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Volume 4

CHARACTERISTICS OF POTENTIAL REPOSITORY WASTES

JULY 1992

Prepared for the
U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
Washington, D.C. 20585

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under
Contract No. DE-AC05-84OR21400

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Characteristics of Potential Repository Wastes

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LIST OF ACRONYMS

AC	Allis Chalmers
ANF	Advanced Nuclear Fuels Corporation
ANL	Argonne National Laboratory
AP	Activation products
APSR	Axial power shaping rod
ASTM	American Society for Testing and Materials
B-C	Battelle-Columbus
B&W	Babcock and Wilcox
BPRA	Burnable poison rod assembly
BWR	Boiling-water reactor
CC	Complexant concentrate
CDB	Characteristics Data Base
CE	Combustion Engineering
CEA	Control element assembly
CEU	Consolidated Edison uranium
CFR	Code of Federal Regulations
CH	Contact handled
CWMS	Civilian Waste Management System
DHLW	Defense high-level waste
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
ECF	Expended Core Facility
EFPD	Equivalent full-power days
EIA	Energy Information Administration
EIS	Environmental impact statement
EPRI	Electric Power Research Institute
FFTF	Fast Flux Test Facility
FIS	Federal Interim Storage
FP	Fission products
FSV	Fort St. Vrain
GAPSR	Gray axial power shaping rod
GE	General Electric
GTCC	Greater than Class C
GWd	Gigawatt-days
GW(e)	Gigawatts (electric)
HANF	Hanford Site
HEDL	Hanford Engineering Development Laboratory
HEPA	High-efficiency particulate air
HLW	High-level waste
HTGR	High-temperature gas-cooled reactor
HWVP	Hanford Waste Vitrification Plant
ICPP	Idaho Chemical Processing Plant
IDB	Integrated Data Base
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory
LER	Licensee Event Report
LLW	Low-level waste
LTA	Lead test assembly
LWBR	Light-water breeder reactor
LWR	Light-water reactor
MOX	Mixed oxide
MRS	Monitored retrievable storage

LIST OF ACRONYMS (continued)

MSRE	Molten Salt Reactor Experiment
MT	Metric tons
MTIHM	Metric tons of initial heavy metal
MTR	Materials Test Reactor
MW(t)	Megawatts (thermal)
MW(e)	Megawatts (electric)
NCAW	Neutralized current acid waste
NCRW	Neutralized cladding removal waste
NFA	Non-fuel assembly
NFB	Non-fuel bearing
NFS	Nuclear Fuel Services, Inc.
NMMSS	Nuclear Materials Management and Safeguards System
NPR	New Production Reactor
NRC	Nuclear Regulatory Commission
NRF	Naval Reactors Facility
NWTSP	National Waste Terminal Storage Program
O/U	Oxygen/uranium atom ratio
OCRWM	Office of Civilian Radioactive Waste Management
OFA	Optimized fuel assembly
ORA	Orifice rod assembly
ORNL	Oak Ridge National Laboratory
PB1	Peach Bottom Unit 1
PC	Personal computer
PCI	Pellet-clad interaction
PFP	Plutonium finishing plant
PIE	Postirradiation examination
PNL	Pacific Northwest Laboratory
PNS	Primary neutron source
PWR	Pressurized-water reactor
QA	Quality assurance
QC	Quality control
RH	Remotely handled
RNS	Regenerative neutron source
SAS	Statistical Analysis System
SFD	Spent fuel disassembly
SNF	Spent nuclear fuel
SRL	Savannah River Laboratory
SRP	Savannah River Plant
SRS	Savannah River Site
SS	Stainless steel
SST	Single-shell tanks
TMI-2	Three Mile Island 2
TRIGA	Training Research Isotopes - General Atomics
TRU	Transuranic (waste)
TRUW	Transuranic waste
UN	United Nuclear
VEPCO	Virginia Electric Power Co.
WAC	Waste acceptance criteria
WAPS	Waste Acceptance Preliminary Specification
WE or W	Westinghouse
WIPP	Waste Isolation Pilot Plant
WVDP	West Valley Demonstration Project

APPENDIX 4A. NUCLEAR REACTORS AT EDUCATIONAL INSTITUTIONS IN THE UNITED STATES

4A. NUCLEAR REACTORS AT EDUCATIONAL INSTITUTIONS IN THE UNITED STATES

4A.1 INTRODUCTION

There are 61 reactors at educational institutions in the United States, 35 operational and 26 shut down. These reactors may be categorized into five general types, as follows: (1) open pool type with plate fuel assemblies, (2) open pool TRIGA type with cylindrical fuel pins, (3) open pool AGN type with fuel elements consisting of UO_2-polyethylene discs, (4) open pool type fuel pin arrays containing UO_2 pellets, and (5) aqueous liquid fuel type reactors. Tables 4A.1 and 4A.2 summarize the operating and permanently shut-down reactors in each of these categories, respectively.

4A.2 FUEL SUPPLY ARRANGEMENTS

Under DOE's university assistance program, DOE supplies the fuel for university and educational reactors and retains ownership of the fuel; thus DOE is responsible for disposal of the fuel when it is removed from a reactor. Figure 4A.1 is a schematic representation of the fuel supply arrangements for reactors under this program. The fuel procurement contractor is EG&G, Idaho Falls, Idaho, and procurement arrangements are made by EG&G with the fuel manufacturers. When an order for fuel is received from EG&G, the fuel manufacturer ships the desired number of fuel elements directly to the university reactor. Each university contacts EG&G when it needs to order fuel, and describes the type and number of fuel elements needed. Figure 4A.1 shows only those university reactors that regularly order fuel in appreciable quantities. Many university reactors require fueling only infrequently; for others, no refueling is planned in the foreseeable future. Table 4A.3 shows the approximate refueling rates for some of the major university reactors. Information for this paragraph and Table 4A.3 was supplied by EG&G (Brown 1991).

4A.3 FUEL ELEMENT SERIAL NUMBERS

Tables 4A.4 through 4A.8 list fuel element serial numbers for reactors that use plate-type elements manufactured by Babcock and Wilcox and supplied to the reactors under the EG&G subcontract with DOE. Some of these elements have already been shipped to the reactors and some have not yet been shipped but are being stored at the B&W plant (Brown 1991).

4A.4 REACTOR DATA SHEETS

Appendix 4B consists of detailed data sheets on the 61 university/educational reactors listed in Tables 4A.1 and 4A.2. Supplemental information is included in these data sheets to amplify on the data contained in Sect. 4.4 of this report.

4A.5 REFERENCES

Brown 1991. Keith Brown, EG&G Idaho Falls, Idaho, telephone conversations with R. Salmon, Oak Ridge National Laboratory, June 1991.

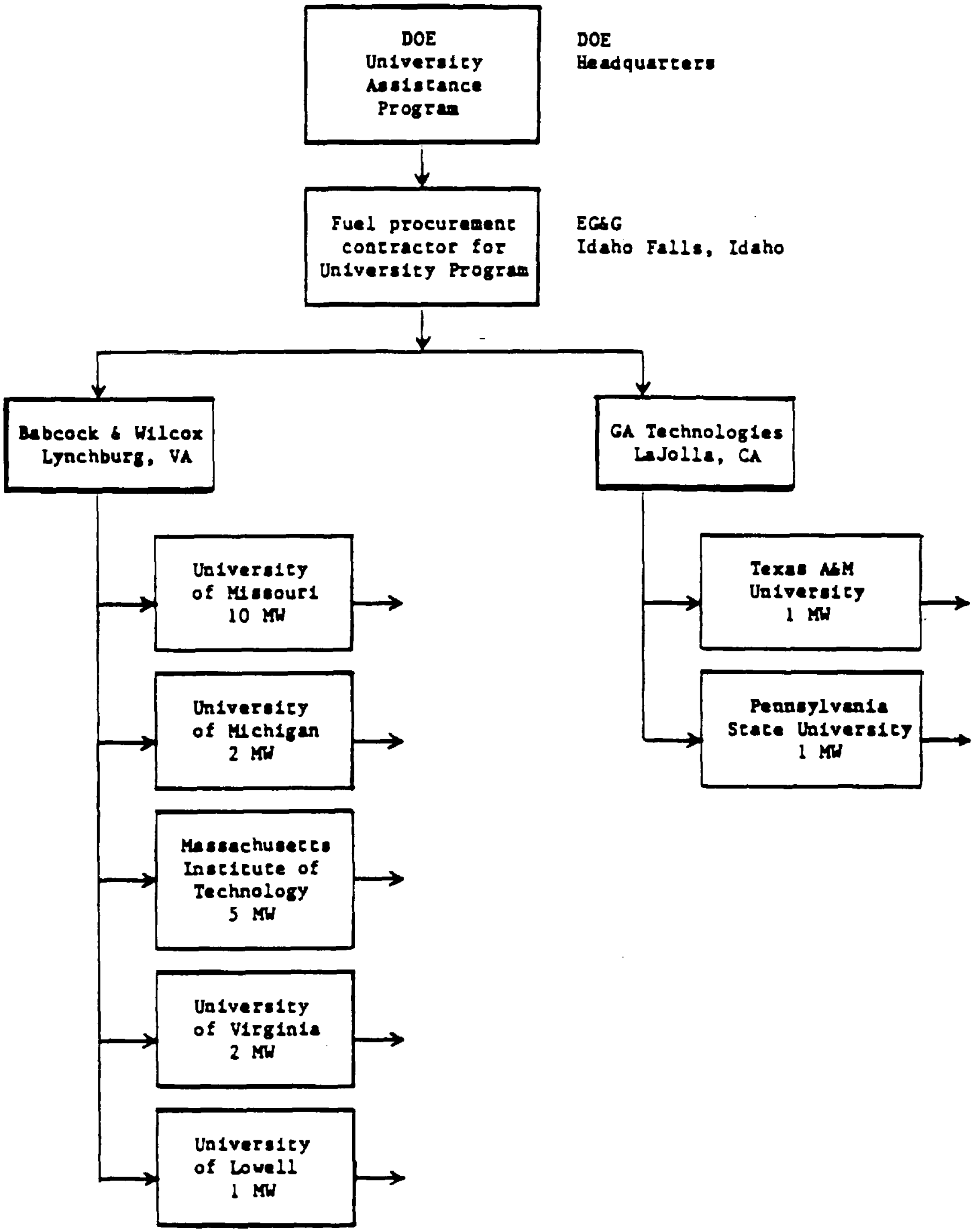

Fig. 4A.1. Typical fuel supply arrangements under the DOE University Assistance Program. Only a few of the larger reactors are shown here. (Arrows leaving reactors indicate discharged fuel.)

Table 4A.1. Operational university/educational reactors — summary[a]

Fuel type and location	Power, kW
Highly-enriched, plate-type fuels	
Georgia Institute of Technology	5,000
Iowa State University	10
Manhattan College	Negligible
Massachusetts Institute of Technology	4,900
Ohio State University	10
Purdue University	10
University of Florida	100
University of Lowell	1,000
University of Michigan	2,000
University of Missouri (Columbia)	10,000
University of Missouri (Rolla)	200
University of Virginia	2,000
Worcester Polytechnic Institute	10
TRIGA type (U-Zr-H fuel)	
Cornell University	500
Kansas State University	250
Oregon State University	1,000
Pennsylvania State University	1,000
Reed College	250
Texas A&M University	1,000
University of Arizona	100
University of California, Irvine	250
University of Illinois LOPRA	10
University of Illinois	1,500
University of Maryland	250
University of Texas	1,100
University of Utah	250
University of Wisconsin	1,000
Washington State University	1,000
UO_2-polyethylene fuel	
Idaho State University	Negligible
Texas A&M University	Negligible
University of New Mexico	Negligible
Low-enriched UO_2 pin-type fuel	
Cornell University zero-power reactor	Negligible
North Carolina State University	1,000
Rensselaer Polytechnic Institute	Negligible
State University of New York (Buffalo)	2,000

[a]Total number of reactors in this table is 35. Reactors that have been permanently shut down are not included. For a list of reactors shut down, see Table 4A.2. Data and references for this table are from Sect. 4.4 of this report (see Table 4.4.18).

Table 4A.2. Educational reactors permanently shut down[a]

Type and location	Power level	Shutdown date	Fuel still at reactor?
High-enriched U-Al plate fuel			
University of California (LA)	100 kW	1984	Shipped to INEL[b]
University of Kansas	10 kW	1987	Shipped to SRP[c]
University of Virginia	100 kW	1987	Still at U. of Virginia
Virginia Polytechnic Institute	100 kW	1984	Shipped to SRP[d]
University of Washington	100 kW	1988	Shipped to INEL[e]
TRIGA type			
Michigan State University	4900 kW	1989	Shipped to USGS and INEL[f]
Columbia University	250 kW	1985	None[g]
University of Illinois		1968	All shipped[b]
University of California (Berkeley)	1000 kW	1987	Shipped to INEL[h]
University of Texas (Austin)	250 kW	1990	Fuel is still at U. of Texas[i]
UO_2-polyethylene fuel			
Catholic University	Negligible	1986	Will be shipped to DOE[j]
Memphis State University	Negligible	1985	
University of Utah	Negligible	1990	In cask for shipping to DOE[k]
University of Oklahoma	Negligible	1988	Shipped to Oak Ridge[l]
Calif. Polytech. Inst.	Negligible	1980	
University of Delaware	Negligible	1978	Shipped to Oak Ridge[b]
Georgia Inst. of Tech.	Negligible	1986	Shipped to Oak Ridge[m]
Colorado State University	Negligible	1974	Shipped to South Korea[n]
Oregon State University	Negligible	1981	Still at Oregon State[o]
Polytech. Inst. of N.Y.	Negligible	1974	Shipped to Oak Ridge[b]
Tuskeegee Institute	Negligible	1984	Returned to DOE[b]
W. Virginia University	Negligible	1972	Shipped to Univ. of Okla.[b]
Rice University	Negligible	1965	Shipped to Texas A&M[b]
Aqueous liquid fuel			
University of California (Santa Barbara)	Negligible	1986	Shipped to INEL[p]
Brigham Young University	Negligible	1987	Shipped to INEL[q]
University of Wyoming	Negligible	1974	Shipped to Atomics Int'l.[b]

[a]List of shut down reactors was compiled from Burn 1988 and OSTI 1990. For a more complete list of university/educational reactors shut down, see OSTI 1990.

[b]Burn 1988.

[c]Telephone conversation, Harold Rosson, Univ. of Kansas, and R. Salmon, ORNL, June 7, 1991.

[d]Telephone conversation, Thomas F. Parkinson, Virginia Polytech, and R. Salmon, ORNL, June 10, 1991.

[e]Telephone conversation, D. L. Fry, Univ. of Washington, and R. Salmon, ORNL, June 7, 1991.

[f]Telephone conversation, Bruce Wilkinson, Mich. State Univ., and R. Salmon, ORNL, June 7, 1991. About one-third was sent to USGS (Denver) and two-thirds to INEL.

[g]No fuel was ever procured for this reactor (Burn 1988).

[h]Telephone conversation, Keith Brown, EG&G Idaho, and R. Salmon, ORNL, March 6, 1989

[i]Telephone conversation, Tom Bauer, Univ. of Texas, and R. Salmon, ORNL, December 11, 1990. Fuel is being used in the 1100 kW TRIGA at Univ. of Texas.

[j]Telephone conversation, Harold Keene, Catholic Univ., and R. Salmon, ORNL, June 7, 1991.

[k]Telephone conversation, Gary Sandquist, Univ. of Utah, and R. Salmon, ORNL, December 11, 1990.

[l]Telephone conversation, Paul Skierkowski, Univ. of Okla., and R. Salmon, ORNL, June 7, 1991.

[m]Telephone conversation, R. Karam, Georgia Inst. of Tech., and R. Salmon, ORNL, June 10, 1991.

[n]Telephone conversation, James Johnson, Colorado State, and R. Salmon, ORNL, June 7, 1991.

[o]Telephone conversation, Brian Dodd, Oregon State, and R. Salmon, ORNL, June 10, 1991.

[p]Telephone conversation, A. E. Profio, Univ. of Calif., and R. Salmon, ORNL, June 10, 1991.

[q]Telephone conversation, Gary Jensen, Brigham Young, and R. Salmon, ORNL, June 7, 1991.

Table 4A.3. Shipments of replacement fuel to some of the larger university reactors[a]

Reactor location	Power (kW)	Type of fuel element	Average number of new fuel elements shipped per year	U-235 content per element (g)
Georgia Inst. of Tech. Atlanta, Georgia	5,000	Plate	2–5	188
Massachusetts Inst. of Tech. Cambridge, Massachusetts	4,900	Plate	6–8	510
University of Missouri Columbia, Missouri	10,000	Plate	24	750
University of Michigan Ann Arbor, Michigan	2,000	Plate	18	167
University of Virginia Charlottesville, Virginia	2,000	Plate	6	195
University of Lowell Lowell, Massachusetts	1,000	Plate	4–5	126
University of Illinois Urbana, Illinois	1,500	TRIGA	1–2	38
Texas A&M University College Station, Texas	1,000	TRIGA	0	120
Pennsylvania State University University Park, Pennsylvania	1,000	TRIGA	1	38
State University of N.Y. Buffalo, N.Y.	2,000	UO_2 pin array	5–10	760

[a]Data provided by EG&G, Idaho Falls, Idaho, and by personnel at educational institutions.

Table 4A.4. University of Michigan fuel element serial numbers[a]

Reactor location: University of Michigan; Ann Arbor, Michigan
2 MW

Total number of elements listed: 121

Element numbers:

MI-01	MI-21	MI-41	MI-205	MI-223	MI-241	MI-259
02	22	42	206	224	242	260
03	23	43	207	225	243	261
04	24	44	208	226	244	262
05	25	45	209	227	245	263
06	28	46	210	228	246	264
07	29	47	211	229	247	265
09	30	48	212	230	248	266
10	31	49	213	231	249	267
11	32	50	214	232	250	268
12	33	51	215	233	251	269
13	34	53	216	234	252	270
15	35	54	217	235	253	271
16	36	200	218	236	254	
17	37	201	219	237	255	
18	38	202	220	238	256	
19	39	203	221	239	257	
20	40	204	222	240	258	

[a]Source: EG&G, Idaho Falls, Idaho. Date: June 24, 1991.

