Burn-Up Measurement
9. Bounding Design Basis Events
10. Q&A

Background & Context

- PBMR Information Release Policy

  Concurrent regulatory interactions in two countries
  Design in progress
  Proprietary Issues

- Extensive German Fuel Qualification Program

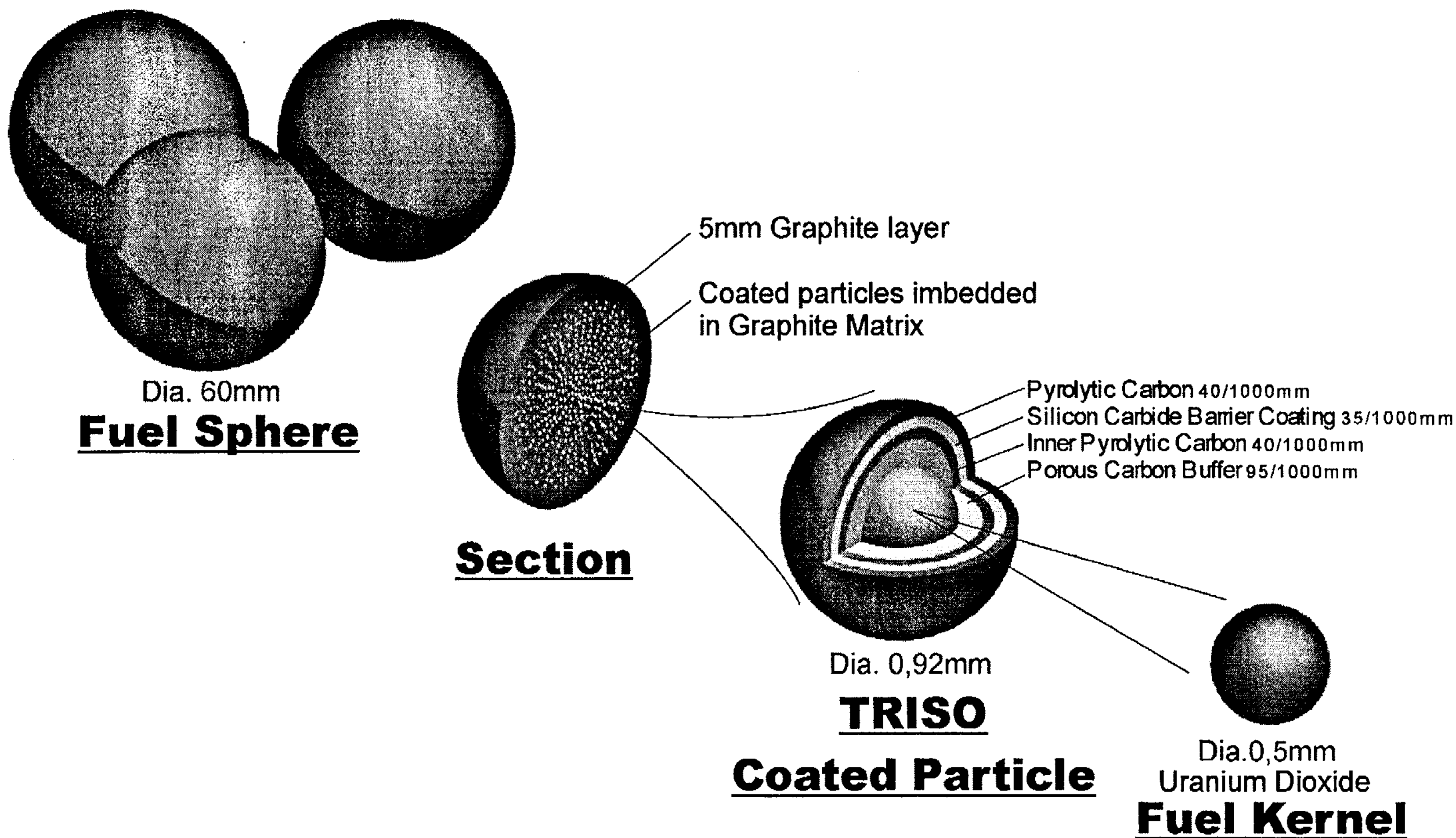
  Over two decades of experience and estimated 7 Billion DM

