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Joint ICTP-IAEA Workshop on Nuclear Reaction Data for Advanced Reactor Technologies

19 - 30 May 2008

Gas-Cooled Reactors – International Reactor Physics Experimental Benchmark Analysis.

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Prescott
USA

IAEA-ICTP Workshop on Nuclear Reaction Data for Advanced Reactor Technologies

ICTP – Trieste, Italy, 18-30 May 2008

Gas-Cooled Reactors – International Reactor Physics Experimental Benchmark Analysis

J. M. Kendall
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Benchmark Activities

IAEA-TECDOC-1249

- **PROTEUS (Pebble Bed) Critical Facility**
- **VHTRC (Prismatic Block) Critical Facility**

IAEA-TECDOC-1382

- **HTR-10 (Pebble Bed) Core Physics**
- **HTTR (Prismatic Block) Core Physics**

http://www.iaea.org/inisnkm/nkm/aws/htgr/abstracts/index.html

IAEA TECDOCS: HTGR (index) - Windows Internet Explorer

http://www.iaea.org/inisnkm/nkm/aws/htgr/abstracts/index.html

Nuclear Energy Knowledge Resources

Find-an-Expert Facility

Nuclear Reactors Knowledge Base

- **High Temperature Gas Cooled Reactor Knowledge Base**

subject index

country index

search

- Fast Reactors and Accelerator Driven
- Nuclear Desalination
- Light Water Cooled Reactors

IAEA Web Resources

Internet Directory

Energy & Env. Data Reference Bank

International Nuclear Information System

Bibliometric Studies

see also:

Nuclear Power

HTGR Knowledge Base

Subject Index to Technical Documents

HTR Conferences

Conference on High Temperature Reactors (HTR-2004)
Proceedings of the Conference on High Temperature Reactors, Beijing, China, September, 22-24, 2004

Conference on High Temperature Reactors (HTR-2002)
Proceedings of the Conference on High Temperature Reactors, Petten, NL, April 22-24, 2002
Organized by HTR-TN in cooperation with the European Nucler Society (ENS) and the IAEA

Reactor Design and General Technology

Evaluation of high temperature gas cooled reactor performance: Benchmark analysis related to initial testing of the HTTR and HTR-10 (IAEA-TECDOC--1382)

Current status and future development of modular high temperature gas cooled reactor technology (IAEA-TECDOC--1198)
Overview of HTGR technology development as of 2001

High temperature gas cooled reactor technology development. (IAEA-TECDOC--988)
Technical committee meeting on high temperature gas cooled reactor technology development. Johannesburg (South Africa). 13-15 Nov 1996.

Design and development of gas cooled reactors with closed cycle gas turbines. (IAEA-TECDOC--899)
Technical committee meeting on design and development of gas cooled reactors with closed cycle gas turbines. Beijing (China). 30 Oct - 2 Nov 1995.

Gas-cooled fast reactors. (IAEA-TECDOC--154)
Proceedings of the IAEA study group meeting sponsored by the USSR State Committee on the Utilization of Atomic Energy, held at the Institute of Nuclear Energy of the Byelorussian Academy of Sciences Minsk, 24-28 July 1972

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http://www.iaea.org/inisnkm/nkm/aws/htgr/abstracts/index.html

IAEA TECDOCS: HTGR (index)

see also:

Nuclear Power Technology Development Section

-- SMRs

-- LWRs and HWRs

-- Fast Reactors and Hybrid Systems

-- HTGRs

-- Nuclear Desalination

-- INPRO

-- Reactor Simulators

Power Reactor Information System (PRIS)

Technical committee meeting on design and development of gas cooled reactors with closed cycle gas turbines. Beijing (China). 30 Oct - 2 Nov 1995.

Gas-cooled fast reactors. (IAEA-TECDOC--154)
Proceedings of the IAEA study group meeting sponsored by the USSR State Committee on the Utilization of Atomic Energy, held at the Institute of Nuclear Energy of the Byelorussian Academy of Sciences Minsk, 24-28 July 1972.

Component Technology

Critical experiments and reactor physics calculations for low-enriched HTGRs (IAEA-TECDOC--1249)
Results of an IAEA Co-ordinated Research Project in support of validation of reactor physics codes for modular HTGRs conducted 1990-1996

Gas turbine power conversion systems for modular HTGRs (IAEA-TECDOC--1238)
IAEA Technical Committee Meeting on "Gas Turbine Power Conversion Systems for Modular HTGRs", held from 14-16 November 2000 in Palo Alto, California

Uncertainties in physics calculations for gas cooled reactor cores. (IWGGCR--24)
Uncertainties in physics calculations for gas cooled reactor cores. Proceedings of a specialist's meeting held in Villigen, Switzerland, 9-11 May 1990

Seismic behaviour of gas cooled reactor components. (IWGGCR--22)
Seismic behaviour of gas cooled reactor components. Proceedings of a specialists' meeting held in Gif-sur-Yvette, France, 14-16 November 1989

Gas-cooled reactor coolant circulator and blower technology (IWGGCR--17)
Specialists' meeting on gas-cooled reactor coolant circulator and blower technology. San Diego, CA (USA). 30 Nov - 2 Dec 1987

Technology of steam generators for gas-cooled reactors (IWGGCR--15)
Specialists' meeting on technology of steam generators for gas-cooled reactors Winterthur (Switzerland) 9-12 Mar 1987

Graphite component structural design (IWGGCR--11)
Specialists' meeting on graphite component structural design, JAERI Tokai (Japan), September 8-11, 1986

Heat exchanging components of gas-cooled reactors (IWGGCR--9)
Specialists' meeting on heat exchanging components of gas-cooled reactors Duesseldorf (Germany) 16-19 Apr 1984

Gas-cooled reactor fuel development and spent fuel treatment (IWGGCR--8)
Specialists' meeting on gas-cooled reactor fuel development and spent fuel treatment Moscow (Russian Federation) 18-21 Oct 1983

Materials Technology

Irradiation damage in graphite due to fast neutrons in fission and fusion systems (IAEA-

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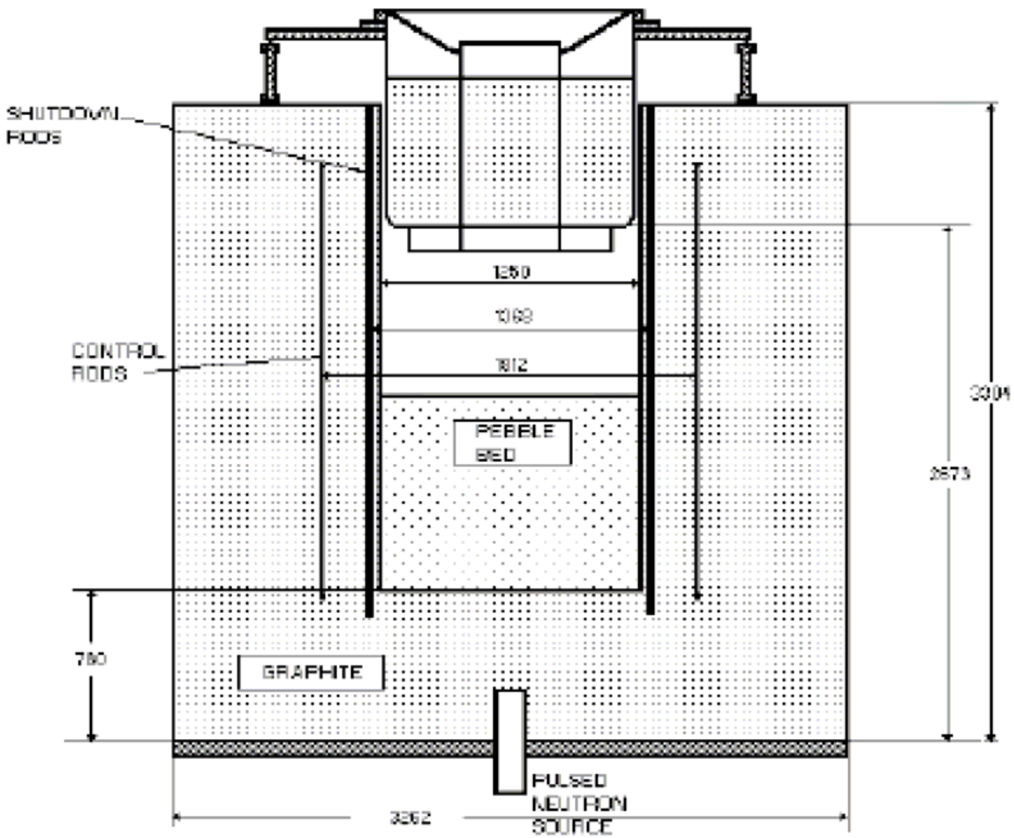
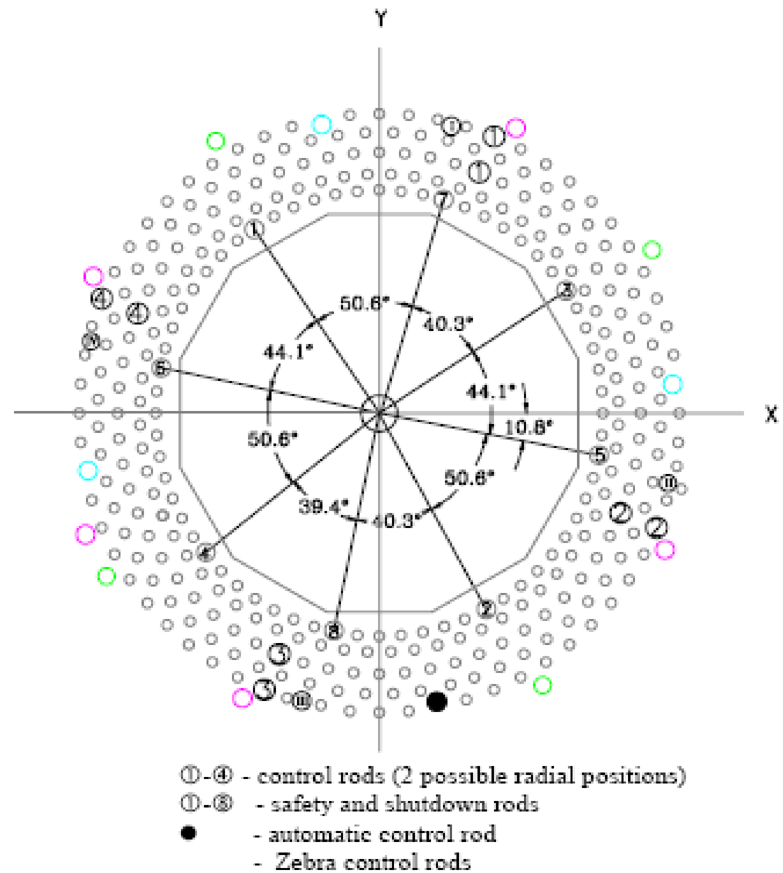
PROTEUS Benchmarks

