TECHNOLOGY INSIGHTS

Fuel Handling & Storage System (FHSS) PBMR

Hans-Wolfgang Chi

MHTGR Brayton Cycle Technology Course

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Objectives

- **Introduce Unique Features of the Pebble Bed Reactor**
- **Describe PBMR FHSS Requirements and the Resulting Design**
- **Elaborate PBMR FHSS Operating Modes**
- **Assess Experience Base for PBMR FHSS**

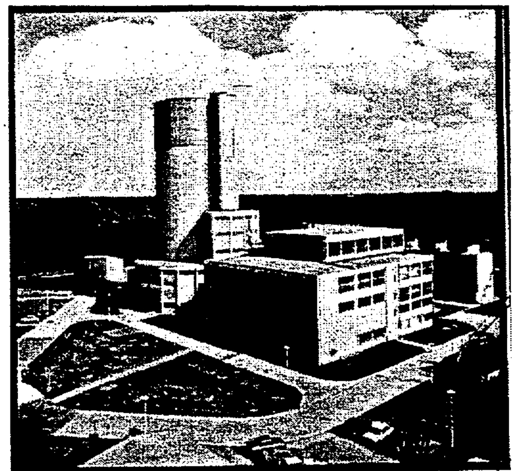
Outline

- Pebble Bed Reactors
- Pebble Flow Pattern in the Core
- Pebble Bed FHSS requirements
- PBMR FHSS Description
- PBMR FHSS Operating Modes
- General FHSS Characteristics
- Pebble Bed FHSS Experience Base
- Are There Any Technology Risks?
- Discussion

Pebble Bed Gas-Cooled Reactors

- Arbeitsgemeinschaft Versuchs Reaktor (AVR), Juelich, Germany (1968 – 1988)
- Thorium Hoch-Temperatur Reaktor (THTR), Schmehausen, Germany (1985 -1988)
- High Temperature Reactor (HTR-10), Beijing, China (2000 -)

AVR Plant

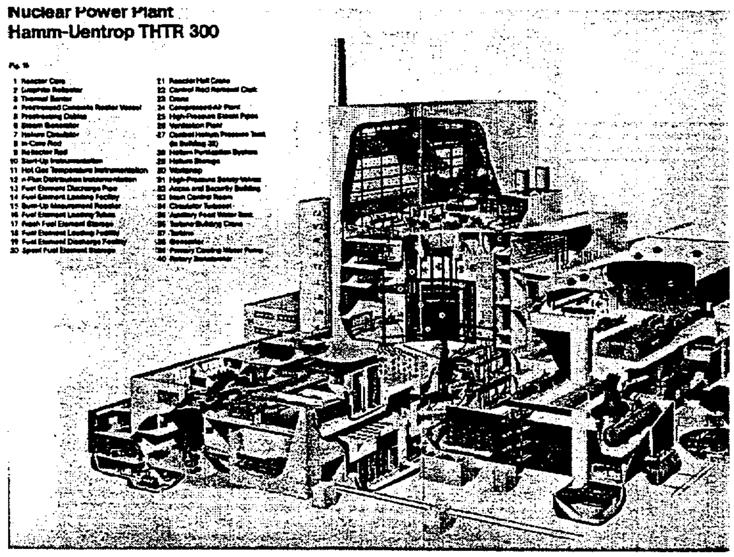


HRB | 15-MW-AVR-Kernkraftwerk Jülich
15-MW-AVR-Nuclear Power Station | AVR
80.8-1

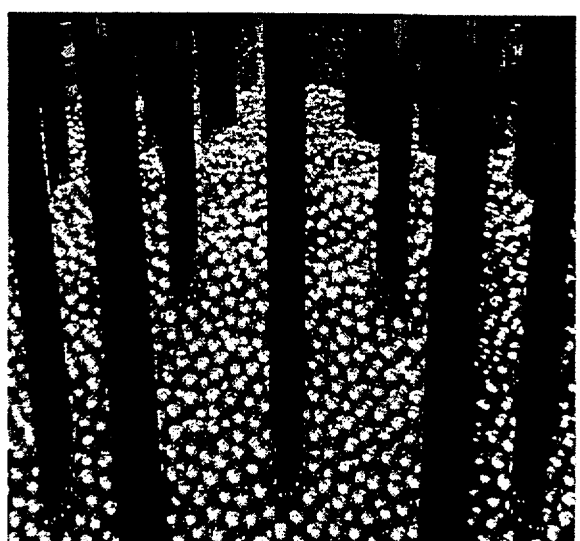
THTR-300

HRB | THTR-300
(rechts im Bild Trockenkühlturm und Baustelle des THTR-300) | THTR-300
81.37-5