Table 4A.5. University of Missouri fuel element serial numbers[a]

Reactor location: University of Missouri; Columbia, Missouri
10 MW

Total number of elements listed: 301

Element numbers:

MO-01	MO-32	MO-67	MO- 99	MO-131	MO-164	MO-229	MO-260	MO-291	MO-322
02	33	68	100	132	165	230	261	292	323
03	34	69	101	133	200	231	262	293	324
04	35	70	102	134	201	232	263	294	325
05	36	71	103	135	202	233	264	295	326
06	37	72	104	136	203	234	265	298	327
07	38	73	105	138	205	235	266	297	328
08	39	74	106	138	205	236	267	298	329
09	40	75	107	140	206	237	268	299	330
10	41	76	108	141	207	238	269	300	331
11	42	77	109	142	208	239	270	301	332
12	43	78	111	143	209	240	271	302	333
13	44	79	112	144	210	241	272	303	334
14	45	80	113	145	211	242	273	304	335
15	46	81	114	146	212	243	274	305	336
16	47	82	115	147	213	244	275	306	337
17	48	83	116	148	214	245	276	307	338
18	53	84	117	149	215	246	277	308	339
19	54	85	118	150	216	247	278	309	340
20	55	87	119	151	217	248	279	310	341
21	56	88	120	152	218	249	280	311	342
22	57	89	121	153	219	250	281	312	343
23	58	90	122	154	220	251	282	313	
24	59	91	123	155	221	252	283	314	
25	60	92	124	156	222	253	284	315	
26	61	93	125	157	223	254	285	316	
27	62	94	126	158	224	255	286	317	
28	63	95	127	159	225	256	287	318	
29	64	96	128	160	226	257	288	319	
30	65	97	129	161	227	258	289	320	
31	66	98	130	162	228	259	290	321	

[a]Source: EG&G, Idaho Falls, Idaho. Date: June 24, 1991.

Table 4A.6. Rhode Island Nuclear Science Center and University of Lowell fuel element serial numbers[a]

Reactor location: Rhode Island Nuclear Science Center; Narragansett, Rhode Island
2 MW

University of Lowell; Lowell, Massachusetts
1 MW

Total number of elements listed: 64

Element numbers:

RI-127	RI-142	RI-158	RI-174	RI-189
128	144	159	175	190
129	145	160	176	191
130	146	161	177	192
131	147	162	178	
132	148	163	179	
133	149	164	180	
135	150	166	181	
136	151	167	182	
137	153	169	184	
138	154	170	185	
139	155	171	186	
140	156	172	187	
141	157	173	188	

[a]Source: EG&G, Idaho Falls, Idaho. These fuel elements are usable in both of the reactors listed here. The Rhode Island Nuclear Science Center reactor is owned by the State of Rhode Island and is not listed as a university reactor in this report.

Table 4A.7. University of Virginia fuel element serial numbers[a]

Reactor location: University of Virginia; Charlottesville, Virginia
2 MW

Total number of elements listed: 26

Element numbers:

VI-001	VI-014
002	015
003	016
004	017
005	018
006	019
007	020
008	021
009	023
010	024
011	025
012	026
013	027

[a]Source: EG&G, Idaho Falls, Idaho. Date: January 13, 1986.

Table 4A.8. Massachusetts Institute of Technology fuel element serial numbers[a]

Reactor location: Massachusetts Institute of Technology; Cambridge, Massachusetts
4.9 MW

Total number of elements listed: 60

Element numbers:

MIT-01	MIT-16	MIT-37	MIT-204
02	17	38	205
03	18	39	206
04	19	40	207
05	20	41	208
06	21	42	209
07	22	43	210
08	23	44	211
09	24	45	212
10	25	46	213
11	32	47	214
12	33	200	215
13	34	201	216
14	35	202	217
15	36	203	218

[a]Source: EG&G, Idaho Falls, Idaho. Date: June 24, 1991.

APPENDIX 4B. DATA SHEETS FOR NUCLEAR REACTORS AT EDUCATIONAL INSTITUTIONS IN THE UNITED STATES

APPENDIX 4B. DATA SHEETS FOR NUCLEAR REACTORS AT EDUCATIONAL INSTITUTIONS IN THE UNITED STATES

This Appendix presents additional details on the educational reactors listed in Tables 4A.1 and 4A.2 of Appendix 4A. Data sheets on currently operational reactors are given first, followed by data sheets on shut-down reactors. Tables 4B.1 and 4B.2 list the operational and recently shut-down reactors, respectively.

One new reactor has been added since the original issue of this report. This is the 1,100 kW TRIGA Mark II reactor at the University of Texas, Austin, which started up in 1988. This will use the same type of TRIGA fuel elements as those used in the 250 kW TRIGA reactor at the same university that was shut down in 1990; that is, the fuel elements of these two reactors are interchangeable.

Table 4B.1. Operational university/educational reactors — summary[a]

Reactor No.	Fuel type and location	Power, kW
	Highly-enriched, plate-type fuels	
PL-1	Georgia Institute of Technology	5,000
PL-2	Iowa State University	10
PL-3	Manhattan College	Negligible
PL-4	Massachusetts Institute of Technology	4,900
PL-5	Ohio State University	10
PL-6	Purdue University	10
PL-7	University of Florida	100
PL-8	University of Lowell	1,000
PL-9	University of Michigan	2,000
PL-10	University of Missouri (Columbia)	10,000
PL-11	University of Missouri (Rolla)	200
PL-12	University of Virginia	2,000
PL-13	Worcester Polytechnic Institute	10
	TRIGA type (U-Zr-H fuel)	
TR-1	Cornell University	500
TR-2	Kansas State University	250
TR-3	Oregon State University	1,000
TR-4	Pennsylvania State University	1,000
TR-5	Reed College	250
TR-6	Texas A&M University	1,000
TR-7	University of Arizona	100
TR-8	University of California, Irvine	250
TR-9	University of Illinois LOPRA	10
TR-10	University of Illinois	1,500
TR-11	University of Maryland	250
TR-12	University of Texas	1,100
TR-13	University of Utah	250
TR-14	University of Wisconsin	1,000
TR-15	Washington State University	1,000
	UO_2-polyethylene fuel	
AGN-1	Idaho State University	Negligible
AGN-2	Texas A&M University	Negligible
AGN-3	University of New Mexico	Negligible
	Low-enriched UO_2 pin-type fuel	
UPIN-1	Cornell University zero-power reactor	Negligible
UPIN-2	North Carolina State University	1,000
UPIN-3	Rensselaer Polytechnic Institute	Negligible
UPIN-4	State University of New York (Buffalo)	2,000

[a]The reactors listed in this table are the same as those listed in Tables 4.4.18 and 4A.1.

Table 4B.2. Educational reactors permanently shut down[a]

Reactor No.	Type and location	Power level	Shutdown date	Fuel still at reactor?
	High-enriched U-Al plate fuel			
SPL-1	University of California (LA)	100 kW	1984	Shipped to INEL[b]
SPL-2	University of Kansas	10 kW	1988	Shipped to SRP[c]
SPL-3	Virginia Polytechnic Institute	100 kW	1984	Shipped to SRP[d]
SPL-4	University of Washington	100 kW	1988	Shipped to INEL[e]
SPL-5	University of Virginia	100 W	1987	Still at U. of Virginia
	TRIGA type			
STR-1	Michigan State University	4900 kW	1989	Shipped to USGS and INEL[f]
STR-2	Columbia University	250 kW	1985	None[g]
STR-3	University of Illinois		1968	All shipped[b]
STR-4	Univ. of California (Berkeley)	1000 kW	1987	Shipped to INEL[h]
STR-5	University of Texas (Austin)	250 kW	1990	Fuel is still at U. of Texas[i]
	UO_2-polyethylene fuel			
SAGN-1	Catholic University	Negligible	1986	Will be shipped to DOE[j]
SAGN-2	Memphis State University	Negligible	1985	
SAGN-3	University of Utah	Negligible	1990	In cask for shipping to DOE[k]
SAGN-4	University of Oklahoma	Negligible	1988	Shipped to Oak Ridge[l]
SAGN-5	Calif. Polytech. Inst.	Negligible	1980	Shipped to Oak Ridge[m]
SAGN-6	University of Delaware	Negligible	1978	Shipped to Oak Ridge[b]
SAGN-7	Georgia Inst. of Tech.	Negligible	1986	Shipped to Oak Ridge[n]
SAGN-8	Colorado State University	Negligible	1974	Shipped to South Korea[o]
SAGN-9	Oregon State University	Negligible	1981	Still at Oregon State[p]
SAGN-10	Polytech. Inst. of N.Y.	Negligible	1974	Shipped to Oak Ridge[b]
SAGN-11	Tuskeegee Institute	Negligible	1984	Returned to DOE[b]
SAGN-12	W. Virginia University	Negligible	1972	Shipped to Univ. of Okla.[b]
SAGN-13	Rice University	Negligible	1965	Shipped to Texas A&M[b]
	Aqueous liquid fuel			
SAQ-1	Univ. of Calif. (Santa Barbara)	Negligible	1986	Shipped to INEL[q]
SAQ-2	Brigham Young University	Negligible	1987	Shipped to INEL[r]
SAQ-3	University of Wyoming	Negligible	1974	Shipped to Atomics Int'l.[b]

[a]This list of 26 shutdown reactors was compiled from Burn 1988 and OSTI 1990.
[b]Burn 1988.
[c]Telephone conversation, Harold Rosson, Univ. of Kansas, and R. Salmon, ORNL, June 7, 1991.
[d]Telephone conversation, Thomas F. Parkinson, Virginia Polytech, and R. Salmon, ORNL, June 10, 1991.
[e]Telephone conversation, D. L. Fry, Univ. of Washington, and R. Salmon, ORNL, June 7, 1991.
[f]Telephone conversation, Bruce Wilkinson, Mich. State Univ., and R. Salmon, ORNL, June 7, 1991. About one-third was sent to USGS (Denver) and two-thirds to INEL.
[g]No fuel was ever procured for this reactor (Burn 1988).
[h]Telephone conversation, Keith Brown, EG&G Idaho, and R. Salmon, ORNL, March 6, 1989
[i]Telephone conversation, Tom Bauer, Univ. of Texas, and R. Salmon, ORNL, December 11, 1990. Fuel is being used in the 1100 kW TRIGA at Univ. of Texas.
[j]Telephone conversation, Harold Keene, Catholic Univ., and R. Salmon, ORNL, June 7, 1991.
[k]Telephone conversation, Gary Sandquist, Univ. of Utah, and R. Salmon, ORNL, December 11, 1990.
[l]Telephone conversation, Paul Skierkowski, Univ. of Okla., and R. Salmon, ORNL, June 7, 1991.
[m]Telephone conversation, Bob Adamson, Cal Poly, and R. Salmon, ORNL, June 13, 1991. Reactor has been dismantled and all fuel shipped to Oak Ridge.
[n]Telephone conversation, R. Karam, Georgia Inst. of Tech., and R. Salmon, ORNL, June 10, 1991.
[o]Telephone conversation, James Johnson, Colorado State, and R. Salmon, ORNL, June 7, 1991.
[p]Telephone conversation, Brian Dodd, Oregon State, and R. Salmon, ORNL, June 10, 1991.
[q]Telephone conversation, A. E. Profio, Univ. of Calif., and R. Salmon, ORNL, June 10, 1991.
[r]Telephone conversation, Gary Jensen, Brigham Young, and R. Salmon, ORNL, June 7, 1991.

APPENDIX 4B. DATA SHEETS FOR NUCLEAR REACTORS AT EDUCATIONAL INSTITUTIONS IN THE UNITED STATES

PART 1. OPERATIONAL REACTORS

REACTOR NO.	PL-1
REACTOR NAME	Georgia Tech Research Reactor
LOCATION	Georgia Institute of Technology, Nuclear Research Center, 900 Atlantic Dr., NW, Atlanta, Georgia 30332
POWER	5 MW
LICENSE NO. NRC DOCKET NO.	R-97 50-160
TYPE	Tank type, heavy water moderated and cooled
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	18 curved plates per element (16 fueled, 2 unfueled)
OVERALL DIMENSIONS	7.52 cm × 7.04 cm × 219.41 cm
U-235 PER ELEMENT, kg	0.19
ELEMENTS/REACTOR	17
ENRICHMENT (% U-235)	93 (conversion to <20% is in planning)
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	17	3.04
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	17	3.04

REFUELING SCHEDULE	2-5 elements/year
SPENT FUEL SHIPMENTS	Spent fuel has been shipped to SRS in BMI-1 cask
CONTACTS	Dr. R. Karam, 404-894-3620

REACTOR NO.	PL-2
REACTOR NAME	Iowa State University Research Reactor
LOCATION	Iowa State University, Ames, Iowa
POWER	10 kW
LICENSE NO. NRC DOCKET NO.	
TYPE	ARGONAUT
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Rectangular fuel plates, 12 plates per element
OVERALL DIMENSIONS	7.62 cm × 14.06 cm × 66.04 cm
U-235 PER ELEMENT, kg	Approximately 0.266
ELEMENTS/REACTOR	12
ENRICHMENT (% U-235)	Approximately 93
DRAWING NO.	
SUPPLIER	American Standard

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	12	3.19
FRESH FUEL	2 plates	
SPENT FUEL		
TOTAL	12	

REFUELING SCHEDULE	Approximately every 2 years
SPENT FUEL SHIPMENTS	Fuel has been shipped to Oak Ridge
CONTACTS	Dr. C. Hendrickson, 515-294-6422

REACTOR NO.	PL-3
REACTOR NAME	Manhattan College Zero Power Reactor
LOCATION	Manhattan College, Leo Engineering Building, Riverdale, New York 10471
POWER	0.1 W
LICENSE NO. NRC DOCKET NO.	R-94 50-199
TYPE	Open pool
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	6 concentric cylinders of 3 plates each, plate is 120° arc
OVERALL DIMENSIONS	8.89 cm diam × 93.98 cm long (outermost cylinder)
U-235 PER ELEMENT, kg	Approximately 0.19
ELEMENTS/REACTOR	16 (15 full and 1 partial)
ENRICHMENT (% U-235)	92%; replacing with <20% in 1991
DRAWING NO.	There are 6 concentric circular shells
SUPPLIER	Sylcor, Hicksville, New York

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	16	3.02
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	16	3.02

REFUELING SCHEDULE	None anticipated. Reactor is used about 4 h/week
SPENT FUEL SHIPMENTS	None
CONTACTS	Dr. Ronald S. Kane, 212-920-0145
	Dr. Robert Berlin, 212-920-0145

REACTOR NO.	PL-4
REACTOR NAME	MIT Research Reactor (MITR-II)
LOCATION	Massachusetts Inst. of Tech. Nuclear, Reactor Laboratory, 138 Albany St., Cambridge, Massachusetts 02139
POWER	4.9 MW
LICENSE NO. NRC DOCKET NO.	R-37 50-20
TYPE	Tank type, plate fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Flat plates, 15 per element
OVERALL DIMENSIONS	Rhomboid; each face is 6.98 cm wide and 66.7 cm long
U-235 PER ELEMENT, kg	0.51
ELEMENTS/REACTOR	24
ENRICHMENT (% U-235)	93
DRAWING NO.	Cross-section of element is 60-120 degree parallelogram
SUPPLIER	Babcock and Wilcox

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	24	12.2
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	24	12.2

REFUELING SCHEDULE	One element every 17 operating days
SPENT FUEL SHIPMENTS	SRS in Aiken, South Carolina, or INEL in Idaho
CONTACTS	O. K. Harling, 617-253-4202
	L. Clark, Jr.
	J. Bernard

REACTOR NO.	PL-5
REACTOR NAME	Ohio State University Research Reactor
LOCATION	Ohio State University, 1298 Kinnear Road, Columbus, Ohio 43212
POWER	10 kW
LICENSE NO. NRC DOCKET NO.	R-75 50-150
TYPE	Open pool type, plate fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	18 plates per element (16 fueled, 2 dummy)
OVERALL DIMENSIONS	7.62 cm × 7.62 cm × 88.9 cm
U-235 PER ELEMENT, kg	0.14
ELEMENTS/REACTOR	20 (16 standard, 4 control)
ENRICHMENT (% U-235)	19.5
DRAWING NO.	
SUPPLIER	Texas Instruments, Dallas, Texas

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	20	4.2
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	20	4.2

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	None
CONTACTS	Don W. Miller, Director, 614-422-6755
	Brian K. Hajek
	Richard D. Myser

REACTOR NO.	PL-6
REACTOR NAME	Purdue University Reactor
LOCATION	School of Nuclear Engineering, Purdue University, West Lafayette, Indiana 47907
POWER	1 kW
LICENSE NO. NRC DOCKET NO.	R-87 50-182
TYPE	Open pool, plate fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	10 plates per fuel element
OVERALL DIMENSIONS	7.52 cm × 7.52 cm × 81.92 cm
U-235 PER ELEMENT, kg	0.17
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	93
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	16	2.65
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	Paul S. Lyroudis, 317-494-5764
	Frank M. Clikeman
	Eldon R. Stansberry

REACTOR NO.	PL-7
REACTOR NAME	University of Florida Training Reactor
LOCATION	University of Florida, Nuclear Sciences Center, Gainesville, Florida 32611
POWER	100 kW
LICENSE NO.	R-56
NRC DOCKET NO.	50-83
TYPE	ARGONAUT (modified)
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	11 flat plates per element
OVERALL DIMENSIONS	7.23 cm × 5.44 cm × 65.09 cm
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	24
ENRICHMENT (% U-235)	93
DRAWING NO.	
SUPPLIER	Babcock and Wilcox

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	24	3.35
FRESH FUEL		0.17
SPENT FUEL		0.00
TOTAL		3.52

REFUELING SCHEDULE	Refueled once to change from 20% to 93% enrichment
SPENT FUEL SHIPMENTS	Shipment made to SRS in National Lead Cask
CONTACTS	W. H. Chen, 904-392-1429
	J. A. Wethington
	W. G. Vernetson
	N. J. Diaz

REACTOR NO.	PL-8
REACTOR NAME	University of Lowell Nuclear Reactor
LOCATION	University of Lowell, North Campus, Lowell, Massachusetts 01854
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-125 50-233
TYPE	Open pool, plate fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	18 flat plates per element
OVERALL DIMENSIONS	7.62 cm × 7.62 cm × 101.6 cm
U-235 PER ELEMENT, kg	0.14
ELEMENTS/REACTOR	26
ENRICHMENT (% U-235)	93
DRAWING NO.	
SUPPLIER	Babcock and Wilcox