- Critical Balances
- Reaction rate ratios and distributions
- Control rod worths
- Water ingress effects
- Reactivity of small samples
- Kinetic parameter (β/Λ)

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

PROTEUS Benchmarks





IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

PROTEUS Benchmarks

CORE	DATES	F:M	PACKING	COMMENTS
G1	3/92-5/92	-	-	ONLY PNS MEASUREMENTS , NO FUEL IN CAVITY, WITH AND WITHOUT MODERATOR PEBBLES. ZEBRA RODS IN-SITU
1	7/92-6/93	2:1	HCP	ONLY CORE WITH ZEBRA RODS
1A	6/93-8/93, 2/94-3/94	2:1	HCP	CORE 1 WITH ZEBRA RODS REPLACED BY CONVENTIONAL CONTROL RODS
2	8/93-10/93	2:1	HCP	CORE 1A WITH FIVE FUELED LAYERS REPLACED BY MODERATOR PEBBLES - "CAVITY EFFECT"
G2	10/93	-	-	PNS MEASUREMENTS WITHOUT FUEL IN CAVITY. ZEBRA RODS COMPLETELY REMOVED
3	10/93-2/94	2:1	HCP	CORE 1A WITH SIMULATED WATER INGRESS - EVERY AVAILABLE VERTICAL CHANNEL CONTAINED A 9mm CH_2 ROD
4(1,2,3)	3/94-6/94	1:1	RANDOM	THIS CONFIGURATION REPEATED THREE TIMES
5	7/94-4/95, 11/95-1/96	2:1	P-O-P	FIRST COLUMN HEX LOADING
6	4/95-5/95	2:1	P-O-P	CORE 5 WITH MAXIMUM CH_2 LOADING, COMPENSATED WITH COPPER WIRE
7	5/95-10/95	2:1	P-O-P	CORE 5 WITH MAXIMUM CH_2 LOADING, COMPENSATED BY REDUCING CORE HEIGHT
8	1/96-2/96	2:1	P-O-P	CORE 5 WITH EVERY VERTICAL CHANNEL CONTAINING A 15cm LONG TRIANGULAR CH_2 ROD
9	2/96-5/96	1:1	P-O-P	CORE 5 REPEATED WITH F:M OF 1:1
10	5/96-6/96	1:1	P-O-P	CORE 9 WITH MAXIMUM CH_2 LOADING, COMPENSATED BY REDUCING CORE HEIGHT

HCP = hexagonal close packed
P-O-P = point-on-point (column hexagonal),

F:M = fuel-to-moderator ratio
[shaded] indicates simulated water ingress in this core

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

PROTEUS Benchmarks

	CRITICAL LOADING	Σ_a	SUBCRIT CORE	SHUTDOWN RODS		CONTROL RODS		UPPER REFL.	β/A	MEAS. RODS	CENT. CONT. ROD	TEMP. COEFF	COM-PONENT WORTHS	MISC.
METHOD / CORE	PEBBLE COUNT	PNS	PNS	PNS	IK	SP	PNS	PNS (SP)	PNS	PNS	PNS	COMP	COMP	-
G1		✓												
1	✓		✓	✓	✓	✓	✓		✓	✓			✓	
1A	✓				✓	✓								
2	✓			✓	✓	✓	✓	✓	✓					
G2		✓												
3	✓		✓	✓	✓	✓	✓		✓					
1A	✓			✓		✓								
4(1)	✓					✓								
4(2)	✓			✓	✓	✓								
4(3)	✓			✓		✓								
5	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	water/ CH_2 CH_2 in lower axial reflector
6	✓					✓								
7	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		water/ CH_2 CH_2 in lower axial reflector
8	✓						✓							
9	✓				✓	✓	✓	✓	✓	✓				
10	✓		✓		✓	✓	✓	✓	✓	✓				subcriticalit y with CH_2 removed

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

PROTEUS Benchmarks

Methods - Critical Balances Including Streaming

At PSI:	The TWODANT [8.1] transport theory code with cross sections obtained from the MICROX-2 [8.2] cell calculation code, using JEF-1 based nuclear data, as well as the MCNP-4B [8.3] Monte Carlo code using an ENDF/B-V based continuous cross-section data library.
At IRI:	The DORT [8.4] transport theory and the BOLD-VENTURE [8.5] diffusion theory codes with inputs processed by the INAS code system (IRI-NJOY-AMPX-SCALE) [8.6] using JEF-2.2 basic nuclear data files, as well as the multigroup Monte Carlo code KENO-Va.
At JAERI:	The SRAC95 [8.7] code system with its library based on both ENDF/B-IV and JENDL-3.2.
At KFA:	The CITATION diffusion calculation code, part of the VSOP [8.8] code system using JEF-1 and ENDF/B-V based libraries.
At INET:	The VSOP computer code system.

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

PROTEUS Benchmarks

Experimental and Calculated Critical Balances
Cores 1A, 2, 3 and 4.3

	Core 1A	Core 2	Core 3	Core 4.3
experimental	1.0147±0.0006	1.0106±0.0006	1.0033±0.0004	1.0132±0.001
VSOP (INET)	1.01299	1.00389	1.01333	1.00512
C/E	**0.9983±0.0006**	**0.9934±0.0006**	**1.0100±0.0004**	**0.992±0.001**
VSOP (KFA)	-	-	-	1.0246
C/E	-	-	-	**1.011±0.001**
SRAC-ENDF/B-IV (JAERI) *	1.0384	1.0376	-	-
C/E	**1.0234±0.0006**	**1.0267±0.0006**	-	-
SRAC-JENDL-3.2 (JAERI) *	1.0427	1.0412	-	-
C/E	**1.0276±0.0006**	**1.0303±0.0006**	-	-