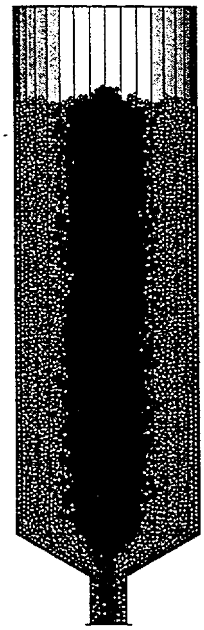
THTR Cut-Away



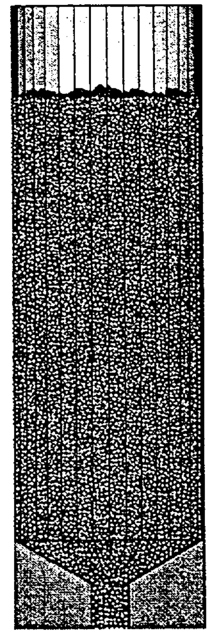
THTR Core



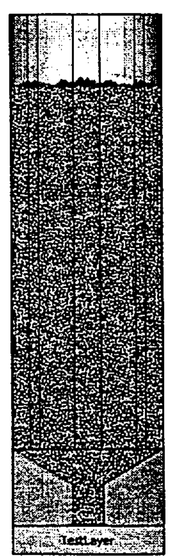
Core Sphere flow



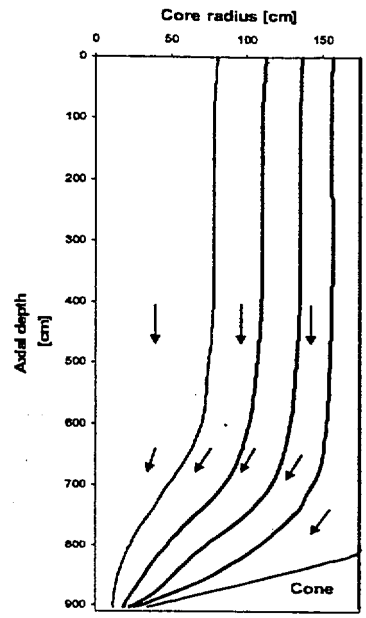
The motion of the fuel and graphite spheres in the PBMR core is an important area of study. Large scale simulations using the Discrete element modeling technique have been carried out.
The picture on the left shows simulation results for the core simulation, these results show a clearly defined two zone core.
A validation exercise has been undertaken. The animation on the right shows the simulated equivalent to the ANNABEK tests completed in Germany in the mid 80's. The correlation between simulation and experiment was within 10%.



ANNABEK Flow Model



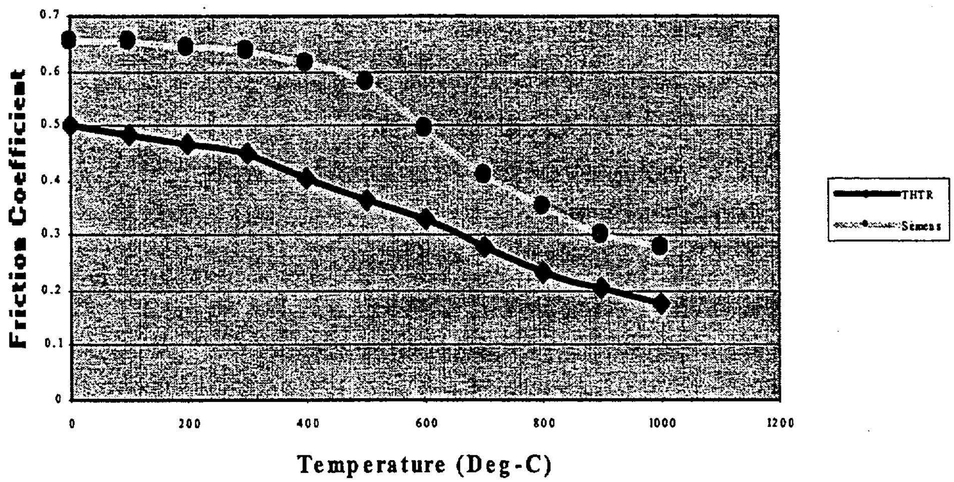
Pebble Flow Pattern



Factors Influencing Pebble Flow Pattern

- Core Height to Diameter Ratio
- Core Diameter to Extraction Tube Diameter Ratio
- Pressure Drop Across Bed
- Friction Coefficient Variation
- Fragments