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	26	3.5
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	26	3.5

REFUELING SCHEDULE	
SPENT FUEL SHIPMENTS	
CONTACTS	Leon Beghian, 627-542-0500, ext. 2232 and 2245
	Thomas Wallace
	George Chabot

REACTOR NO.	PL-9
REACTOR NAME	University of Michigan Ford Nuclear Reactor
LOCATION	University of Michigan, North Campus, Ann Arbor, Michigan 48109
POWER	2 MW
LICENSE NO. NRC DOCKET NO.	R-28 50-2
TYPE	Open pool, plate type fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Curved plates, 18 plates per element
OVERALL DIMENSIONS	7.47 cm × 8.25 cm × 87.38 cm
U-235 PER ELEMENT, kg	0.167
ELEMENTS/REACTOR	40 (35 standard, 5 control)
ENRICHMENT (% U-235)	19.5
DRAWING NO.	
SUPPLIER	Babcock and Wilcox, Lynchburg, West Virginia

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	35	~5.84
FRESH FUEL	43	
SPENT FUEL	66	
TOTAL	144	

REFUELING SCHEDULE	One element per 28 days
SPENT FUEL SHIPMENTS	Shipped to SRS in BMI-1 or GE USA-5942 cask
CONTACTS	William Kerr, 313-764-6223
	Reed R. Burn
	Gary M. Cook

REACTOR NO.	PL-10
REACTOR NAME	University of Missouri Research Reactor
LOCATION	University of Missouri, Research Park, Columbia, Missouri 65211
POWER	10 MW
LICENSE NO. NRC DOCKET NO.	R-103 50-186
TYPE	Open pool, plate fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	24 curved plates per element
OVERALL DIMENSIONS	7.04 cm × 14.63 cm × 82.55 cm
U-235 PER ELEMENT, kg	0.78
ELEMENTS/REACTOR	Eight elements form a circular cylinder 30.5 cm diam
ENRICHMENT (% U-235)	93.15; no change to <20% is expected
DRAWING NO.	Element cross-section is 45° sector of circle
SUPPLIER	EG&G, Idaho

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	8	6.2
FRESH FUEL		
SPENT FUEL	27	
TOTAL	35	

REFUELING SCHEDULE	24 elements/year
SPENT FUEL SHIPMENTS	Shipped to SRS in GE-700 cask
CONTACTS	Don Alger, 314-882-4211
	Rolly Hultsch, 314-882-5205
	Charles McKibben
	R. Brugger

REACTOR NO.	PL-11
REACTOR NAME	University of Missouri-Rolla Reactor
LOCATION	University of Missouri, Rolla, Missouri 65401
POWER	200 kW
LICENSE NO. NRC DOCKET NO.	R-79 50-123
TYPE	Open pool, plate type fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	10 curved plates per element
OVERALL DIMENSIONS	7.57 cm × 8.74 cm × 87.0 cm
U-235 PER ELEMENT, kg	0.17
ELEMENTS/REACTOR	28
ENRICHMENT (% U-235)	89-93
DRAWING NO.	
SUPPLIER	W. R. Grace & Co., Erwin, Tennessee

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	28	2.85
FRESH FUEL		
SPENT FUEL		
TOTAL		2.85

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	
CONTACTS	Albert E. Bolon, Director, 314-341-4236

REACTOR NO.	PL-12
REACTOR NAME	University of Virginia Reactor
LOCATION	University of Virginia Reactor Facility, Charlottesville, Virginia 22901
POWER	2 MW
LICENSE NO. NRC DOCKET NO.	R-66 50-62
TYPE	Open pool, plate fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Either 18 curved plates or 12 flat plates
OVERALL DIMENSIONS	7.61 cm × 8.26 cm × 93.66 cm
U-235 PER ELEMENT, kg	0.19 (curved) or 0.17 (flat)
ELEMENTS/REACTOR	20
ENRICHMENT (% U-235)	93; to be converted to <20% in 1991
DRAWING NO.	
SUPPLIER	Atomics International

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	20	3.3
FRESH FUEL		
SPENT FUEL		
TOTAL	20	3.3

REFUELING SCHEDULE	Reactor is used 30 h/week or more
SPENT FUEL SHIPMENTS	Shipped to SRS in BMI-1 cask
CONTACTS	Dr. Robert Mulder, 804-924-7136
	J. P. Farrar

REACTOR NO.	PL-13
REACTOR NAME	Worcester Polytechnic Institute Reactor
LOCATION	Worcester Polytechnic Institute, Worcester, Massachusetts 01609
POWER	10 kW
LICENSE NO. NRC DOCKET NO.	R-61 50-134
TYPE	Open pool, plate fuel
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	18 flat plates per element
OVERALL DIMENSIONS	7.75 cm × 7.75 cm × 101.6 cm
U-235 PER ELEMENT, kg	0.17
ELEMENTS/REACTOR	24
ENRICHMENT (% U-235)	19.75
DRAWING NO.	
SUPPLIER	General Electric

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	24	4.08
FRESH FUEL		
SPENT FUEL		
TOTAL	24	4.08

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	None shipped
CONTACTS	Prof. Leslie C. Wilbur, 617-793-5276 or 617-793-5688

REACTOR NO.	TR-1
REACTOR NAME	Cornell University TRIGA Mk II
LOCATION	Cornell University, Ward Laboratory, Ithaca, New York 14853
POWER	500 kW
LICENSE NO. NRC DOCKET NO.	R-80 50-157
TYPE	TRIGA Mk II
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	
DRAWING NO.	
SUPPLIER	General Atomic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	David Clark, 607-256-3480
	Howard Aderhold

REACTOR NO.	TR-2
REACTOR NAME	Kansas State University Nuclear Reactor Facility
LOCATION	Kansas State University, Manhattan, Kansas 66506
POWER	250 kW
LICENSE NO. NRC DOCKET NO.	R-88 50-188
TYPE	TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin, 3.74 cm diam × 72.05 cm long
OVERALL DIMENSIONS	3.74 cm × 72.05 cm
U-235 PER ELEMENT, kg	0.034
ELEMENTS/REACTOR	80
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	General Atomic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	80	2.70
FRESH FUEL	0	0
SPENT FUEL	8	0.27
TOTAL	88	2.97

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	None stated
CONTACTS	Richard E. Faw, Director, 913-532-5624
	Timothy M. DeBey, Reactor Supervisor

REACTOR NO.	TR-3
REACTOR NAME	Oregon State TRIGA Reactor
LOCATION	Oregon State University, Radiation Center, Corvallis, Oregon 97331
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-106 50-243
TYPE	Open pool, TRIGA type
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.73 cm diam × 72.06 cm
U-235 PER ELEMENT, kg	Approximately 0.13
ELEMENTS/REACTOR	85
ENRICHMENT (% U-235)	70%; will be converted to 20% about 1994
DRAWING NO.	
SUPPLIER	General Atomic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	85	11.17
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	85	

REFUELING SCHEDULE	About 1 element/year
SPENT FUEL SHIPMENTS	One shipment made to HEDL in BMI-1 cask
CONTACTS	Dr. C. H. Wang, Director, 503-737-2341
	Prof. A. G. Johnson
	Dr. B. Dodd

REACTOR NO.	TR-4
REACTOR NAME	Pennsylvania State University Brazeale Reactor
LOCATION	Brazeale Nuclear Reactor, Pennsylvania State University, University Park, Pennsylvania 16802
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-2 50-5
TYPE	Open pool, TRIGA Mk III
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.73 cm diam × 72.14 cm long
U-235 PER ELEMENT, kg	0.056
ELEMENTS/REACTOR	87
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	General Atomic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	87	4.87
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	87	4.87

REFUELING SCHEDULE	About 6 elements every 2 years
SPENT FUEL SHIPMENTS	Spent fuel stored on site
CONTACTS	Samuel H. Levine, Director, 814-865-6351
	Ira B. McMaster, Deputy Director

REACTOR NO.	TR-5
REACTOR NAME	Reed Reactor Facility
LOCATION	Reed College, Portland, Oregon 97202
POWER	250 kW
LICENSE NO. NRC DOCKET NO.	R-112 50-288
TYPE	Open pool, TRIGA Mk I
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.73 cm diam × 72.14 cm long
U-235 PER ELEMENT, kg	Approximately 0.038
ELEMENTS/REACTOR	60
ENRICHMENT (% U-235)	20
DRAWING NO.	
SUPPLIER	General Atomic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	60	2.3
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	60	2.3

REFUELING SCHEDULE	About 1 element every 5 years; operates 10–15 h/week
SPENT FUEL SHIPMENTS	
CONTACTS	Michael Pollock, Acting Director

REACTOR NO.	TR-6
REACTOR NAME	Texas A&M Nuclear Science Center Reactor
LOCATION	Texas A&M University, Nuclear Science Center, College Station, Texas 77843
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-83 50-128
TYPE	Open pool, TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.58 cm diam × 76.2 cm
U-235 PER ELEMENT, kg	Approximately 0.12
ELEMENTS/REACTOR	90
ENRICHMENT (% U-235)	70%; will be changed to 19.8% about 1994
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	90	10.48
FRESH FUEL	1	0.122
SPENT FUEL	84	
TOTAL	175	

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	Donald E. Feltz, Director, 409-845-5907

REACTOR NO.	TR-7
REACTOR NAME	University of Arizona TRIGA Reactor
LOCATION	University of Arizona, Department of Nuclear and Energy Engineering, Tucson, Arizona 85721
POWER	100 kW
LICENSE NO. NRC DOCKET NO.	R-52 50-113
TYPE	Open pool TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.73 cm diam × 72.31 cm long
U-235 PER ELEMENT, kg	Approximately 0.038
ELEMENTS/REACTOR	87
ENRICHMENT (% U-235)	19.8
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	87	3.31
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	87	3.31

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	
CONTACTS	R. L. Seale, 602-626-3903
	G. W. Nelson
	H. J. Doane

REACTOR NO.	TR-8
REACTOR NAME	University of California Irvine TRIGA Mk I
LOCATION	University of California Irvine, Irvine, California 92717
POWER	250 kW
LICENSE NO. NRC DOCKET NO.	R-116 50-326
TYPE	Open pool, TRIGA Mk I
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin, stainless steel clad
OVERALL DIMENSIONS	3.81 cm diam × 71.12 cm
U-235 PER ELEMENT, kg	(8.5 wt % U)
ELEMENTS/REACTOR	81
ENRICHMENT (% U-235)	19.8
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	81	2.9
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None needed. Reactor runs about 10 h/month
SPENT FUEL SHIPMENTS	
CONTACTS	F. S. Rowland, 714-833-6015
	G. E. Miller

REACTOR NO.	TR-9
REACTOR NAME	University of Illinois Low Power Reactor
LOCATION	University of Illinois, Nuclear Reactor Laboratory, Urbana, Illinois 61801
POWER	10 kW
LICENSE NO. NRC DOCKET NO.	R-117 50-356
TYPE	Open pool, TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.73 cm diam × 71.12 cm long
U-235 PER ELEMENT, kg	Approximately 0.038 (7.0 g/cc U235)
ELEMENTS/REACTOR	55
ENRICHMENT (% U-235)	19.8
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	55	2.09
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	55	2.09

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	Gerald P. Beck, 217-333-0866
	Craig Pohlod, 217-333-7755
	Jerome J. Steerman

REACTOR NO.	TR-10
REACTOR NAME	University of Illinois TRIGA
LOCATION	University of Illinois, Nuclear Reactor Laboratory, Urbana, Illinois 61801
POWER	1.5 MW
LICENSE NO. NRC DOCKET NO.	R-115 50-151
TYPE	Open pool, TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.73 cm diam × 71.12 cm long
U-235 PER ELEMENT, kg	About 0.038 (7.0 g/cc U235)
ELEMENTS/REACTOR	100
ENRICHMENT (% U-235)	19.8
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	100	3.8
FRESH FUEL	8	0.30
SPENT FUEL		0
TOTAL	108	4.10

REFUELING SCHEDULE	About 2 elements/year
SPENT FUEL SHIPMENTS	
CONTACTS	Gerald P. Beck, 217-333-0866
	Craig Pohlod, 217-333-7755
	Jerome J. Steerman

REACTOR NO.	TR-11
REACTOR NAME	Maryland University Training Reactor
LOCATION	University of Maryland, College Park, Maryland 20740
POWER	250 kW
LICENSE NO. NRC DOCKET NO.	R-70 50-166
TYPE	Open pool, TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.58 cm diam × 68.58 cm
U-235 PER ELEMENT, kg	Approximately 0.0354
ELEMENTS/REACTOR	96
ENRICHMENT (% U-235)	19.8
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	96	3.4
FRESH FUEL	0	0
SPENT FUEL	0	0
TOTAL	96	3.4

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	Ralph L. Belcher, Director, 301-454-2436

REACTOR NO.	TR-12
REACTOR NAME	University of Texas TRIGA Mk-II
LOCATION	University of Texas, Austin, Texas
POWER	1100 kW
LICENSE NO. NRC DOCKET NO.	
TYPE	TRIGA Mk II
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin, stainless steel cladding
OVERALL DIMENSIONS	3.76 cm diam. × 72.06 cm long
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	19.8
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		2.8
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Two to five elements per year, but probably no new fuel needed before 1995
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. Tom Bauer, 512-471-5787

REACTOR NO.	TR-13
REACTOR NAME	University of Utah TRIGA Reactor
LOCATION	University of Utah, Salt Lake City, Utah 84112
POWER	100 kW
LICENSE NO. NRC DOCKET NO.	R-126 50-407
TYPE	Open pool, TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin, one pin per element
OVERALL DIMENSIONS	3.75 cm diam × 72.2 cm long
U-235 PER ELEMENT, kg	0.037
ELEMENTS/REACTOR	84
ENRICHMENT (% U-235)	19.8
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	84	3.11
FRESH FUEL	2	0.074
SPENT FUEL		
TOTAL	86	3.18

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	
CONTACTS	H. R. Jacobs, 801-581-7109
	Gary M. Sandquist
	Craig M. Jensen

REACTOR NO.	TR-14
REACTOR NAME	University of Wisconsin Nuclear Reactor
LOCATION	University of Wisconsin, Mechanical Engineering Building, Madison, Wisconsin 53706
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-74 50-156
TYPE	Open pool, TRIGA FLIP
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin (one pin per element)
OVERALL DIMENSIONS	3.58 cm diam × 68.3 cm
U-235 PER ELEMENT, kg	0.088 (8.5% total U)
ELEMENTS/REACTOR	91
ENRICHMENT (% U-235)	70% FLIP, changing to 19.8% LEU
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	91	8.0
FRESH FUEL (19.8% enriched)	116	
SPENT FUEL		
TOTAL	207	

REFUELING SCHEDULE	10 years
SPENT FUEL SHIPMENTS	
CONTACTS	R. J. Cashwell, Director, 608-262-3392
	S. M. Matusewic

REACTOR NO.	TR-15
REACTOR NAME	Washington State University Reactor
LOCATION	Washington State University, Pullman, Washington 99164
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-76 50-27
TYPE	Open pool, TRIGA
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin, one pin per element
OVERALL DIMENSIONS	(Cluster of 4) 7.92 cm × 7.92 cm × 93.9 cm
U-235 PER ELEMENT, kg	Approximately 0.066
ELEMENTS/REACTOR	102
ENRICHMENT (% U-235)	20 and 70
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	102	6.7
FRESH FUEL		
SPENT FUEL		
TOTAL	102	6.7

REFUELING SCHEDULE	
SPENT FUEL SHIPMENTS	None
CONTACTS	Dr. R. Filby, 509-335-8317
	W. E. Wilson
	J. Neidiger

REACTOR NO.	AGN-1
REACTOR NAME	Idaho State University AGN-201 M
LOCATION	Idaho State University, Lillibridge Engineering Laboratory, Pocatello, Idaho 83209
POWER	5 W
LICENSE NO. NRC DOCKET NO.	R-110 50-284
TYPE	Aerojet General Nucleonics AGN-201 M
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Discs of dispersed UO_2 in polyethylene
OVERALL DIMENSIONS	25.0 cm diam; thickness 5.0, 2.5, or 1.0 cm
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	Nine discs per reactor
ENRICHMENT (% U-235)	19.88
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	9	0.67
FRESH FUEL		0
SPENT FUEL		0
TOTAL	9	0.67

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	None
CONTACTS	Albert E. Wilson, Reactor Administrator, 208-236-2417
	Terry W. Smith, Reactor Supervisor, 208-236-2311

REACTOR NO.	AGN-2
REACTOR NAME	Texas A&M AGN-201 Training Reactor Facility
LOCATION	Texas A&M University, Department of Nuclear Engineering, College Station, Texas 77843
POWER	5 W
LICENSE NO. NRC DOCKET NO.	R-23 50-59
TYPE	AGN-201 homogeneous disc-type fuel, critical facility
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Homogeneous disc, UO_2 - polyethylene
OVERALL DIMENSIONS	25 cm diam × 3.9, 2.3, or 1.0 cm thick
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	9
ENRICHMENT (% U-235)	20
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	9	0.69
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. Carl A. Erdman, 713-845-4161

REACTOR NO.	AGN-3
REACTOR NAME	University of New Mexico AGN-201
LOCATION	University of New Mexico, Nuclear Engineering Laboratory, Albuquerque, New Mexico 87131
POWER	5 W
LICENSE NO. NRC DOCKET NO.	R-102 50-252
TYPE	Open pool, AGN-201
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Uranium oxide-polyethylene disc
OVERALL DIMENSIONS	25.6 cm diam, height 4.0, 2.0, and 1.0 cm
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	9
ENRICHMENT (% U-235)	20
DRAWING NO.	
SUPPLIER	Aerojet General Nucleonics

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		0.67
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. Craig Robertson, 505-277-5431
	Dr. David Woodall

REACTOR NO.	UPIN-1
REACTOR NAME	Cornell University Zero Power Reactor
LOCATION	Cornell University, Ward Laboratory, Ithaca, New York 14850
POWER	100 W
LICENSE NO. NRC DOCKET NO.	R-89 50-97
TYPE	Open tank critical facility
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	1.69 cm diam × 158.0 cm long
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	2.1
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	815	35.0
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	
SPENT FUEL SHIPMENTS	
CONTACTS	David Clark, 607-256-3480
	Howard Aderhold