* Not corrected for streaming effect

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

PROTEUS Benchmarks

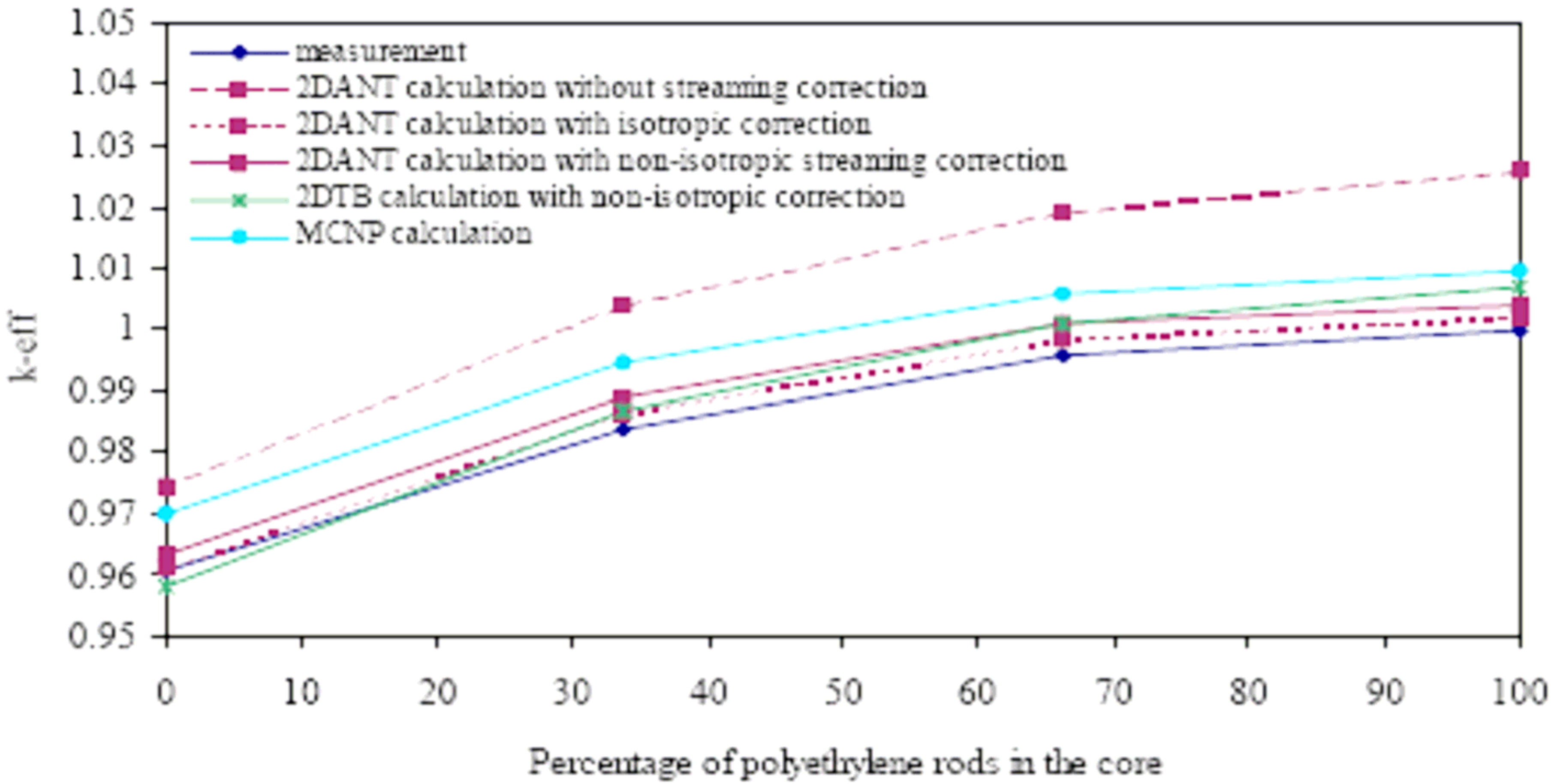
Experimental and Calculated Critical Balances
Cores 5, 7, 9 and 10

	Core 5	Core 7	Core 9	Core 10
experimental	1.0112±0.0005	1.0067±0.0004	1.0142±0.0007	1.0075±0.0001
TWODANT (PSI)	1.0218	1.0384	1.0262	1.0330
C/E	**1.0105±0.0005**	**1.00315±0.0004**	**1.0118±0.0007**	**1.0253±0.0001**
DORT (IRI)	1.03126	1.03962	1.03017	1.03395
C/E	**1.0198±0.0005**	**1.0327±0.0004**	**1.0157±0.0007**	**1.0263±0.0001**
BOLD-VENTURE (IRI)	1.03147	1.03600	1.03018	1.03138
C/E	**1.0200±0.0005**	**1.0291±0.0004**	**1.0158±0.0007**	**1.0237±0.0001**
SRAC-ENDF/B-IV (JAERI)	1.0358	1.0515	-	-
C/E	**1.0243±0.0005**	**1.0445±0.0004**	-	-
SRAC-JENDL-3.2 (JAERI)	1.0394	1.0545	-	-
C/E	**1.0289±0.0005**	**1.0475±0.0004**	-	-
VSOP (KFA)	1.0379	1.0446	-	-
C/E	**1.0264±0.0005**	**1.0376±0.0004**	-	-
KENO (IRI)	1.03125±0.0007	1.03881±0.0006	1.02933±0.0005	1.03222±0.0005
C/E	**1.0198±0.0009**	**1.0319±0.0007**	**1.0149±0.0009**	**1.0245±0.0005**