Pebble Friction Coefficient in Helium

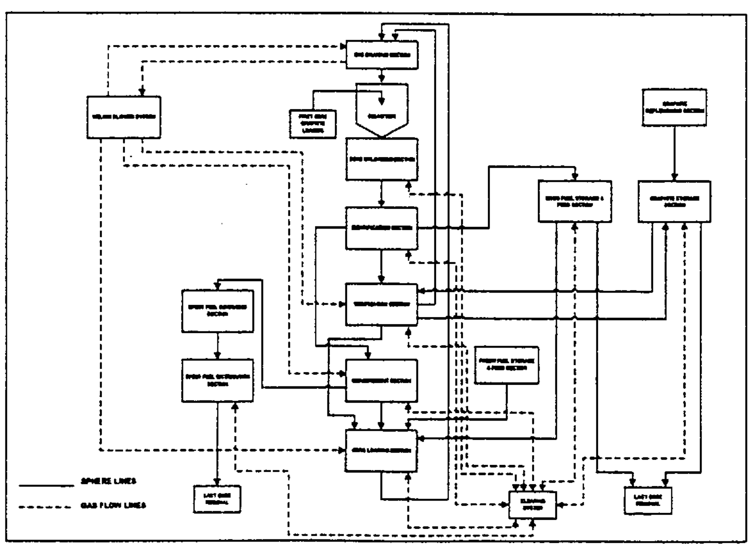


Historical Pebble Flow Data

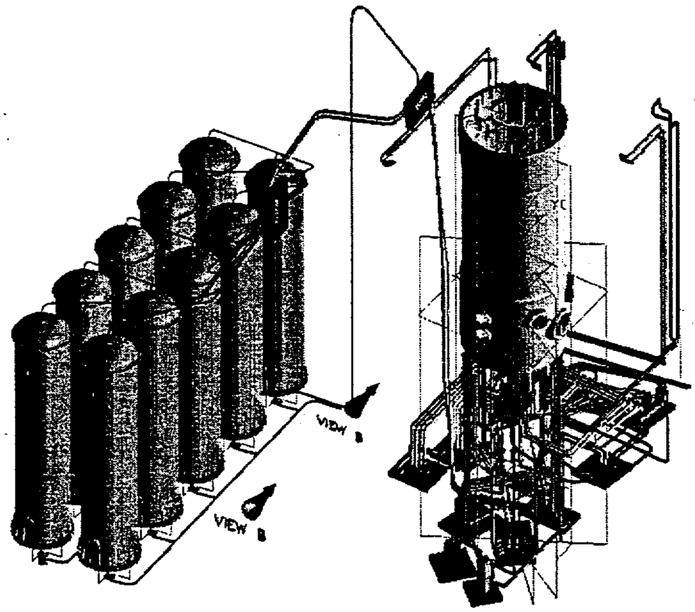
- **AVR**
  - 1:2
- **THTR**
  - Expected 1:3
  - Apparent 1:10 (may have been due to Pebble Fragments)
- **ANNABEK Experiment (1980s)**
  - 1:10 Scale; Glass/Graphite Pebbles; Air
- ***PBMR Prediction***
  - *1:1.6*

Pebble Bed FHSS Requirements

- **Maintain On-line Refueling**
  - ➢ Add Fresh Fuel Elements
  - ➢ Remove Spent Fuel Elements
- **Maintain Pebble Circulation**
  - ➢ MEDUL (multiple passes through the Core)
    - *Two Zone Core*
  - ➢ OTTO (Once Through Then Out)
- **Maintenance Requirements**
  - ➢ Unload/Reload Core (New Requirement)



PBMR FHSS Layout



The Fuel Handling and storage system (FHSS) is one of the PBMR Main support systems. It is very complex and accounts for over 50% of the PBMR control systems IO.
Its prime functions are the formation and maintenance of the two zone core and the online refueling of the PBMR.