  Primary emphasis on empirical/experimental validation, in addition to analytical modeling

  Possible approach – leverage German experience; identify and close gaps

FUEL DESIGN AND SPECIFICATION

FUEL ELEMENT DESIGN FOR PBMR



PBMR FUEL REQUIREMENTS

Coated Particles per Fuel Element

Fuel Temperature Range

Design Burn-up

Fast Neutron Dose

PBMR Product Specification (Nominal Values)

Kernel:

Property	Unit	Specification

TRISO Coated Particles:

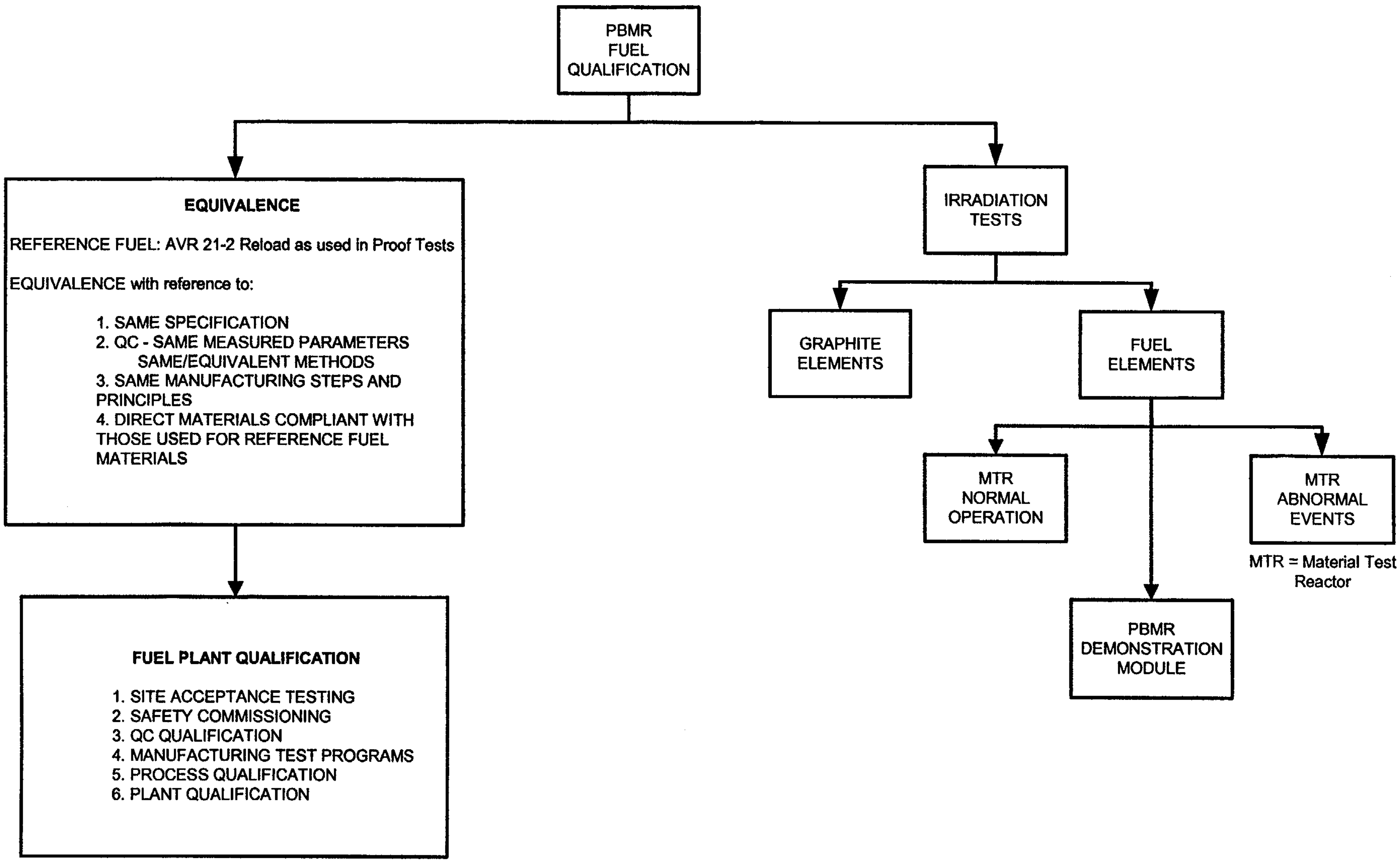
Layer	Thickness (μm)	Density	Anisotropy

Fuel Spheres:

Property	Unit	Specification

FUEL EQUIVALENCE PLAN

OVERALL RSA FUEL QUALIFICATION PLAN



RSA FUEL PLANT QUALIFICATION

1.Site Acceptance Testing	Demonstrate equipment is capable of performing as required
2.QC Qualification	Preparation of QC documentation
	Qualification of QC Tests
3.Manufacturing Tests	Preparation of manufacturing documentation
	Determination of production range of variable equipment parameters Comparison with NUKEM results
	Comparison with PBMR results on reference fuel spheres
	Review with German experts
4.Qualification of Special Processes	Processes of which results are highly dependent on control or skill of operators and whose quality cannot be readily determined by inspection or testing
5. Plant Qualification	Formal demonstration of plant manufacturing and QC methods and procedures to meet intent of FTP under production scale conditions
	Formal demonstration of fuel plant quality management program
6. Routine Production	Routine production of fuel elements conforming to specification

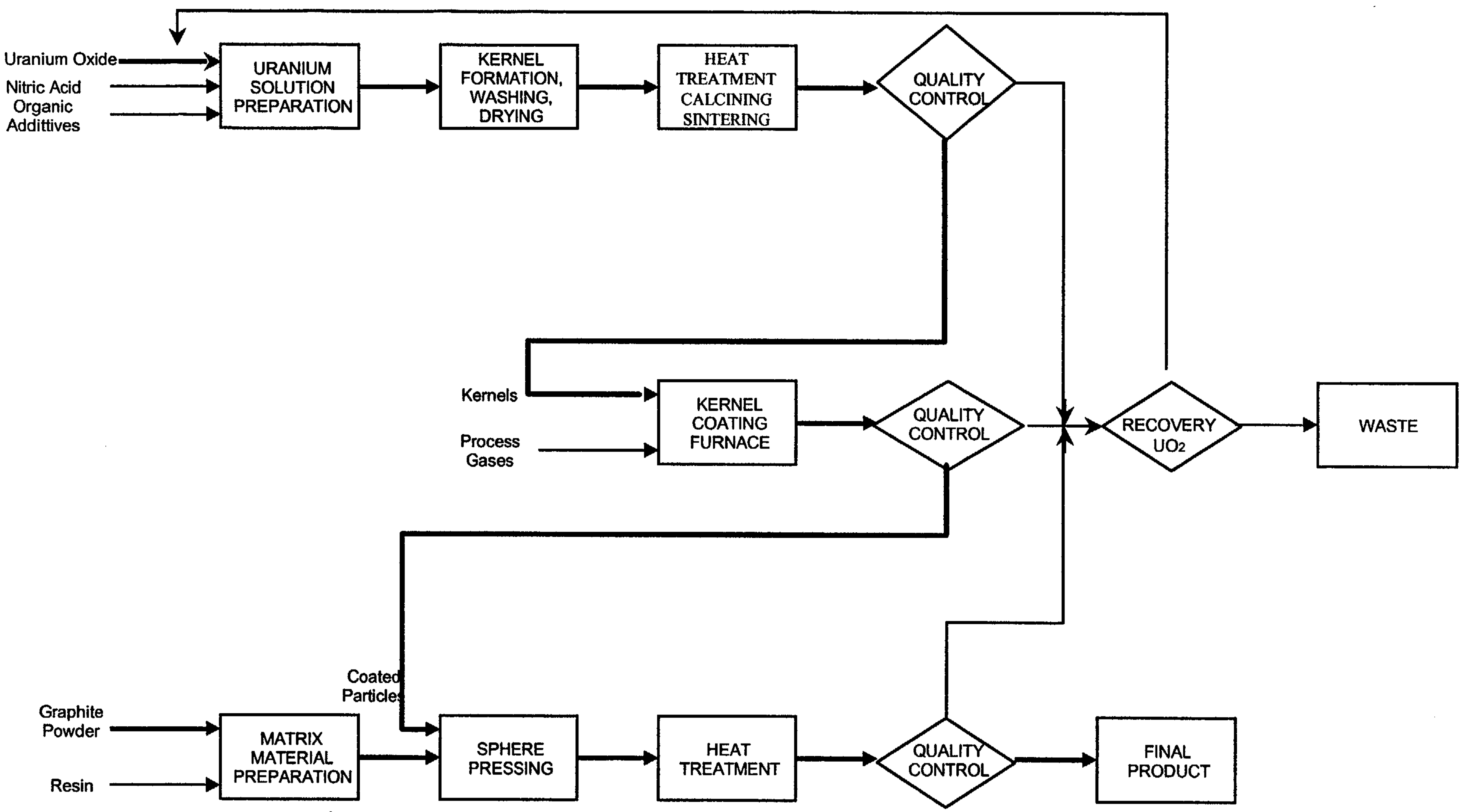
DIRECT MATERIALS

Proprietary per 10CFR2.790