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

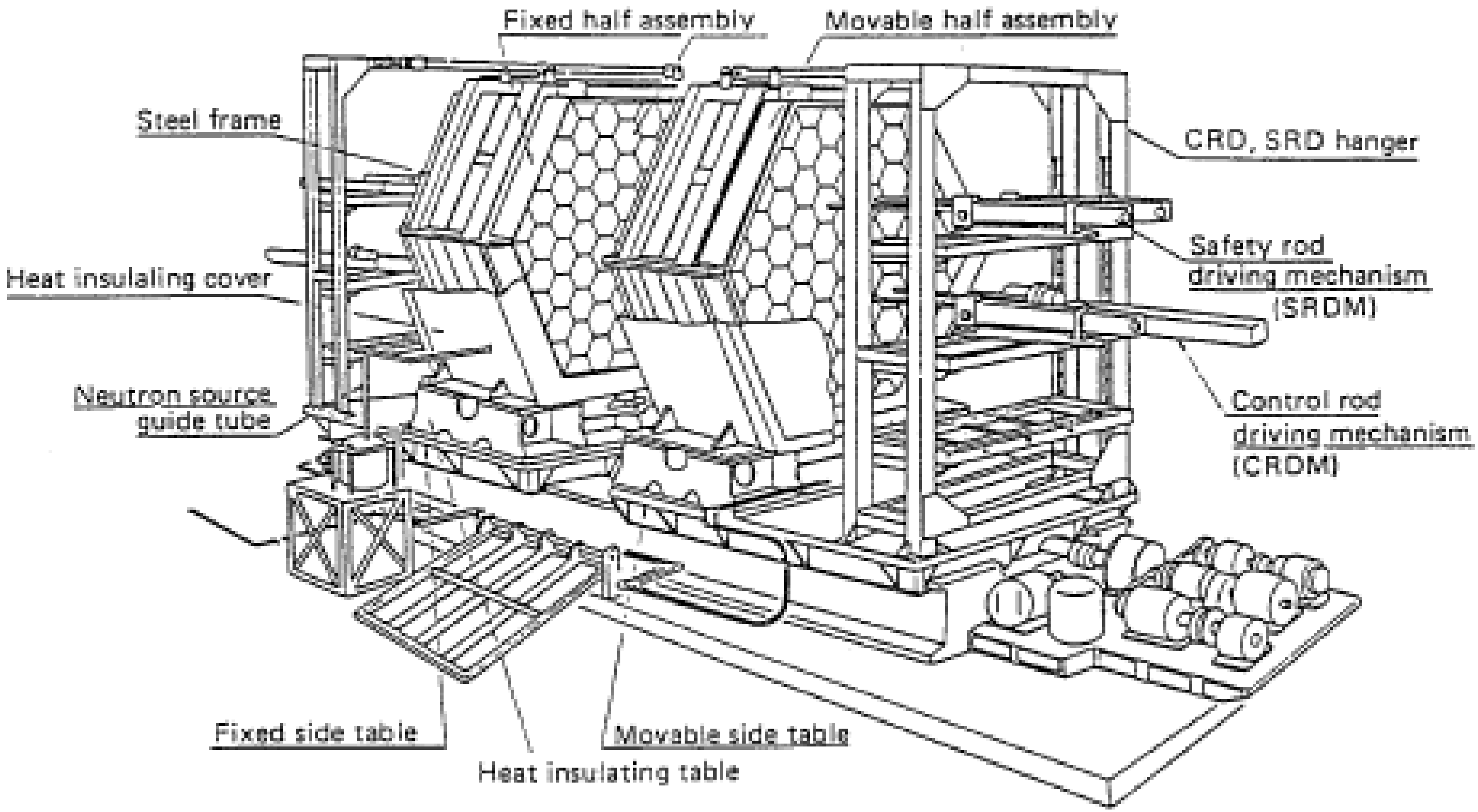
PROTEUS Benchmarks

Reactivity vs. Percentage of Polyethylene Rods in Core 10



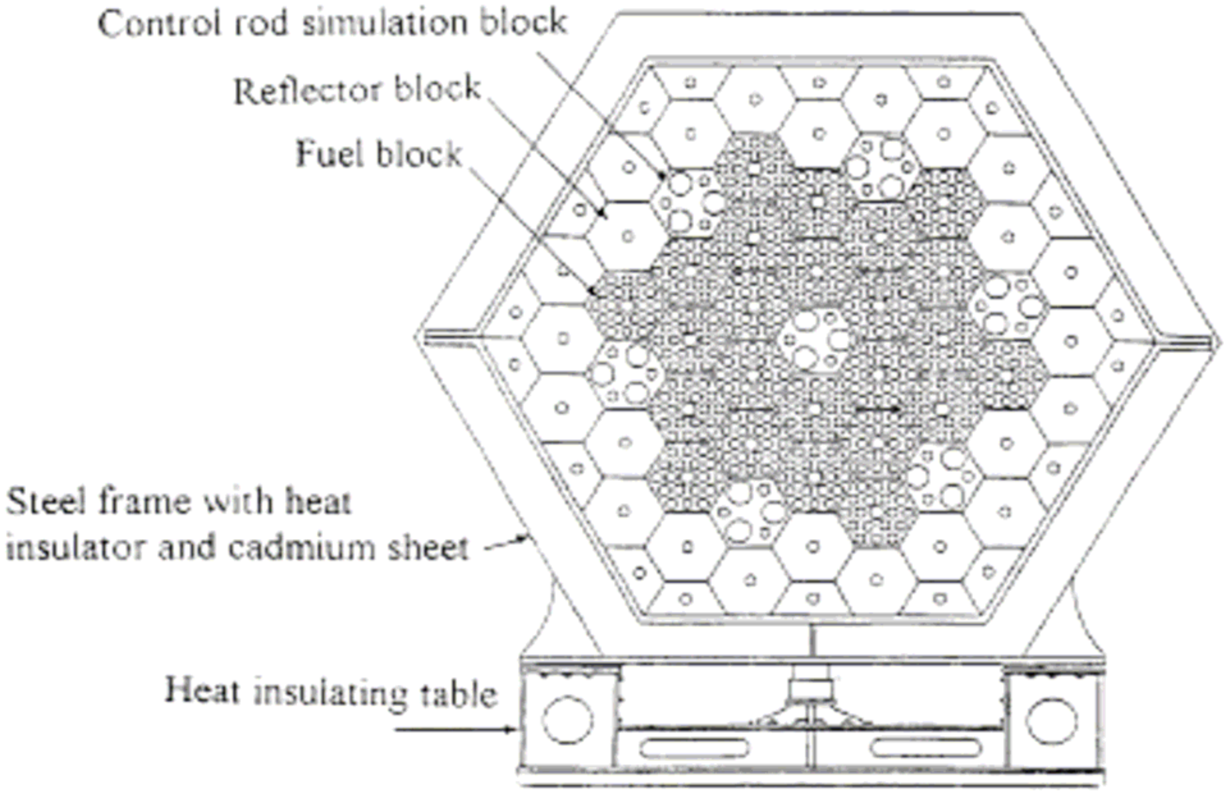
IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

VHTRC Benchmark



IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

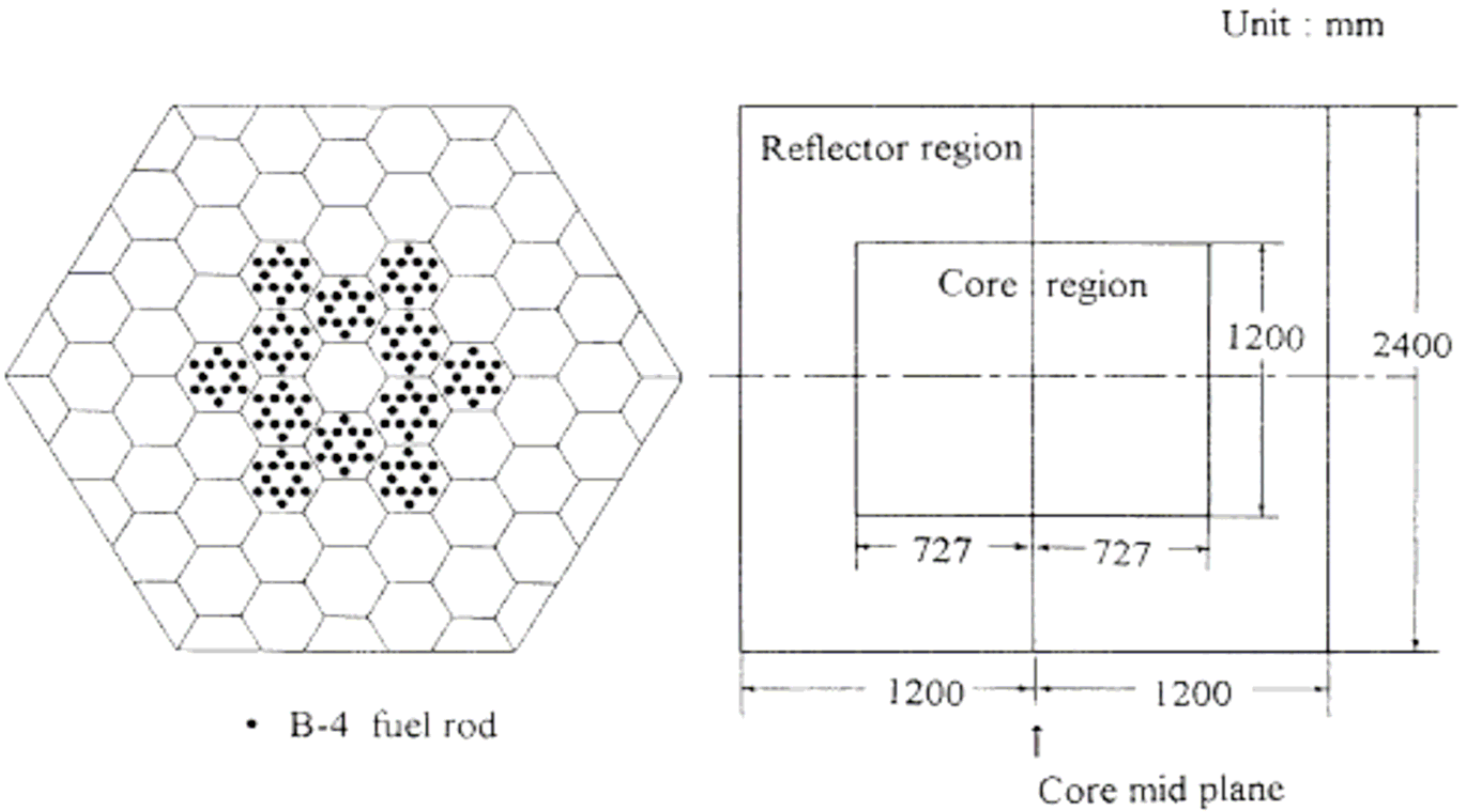
VHTRC Benchmark



Circles in core and reflector indicate graphite rods. The rods in core can be replaced with fuel rods, while those in reflector can be replaced with heater rods.