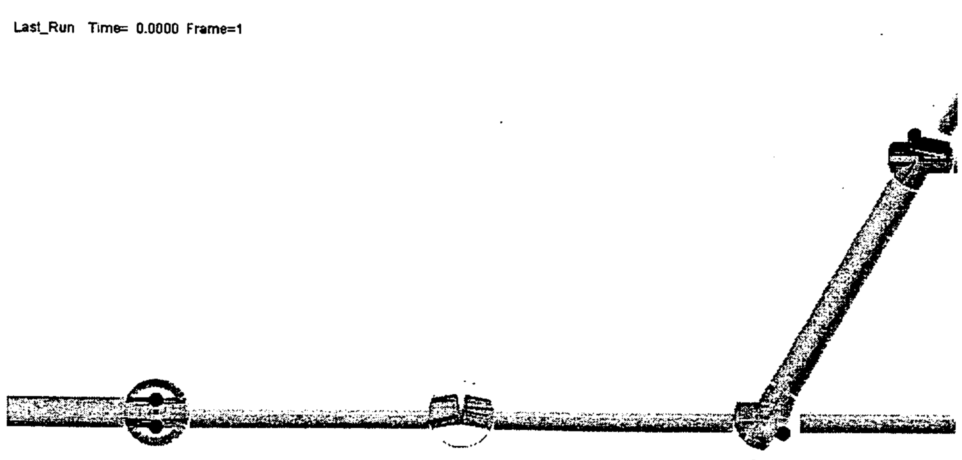
PBMR Design Approach

- **Follow THTR's Example to the Extent Practicable**
  - Functional Blocks Mounted in the Floor
  - Components Installed in Functional Blocks
  - All Components monitored for leaks
- **Improve Those Components with Known Deficiencies**
  - Pebble Counter
  - Core Unloading Device and Lead-in Plenum
- **Use Alternate Components where Circumstances Dictate**
  - Graphite/Fuel Discrimination Unit
  - Burnup Measurement

Types of Components

- **Components without Drives**
  - Pebble Counter
  - Identifier/Verifier (Ion Chamber)
  - Burn-up Measurement (Gamma-Spectrometer)
  - Pebble Braking Device
  - Filter
- **Components with Drives**
  - Core Unloading Device (CUD)
  - Fuel Loading Station
  - Double Seal Isolation Valves
  - Diverter
  - Collector
  - Indexer
  - Blower

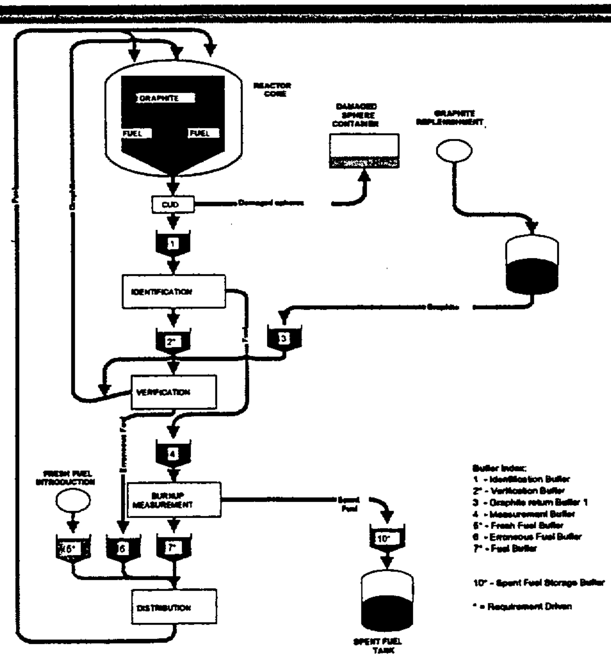
Some PBMR Components with Drives



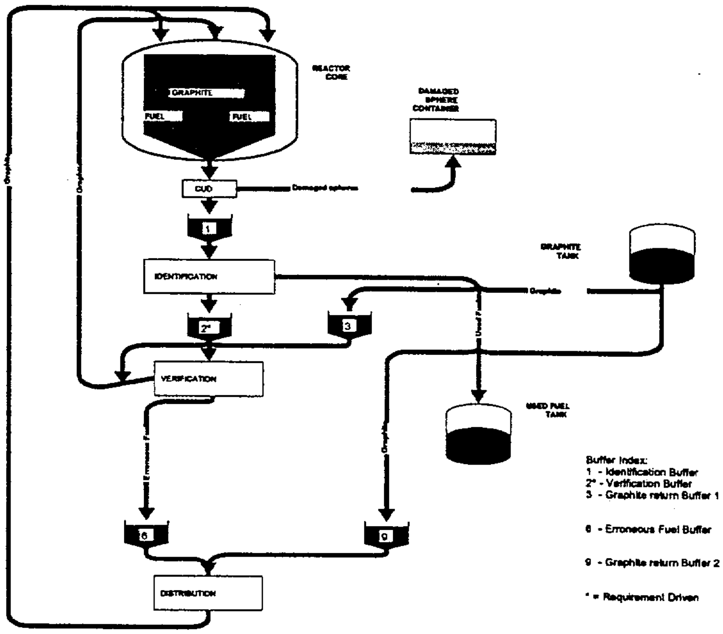
Key PBMR Operating Modes

- *Initial Core Loading*
- **Normal Online Refueling**
  - ➢ Circulation
  - ➢ Adding Fresh Fuel
  - ➢ Removing Spent Fuel
- **Core Unloading/Reloading for Maintenance**
- ***Final De-fueling***