Material	Natural Graphite Powder	Electrographite Powder	Machined Graphite Spheres	**Phenolic Resin**

OVERVIEW OF MANUFACTURING PROCESS AND QUALITY CONTROL

Fuel Manufacturing Process



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CHARACTERISTICS MEASURED FOR QC CHECKS

(U_3O_8)

Product	Characteristic
U_3O_8	

CHARACTERISTICS MEASURED FOR QC CHECKS

(UO_2 Kernels)

Product	Characteristic
UO_2 Kernels	

CHARACTERISTICS MEASURED FOR QC CHECKS

(Coated Particles)

Product	Characteristic
Coated Particles	

CHARACTERISTICS MEASURED FOR QC CHECKS

(Fuel Spheres)

Proprietary per 10CFR2.790

Product	Characteristic
Fuel Spheres	

CHARACTERISTICS MEASURED AND METHODS USED

(Kernels, Coated Particles)

Product	Characteristic	Method
UO_2 Kernels		
Coated Particles		

FAILED COATED PARTICLE FRACTION IN NEW FUEL

- EXPRESSED IN TERMS OF **FREE URANIUM FRACTION**
- FREE URANIUM FRACTION INCLUDES ALL URANIUM IN A FUEL ELEMENT THAT NOT COVERED BY AN INTACT SiC LAYER AS DETERMINED BY A **BURN-LEACH** TEST. IT IS EXPRESSED AS THE RATIO OF THE MASS OF FREE URANIUM IN A FUEL ELEMENT TO THE TOTAL URANIUM MASS IN THE FUEL ELEMENT
- BURN-LEACH TEST:

  BURNING OF A FUEL ELEMENT IN A FURNACE AT 750^{o}C

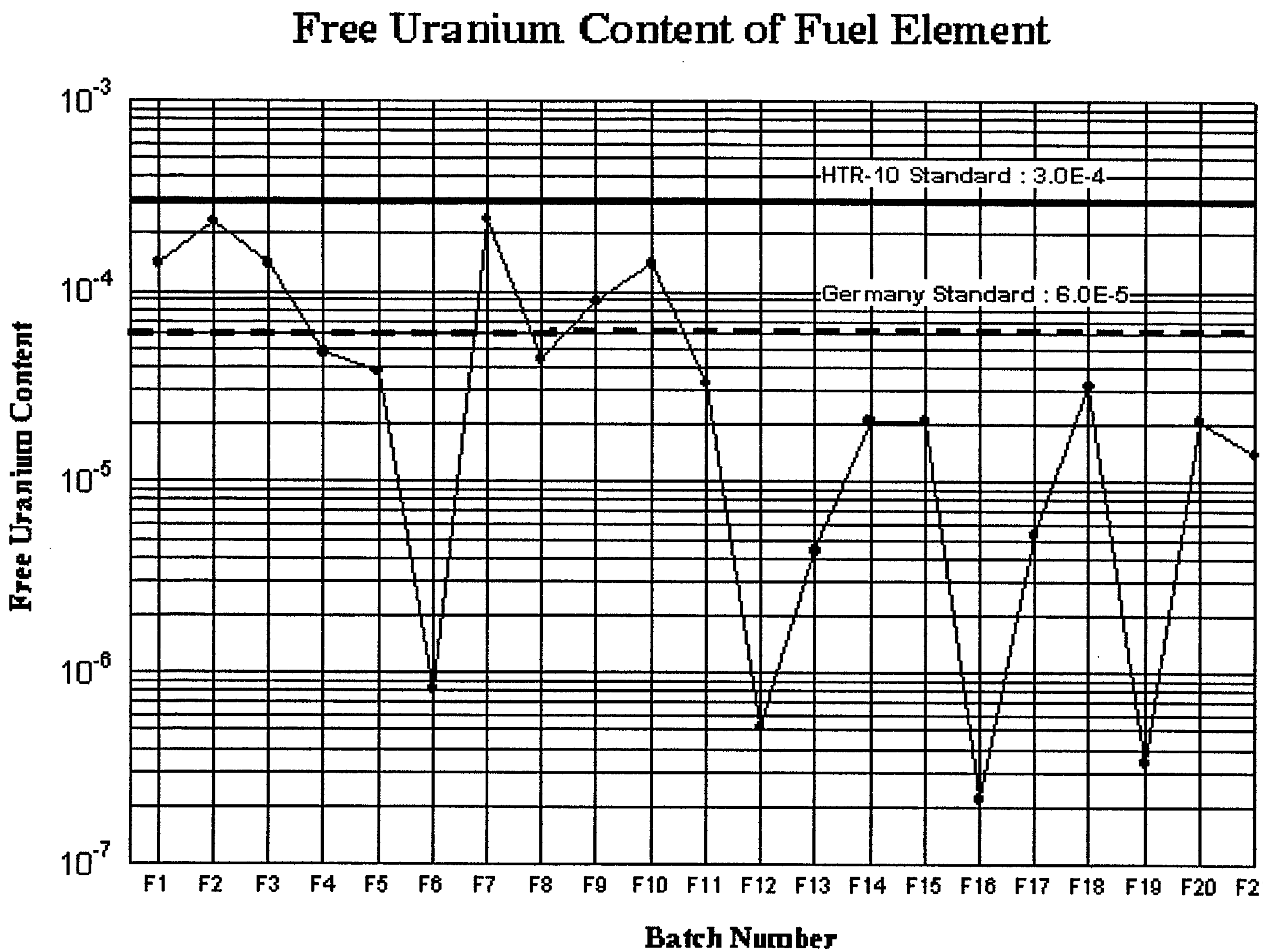
  LEACHING THE REMAINS IN NITRIC ACID AT 95^{o}C

  FLUOROMETRIC DETERMINATION OF THE URANIUM CONCENTRATION IN THE SOLUTION
- GERMAN SPECIFICATION: 6×10^{-5}

RESULTS OF BURN-LEACH TESTS ON LEU-TRISO FUEL IN GERMANY

Fuel Element Population Détail	LEU PHASE 1	AVR 19	AVR 21	AVR 21-2	Proof Test
Year of Production	1981	1981	1983	1985	1988
Number of Fuel Elements Produced	<100	24,600	20,500	14,000	<200
Number of Fuel Element Lots	-	14	11	8	-
Coating Batch Size	5 kg	5 kg	3 kg	3 kg	5 kg
Number of Coating Batches	1	65	54	29	8
Number of Coated Particles per Fuel Element	16,400	16,400	9,560	9,560	14,600
U^{235} Enrichment	9.8%	9.8%	16.7%	16.7%	10.6%
Free Uranium Fraction	35×10^{-6}	50.7×10^{-6}	43.2×10^{-6}	7.8×10^{-6}	13.5×10^{-6}

Recent Chinese HTR-10 Experience



FUEL QUALIFICATION AND TESTING

PLANNED RSA IRRADIATION TESTS

OBJECTIVES:

1. To provide a realistic experimental basis for the determination of source terms for the PBMR
2. To provide proof that PBMR fuel and graphite elements will meet core design criteria with respect to normal temperature cycles and abnormal temperature transients, burn-up, and fast neutron fluence
3. To provide experimental data that could be used to develop and validate fuel behaviour models