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

VHTRC Benchmark



IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

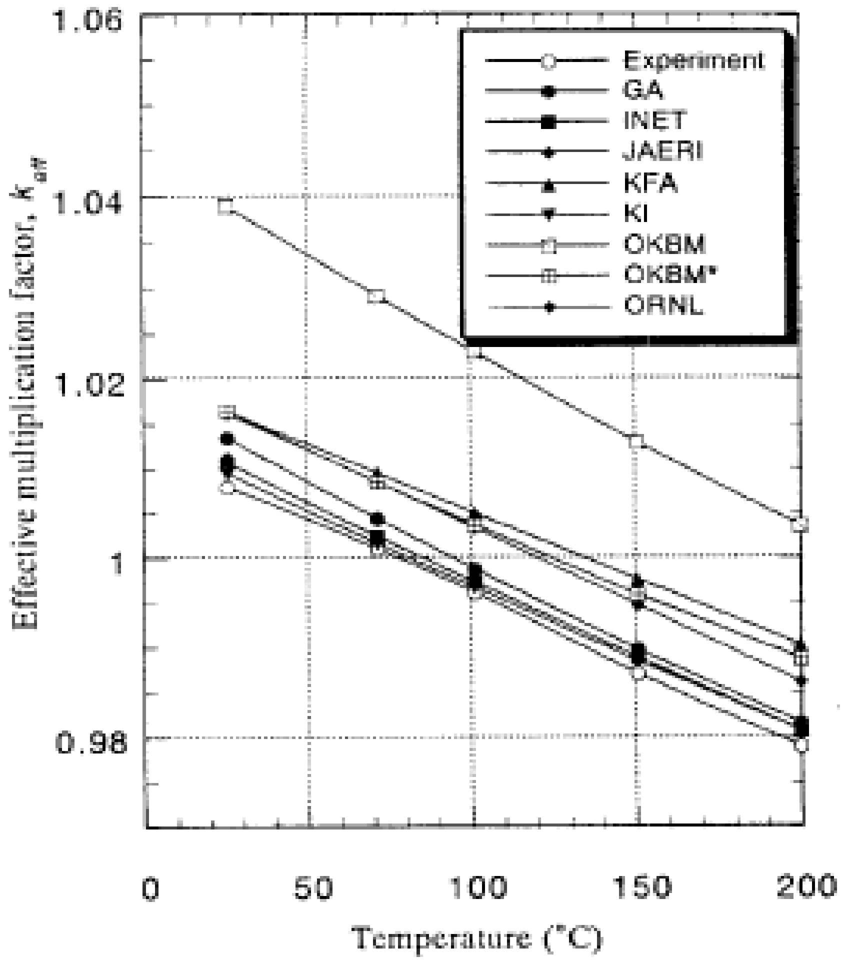
VHTRC Benchmark

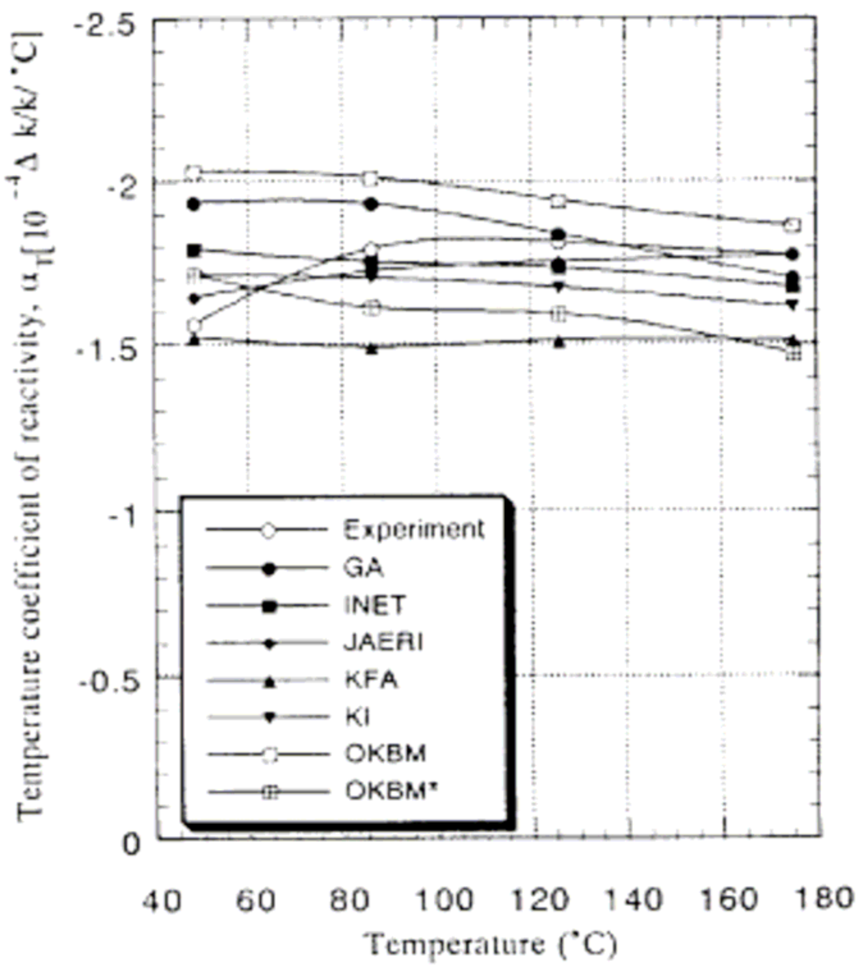
Institute	Nuclear data	Resonance calculation		Cell calculation			Whole reactor calculation		
		Code	Group	Code	Group	Geometry	Code	Group	Geometry
GA	ENDF / B-V	GAR	9k–15k	GAM GATHER MICROX	92 101 92+101	Coaxial cylinders	DIF3D	9	3D(T-Z)
INET	ENDF / B-IV	ZUT		GAM THERMOS		Cylinder	CITATION	4	2D(R-Z)
JAERI	ENDF / B-IV ENDF / B-III	PEACO	4.6k	[SRAC] PIJ	21+41	Hexagonal cylinder	[SRAC] CITATION	25	3D(T-Z)
KFA	ENDF / B-V JEF-1	ZUT-DGL		[VSOP] GAM THERMOS		Cylinder	[VSOP] CITATION	5	2D(R-Z)
KI	Domestic	Experiment correlated		FLY	26+77	Cylinder	CONSUL (Diffusion)	4	3D(T-Z)
OKBM	Domestic UKNDL	NEKTAR (plane)		WIMS-D4 THERMOS	67	Cylinder	JAR (Diffusion)	2	3D
ORNL	ENDF/B-V	[MCNP] V 4.X	Conti.	[MCNP] V 4.X	Cont.	Hexagonal cylinder	[MCNP] V 4.X	Cont.	3D(xyz)

Cont. : Continuous energy

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

VHTRC Benchmark

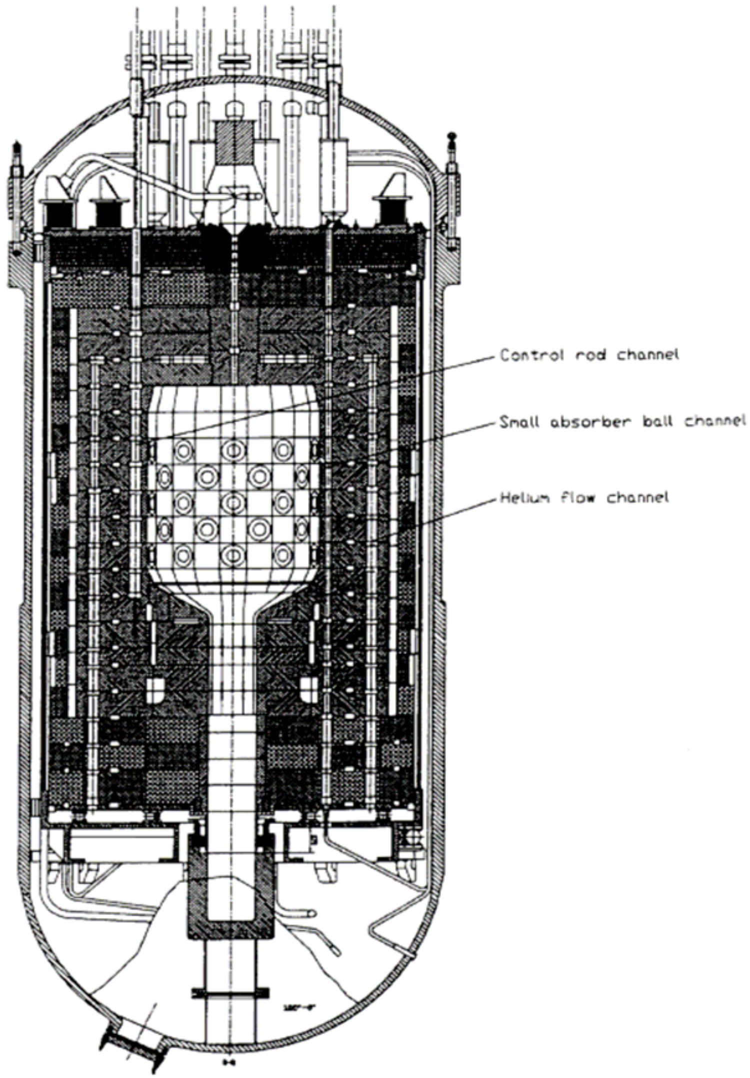


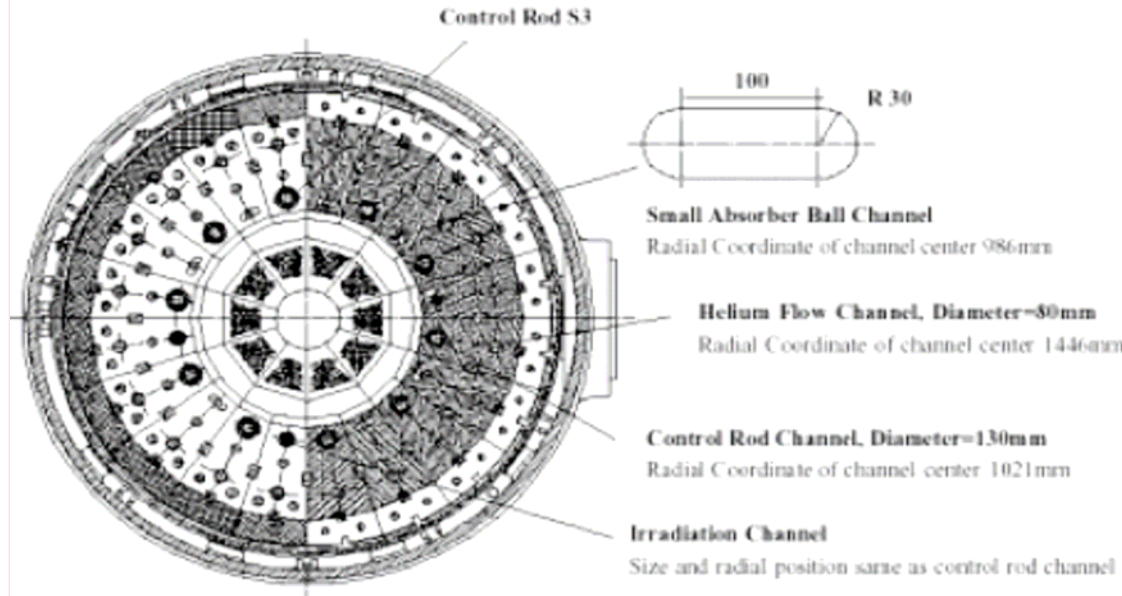


OKBM* - Macroscopic cross sections by WIMS-D4/UKNDL

IAEA-TECDOC-1249, Critical experiments and reactor physics calculations for low enriched high temperature gas cooled reactors, October 2001.