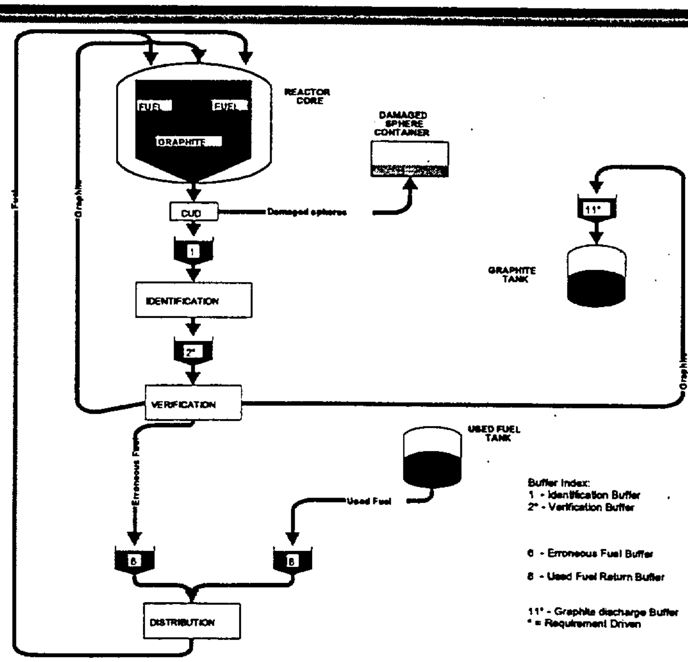
FHSS Normal Operation



FHSS Core Unloading



FHSS Core Reloading



General FHSS Characteristics

Characteristic	Value	Units
Daily Sphere Circulation Rate (normal)	5720	spheres/ FPD
Sphere circulation rate (normal)	515	spheres/hr
Sphere circulation rate (max)	900	spheres/hr
Daily operating time (normal)	12	hr/FPD
Number of fuel passes through core (nominal)	10	-
FHSS operating pressure	1 to 7.2	MPa
FHSS operating temperature	0 to 260	° C
Total spheres in core (nominal)	440 000	spheres
Core sphere composition	75	% fuel

General FHSS Characteristics (continued)

Fuel spheres in core	330 000	spheres
Fuel sphere feeding points in core	9	-
Graphite sphere feeding points in core	1	-
Fresh fuel storage capacity	70	canisters
Fresh fuel canister capacity	1000	spheres
Reactor fuel consumption (at full power)	375	spheres/FPD
Spent fuel storage capacity	5 000 000	spheres
Number of Spent Fuel Tanks	10	-
Storage medium	helium	at 100 kPa

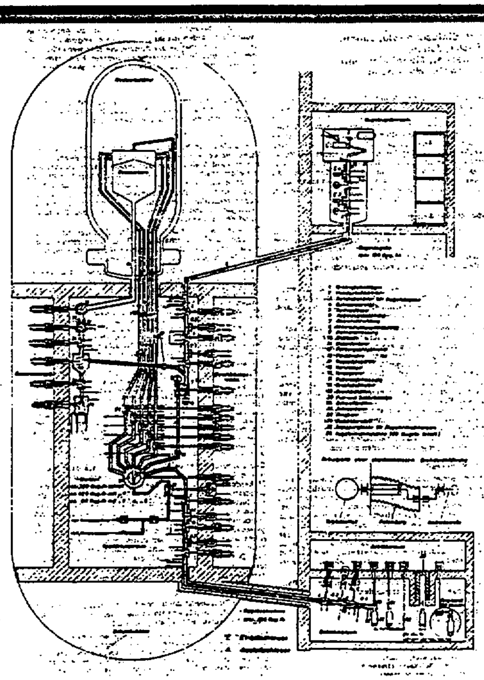
General FHSS Characteristics (continued)

Storage period	80	yrs
Spent fuel burn-up	80 000	MWd/tU
Spent fuel heat load (max per tank)	48	kW
Spent fuel storage temperature (max)	375	° C
Spent fuel tank wall temperature (max)	175	° C
Used Fuel Tank storage capacity	330 000	spheres
Time to unload full core of fuel	26	days
Used fuel tank decay heat load	0.6	MW