REACTOR NO.	UPIN-2
REACTOR NAME	North Carolina State University PULSTAR
LOCATION	North Carolina State University, Department of Nuclear Engineering, Raleigh, North Carolina 27650
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-120 50-297
TYPE	PULSTAR, pool type
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	Element consists of 25 pins in 5 × 5 array
OVERALL DIMENSIONS	8.0 cm × 6.96 cm × 96.47 cm
U-235 PER ELEMENT, kg	0.57
ELEMENTS/REACTOR	25
ENRICHMENT (% U-235)	4
DRAWING NO.	
SUPPLIER	Westinghouse Canada

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	25	12.7
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Not stated
SPENT FUEL SHIPMENTS	None
CONTACTS	Dr. Robert G. Cockrell, 919-737-2322 and 2323
	Thomas C. Bray
	David P. Coccamo

REACTOR NO.	UPIN-3
REACTOR NAME	Rensselaer Critical Experiment Facility
LOCATION	Nuclear Engineering Department, Rensselaer Polytechnic Institute, Troy, New York 12181
POWER	<100 W
LICENSE NO. NRC DOCKET NO.	CX-22 50-225
TYPE	Tank type critical facility
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	SPERT-type fuel pins in square array
OVERALL DIMENSIONS	1.18 cm diam × 105.73 cm long
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	497 fuel pins
ENRICHMENT (% U-235)	4.81%
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. Donald R. Harris, Director, 518-393-4281
	Dr. Frank Wicks, Supervisor, 518-270-6403

REACTOR NO.	UPIN-4
REACTOR NAME	State University of New York NSTF
LOCATION	State University of New York, Rotary Road, Buffalo, New York 14214
POWER	2 MW
LICENSE NO.	R-77
NRC DOCKET NO.	50-57
TYPE	Open pool, tank type PULSTAR
STATUS	Operational
FUEL ELEMENT	
DESCRIPTION	25 cylindrical pins in 5 × 5 array
OVERALL DIMENSIONS	6.96 cm × 8.0 cm × 96.52 cm
U-235 PER ELEMENT, kg	0.76
ELEMENTS/REACTOR	24
ENRICHMENT (% U-235)	6
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	24	18.2
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	>10 years
SPENT FUEL SHIPMENTS	Shipment made to INEL in BMI-1 cask
CONTACTS	Lewis G. Henry, 716-831-2826
	Philip Orlosky

APPENDIX 4B. DATA SHEETS FOR NUCLEAR REACTORS AT EDUCATIONAL INSTITUTIONS IN THE UNITED STATES

PART 2. SHUT-DOWN REACTORS

REACTOR NO.	SPL-1
REACTOR NAME	University of California Los Angeles Training Reactor
LOCATION	University of California Los Angeles, Boelter Hall, Los Angeles, California 90024
POWER	100 kW
LICENSE NO. NRC DOCKET NO.	R-71 50-142
TYPE	ARGONAUT
STATUS	Shut down since 1984
FUEL ELEMENT	
DESCRIPTION	MTR plate-type fuel, 11 plates/element
OVERALL DIMENSIONS	6.03 cm × 7.23 cm × 68.56 cm
U-235 PER ELEMENT, kg	0.14
ELEMENTS/REACTOR	24
ENRICHMENT (% U-235)	93
DRAWING NO.	
SUPPLIER	Atomics International

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	All fuel shipped to INEL	
TOTAL		

REFUELING SCHEDULE	Reactor has been shut down
SPENT FUEL SHIPMENTS	Shipped to INEL in GE-700 cask
CONTACTS	Ivan Catton, Director, 213-825-2040
	Neill Ostrander, 213-825-2825
	Tony Zane

REACTOR NO.	SPL-2
REACTOR NAME	University of Kansas, Bendix Research and Training Reactor
LOCATION	Nuclear Reactor Center, University of Kansas, Lawrence, Kansas 66045
POWER	10 kW
LICENSE NO. NRC DOCKET NO.	R-78 50-148
TYPE	Open pool, plate type fuel
STATUS	Shut down since 1987
FUEL ELEMENT	
DESCRIPTION	Flat plate type, 10 plates/element
OVERALL DIMENSIONS	7.62 cm × 7.62 cm × 86.31 cm
U-235 PER ELEMENT, kg	0.17
ELEMENTS/REACTOR	16
ENRICHMENT (% U-235)	90
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	All fuel shipped to Savannah River Site	
TOTAL		

REFUELING SCHEDULE	
SPENT FUEL SHIPMENTS	Shipped to Savannah River Site
CONTACTS	Russell Mesler, 913-864-3938
	Harold Rosson
	Benjamin Friesen

REACTOR NO.	SPL-3
REACTOR NAME	Virginia Polytechnic Institute and State University Research Reactor
LOCATION	Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24060
POWER	100 kW
LICENSE NO. NRC DOCKET NO.	R-62 50-124
TYPE	ARGONAUT
STATUS	Shut down since 1984
FUEL ELEMENT	
DESCRIPTION	Rectangular fuel plates, 12 plates per element
OVERALL DIMENSIONS	7.62 cm × 15.24 cm × 66.04 cm
U-235 PER ELEMENT, kg	Approximately 0.266
ELEMENTS/REACTOR	12
ENRICHMENT (% U-235)	90
DRAWING NO.	
SUPPLIER	American Standard

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	All fuel shipped to Savannah River Site	
TOTAL		

REFUELING SCHEDULE	Shut down
SPENT FUEL SHIPMENTS	All shipped to Savannah River Site
CONTACTS	T. F. Parkinson, 703-961-6510
	P. D. Holian

REACTOR NO.	SPL-4
REACTOR NAME	University of Washington Nuclear Reactor
LOCATION	University of Washington Nuclear Reactor Building, Seattle, Washington 98195
POWER	100 kW
LICENSE NO.	R-73
NRC DOCKET NO.	50-139
TYPE	ARGONAUT
STATUS	Shut down since 1988
FUEL ELEMENT	
DESCRIPTION	Flat plates, 11 plates per element
OVERALL DIMENSIONS	7.11 cm × 6.1 cm × 65.09 cm
U-235 PER ELEMENT, kg	~0.143
ELEMENTS/REACTOR	24
ENRICHMENT (% U-235)	93
DRAWING NO.	
SUPPLIER	Babcock & Wilcox

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	All fuel shipped to INEL	
TOTAL		

REFUELING SCHEDULE	Shut down
SPENT FUEL SHIPMENTS	All shipped to INEL
CONTACTS	William S. Chalk, Director, 206-543-4170
	William P. Miller

REACTOR NO.	SPL-5
REACTOR NAME	University of Virginia CAVALIER
LOCATION	University of Virginia Reactor Facility, Charlottesville, Virginia 22901
POWER	100 W
LICENSE NO. NRC DOCKET NO.	R-123 50-396
TYPE	Open pool, plate type fuel CAVALIER
STATUS	Shut down; decommissioned 1987
FUEL ELEMENT	
DESCRIPTION	Flat plates, 12 plates per element
OVERALL DIMENSIONS	7.61 cm × 8.26 cm × 93.66 cm
U-235 PER ELEMENT, kg	0.165
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	93
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. Robert Mulder, 804-924-7136
	J. P. Farrar

REACTOR NO.	STR-1
REACTOR NAME	Michigan State University TRIGA Mk I
LOCATION	Michigan State University, Nuclear Reactor Laboratory, East Lansing, Michigan 48824
POWER	250 kW
LICENSE NO. NRC DOCKET NO.	R-114 50-294
TYPE	Pool type, TRIGA Mk I
STATUS	Shut down since 1989
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.76 cm diam × 72.39 cm long
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	20
DRAWING NO.	
SUPPLIER	General Atomic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	Fuel was shipped to U.S. Geological Survey (1/3) and INEL (2/3)	
TOTAL		

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	Shipped to USGS and INEL
CONTACTS	Dr. Bruce Wilkinson, 517-769-2836

REACTOR NO.	STR-2
REACTOR NAME	Columbia University TRIGA Mk II
LOCATION	Columbia University, 520 W. 120 St., New York, New York 10027
POWER	250 kW
LICENSE NO. NRC DOCKET NO.	R-128 50-208
TYPE	Open pool, TRIGA Mk II
STATUS	Built but never operated; shut down and decommissioned
FUEL ELEMENT	
DESCRIPTION	Cylindrical pins, 3.74 cm diam × 72.05 cm long
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	65–80
ENRICHMENT (% U-235)	19.8%
DRAWING NO.	
SUPPLIER	General Atomic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	This reactor was never started up, and no fuel was ever procured	
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	None
CONTACTS	Prof. Charles F. Bonilla, 212-280-4441
	Prof. Edward Melkonian, 212-280-4442

REACTOR NO.	STR-3
REACTOR NAME	University of Illinois TRIGA Mk1
LOCATION	Urbana, Illinois
POWER	
LICENSE NO. NRC DOCKET NO.	R-69 50-151
TYPE	TRIGA Mark 1
STATUS	Shut down and decommissioned in 1968
FUEL ELEMENT	
DESCRIPTION	
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	All fuel was shipped to Michigan State	
TOTAL		

REFUELING SCHEDULE	Shut down in 1968
SPENT FUEL SHIPMENTS	
CONTACTS	Craig Pohlod, 217-333-0866

REACTOR NO.	STR-4
REACTOR NAME	University of California Berkeley Research Reactor
LOCATION	Department of Nuclear Engineering, University of California, Berkeley, California 94720
POWER	1 MW
LICENSE NO. NRC DOCKET NO.	R-101 50-224
TYPE	Open pool TRIGA
STATUS	Shut down since 1987; decommissioned 1988
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin
OVERALL DIMENSIONS	3.63 cm diam × 38.1 cm long
U-235 PER ELEMENT, kg	Approximately 0.034 (8.5 wt % U)
ELEMENTS/REACTOR	106
ENRICHMENT (% U-235)	19.8%
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	Fuel was all shipped to INEL	
TOTAL		

REFUELING SCHEDULE	Reactor is shut down
SPENT FUEL SHIPMENTS	Shipped to INEL
CONTACTS	Selig N. Kaplan, 415-642-5213
	Tek H. Lim, 415-642-5224
	Harry G. Braun

REACTOR NO.	STR-5
REACTOR NAME	University of Texas TRIGA Mk-I
LOCATION	University of Texas, Nuclear Engineering Teaching Laboratory, Austin, Texas 78712
POWER	250 kW
LICENSE NO. NRC DOCKET NO.	R-92 50-192
TYPE	Open pool, TRIGA
STATUS	Decommissioned Dec. 31, 1988
FUEL ELEMENT	
DESCRIPTION	Cylindrical pin, one pin per element
OVERALL DIMENSIONS	3.76 cm diam × 72.06 cm long
U-235 PER ELEMENT, kg	(8.5 wt % U)
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	19.8%
DRAWING NO.	
SUPPLIER	GA Technologies

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL		
SPENT FUEL	The fuel from this reactor has been been kept at the University of Texas for use in another reactor (1100 kW TRIGA)	
TOTAL		

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. Dale Klein, 512-471-5136
	Dr. T. L. Bauer, 512-471-5787

REACTOR NO.	SAGN-1
REACTOR NAME	Catholic University AGN-201 CU
LOCATION	The Catholic University of America, Washington, DC 20064
POWER	0.1 W
LICENSE NO. NRC DOCKET NO.	R-31 50-77
TYPE	Aerojet General Nucleonics AGN-201
STATUS	Shut down since 1986; decommissioned 1987
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene discs
OVERALL DIMENSIONS	25.75 cm diam, thickness 3.9, 2.3, and 1.0 cm
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	Nine discs per reactor
ENRICHMENT (% U-235)	19.9
DRAWING NO.	
SUPPLIER	Aerojet General Nucleonics

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel is to be sent to DOE	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None anticipated; reactor is shut down
SPENT FUEL SHIPMENTS	None; fuel is to be sent to DOE
CONTACTS	Edward Jordan, Reactor Administrator, 202-635-5170
	Y. C. Whang, Chairperson, Mech. Eng. Dept.
	D. D. Ebert, Reactor Supervisor

REACTOR NO.	SAGN-2
REACTOR NAME	Memphis State University AGN-201-108
LOCATION	Memphis State University, Center for Nuclear Studies, Memphis, Tennessee 38152
POWER	0.1 W
LICENSE NO. NRC DOCKET NO.	R-127 50-538
TYPE	Aerojet General Nucleonics AGN-201
STATUS	Shut down since 1985; decommissioned 1987
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene discs
OVERALL DIMENSIONS	25.4 cm diam, thickness 4.0, 2.0, and 1.0 cm
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	Nine discs per reactor
ENRICHMENT (% U-235)	19.9
DRAWING NO.	
SUPPLIER	Fuel available from decommissioned reactors

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been shipped to ORNL	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None anticipated; shut down in 1985
SPENT FUEL SHIPMENTS	To Oak Ridge National Laboratory, Oak Ridge, Tennessee, in DOT type 6J drums
CONTACTS	Dr. D. W. Jones, 901-454-2687
	R. L. Dietz

REACTOR NO.	SAGN-3
REACTOR NAME	University of Utah AGN-201-107
LOCATION	University of Utah, Merrill Engineering Building, Salt Lake City, Utah 84112
POWER	5 W
LICENSE NO. NRC DOCKET NO.	R-25 50-72
TYPE	AGN-201 homogeneous disc fuel
STATUS	Decommissioned 1988
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene discs
OVERALL DIMENSIONS	25.6 cm diam × 4.0, 2.0, and 1.0 cm thick
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	Nine, about 0.69 kg U-235 total
ENRICHMENT (% U-235)	19.5%
DRAWING NO.	
SUPPLIER	Aerojet General Nucleonics

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been put into a shipping cask and will be sent to a DOE site	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None anticipated; reactor is shut down
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. Gray M. Sandquist, 801-581-7109
	Dr. H. R. Jacobs, 801-581-7372

REACTOR NO.	SAGN-4
REACTOR NAME	University of Oklahoma AGN-211P
LOCATION	University of Oklahoma, Nuclear Reactor Laboratory, Norman, Oklahoma 73019
POWER	15 W
LICENSE NO. NRC DOCKET NO.	R-53 50-112
TYPE	Open pool, AGN-211
STATUS	Shut down since 1988
FUEL ELEMENT	
DESCRIPTION	Uranium oxide-polyethylene blocks (two blocks per element)
OVERALL DIMENSIONS	7.32 cm × 7.77 cm × 70.17 cm
U-235 PER ELEMENT, kg	Approximately 0.7 kg U-235
ELEMENTS/REACTOR	12
ENRICHMENT (% U-235)	19.84%
DRAWING NO.	
SUPPLIER	Aerojet General Nucleonic

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been sent to Oak Ridge National Laboratory	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None anticipated
SPENT FUEL SHIPMENTS	Shipped to Oak Ridge National Laboratory
CONTACTS	Dr. C. W. Terrell, 405-325-5084
	Johnny James
	Dr. Duaine Lindstrom

REACTOR NO.	SAGN-5
REACTOR NAME	California Polytechnic Institute AGN-201
LOCATION	San Luis Obispo, California
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-121 50-394
TYPE	
STATUS	Shut down 1980 and decommissioned
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene discs
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	Total of about 0.67 kg U-235
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been shipped to Oak Ridge	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Reactor is shut down and dismantled
SPENT FUEL SHIPMENTS	
CONTACTS	Prof. R. W. Adamson, 805-756-1346

REACTOR NO.	SAGN-6
REACTOR NAME	University of Delaware AGN-201
LOCATION	Newark, Delaware
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-43 50-98
TYPE	
STATUS	Shut down and decommissioned 1978
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been shipped to Oak Ridge National Laboratory	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	All fuel shipped to ORNL
CONTACTS	

REACTOR NO.	SAGN-7
REACTOR NAME	Georgia Institute of Technology AGN-201
LOCATION	Atlanta, Georgia
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-111 50-276
TYPE	
STATUS	Shut down and decommissioned 1987
FUEL ELEMENT	
DESCRIPTION	UO_2 – polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel shipped to Oak Ridge National Laboratory	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. R. Karam, 404-894-3620

REACTOR NO.	SAGN-8
REACTOR NAME	Colorado State University AGN-201
LOCATION	Fort Collins, Colorado
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	
TYPE	
STATUS	Shut down in 1974; decommissioned 1976
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR	Information is not available, but AGN-201 reactors typically have 9 fuel elements and a total core loading of about 0.67 kg U-235	
FRESH FUEL		
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Shut down; reactor and fuel were shipped to South Korea
SPENT FUEL SHIPMENTS	
CONTACTS	Dr. James Johnson, 303-491-5380

REACTOR NO.	SAGN-9
REACTOR NAME	Oregon State University AGN-201
LOCATION	Corvallis, Oregon
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-51 50-106
TYPE	AGN-201
STATUS	
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	Fuel is being held at Oregon State University	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Shut down and decommissioned
SPENT FUEL SHIPMENTS	Fuel is being held at site
CONTACTS	Dr. Brian Dodd, 503-737-7047

REACTOR NO.	SAGN-10
REACTOR NAME	Polytechnic Institute of New York AGN-201
LOCATION	New York, New York
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-105 50-126
TYPE	AGN-201
STATUS	
FUEL ELEMENT	
DESCRIPTION	UO_2 -polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	About 0.7 kg U-235
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	
DRAWING NO.	
SUPPLIER	

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been shipped to Oak Ridge National Laboratory	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Decommissioned
SPENT FUEL SHIPMENTS	
CONTACTS	

REACTOR NO.	SAGN-11
REACTOR NAME	Tuskeegee Institute AGN-201
LOCATION	
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-122 50-406
TYPE	
STATUS	Shut down and decommissioned 1982
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	Aerojet General Nucleonics

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been returned to DOE	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None; reactor is decommissioned
SPENT FUEL SHIPMENTS	
CONTACTS	

REACTOR NO.	SAGN-12
REACTOR NAME	West Virginia University AGN-201
LOCATION	
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-158 50-129
TYPE	
STATUS	Shut down and decommissioned 1972
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	Approximately 0.7 kg U-235
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	
DRAWING NO.	
SUPPLIER	Aerojet General Nucleonics

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been sent to the University of Oklahoma	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Reactor is decommissioned
SPENT FUEL SHIPMENTS	
CONTACTS	

REACTOR NO.	SAGN-13
REACTOR NAME	Rice University AGN-201
LOCATION	
POWER	Negligible
LICENSE NO. NRC DOCKET NO.	R-54 50-101
TYPE	
STATUS	Shut down and decommissioned
FUEL ELEMENT	
DESCRIPTION	UO_2 - polyethylene
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	Approximately 0.7 kg U-235
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	
DRAWING NO.	
SUPPLIER	Aerojet General Nucleonics