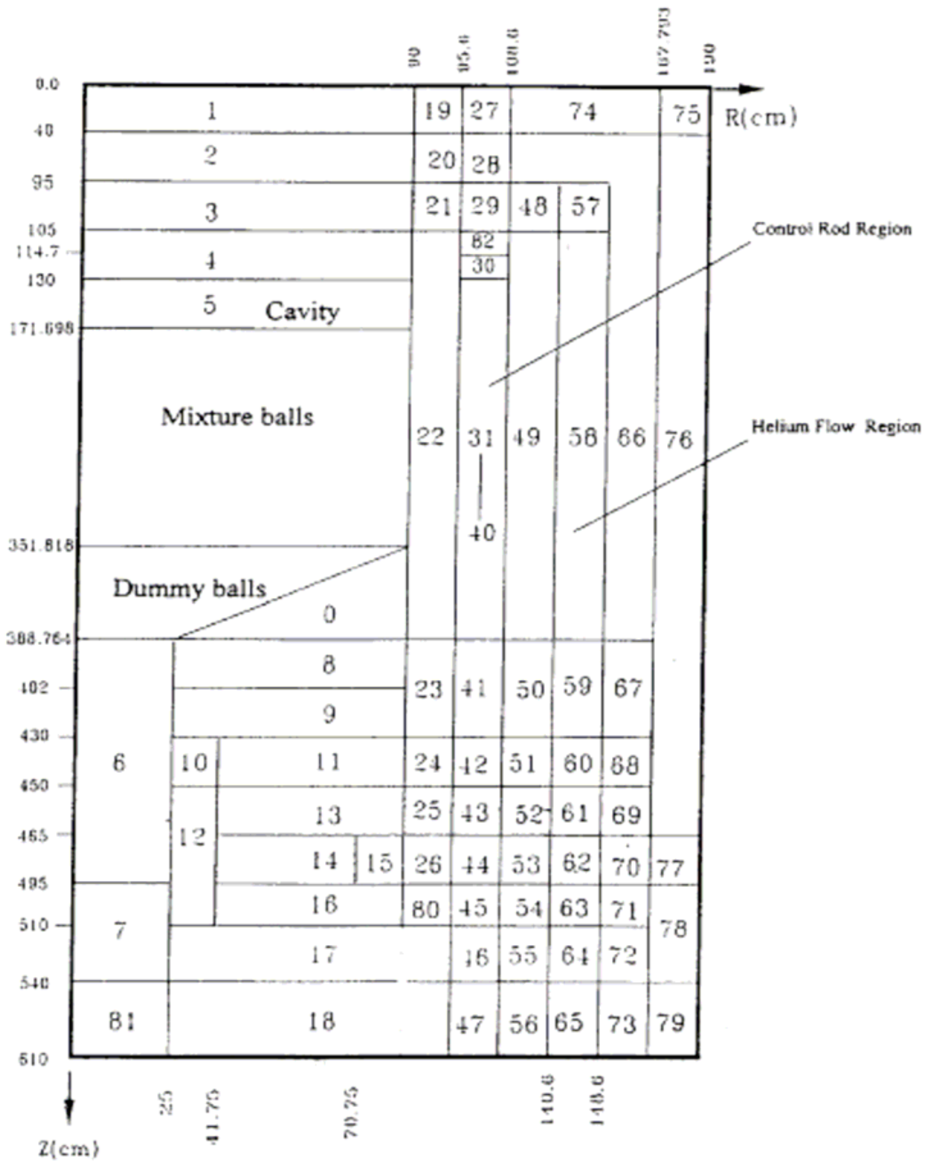
HTR-10 Benchmarks





IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

HTR-10 Benchmarks



Core physics calculation
Geometric model

IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

HTR-10 Benchmarks

HTR-10 Benchmark Problems		
B1	Initial Criticality	Pebble loading height for k_{eff} = 1.0 with no control rods inserted
B2	Temperature Coefficient	k_{eff} of the full core (5 m^3) at 20˚C (B21), 120˚C (B22), and 250˚C (B23) with no control rods inserted
B3	Control Rod Worth, Full Core	Δk_{eff} for ten (B31) and one (B32) fully inserted control rods, with other rods in withdrawn position, full core (5 m^3) at 20˚C
B4	Control Rod Worth, Initial Core	Δk_{eff} for ten (B31) and one (B32) fully inserted control rods, with other rods in withdrawn position, core loading height of 126 cm at 20˚C
All cases to assume helium atmosphere		

Post-Test Adjustment to Benchmark Problem Assumptions/Conditions

- Density of dummy balls: 1.73 → 1.84 g/cm3
- Boron equivalent of impurities in dummy balls: 1.3 → 0.125 ppm
- Core atmosphere: Helium → Air
- Temperature: 20˚C → 15˚C

IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

HTR-10 Benchmarks

Example Results – Initial Criticality (B1)

	Original Benchmark Problems		Revised (Deviated) Benchmark Problems	
	Diffusion/Transport	Monte Carlo	Diffusion/Transport	Monte Carlo
China	125.8	126.1	122.558	122.874
France[1]	-	-	-	115.36 117.37
Germany[2]	124.2 126.8	-	121.0 123.3	-
Indonesia[3]	107 120	-	-	-
Japan	113	-	-	-
Netherlands	125.3	-	122.1	-
Russia	136	137.3	-	-
South Africa	-	-	122.537	-
Turkey[4]	119.27	129.7 135.3	-	-
USA[5]	-	127.5 128	-	-

Experimental result of critical loading height: 123.06cm. It is noted that the experimental conditions are those conditions for the revised (deviated) benchmarks except the temperature is 15°C instead of 20°C (or 27°C).

1. The first row of data is obtained with simplified PB modeling, and the second row of data with improved PB modeling.
2. The first row of data is obtained with 2-dimensional VSOP, and the second row of data with 3-dimensional VSOP.
3. The first row of data is obtained with the DELIGHT code, and the second row of data with SRAC code.
4. The first row of data in the Monte Carlo approach is obtained with the ENDF/B-IV nuclear data set, and the second row of data with ENDF/B-V nuclear data set.
5. The first row of data is obtained with the UTXS nuclear data set, and the second row of data with ENDF/B-VI nuclear data set.

IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

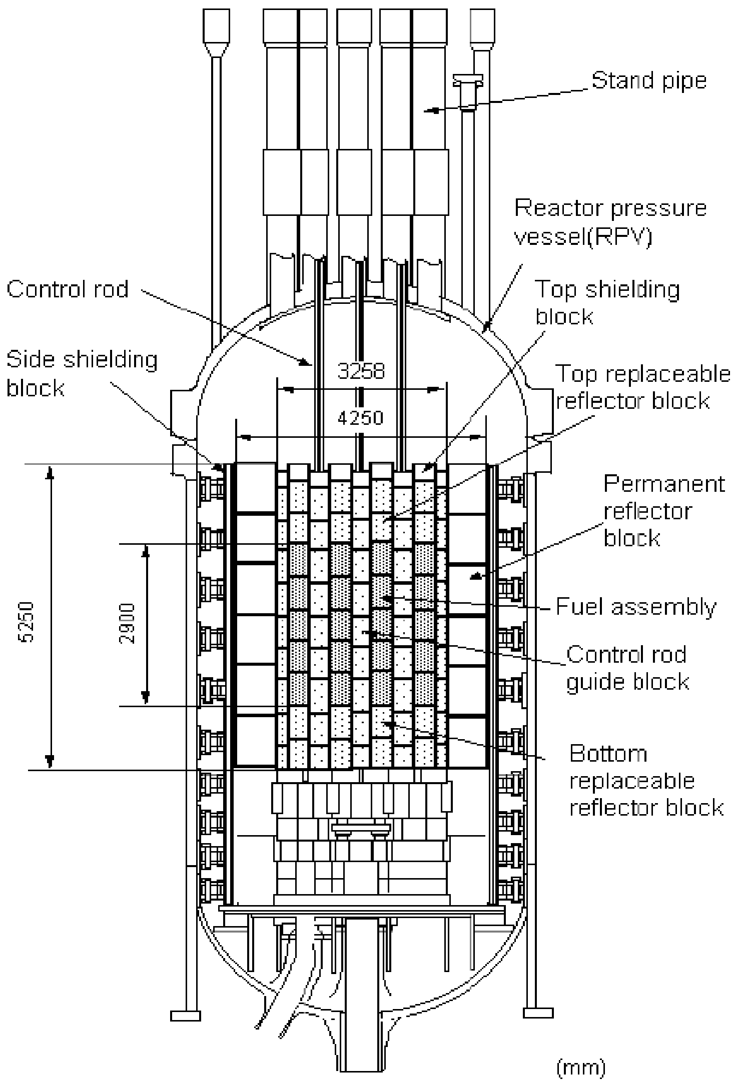
HTR-10 Benchmarks

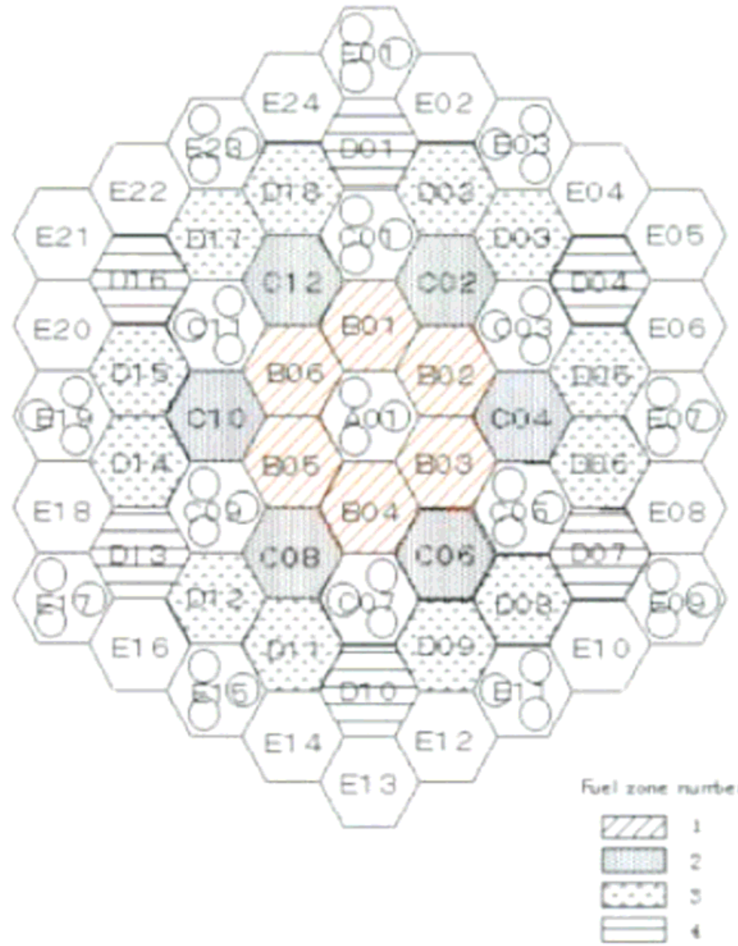
Reasons for Differences in Results

- Some control rod cross section cell calculations more appropriate for rod array than single rod worth evaluations
- Uncertainty in the modeling of neutron streaming
- Choice of selected cross section library (JEFF, ENDF, JENDL, etc.)
- Water content of graphite pores
- Library dependent cross-sections for temperature coefficients
- Effective fuel homogenization methods
- Modeling of fuel with Monte Carlo Calculations
  - Explicit geometry (particle distribution in pebble, pebble distribution in core)
  - Modeling of fuel/dummy ball ratio

IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

HTTR Benchmarks

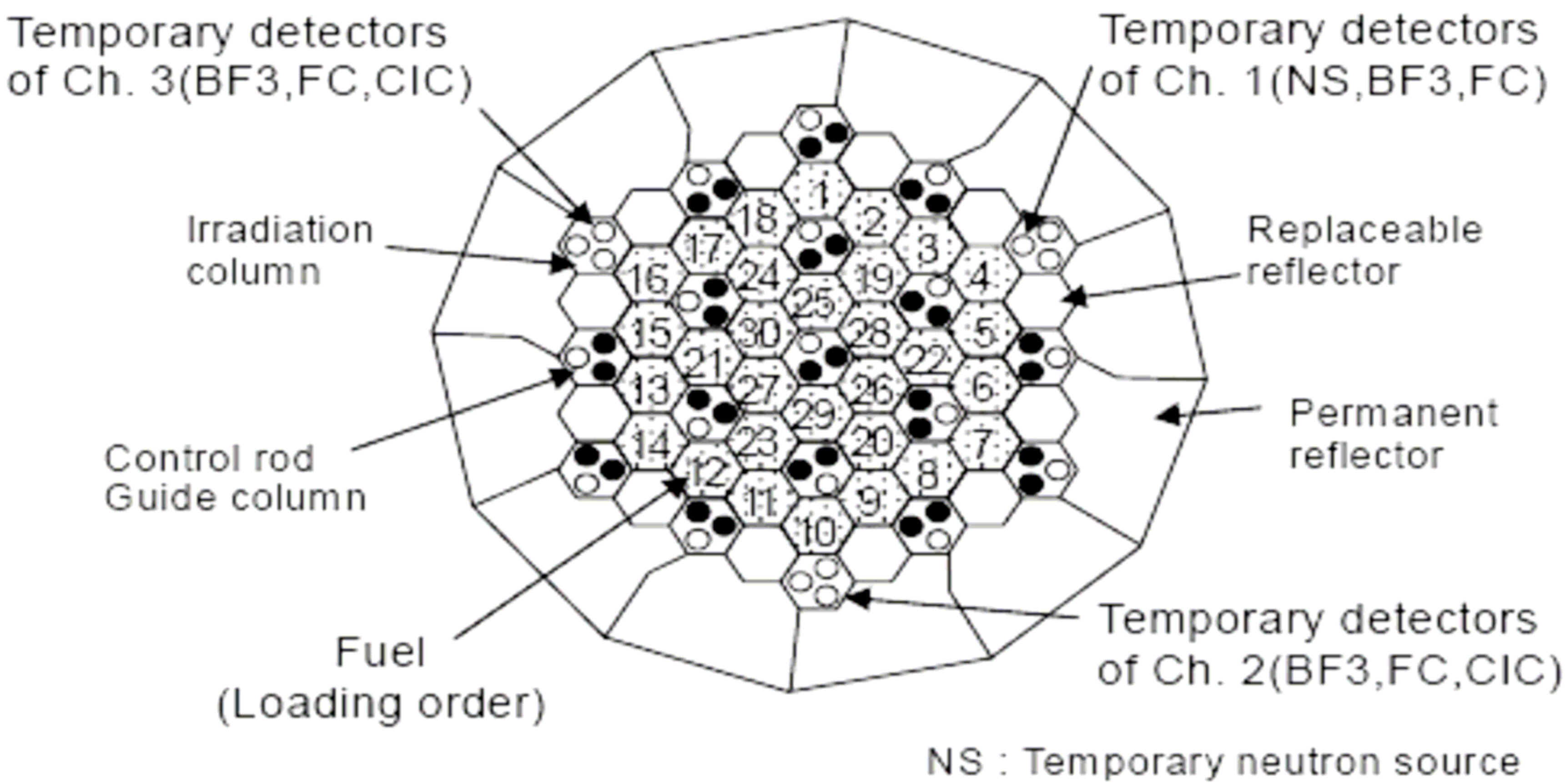




IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

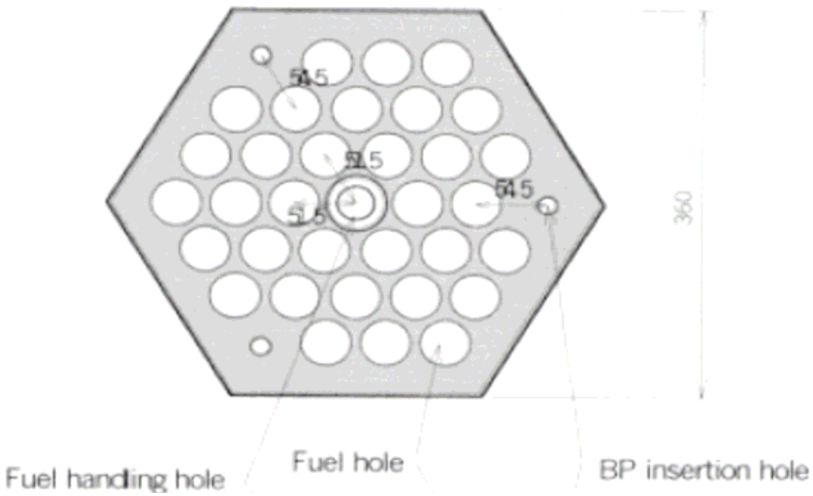
HTTR Benchmarks

Core Cross Section with Fuel Block Loading Order

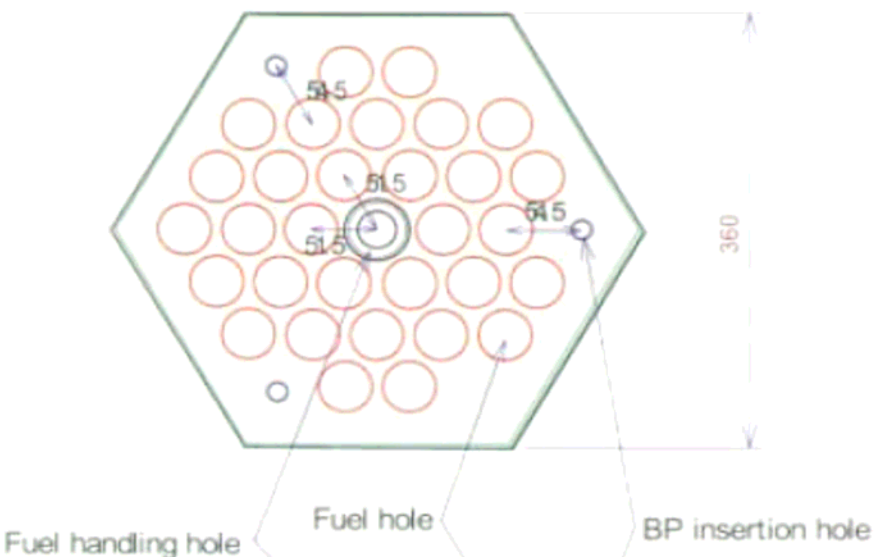


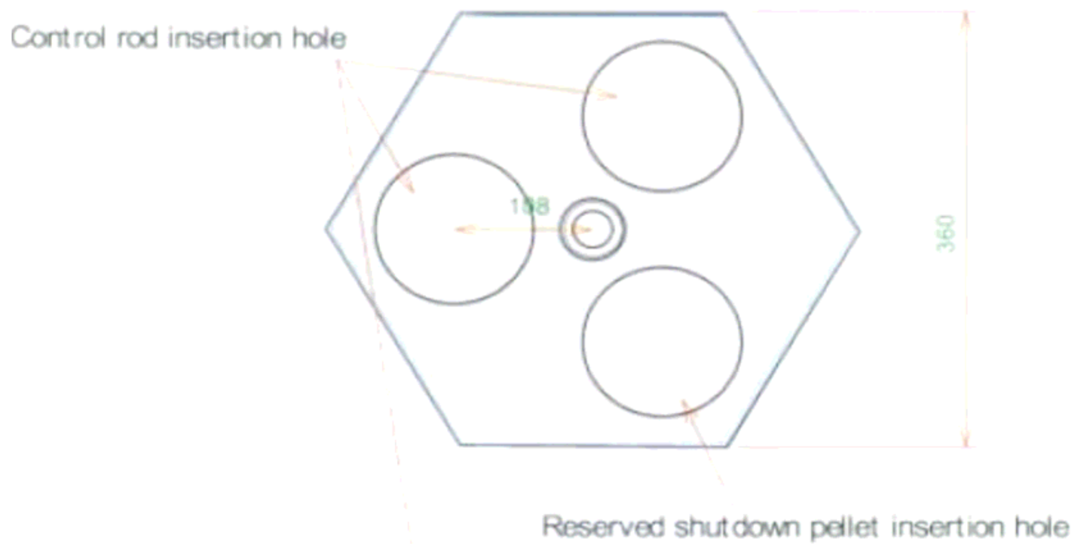
IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

HTTR Benchmarks



Core Region Block Configurations





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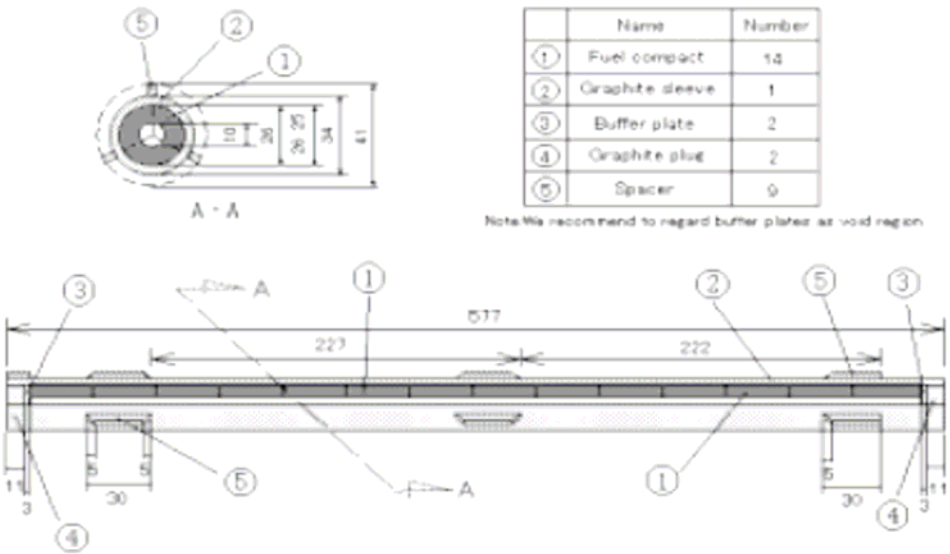
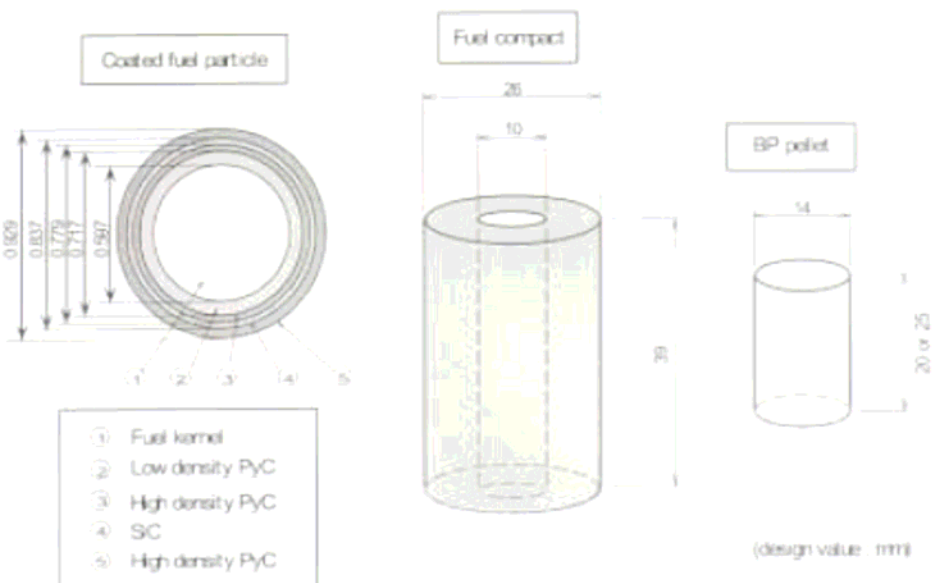
HTTR Benchmarks



Fuel Rod



Fuel Compacts & Burnable Poison Pellets

IAEA-TECDOC-1382, Evaluation of HTGR performance: Benchmark analysis related to initial testing of the HTTR and HTR-10, November 2003.

HTTR Benchmarks

Analysis Methods – Diffusion Calculations

Items	Germany	Russia	Japan	Netherlands	
	FZJ	OKBM	HTTR	NRG	IRI
Nuc. Data File	JEF-2.2	ENDF/B6	ENDF/B-4	JEF2.2	JEF2.2
Fuel Cell Code Theory Model No. of Groups	TOTMOS Col. Cyl. 123	WIMS-D/4 S4 Cyl. 69	DELIGHT Col. Cyl. 40	WIMS Col. Cyl. 69	SCALE4 Transport Cyl. 172
BP Cell Code Theory Model No. of Groups	TOTMOS DORT Transport Cyl. 123	WIMS-D/4 S4 Cyl. 69	TWOTRAN Transport Cyl. 6	WIMS Col. Hex. 16	SCALE4 Transport Cyl. 172
Core Cal. Code Model No. of Groups (Fast +Thermal)	CITATION Tri. (24mesh) 26	JAR-3D Tri. (6 mesh) 1 + 1	CITATION-1000VP Tri. (24mesh) 6 (3+3)	PANTHER Hex. 2	BOLD-VENTURE 13
Cut-off Energy (eV)	1.86	0.625	2.38	2.1	2.1

Col. = Collision Probability
Cyl. = Cylindrical

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HTTR Benchmarks

Analysis Methods – Monte Carlo Calculations

Items	Russia		Japan	Netherlands	
	RRC KI	IBRAE	HTTR	NRG	IRI
Nuc. Data File	DLC/MCUDAT-1.0	ENDF/B6	JENDL-3.2	--	JEF2.2
Energy Struct.	Continuous	Continuous	Continuous		Group
Code	MCU	MCNP 4A	MVP	--	KENO V.a
History	200	2000 (up to 16000)	20000		10000
Batches	5000	1000	150		200
Skipped-Batches	1	10	5		1

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HTTR Benchmarks

HTTR Benchmark Problems		
FC	Initial Criticality	Number of fuel blocks in sequenced loading
CR	Control Rod Position at Criticality	Control rod insertion depth at criticality for 18, 24 and 30 column core
EX	Excess Reactivity	Excess reactivity for an unrodded 18, 24 and 30 core
SC	Scram Reactivity	Scram reactivity for 1) all reflector CRs, 2) all CRs in reflector and core (30 column core)
TC	Isothermal Temperature Coefficient	Isothermal temperature coefficients at 290, 320, 360, 400, 440 and 470˚C for 30 column core with control rod position for criticality at 480˚C

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HTTR Benchmarks

FC - Initial Criticality

Diffusion Calculations

Member state	Number of fuel columns	Keff	Excess(%dk/k)
Japan	17	1.0005	0.05
France	17	1.0061	0.61
Germany	18	1.008	0.79
Indonesia	18	1.0058	0.577
Russia (OKBM)	16	1.005	0.498
Experimental results	19		

Monte Carlo Calculations

Member state	Number of fuel columns	Keff	Excess(%dk/k)
Japan	18	1.0061	0.61
France	18	1.0085	0.85
Netherlands(IRI)	17	1.0062	0.62
Russia(IBRAE)	16	1.006	0.596
Russia(RRCKI)	17	1.004	0.398
Turkey	15	1.005	0.50
Experimental results	19		

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HTTR Benchmarks

Reasons for Differences in Results

- Uncertainties in levels of impurities in dummy blocks, and in water and air or nitrogen in graphite pores
- Monte Carlo model geometry representation
- Choice of selected cross section data library and version (JEF, ENDF, JENDL, etc.)
- Uncertainties in modeling neutron streaming with diffusion methods
- Difficulties in modeling harmonics in thin annular cores with diffusion methods

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