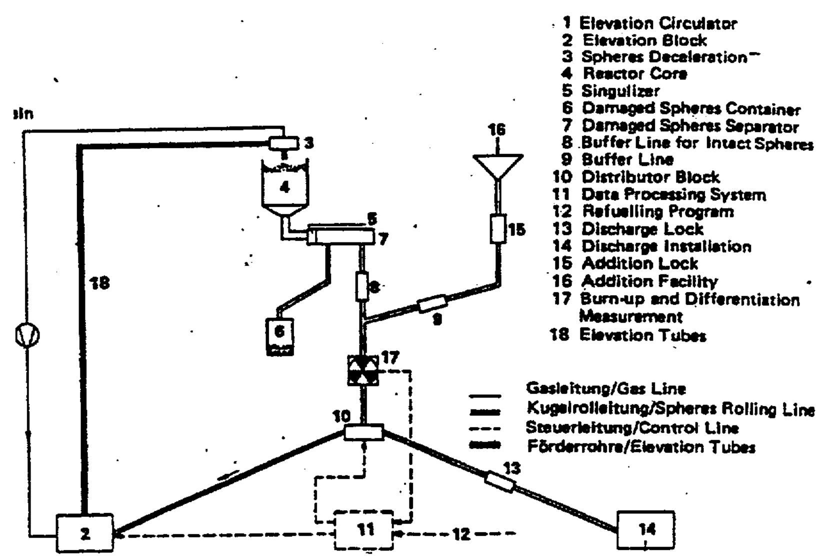
Pebble Bed FHSS Experiences

- **AVR Operated Over 20 Years With Good Experience (2.4 Million pebbles processed)**
  - Only 3% Outage due to FHSS
  - Problems with Core Unloading Device (singulizer) and Electric Motor Drives
- **THTR Limited Experience Showed Improvements and New Problems**
  - Revised Core Unloading Device (CUD), Changed Drives from Electro to Pneumatic
  - Problem with Core Discharge Tube (lead-in to the CUD)
  - Problem with Addressing of Pebbles
- **PBMR Design Based on Previous German Experience**
  - Retained Proven Components
  - Revise Core Discharge Area
  - Improved Pebble Counters
  - Change Burnup Measurement