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	All fuel has been shipped to Texas A&M University	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Reactor was shut down in 1965
SPENT FUEL SHIPMENTS	
CONTACTS	

REACTOR NO.	SAQ-1
REACTOR NAME	University of California Santa Barbara L-77
LOCATION	University of Santa California, Santa Barbara, California 93106
POWER	10 W
LICENSE NO. NRC DOCKET NO.	R-124 50-433
TYPE	Liquid fuel
STATUS	Shut down since 1986; decommissioned in 1987
FUEL ELEMENT	
DESCRIPTION	Spherical core, liquid fuel
OVERALL DIMENSIONS	30.3 L
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	89
DRAWING NO.	
SUPPLIER	Atomics International

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	Fuel has been sent to INEL	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Reactor has been disassembled and fuel has been shipped to INEL
SPENT FUEL SHIPMENTS	
CONTACTS	Prof. A. E. Profio, 805-961-4146 or 805-961-3412

REACTOR NO.	SAQ-2
REACTOR NAME	Brigham Young University Reactor L-77
LOCATION	Bringham Young University, Provo, Utah 84602
POWER	10 W
LICENSE NO. NRC DOCKET NO.	R-109 50-262
TYPE	Atomics International Model L-77
STATUS	Shut down since 1987
FUEL ELEMENT	
DESCRIPTION	Liquid fuel
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	<20%
DRAWING NO.	
SUPPLIER	Atomics International

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	Fuel has been sent to INEL	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	None; shut down
SPENT FUEL SHIPMENTS	Fuel has been sent to INEL
CONTACTS	J. Rex Goates, Administrator, 801-378-2093
	Dwight R. Dixon, Facility Chief, 801-378-2093
	Gary Lee Jensen, Sr., Operator, 801-378-2093

REACTOR NO.	SAQ-3
REACTOR NAME	University of Wyoming L-77
LOCATION	Laramie, Wyoming
POWER	
LICENSE NO. NRC DOCKET NO.	
TYPE	Liquid fuel L-77
STATUS	Shut down since 1974
FUEL ELEMENT	
DESCRIPTION	
OVERALL DIMENSIONS	
U-235 PER ELEMENT, kg	
ELEMENTS/REACTOR	
ENRICHMENT (% U-235)	
DRAWING NO.	
SUPPLIER	Atomics International

INVENTORY OF U-235	FUEL ELEMENTS	kg U-235
IN REACTOR		
FRESH FUEL	Liquid fuel has been shipped to Atomics International	
SPENT FUEL		
TOTAL		

REFUELING SCHEDULE	Reactor has been dismantled
SPENT FUEL SHIPMENTS	
CONTACTS	

APPENDIX 4C. SUPPLEMENTAL DATA FOR FORT ST. VRAIN SPENT FUEL

4C. SUPPLEMENTAL DATA FOR FORT ST. VRAIN SPENT FUEL

4C.1 INTRODUCTION

The Fort St. Vrain (FSV) reactor is discussed in Sect. 4.2 of the main body of this report. The reactor is of the high-temperature, helium-gas-cooled type with a rated thermal power of 842 MW. It started up in 1979 and was permanently shut down in August 1989. The fuel is scheduled to be removed by the end of 1991. This appendix contains additional data on inventory, fuel element description, fuel types and markings, and postirradiation condition.

4C.2 INVENTORY OF FORT ST. VRAIN FUEL

As of September 1987, three reactor segments had been discharged from the FSV reactor. The discharge dates and the number of elements discharged were as follows:

Discharge 1	February 1, 1979	245 elements
Discharge 2	May 13, 1981	240 elements
Discharge 3	January 2, 1984	240 elements

The serial numbers for the above 725 fuel elements are provided in Tables 4C.1, 4C.2, and 4C.3. The remains of one element, which was destructively examined, are at General Atomics, San Diego. The remaining 724 are in storage at INEL (Morissette 1986).

Table 4C.4 shows the complete schedule of spent fuel discharged from the FSV reactor through the end of 1989 and the projected schedule through 1991. The total in-core inventory at the time of shutdown was 1,482 elements. All this fuel is scheduled to be removed by the end of 1991, giving a total cumulative discharge of 2,208 elements (Brey 1990, DOE 1990). All spent fuel discharged prior to December 31, 1988, is located at the Idaho Chemical Processing Plant (ICPP). Fuel removed from the core in 1989 and 1990 remains on-site in temporary storage wells until shipment to the ICPP can be accomplished or an independent spent fuel storage installation is built for permanent storage.

Burnups of fuel elements are available on floppy discs, as discussed in Sect. 4.2.4 of this report.

4C.3 FSV REACTOR FUEL ELEMENT

The following description of FSV fuel is from a report by Bingham and Evans (Bingham 1976):

> A Fort St. Vrain fuel element consists of a 300 lb hexagonal, needle-coke graphite block, 14.2 in. across the flats and 31.2-in.-high. Each graphite fuel block (see Fig. 4.2.1) contains 108 coolant channels and 210 fuel holes, all drilled from the top face of the element. The coolant holes extend through the element; the fuel holes extend to within about 0.3 in. of the bottom face. The fuel holes occupy alternating positions with the coolant channels in a triangular array within the element structure and contain the active fuel. After the fuel is inserted in a fuel hole, the hole is sealed with a graphite plug cemented into place.
>
> The fresh fuel itself is in the form of carbide particles coated with layers of pyrolytic carbon and silicon carbide, loosely bonded by a carbonaceous matrix material into fuel sticks. The fuel bed contains a homogeneous mixture of two types of particles, called fissile and fertile. Fresh fissile particles contain thorium and 93.5% enriched uranium; fresh fertile particles contain only thorium. The important parameters of fresh particles are:
>
> | Parameter | Fissile | Fertile |
> |---|---|---|
> | Th/U (atomic ratio) | 4.25 | All Th |
> | Particle composition | $(Th/U)C_2$ | Th C_2 |
> | Average fuel particle diameter, μm | 200 | 450 |
> | Average total coating thickness, μm | 130 | 140 |
>
> Besides fission products, the irradiated fuel contains thorium, U-233, U-235, other uranium isotopes, and a small quantity of plutonium. In the fertile particles, the fissile material is essentially U-233, while the fissile particles contain the residual U-235 and bred U-233.

4C.4 FUEL TYPES AND IDENTITY MARKINGS

This information is from Bingham 1976, GA 1985, and Kowal 1984. The initial core loading consisted of 84 different types of fuel elements. The large number of different types was due to variations in design of the blocks, different fuel loadings in blocks of the same design, variations in positioning of the burnable poison rods, and the neutron sources. Each fuel element has a permanent three-digit-type number engraved on the side of the hexagonal block. This type number identifies the specific contents of the element. In addition, each element has a permanent serial number engraved on the side of the hexagonal block. The serial number is unique for each element and can be used to trace the entire fabrication history of the components within an element. Table 4C.5

shows a listing of the various types of fuel elements, along with their corresponding drawing numbers.

The fuel element assembly type number, as illustrated in Fig. 4C.1, is painted on the top surface of each initial core fuel element. The assembly type number and serial number are engraved on the side of each element for all segments.

The format of the serial number is as follows:

Y - XXXX for H-327 graphite

and

Y - XXXXX for H-451 graphite.

The "X's" represent a 4-digit or 5-digit manufacturer's serial number for fuel elements made from H-327 or H-451 graphite, respectively. The "Y" denotes the style of fuel element, as follows:

Y = 1 denotes standard fuel element,
- 2 denotes control fuel element,
- 3 denotes bottom control fuel element,
- 4 denotes neutron source element,
- 5 denotes standard fuel element with enlarged handling hole,
- 6 denotes control fuel element with enlarged handling hole,
- 7 denotes bottom control fuel element with enlarged handling hole,
- 8 denotes fuel test elements,
- 11 denotes californium neutron source fuel element.

Certain selected elements within the core are designated as surveillance elements and as fuel test elements. The element identification includes the core location number and identification as shown in Fig. 4C.1.

4C.4.1 Fuel Element Types

Figures 4C.2 through 4C.8 depict variations of the basic fuel element design. This basic design has been used not only for standard fuel element service, but also for surveillance elements, neutron source elements, and test elements. Considering differences in fuel loadings, there are 64 types of fuel elements, as listed in Table 4C.5.

All fuel elements have 210 fuel holes, containing a total of 3,132 fuel rods and 108 coolant passages. All the graphite blocks for the regular elements have a 0.500-in. diameter hole in each of their six corners. Some of these elements contain burnable poison rods in selected corner holes (see Figs. 4C.4 through 4C.7) and some elements have an enlarged fuel pickup hole as shown in Fig. 4C.3.

Surveillance elements were extensively characterized prior to loading into the reactor core, including a detailed characterization of the fuel rods, burnable poison rods, and the graphite blocks. In addition, these fuel elements include small temperature and fluence monitors in selected fuel rod stacks. The purpose of the preirradiation characterization of fuel and reflector elements was to provide a means for future evaluation of the in-core element performance, as a part of the overall development program for future FSV and other HTGR fuel.

The test elements are designed to operate within the limits of peak fuel temperature, neutron fluence, and burnup specified for the initial core and reload fuel elements. Instrumentation is included in the test elements to measure each of these parameters. The purpose of these fuel test elements is to test new graphites and fuel forms for commercial HTGRs and to test improved fuel contemplated for use in future FSV reload segments.

The bottom of the fuel handling hole has been extended in some of the fuel elements to accommodate a neutron source. Sources are placed in neutron source elements as shown in Fig. 4C.6.

Two startup neutron sources consisting of californium-252 encapsulated in platinum and stainless steel were originally installed in the core. A third source consisting of californium-252 doubly encapsulated in stainless steel was added during the second refueling outage, and a fourth source was added during the third refueling outage. The californium neutron source element is shown in Fig. 4C.8.

4C.4.2 Control Fuel Elements

The center control rod fuel element in each region is similar to the surrounding fuel elements, but contains enlarged channels for the two control rods and the reserve shutdown absorber material. The control rod channels have a 9.72 in. centerline spacing and a diameter of 4.00 in. The reserve shutdown channel has a diameter of 3.75 in. Each control rod fuel element contains 120 fuel holes, loaded with a total of 1,782 fuel rods and 57 coolant channels.

All control fuel elements have a 0.500-in. diameter hole in four corners of the hexagonal block for burnable poison rods. None of the control elements in the initial core contain burnable poison rods.

Figure 4C.9 depicts a control fuel element with an enlarged fuel pickup hole. Some of the control fuel elements are surveillance elements as described above. Considering differences in fuel loadings, there are 13 types of control fuel elements, as listed in Table 4C.5.

4C.4.3 Bottom Control Fuel Elements

The bottom element in the control rod column extends below the core about 7.5 in. The fuel holes in the bottom control rod element are 22.3 in. deep so the bottom of the fuel holes of all elements at the bottom of the core are at the same elevation. The reserve shutdown absorber channel hole is also 22.3 in. deep. Each bottom control fuel element contains 120 fuel holes loaded with a total of 1,302 fuel rods. All bottom control elements have a 0.500-in. diameter hole in four corners of the hexagonal block for burnable poison rod loading. None of the bottom control fuel elements in the initial core contain burnable poison rods.

Figure 4C.10 depicts a bottom control fuel element with an enlarged fuel pickup hole. Considering differences in fuel loadings, there are seven types of bottom control fuel elements, as listed in Table 4C.5.

4C.5 POSTIRRADIATION CONDITION OF FUEL

A nondestructive examination of various fuel elements was performed once the elements were removed from the core. Nearly all of the examined elements shrank slightly in both axial and radial dimensions. The inspected elements were in good condition.

4C.5.1 Segment 1 Discharge

Common fuel elements. No cracks were observed on any of the element surfaces. With the exception of two large chips on chamfers (both noted during preirradiation visual inspection), all observed abnormalities were surface markings only. These markings had not etched the graphite to any harmful extent. Most blemishes observed on the elements were stains, rub marks, interface marks, soot deposits, scratches, and fingerprints.

The average axial and radial shrinkages measured for fuel elements which attained maximum burnup were 0.073 and 0.031 in., respectively. A few of the elements expanded slightly in the radial direction. The maximum expansion was 0.004 in. The maximum observed bow was 0.012 in (Miller 1980).

Surveillance element. A postirradiation examination and evaluation was performed on surveillance element 1-0743. All observed abnormalities were surface markings only and had not etched the graphite to any harmful extent. Observed abnormalities included rub marks, soot deposits, scrapes, and scratches.

No evidence of mechanical interaction between the fuel rods and fuel body was found. Although minor cracking in the matrix end caps and some surface debonding were observed, the fuel rods were in good condition. About 3% of the rods were broken, but the majority of these were broken during unloading, and the evidence indicates that the remainder were broken prior to (or during) assembly of the element (Saurwein 1981).

4C.5.2 Segment 2 Discharge

Little evidence was observed of graphite oxidation or erosion. Most blemishes observed on the elements were stains, scratches, scrapes, rub marks, and flow marks. The maximum average shrinkages observed for the elements were 0.115 in. in the length and 0.037 in. between opposing side faces. The maximum observed bow was 0.017 in.

Two fuel elements each had a single localized crack. The more prominent crack, observed in element 1-2415, was located in the center of the face adjacent to the single large dowel and extended the length of the element. The second crack was observed in fuel element 1-0172, which was located directly beneath element 1-2415 in the core. This crack was also located in the center of the face adjacent to the large dowel and ran vertically down the element.

The preirradiation inspection reports indicate that neither element was cracked prior to insertion into the core, and there is no record of any damage having been done during handling. Therefore, these cracks are assumed to have developed during irradiation (Saurwein 1982).

4C.5.3 Segment 3 Discharge

Little evidence was observed of graphite oxidation or erosion. Most blemishes observed on the elements were typical scratches, scrapes, rub marks, interface marks, and flow marks. The core Segment 3 maximum element average shrinkages in length and between-flats dimensions were 0.23 and 0.08 in., respectively. The maximum observed bow was 0.027 in. One H-327 graphite fuel element expanded slightly (0.001 in.) between flats.

There were a few small nicks and chips on the elements. Most of these were very minor and insignificant. However, element 1-1228 had minor damage to all three of its dowel pins. Element 2-1707 had damage to one dowel socket. A small chip of the graphite web between that socket and the central coolant hole on the nearest face edge was missing (McCord 1985).

4C.6 REFERENCES

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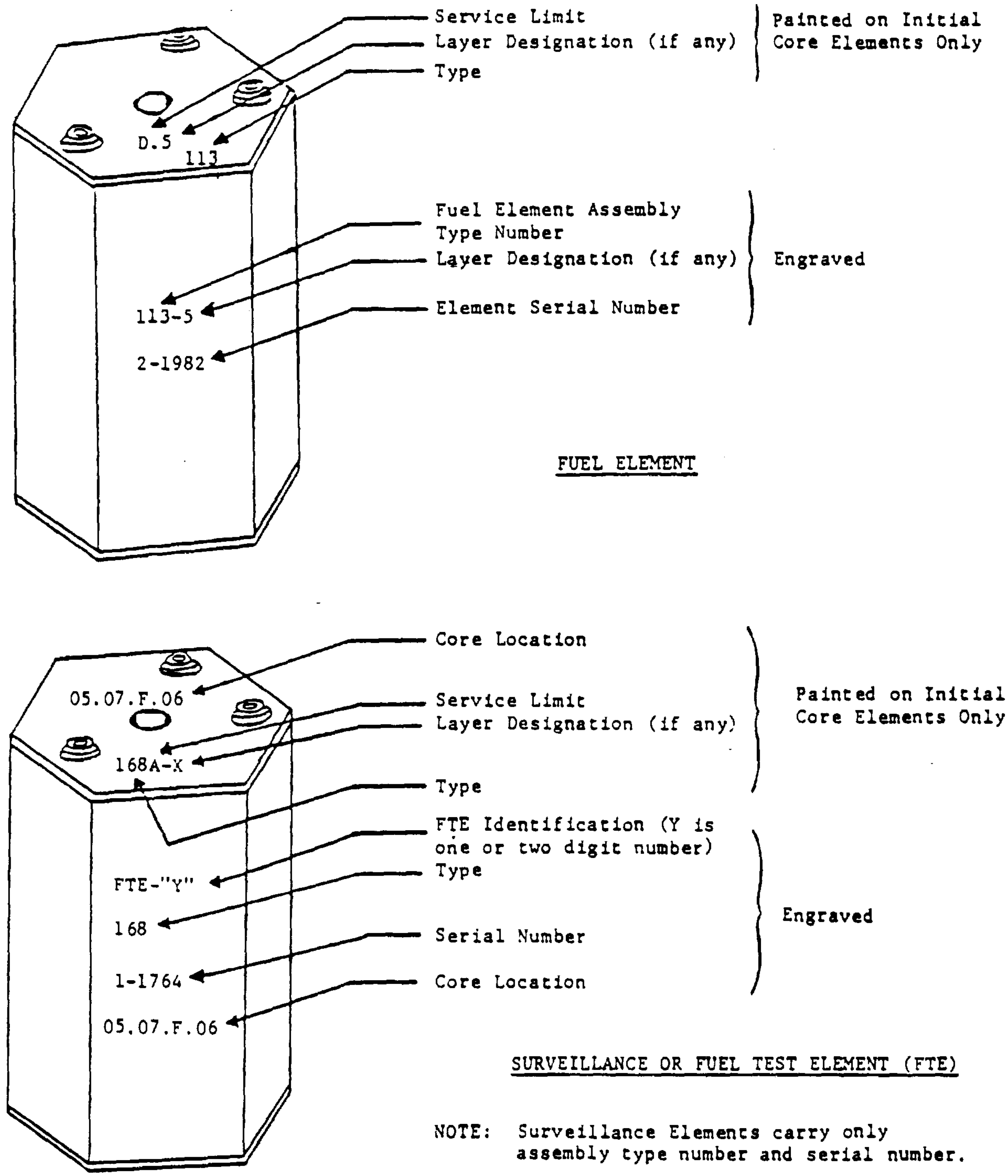
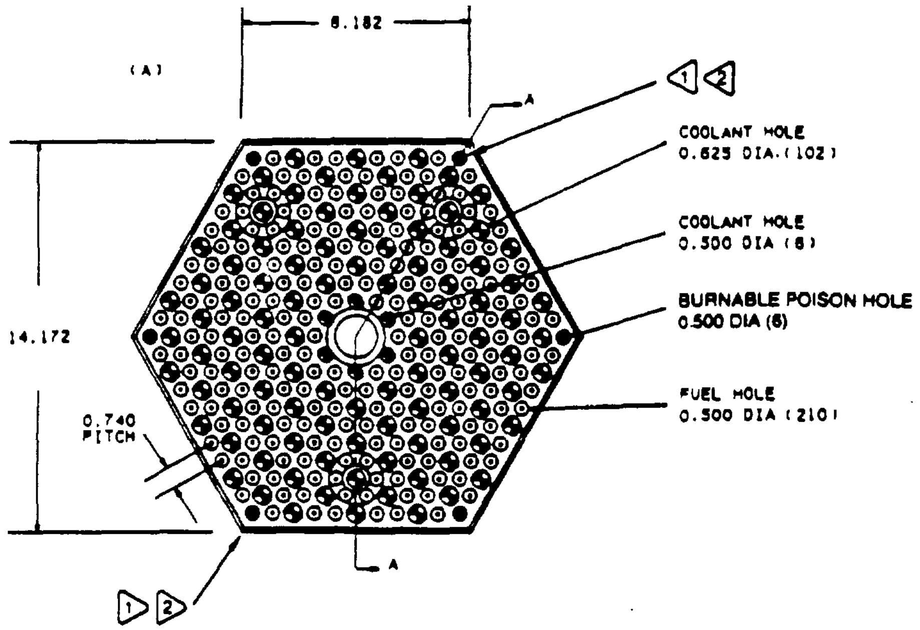


Fig. 4C.1. FSV fuel element identification system.