MATERIAL TEST REACTOR (MTR) TESTS:

1. Irradiation of fuel elements from qualified production line
2. Post Irradiation Examination (PIE) on fuel elements before heating test
3. Heating test
4. PIE after heating
5. Irradiation of graphite

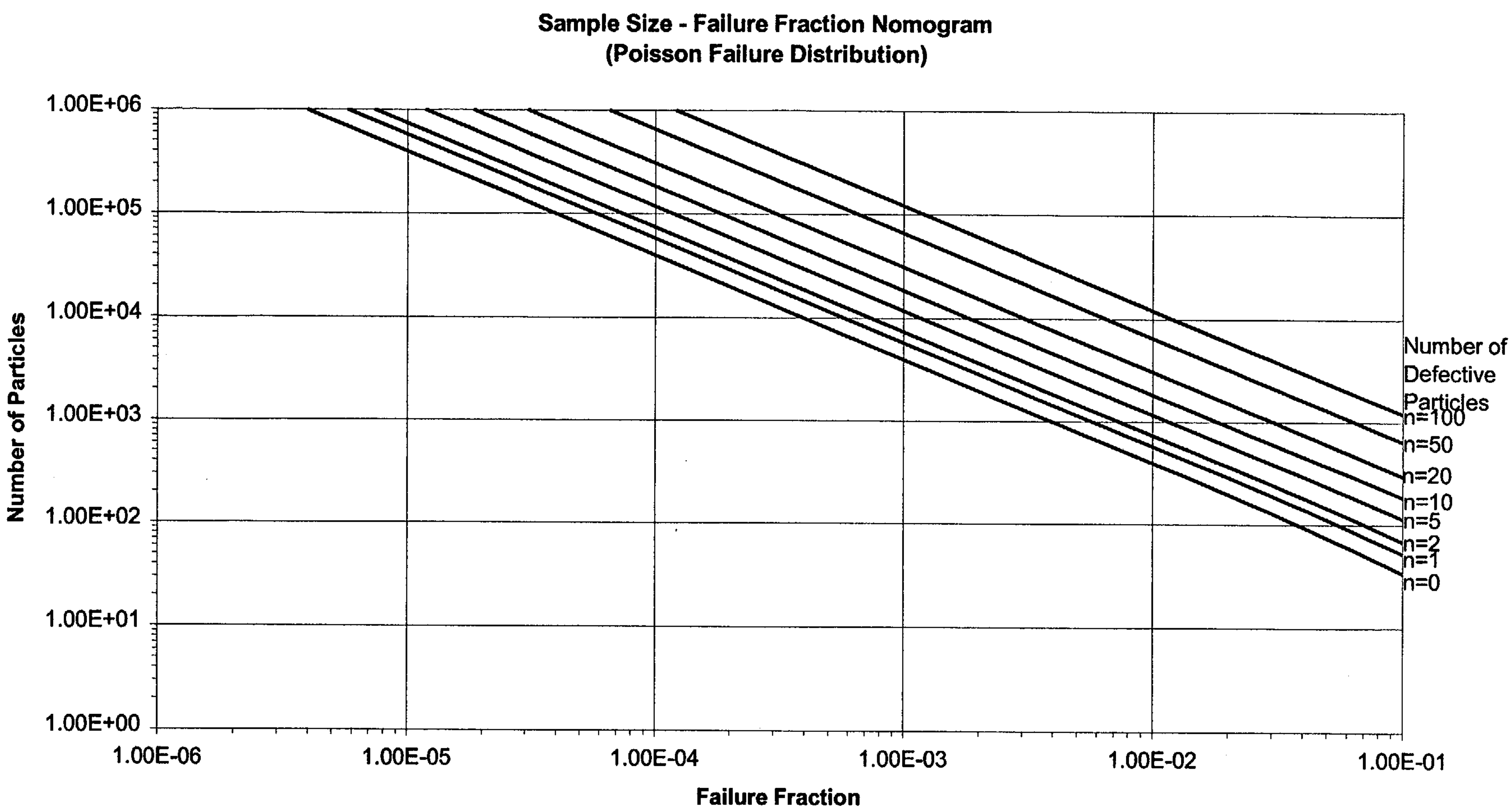
OPERATIONAL TESTS:

Remove fuel elements irradiated in the PBMR at different burn-up values until the first fuel elements reach target burn-up and perform heating tests as well as PIE on these fuel elements

COATED PARTICLE FAILURE FRACTIONS

COATED PARTICLE FAILURE FRACTIONS

COATED PARTICLE FAILURE FRACTIONS (CONTINUED)



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FAILURE FRACTION vs. TEMPERATURE

HTR-Modul Temperature – Time History

Failed Particle Fraction (HTR-Modul Temperature Distribution)

Comparison of PBMR Irradiation Targets with Phase 1 Results

PBMR Irradiation Targets in Relation to Phase 1 and AVR Tests

FISSION PRODUCT RELEASE (OPERATIONAL)

- Computer Codes Used:

Computer Codes Used:	VSOP/TINTE	Time/Temperature history
	FRESCO II	Fission Product Release Rate (Diffusion)
	SPATRA	Plate-out of Fission Products

FISSION PRODUCT RELEASE (ABNORMAL EVENTS)

- Failure Fraction vs. Temperature graph
- Fraction of Core Volume above T vs. Time graph
- Combine the graphs to produce a graph of Number of Coated Particles failed vs. Time
- Assume complete release of fission products in the failed particles the moment they fail

PBMR Temperature in Relation to Phase 1 and AVR Temperatures

CORE CONDITION MONITORING

CORE CONDITION MONITORING

1. Neutron Flux	9 Detectors situated outside the Reactor Pressure Vessel Sacrificial In-core neutron flux detectors situated in the graphite core structure (demo plant)
2. Temperature	Inlet Pipes and outlet pipes for He Internal thermocouples in vessel (demo plant)
3. Pressure	Inlet Pipes Differential between inlet and outlet pipes
4. Flow	Inlet pipes
5. Power	Derived from above measurements via heat balance
6. Coolant Condition	Measured in Helium Purification System:

Gas Chromatograph	H_2, CH_4, CO, CO_2, N_2, Xe, Kr
Moisture Analyser	Water
Trace Oxygen Analyser	O_2
Gamma Spectroscope	Dust

7. Fuel Integrity	Measurement for noble gas fission products

PEBBLE FLOW TESTING

PEBBLE FLOW MODEL EXPERIMENTS

- Several pebble flow experiments done to develop and verify pebble flow models during the design of the AVR, THTR, and HTR-Modul reactors
- These models varied in scale
- Spheres of different materials used to simulate different densities and frictional effects:

    Graphite, steel, glass, glazed and unglazed clay

- Different aspects studied:

    Transition Time
    Residence Spectra
    H/D Ratio
    Density
    Friction – Core/wall and core/bottom
    Mixing between zones

Conclusion: Pebble flow characteristics well understood and reflected in VSOP pebble flow modeling

PEBBLE FLOW MODEL EXPERIMENTS (Cont)

Reactor	Scale of Model
AVR	1:7.5
	1:1
THTR	1:15
	1:6
	1:2
	1:1 (30° Section)
HTR-Modul	1:6

BURNUP MEASUREMENT

BURN-UP MEASUREMENT

1. Measurement Principle

- Based on measurement of the Cs 137 activity in a fuel sphere using gamma spectrometry
- Uses Cs 137 gamma line at 661.6 keV
- High Purity Ge Detector resolution 1.6 keV at this energy
- Interfering nuclides: Nb-97, Ce-143, and I-132

Nuclide	Gamma Energy (keV)
Nb 97	657.9
Cs 137	661.6
Ce 143	664.6
I 132	667.7

- Method based on German experiment performed on irradiated fuel element to test the concept

BURN-UP MEASUREMENT

2. Measurement System

- Operational Modes: Distinguish between Graphite Elements and Fuel Elements

  Distinguish between Used Fuel Elements and Spent Fuel Elements

- Measurement Time

- Error <) at target burn-up

- Operational Checks: Benchmark check using Cs 137 source

  Quality check using Ba 133 source with every measurement

Proprietary per 10CFR2.790

Fuel Handling & Storage System

Process Flow - Normal Operation

BOUNDING DESIGN BASIS EVENTS