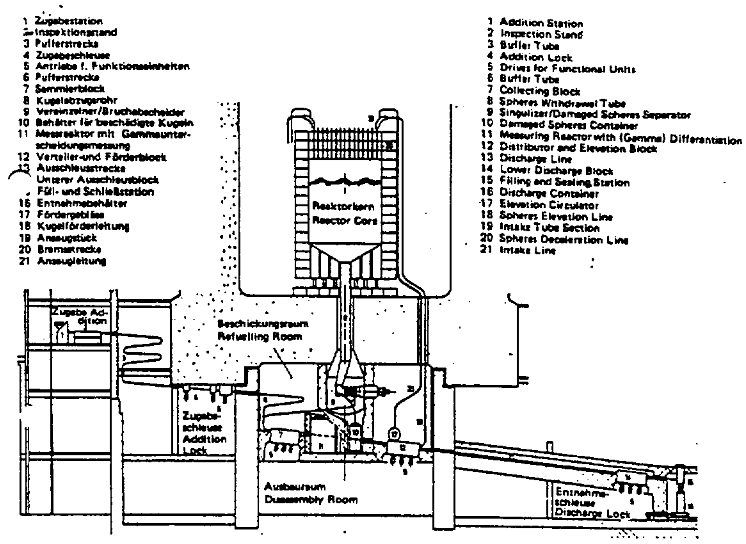
AVR FHSS Layout



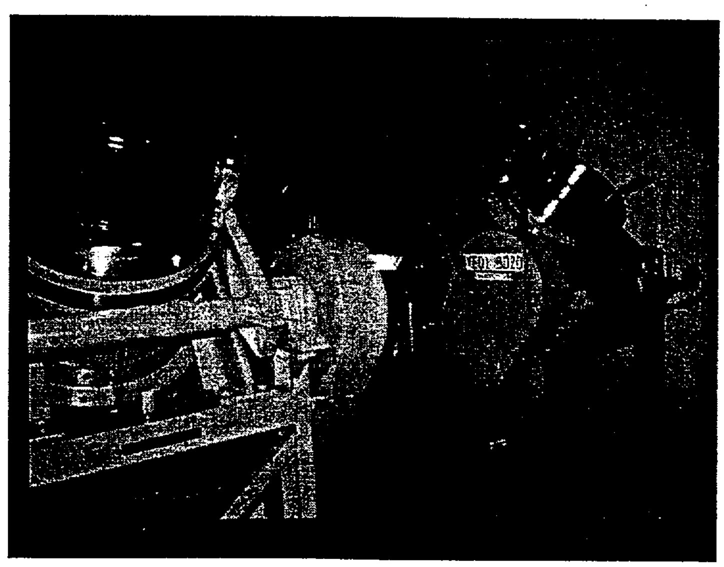
THTR FHSS Process



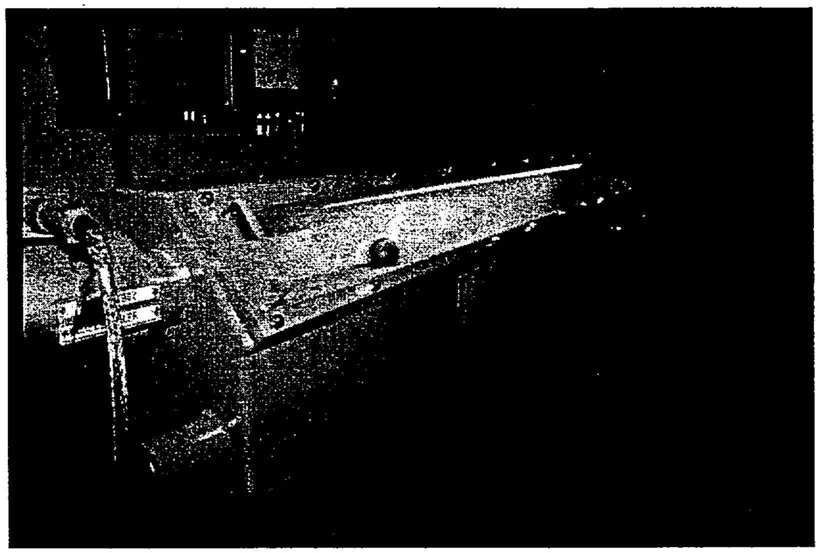
THTR FHSS Layout



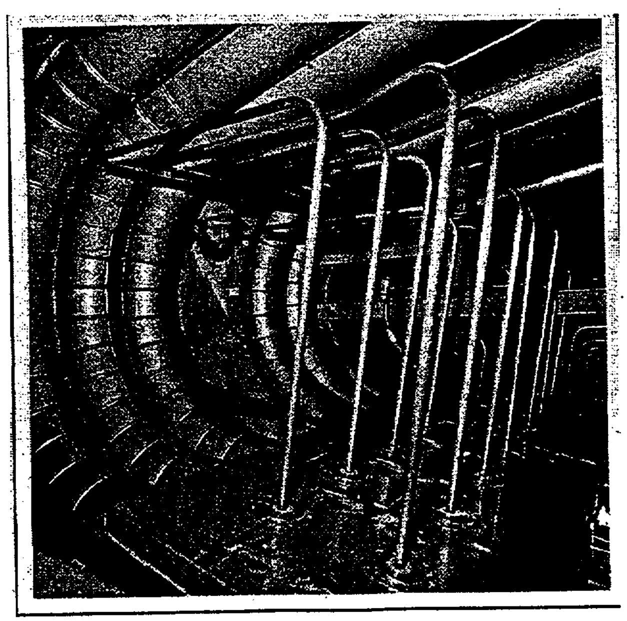
THTR Fuel Loading Station



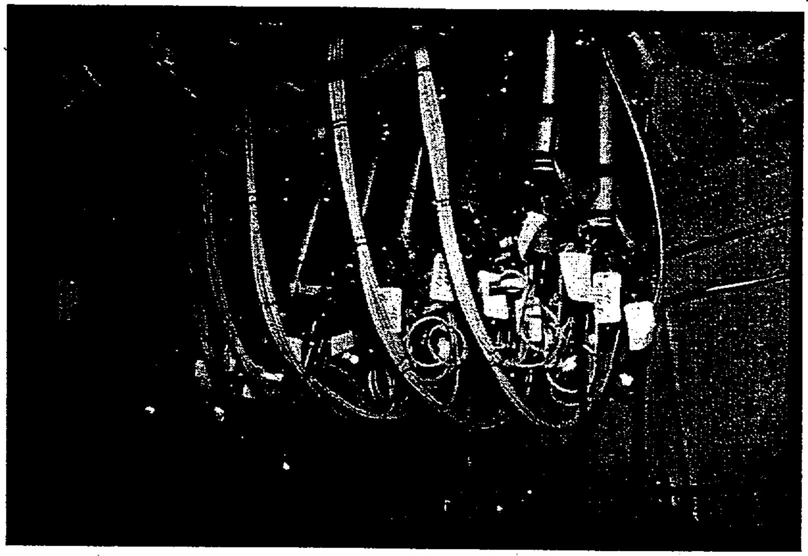
THTR Fuel Inspection Station



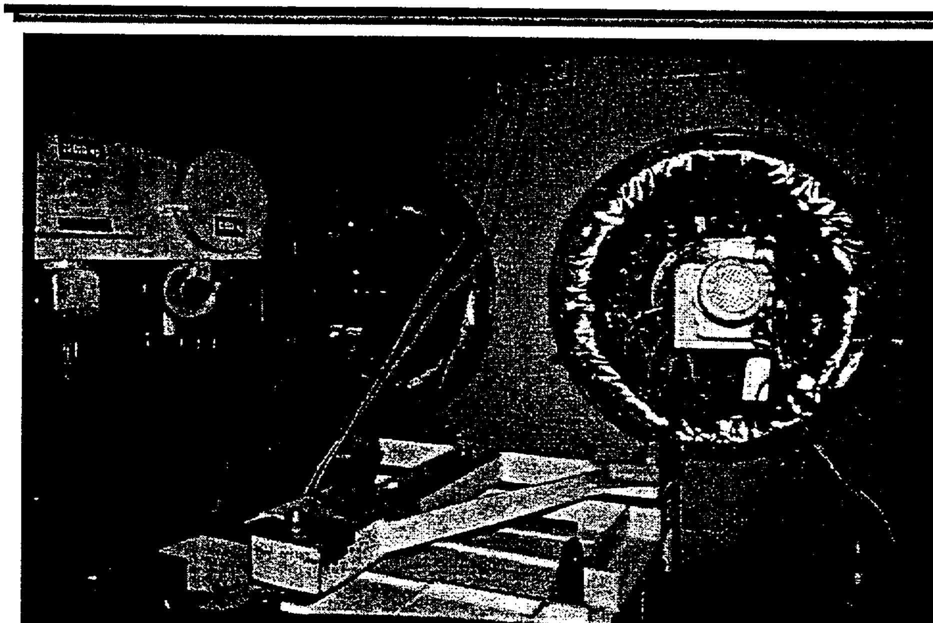