		FUEL TYPES
1	UNLOADED. THIS APPLIES TO DRAWING NUMBERS.	
	90-R1801-110-101 & 102	101, 102
	90-R1801-810-168 & 169	168, 169
	90-R1802-140-205	205
	90-R1802-160-206	206
	90-R1802-570-207	207
2	LOADED WITH BURNABLE POISON RODS. THIS APPLIES TO DRAWING NUMBERS:	
	90-R1801-110-103 THRU 112	103 THRU 112
	90-R1801-810-170 & 175	170, 175

Fig. 4C.2. Standard fuel element with Type I burnable poison loading.

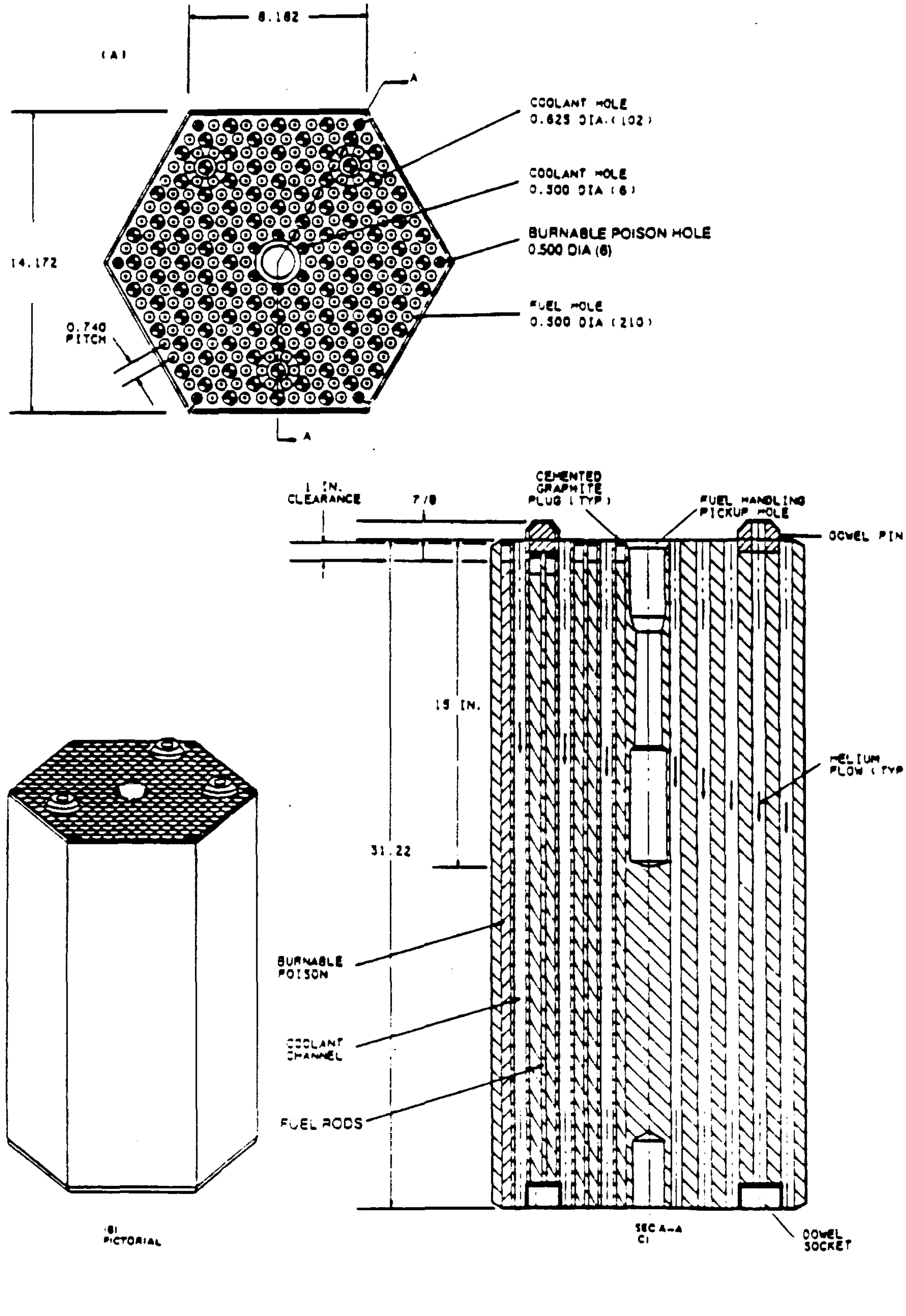
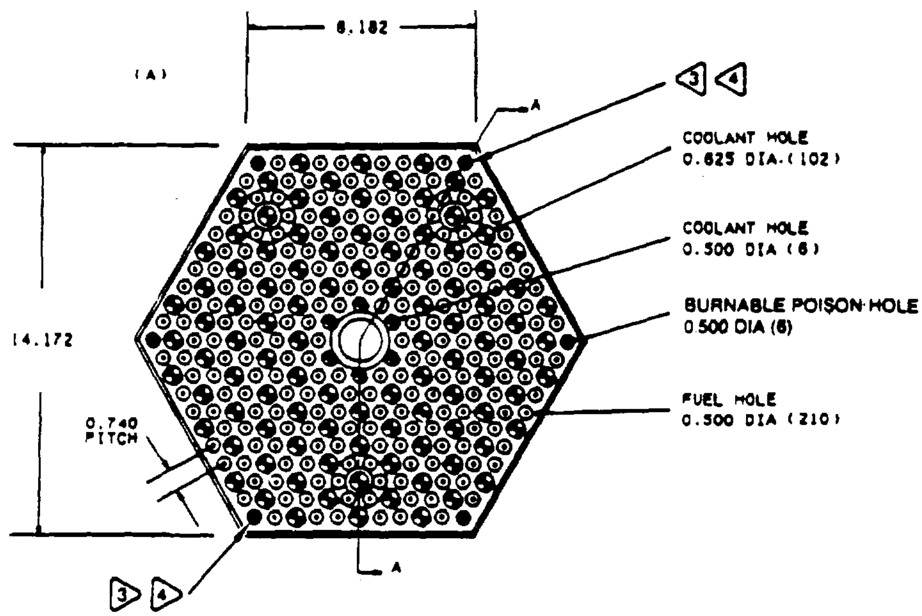


Fig. 4C.3. Standard fuel element with enlarged pickup hole.



		FUEL TYPES
3	UNLOADED. THIS APPLIES TO DRAWING NUMBERS:	
	90-R1801-510-136 & 137	136, 137
	520-142 & 143	142, 143
	530-148 & 149	148, 149
	540-154 & 155	154, 155
	90-R1801-550-160 & 161	160, 161
4	LOADED WITH BURNABLE POISON RODS. THIS APPLIES TO DRAWING NUMBERS:	
	90-R1801-510-140 & 141	140, 141
	520-146 & 147	146, 147
	530-152 & 153	152, 153
	540-158 & 159	158, 159
	550-164 & 165	164, 165
	90-R1801-830-180	180

Fig. 4C.4. Standard fuel element with enlarged pickup hole and Type II burnable poison loading.

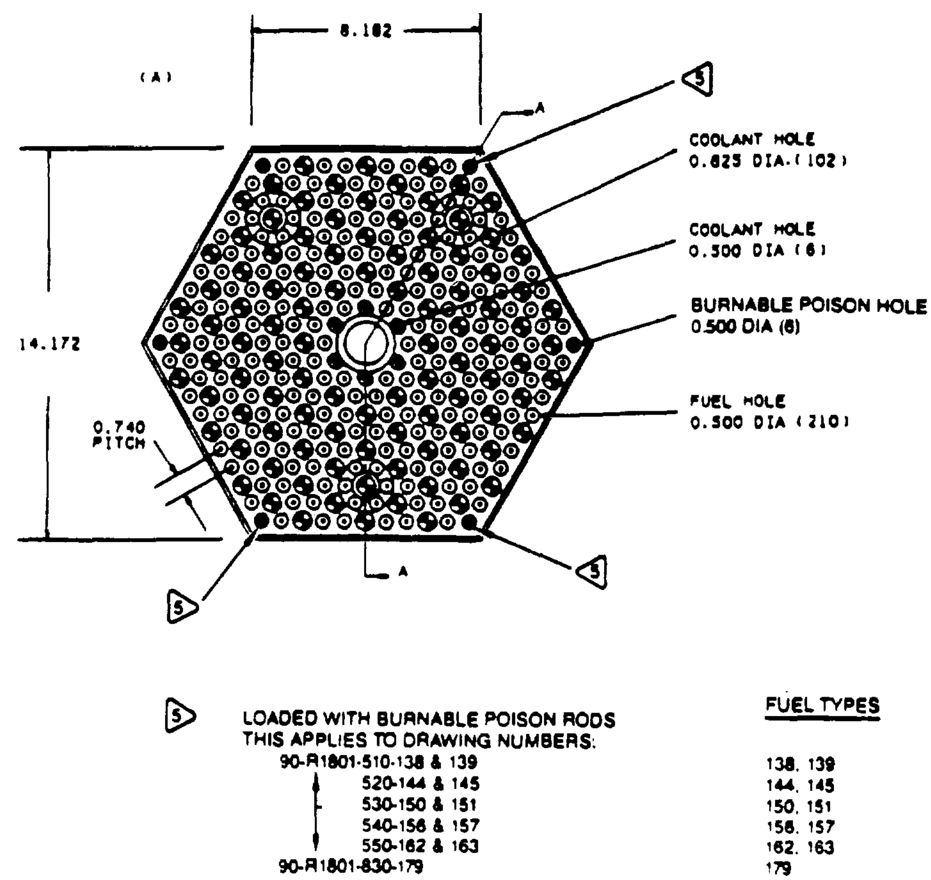


Fig. 4C.5. Standard fuel element with enlarged pickup hole and Type III burnable poison loading.

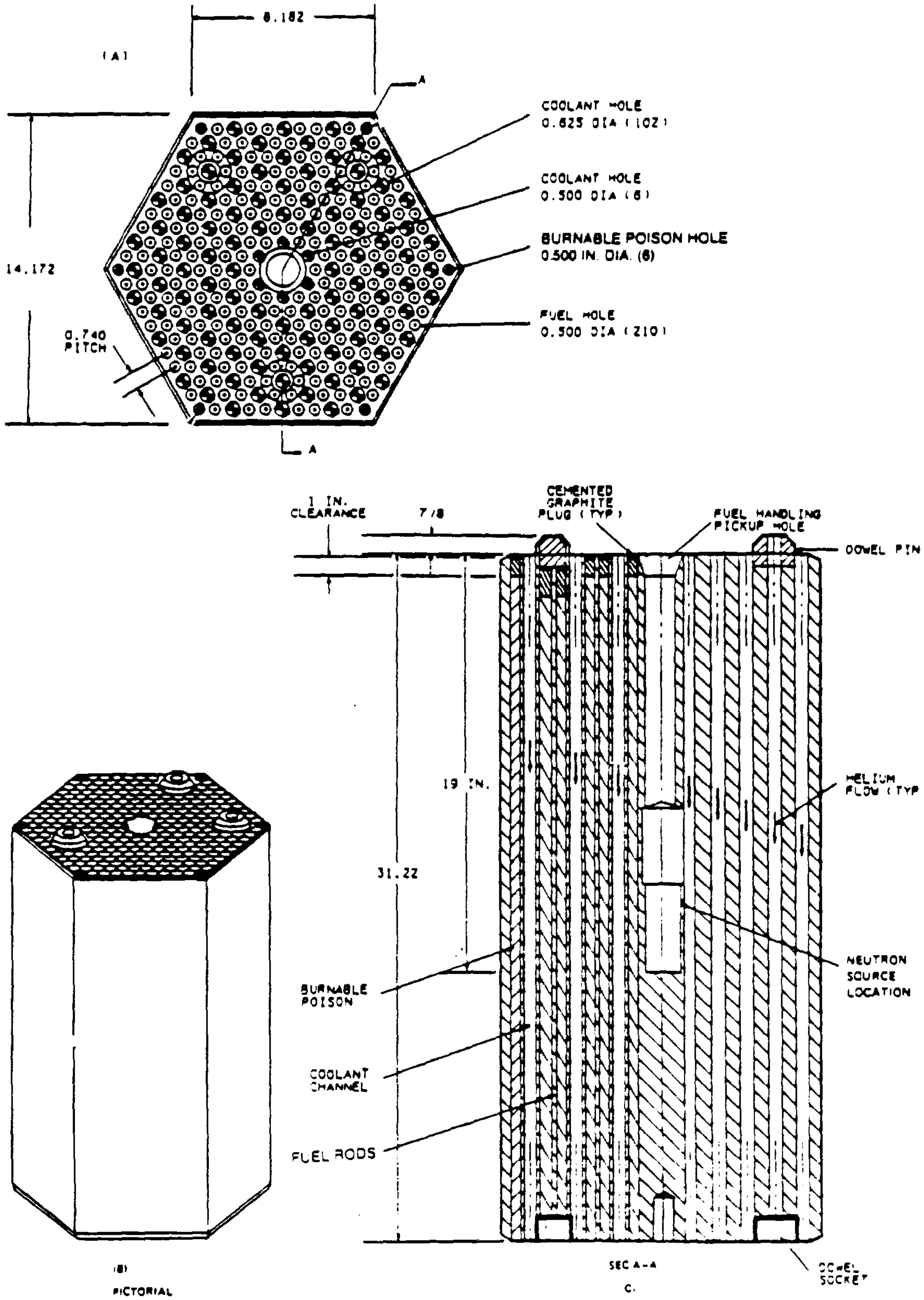
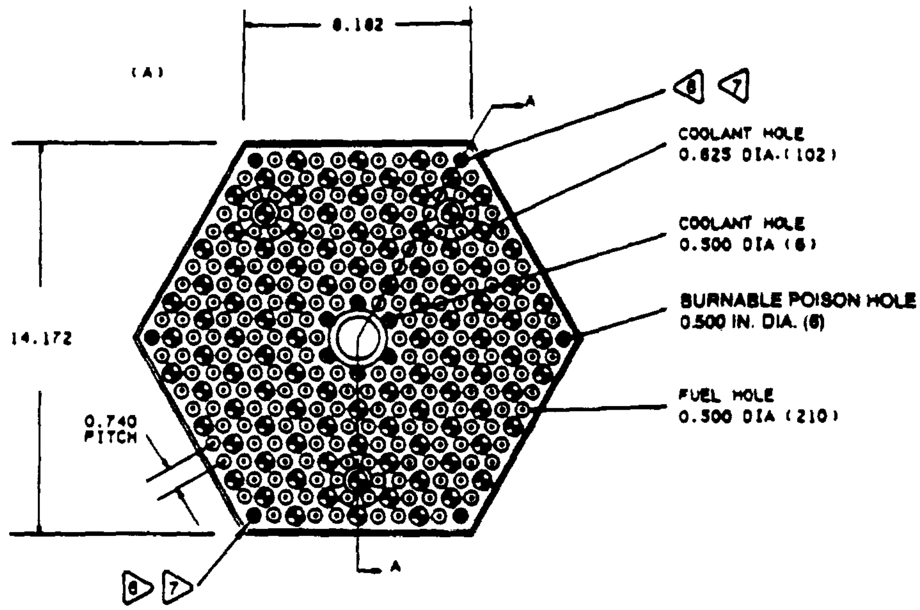


Fig. 4C.6. Standard fuel element modified for neutron source.



		FUEL TYPES
6	UNLOADED: THIS APPLIES TO DRAWING NUMBER: 90-R1801-410-131	131
7	LOADED WITH BURNABLE POISON RODS. THIS APPLIES TO DRAWING NUMBERS: 90-R1801-410-132 THRU 135	132 THRU 135

Fig. 4C.7. Standard fuel element with Type IV burnable poison loading.