THTR FHSS R121



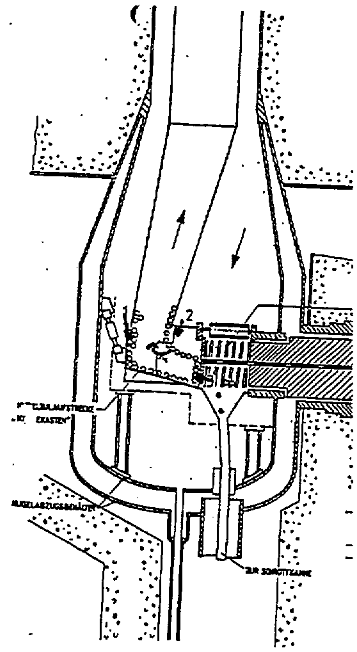
THTR FHSS Block



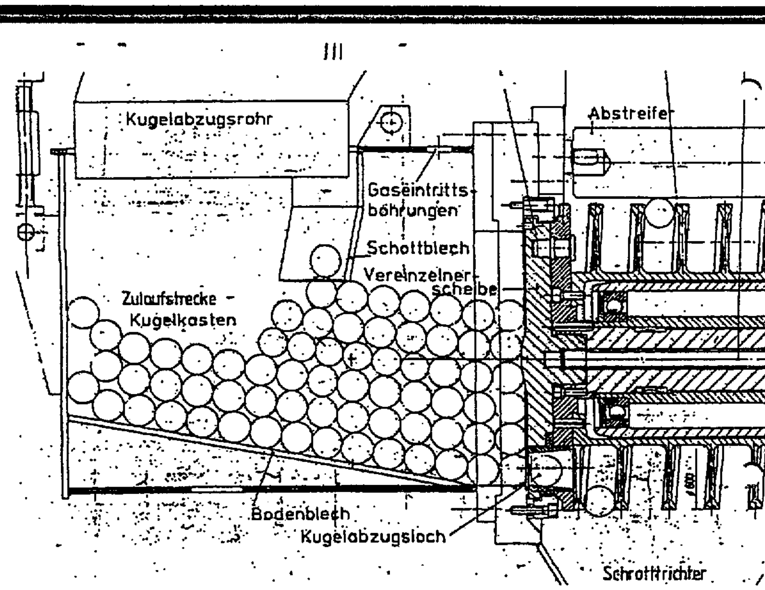
THTR Core Unloading Device



THTR CUD Inlet Plenum



THTR CUD



What Technology Development is Needed

- Fundamentally All Required Technology Exists
- Some Evolutionary Development May Help Improve Operability or Maintainability and may Help Reduce Cost