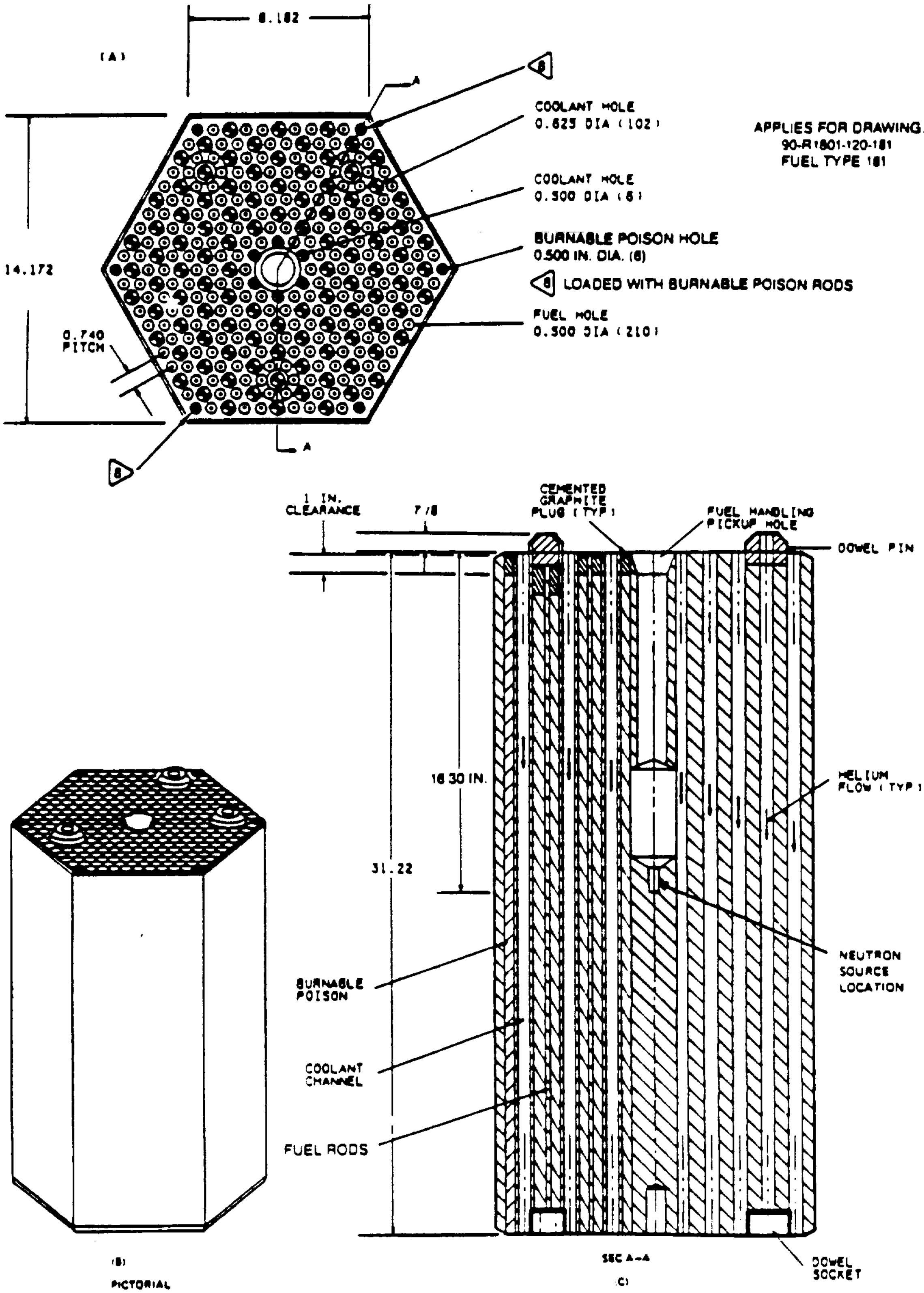


Fig. 4C.8. Standard fuel element modified for californium neutron source.

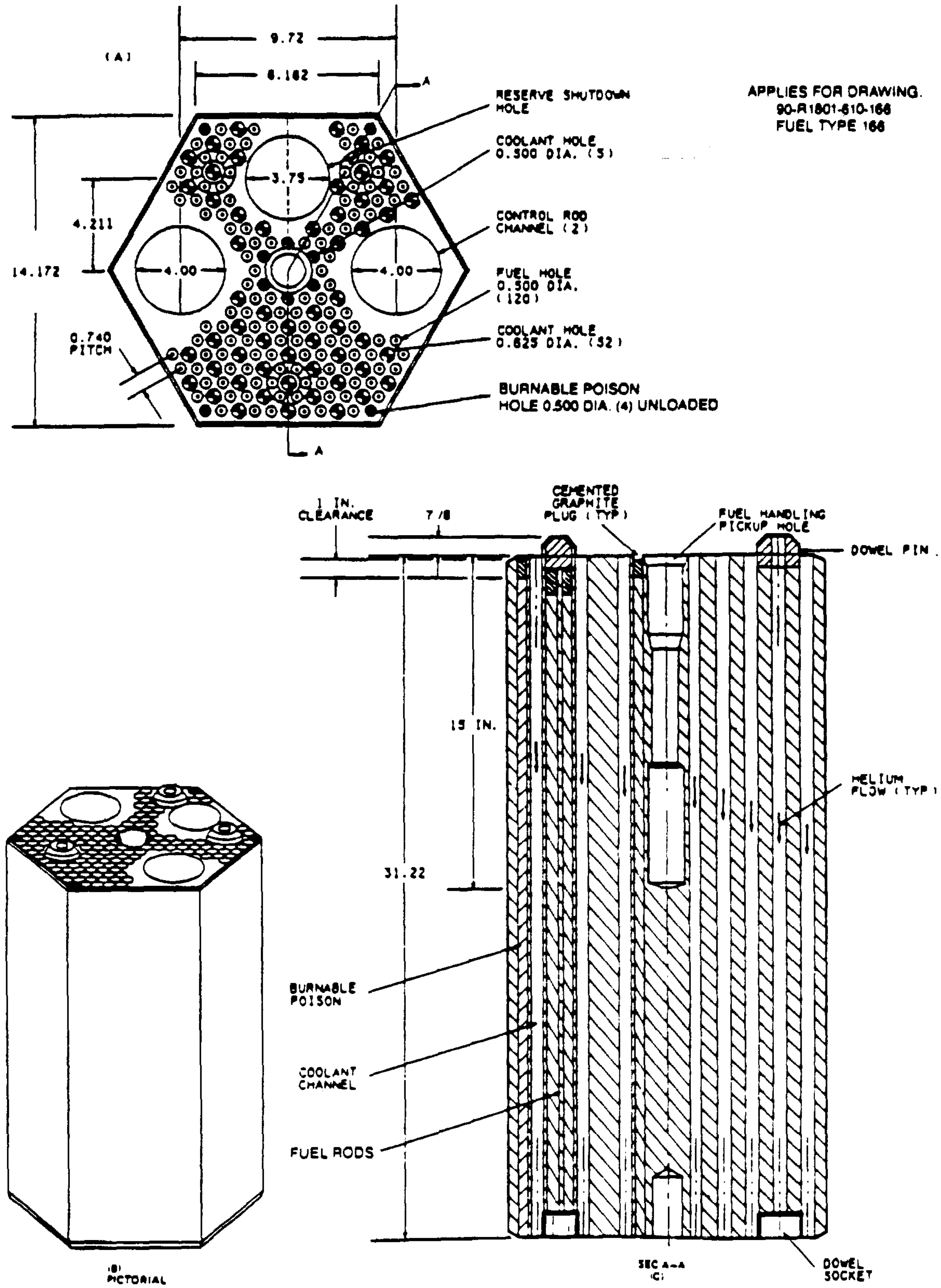


Fig. 4C.9. Control fuel element with enlarged pickup hole.

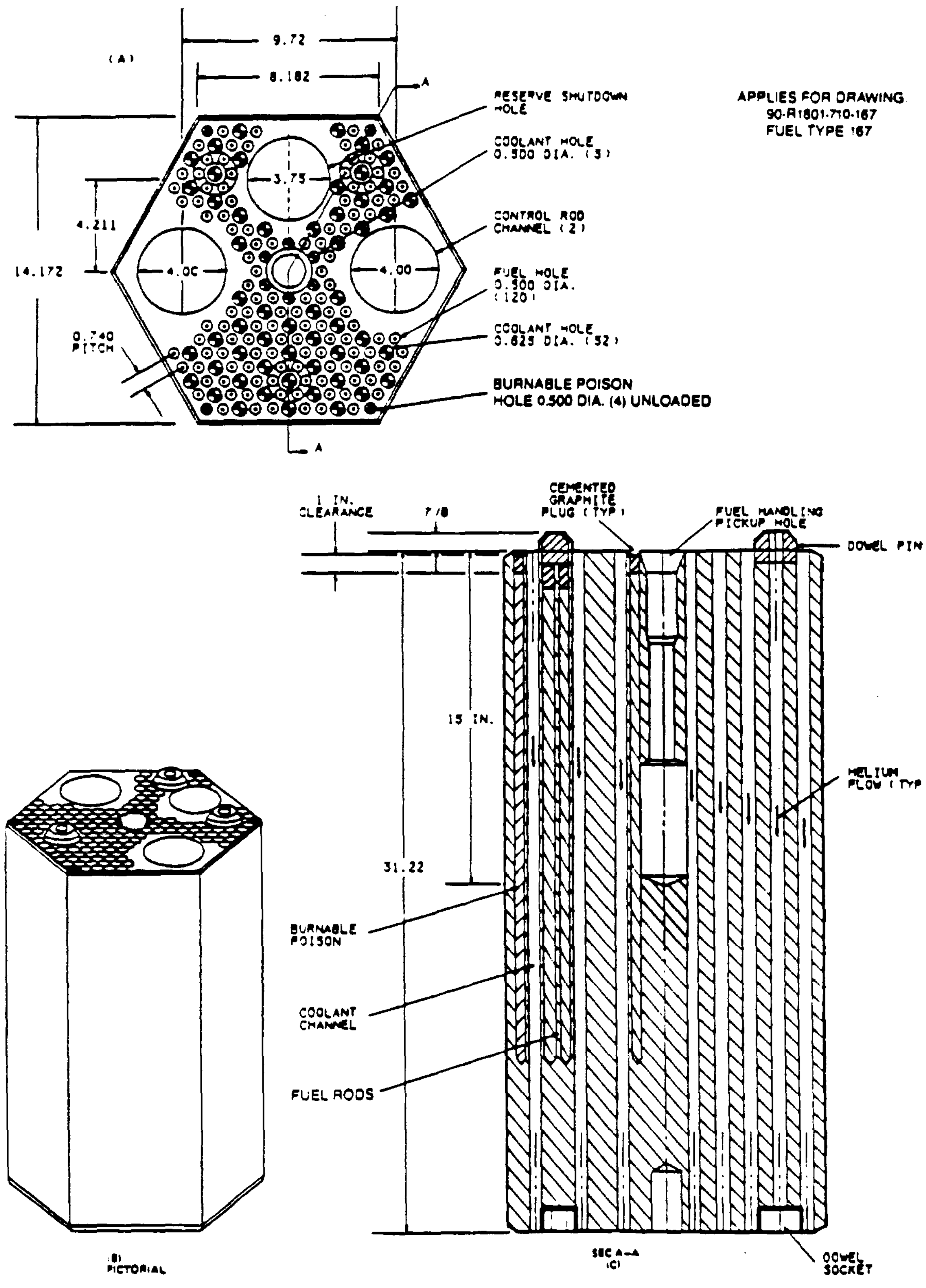


Fig. 4C.10. Bottom control fuel element with enlarged pickup hole.

Table 4C.2. FSV fuel discharge No. 2[a]

Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type
1-0023	101	1-0798	101	1-1787	169	1-2869	102	5-0700	155
1-0033	102	1-0811	102	1-1797	101	1-2929	102	5-0782	160
1-0048	102	1-0812	101	1-1825	102	1-2931	102	5-0801	155
1-0108	101	1-0839	102	1-1829	102	1-2936	101	5-0836	149
1-0140	102	1-0858	101	1-1832	102	1-4361	102	5-0850	155
1-0143	102	1-0874	101	1-1869	102	1-4716	101	5-0903	154
1-0161	101	1-0882	102	1-1913	101	1-4834	102	5-0928	137
1-0166	102	1-0901	101	1-1914	102	1-4987	101	5-0957	148
1-0169	102	1-0910	102	1-1931	102	2-0228	114	5-1008	148
1-0172	102	1-0931	102	1-1952	102	2-0298	113	5-1039	155
1-0175	101	1-0951	102	1-1961	101	2-0400	114	5-1086	154
1-0199	101	1-0989	101	1-1969	102	2-0415	113	5-1144	161
1-0212	102	1-1011	102	1-2000	102	2-0518	113	5-1192	160
1-0238	102	1-1015	102	1-2017	101	2-0532	113	5-1225	154
1-0250	102	1-1030	102	1-2038	101	2-0655	114	5-1307	143
1-0272	102	1-1033	102	1-2087	102	2-0806	113	5-1388	142
1-0276	101	1-1057	102	1-2155	101	2-0962	113	5-1417	142
1-0284	102	1-1142	101	1-2156	101	2-1131	113	5-1628	136
1-0294	101	1-1177	102	1-2157	102	2-1133	114	5-1682	136
1-0304	101	1-1184	101	1-2199	101	2-1299	113	5-1722	148
1-0308	101	1-1210	101	1-2223	101	2-1529	114	5-1837	154
1-0342	102	1-1212	102	1-2256	101	2-1532	114	5-1844	148
1-0347	101	1-1243	102	1-2281	101	2-1570	114	5-1912	142
1-0351	102	1-1251	102	1-2284	102	2-1590	114	5-1954	155
1-0368	101	1-1268	101	1-2306	101	2-1835	113	5-1963	143
1-0380	101	1-1296	101	1-2364	101	2-2084	113	5-2037	142
1-0393	102	1-1305	102	1-2371	101	2-2350	113	5-2151	143
1-0396	101	1-1315	102	1-2373	101	2-2501	114	5-2181	155
1-0419	101	1-1321	101	1-2377	101	2-2531	113	5-2360	143
1-0456	102	1-1329	101	1-2392	102	2-2693	113	5-2478	148
1-0471	101	1-1357	102	1-2423	101	2-2769	176	5-2549	149
1-0510	102	1-1361	102	1-2445	102	2-2851	113	5-2692	142
1-0515	101	1-1367	102	1-2458	102	2-2893	114	5-2713	149
1-0538	101	1-1374	101	1-2515	101	3-1171	125	5-2839	137
1-0542	102	1-1421	102	1-2535	101	3-1412	125	5-2841	154
1-0553	169	1-1497	101	1-2561	101	3-1814	125	5-2846	143
1-0589	101	1-1516	101	1-2650	101	3-1965	125	5-2879	160
1-0612	102	1-1535	101	1-2676	102	3-2852	128	5-2907	149
1-0613	102	1-1571	101	1-2719	102	4-0930	131	5-4764	149
1-0623	102	1-1694	102	1-2731	102	4-2646	131	5-4837	136
1-0649	102	1-1706	102	1-2738	101	5-0100	148	6-0675	166
1-0658	101	1-1717	102	1-2759	101	5-0255	154	6-0735	166
1-0702	102	1-1720	101	1-2777	101	5-0268	148	6-1715	166
1-0711	102	1-1727	101	1-2783	102	5-0333	149	6-2222	166
1-0727	101	1-1742	102	1-2820	168	5-0373	143	6-2285	166
1-0736	101	1-1764	168	1-2832	102	5-0401	161	7-1670	167
1-0778	102	1-1767	101	1-2842	102	5-0517	161	8-0085	205
1-0792	101	1-1780	101	1-2857	101	5-0654	137	8-0139	101

[a]Fuel in storage at ICPP unless indicated otherwise. Source: Morissette 1986.

Table 4C.1. FSV fuel discharge No.1[a]

Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type
1-0003	101	1-1032	102	1-1690	102	1-2865	102	5-0610	137
1-0022	102	1-1035	101	1-1714	102	1-2873	102	5-0683	154
1-0030	102	1-1043	102	1-1741	102	1-2928	107	5-0704	155
1-0052	101	1-1054	102	1-1782	101	1-2935	101	5-0766	142
1-0089	102	1-1062	102	1-1822	101	1-2942	101	5-0773	143
1-0094	101	1-1066	102	1-1861	102	1-2952	102	5-0785	142
1-0099	102	1-1069	101	1-1894	101	1-4381	101	5-0799	155
1-0126	102	1-1075	102	1-1903	102	1-5198	102	5-0819	149
1-0148	101	1-1099	101	1-1908	102	2-0047	113	5-0825	149
1-0204	101	1-1108	102	1-1923	102	2-0095	113	5-0965	143
1-0205	102	1-1116	101	1-1949	102	2-0211	113	5-1014	155
1-0215	102	1-1135	101	1-1977	102	2-0286	113	5-1024	149
1-0239	102	1-1136	102	1-1985	102	2-0455	113	5-1269	148
1-0242	102	1-1147	101	1-1989	169	2-0688	113	5-1486	160
1-0323	101	1-1161	102	1-2008	102	2-0732	113	5-1515	148
1-0326	102	1-1178	101	1-2035	102	2-0827	114	5-1818	155
1-0343	102	1-1183	101	1-2068	102	2-0980	114	5-1887	143
1-0344	101	1-1186	102	1-2080	102	2-1324	114	5-1979	160
1-0411	102	1-1215	101	1-2086	102	2-1468	114	5-1987	137
1-0424	101	1-1223	102	1-2119	102	2-1520	114	5-2020	143
1-0449	101	1-1253	168	1-2120	101	2-2102	113	5-2039	160
1-0457	101	1-1262	107	1-2140	168	2-2138	114	5-2089	156
1-0467	101	1-1264	101	1-2143	102	2-2158	113	5-2110	161
1-0469	102	1-1271	101	1-2175	102	2-2169	114	5-2154	136
1-0478	101	1-1278	102	1-2179	102	2-2187	176	5-2165	142
1-0494	101	1-1301	101	1-2230	101	2-2209	114	5-2238	142
1-0529	102	1-1311	101	1-2243	102	2-2260	113	5-2353	161
1-0537	101	1-1331	101	1-2255	101	2-2385	113	5-2417	148
1-0551	102	1-1345	101	1-2309	102	2-2548	113	5-2436	154
1-0552	101	1-1346	101	1-2336	102	2-2683	113	5-2456	149
1-0599	101	1-1349	101	1-2337	101	2-2722	114	5-2481	154
1-0641	101	1-1440	101	1-2352	102	2-2733	114	5-2528	136
1-0666	101	1-1446	102	1-2368	101	2-2880	113	5-2579	154
1-0681	101	1-1450	102	1-2407	102	3-0574	125	5-2608	149
1-0733	101	1-1459	101	1-2427	102	3-0919	125	5-2670	143
1-0768	101	1-1544	102	1-2485	101	3-1282	125	5-2685	154
1-0771	101	1-1574	102	1-2543	102	3-1711	125	5-2703	148
1-0791	101	1-1585	101	1-2551	101	3-2422	125	5-2728	136
1-0794	101	1-1589	101	1-2642	102	4-0101	131	5-2736	142
1-0867	169	1-1593	102	1-2665	102	4-0716	131	5-2802	149
1-0890	101	1-1614	102	1-2674	101	4-1050	131	5-2813	142
1-0891	102	1-1624	101	1-2682	101	4-1055	131	5-2826	161
1-0904	102	1-1625	102	1-2718	102	4-2464	131	5-2838	143
1-0938	101	1-1649	102	1-2735	101	5-0068	148	6-0111	166
1-0963	102	1-1658	101	1-2755	101	5-0279	155	6-0488	166
1-0990	111	1-1669	101	1-2758	102	5-0365	155	6-0820	166
1-0993	101	1-1676	101	1-2767	101	5-0375	137	6-0844	166
1-1006	101	1-1677	102	1-2773	102	5-0430	148	6-2792	166
1-1021	101	1-1678	102	1-2798	102	5-0541	154	7-1451	167

[a]Fuel in storage at ICPP unless indicated otherwise. Source: Morissette 1986.

Table 4C.3. FSV fuel discharge No. 3[a]

Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type	Serial No.	Fuel type
1-0024	110	1-0877	111	1-1850	109	1-4304	110	5-0723	146
1-0034	109	1-0912	112	1-1872	112	1-4318	110	5-0731	152
1-0043	109	1-0921	112	1-1876	109	1-4430	110	5-0746	158
1-0057	109	1-0932	112	1-1890	110	1-4715	110	5-0749	140
1-0065	109	1-0940	109	1-1904	110	1-5152	110	5-0751	158
1-0088	110	1-0948	109	1-1918	109	1-5217	110	5-0805	146
1-0091	110	1-0974	109	1-1940	112	2-0265	122	5-0831	159
1-0137	109	1-0975	112	1-1988	109	2-0577	122	5-0854	152
1-0152	111	1-0994	110	1-1990	109	2-0642	124	5-0862	152
1-0157	111	1-1004	111	1-1998	109	2-0673	121	5-0892	164
1-0162	109	1-1018	109	1-2019	112	2-1028	124	5-1058	158
1-0191	110	1-1023	112	1-2021	110	2-1044	122	5-1095	147
1-0192	109	1-1049	110	1-2044	109	2-1120	121	5-1148	147
1-0195	112	1-1053	109	1-2106	110	2-1182	123	5-1176	140
1-0251	110	1-1101	109	1-2134	112	2-1471	123	5-1249	147
1-0285	109	1-1111	112	1-2142	109	2-1489	122	5-1460	159
1-0292	110	1-1117	111	1-2174	112	2-1519	121	5-1563	141
1-0305	109	1-1121	111	1-2206	109	2-1606	122	5-1739	147
1-0324	110	1-1153	109	1-2228	109	2-1707	121	5-1799	158
1-0335	175	1-1163	111	1-2282	109	2-1726	124	5-1801	159
1-0337	109	1-1204	109	1-2351	109	2-1792	123	5-1865	153
1-0367	109	1-1224	112	1-2396	110	2-1950	122	5-1974	153
1-0409	112	1-1235	111	1-2400	111	2-2088	123	5-2001	153
1-0420	111	1-1273	110	1-2403	112	2-2263	121	5-2022	158
1-0428	110	1-1288	109	1-2440	109	2-2424	121	5-2031	153
1-0443	110	1-1336	109	1-2447	109	2-2781	178	5-2104	146
1-0459	112	1-1337	110	1-2455	111	2-2815	121	5-2159	147
1-0462	109	1-1353	112	1-2474	110	2-2836	124	5-2191	180
1-0504	112	1-1378	111	1-2519	110	2-2882	123	5-2213	140
1-0530	110	1-1397	109	1-2521	109	2-2891	123	5-2235	112
1-0536	110	1-1403	111	1-2529	112	2-5178	121	5-2275	146
1-0556	111	1-1410	109	1-2560	109	3-0787	129	5-2349	153
1-0580	109	1-1458	111	1-2563	110	3-0898	130	5-2416	165
1-0581	110	1-1555	109	1-2570	109	3-1719	129	5-2430	158
1-0587	110	1-1584	111	1-2606	174	3-1766	129	5-2460	152
1-0614	110	1-1612	109	1-2640	110	3-2850	130	5-2530	165
1-0647	109	1-1621	110	1-2715	111	4-0463	134	5-2556	141
1-0661	111	1-1673	110	1-2720	110	4-0765	135	5-2688	141
1-0667	110	1-1692	111	1-2760	110	4-0981	134	5-2908	164
1-0670	109	1-1701	110	1-2795	110	4-1994	135	5-2933	147
1-0684	109	1-1737	110	1-2919	109	4-2339	134	5-4278	146
1-0715	110	1-1750	112	1-2920	111	5-0026	146	6-0067	166
1-0720	112	1-1771	109	1-2923	112	5-0027	164	6-0209	166
1-0725	110	1-1773	110	1-2939	110	5-0036	153	6-0961	166
1-0824	112	1-1796	110	1-2940	110	5-0127	159	6-1984	166
1-0834	110	1-1805	110	1-2943	175	5-0129	165	6-2288	166
1-0843	111	1-1806	112	1-2944	110	5-0190	159	7-2499	167
1-0873	109	1-1817	110	1-2946	110	5-0427	152	8-0206[b]	206

[a]Fuel in storage at ICPP unless indicated otherwise. Source: Morissette 1986.
[b]In storage at GA Technologies, La Jolla, California.

Table 4C.4. Historical and projected spent fuel discharged from the Fort St. Vrain HTGR[a]

End of calendar year	Number of fuel assemblies discharged		Mass of fuel discharged (MTIHM)	
	Annual	Cumulative	Annual	Cumulative
1979	246[b]	246	2.80	2.80
1980	0	246	0.00	2.80
1981	240	486	2.77	5.57
1982	0	486	0.00	5.57
1983	0	486	0.00	5.57
1984	240	726	2.85	8.42
1985	0	726	0.00	8.42
1986	0	726	0.00	8.42
1987	0	726	0.00	8.42
1988	0	726[c]	0.00	8.42
1989	126[d]	852	1.32	9.74
1990	615[d,e]	1,467	6.47	16.21
1991	741[f]	2,208	7.49	24.00

[a]Based on Brey 1990 and DOE 1990.

[b]This refueling replaced 246 spent fuel elements made up of 240 standard fuel elements and 6 fuel test elements.

[c]All spent fuel discharged prior to December 31, 1988 is located at the ICPP.

[d]Fuel removed from the core in 1989 and 1990 remains on-site in temporary storage wells until shipment to the ICPP can be accomplished or an independent spent fuel storage installation is built for permanent storage.

[e]1990: 330 fuel blocks have been removed from the core prior to February 28, 1990.

[f]It is expected that the entire core will be defueled by the end of 1991.

Table 4C.5. FSV fuel types and drawings[a]

Element description	Assembly drawing No.	Assembly type No.
Standard fuel elements	90-R1801-110	101-112
Control rod elements	90-R1801-210	113-124
Bottom control rod elements	90-R1801-310	125-130
Neutron source fuel element	90-R1801-410	131-135
Standard fuel elements with enlarged pickup hole	90-R1801-510 90-R1801-520 90-R1801-530 90-R1801-540 90-R1801-550	136-141 142-147 148-153 154-159 160-165
Control rod elements with enlarged pickup hole	90-R1801-610	166
Bottom control rod elements with enlarged pickup hole	90-R1801-710	167
Surveillance fuel elements	90-R1801-810	168-175
Surveillance control elements	90-R1801-820	176-178
Surveillance fuel elements with enlarged pickup hole	90-R1801-830	179-180
Californium neutron source fuel element	90-R1801-120	181
Fuel test elements	90-R1801-130 90-R1801-150 90-R1801-560	205 206 207

[a]Source: GA 1985.

APPENDIX 4D. SUPPLEMENTAL DATA FOR PEACH BOTTOM 1 SPENT FUEL

4D. SUPPLEMENTAL DATA FOR PEACH BOTTOM 1 SPENT FUEL

4D.1 INTRODUCTION

The Peach Bottom Unit 1 reactor is described in Sect. 4.3 of this report. It was a high-temperature, gas-cooled reactor with a rated capacity of 115 MW(t). It was located at Peach Bottom, Pennsylvania, and operated from 1966 to 1974. The reactor contained 804 fuel elements per fuel load. The total number of fuel elements irradiated in the core was 1,639, which exceeds two times 804 because of replacement fuel and test fuel. The graphite-based fuel elements were 3.5 in. in diameter and 12 ft in length, containing varying amounts of uranium and thorium. These heavy metals were present as carbon-coated uranium carbide and thorium carbide particles that had been formed into compacts by sintering with carbonaceous materials.

Two cores were used during the lifetime of the reactor. These cores had total initial heavy metal loadings of 1.686 and 1.419 MT of U + Th, respectively. Design burnup was ~73,000 MWd/MTIHM. Fuel failures experienced during operation of Core 1 resulted in removal of that core at about half the design burnup. The fuel failure was attributed to the fuel particle coating system. This system was modified for the second core, which performed satisfactorily and reached design burnup. The reactor was shut down at this point. This appendix gives additional data on the fuel.

4D.2 INSTRUMENTED FUEL ELEMENT — CORE 1

Thirty-six fuel elements were instrumented for temperature measurement in various locations of the core. Each of these elements was instrumented with two thermocouples, and eight also contained acoustic thermometers. An acoustic thermometer is an instrument which utilizes the proportionality between resonance frequency of a transmitted sound wave and the temperature of helium gas in a cavity within the fuel element to determine the temperature. Table 4D.1 lists the number of instrumented fuel elements in each of the fuel loading types 1 through 4. Figure 4D.1 is a schematic of a typical Core 1 instrumented fuel element (without the canister) as stored at INEL.

The instrumented fuel elements are very similar to the standard fuel elements. The differences involve the bottom connector and certain internal components which are slightly modified to allow passage of the thermocouple leads. These leads extend to different axial locations in the element as listed in Table 4D.1.

4D.3 STANDARD FUEL ELEMENT — CORE 2

Figure 4D.2 shows the Core 2 standard element as currently stored at INEL. The elements are stored in canisters located in the Irradiated Fuels Storage Facility at INEL.

The Core 2 standard fuel elements are essentially the same as the Core 1 elements. The only design difference is in the coated particles and the external appearance of fuel compacts. The coated particles in Core 1 used monolithic laminar pyrolytic coatings whereas the Core 2 coated particles consisted of an inner, low density, pyrolytic carbon coating surrounded by an outer isotropic pyrolytic carbon coating. The coated particles are between 340 and 630 μm in diameter with a total coating thickness of 90 to 130 μm. The Core 2 compacts do not have the axial grooves included in the Core 1 compacts (see Fig. 4D.3) and have slots on the ends which were not included in the Core 1 compacts.

In the as-stored configuration, the Core 2 element differs from the Core 1 element in that the top 18 in. of the upper reflector was cut off at INEL prior to storage in the facility. This is shown as Fig. 4D.2. Note that the bottom connector for the element, placed in the B1610 position (within the core), is somewhat different from a standard fuel element.

4D.4 INSTRUMENTED FUEL ELEMENT — CORE 2

Core 2 shared its instrumented core locations with instrumented fuel elements and instrumented test elements. The instrumented fuel elements for Core 2 are of the same design as the Core 1, with the exceptions noted in the previous sections concerning fuel compact design and the cut off upper reflector. Figure 4D.4 shows a typical Core 2 instrumented fuel element as stored at INEL.

4D.5 TEST FUEL ELEMENTS

Since the PB Unit 1 reactor offered unique capabilities as a test facility for HTGR type fuel, test assemblies were tested in the core to evaluate interactions of fuel particles, fuel beds, and graphite structures. Test elements were included in both Core 1 and Core 2. Figure 4D.5 shows two configurations currently in storage at INEL and ORNL.

Two test elements of the proof test element (PTE) type were irradiated in Core 1. The first, PTE-1, did not perform correctly, and was removed and shipped to INEL for storage. The second, PTE-2, remained in the core for further irradiation with Core 2.

An additional 32 test elements were constructed and irradiated in Core 2. These were manufactured in three classes of test elements: fuel test elements (FTEs)/fuel bed test elements (FBTEs), PTEs, and fuel pin test elements (FPTEs). Of the total 33 elements, 30 were of the FTE/FBTE design, one was of the PTE design, and two of the FPTE design. The FPTEs were irradiated for UKAEA and were returned to the United Kingdom following their irradiation in the PB core and subsequent postirradiation examination (PIE) in the United States.

Table 4D.2 lists the 33 test elements, along with important parameters of each one of these elements.

The PTE test elements are hexagonal in shape, as shown in Fig. 4D.5, and do not utilize graphite sleeves. The element is made up of four separate fuel sections containing fuel holes and coolant holes. These four sections, along with a top reflector, bottom reflector, and bottom connector, were threaded together to form an assembly approximately 3.5 in. across flats and 140 in. long. The top and bottom reflectors were specially designed to allow a special handling tool and coolant flow inlets and exits. The element was instrumented with two thermocouples. A description of the PTEs is given in Christie 1976.

The remaining test elements in storage are similar in external appearance to the standard and instrumented fuel elements. The fueled portion of some elements contain six fuel bodies, as shown in Fig. 4D.6, while others contain only three. Each fuel body has eight fuel holes surrounding a central hole. The fuel holes contain either fuel rods or loose fuel particles. Descriptions of the test elements are included in Scheffel 1972c, Scheffel 1972a, Scheffel 1972b, Sanders 1973, Wallroth 1980, Christie 1976, Wallroth 1974, Wallroth 1977, Wallroth 1976, Fitzgerald 1976, Morissette 1971, and Long 1974.

4D.6 CORE 1 STORAGE CANISTERS

Figures 4D.7 and 4D.8 are sketches of two fuel element storage canister types not described in Section 4.3.

4D.7 CORE 1 PACKAGE TYPES

Removal and canning of the failed Core 1 fuel resulted in a number of package types. These are described in Table 4D.3 (USAEC 1971).

4D.8 INVENTORY-RELATED DATA

The data received from INEL (Denney 1986) on the PB1 spent fuel does not allow a detailed inventory of each element by serial number or type. The elements are stored in groups of 18 or less. Table 4D.4 is the listing received from INEL on Core 1, which includes 814 elements (813 regular elements and one test element). Table 4D.5 is the listing on Core 2 which accounts for 785 elements. Additional information was provided to INEL by Philadelphia Electric for Core 1 (Denney 1986).

4D.9 ADDITIONAL ACCOUNTABILITY DATA

Tables 4D.6, 4D.7, and 4D.8 provide data on heavy metal loadings of the various Core 1 package types and the many types of test elements.

4D.10 REFERENCES FOR SECTION 4D

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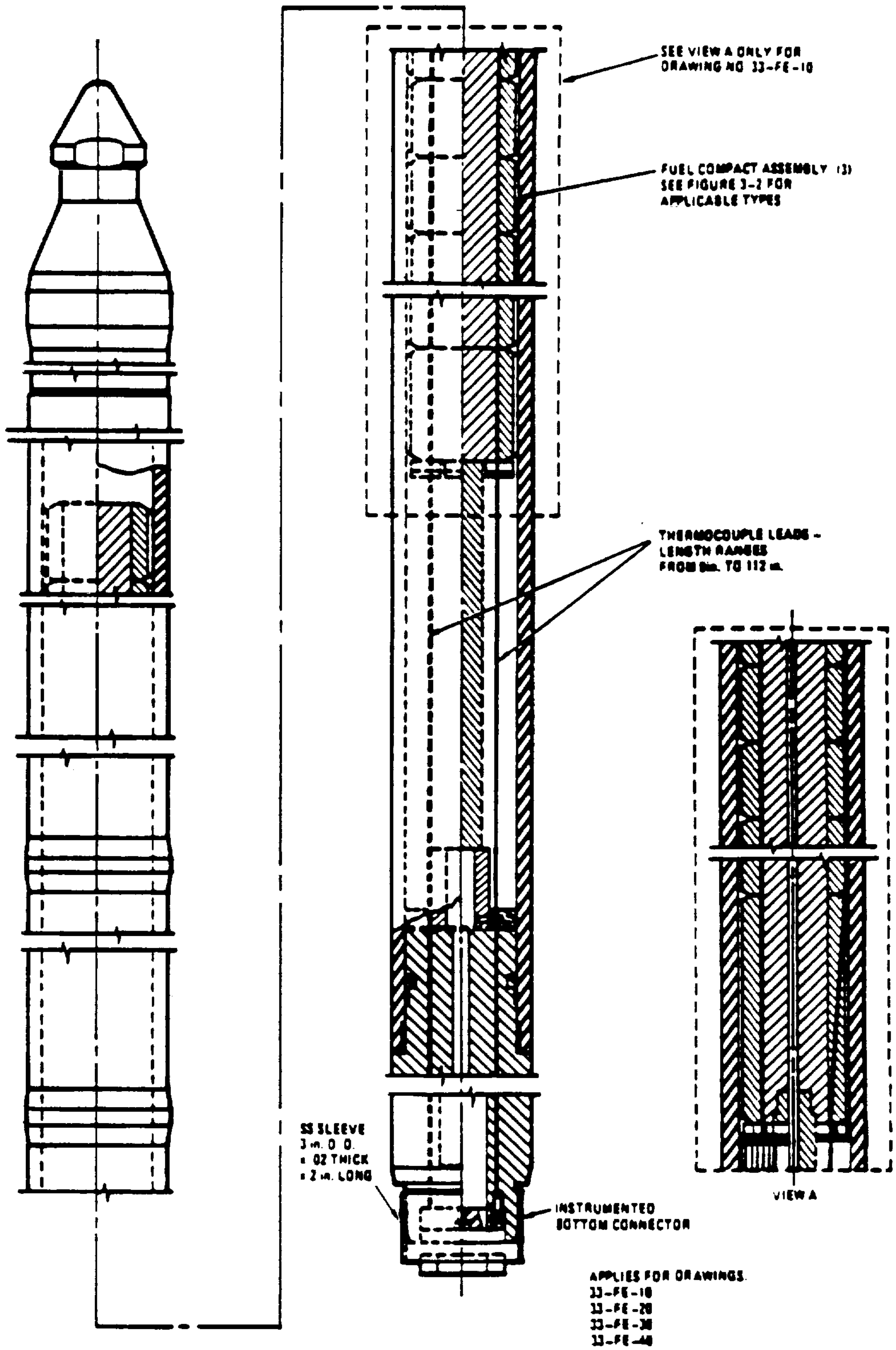


Fig. 4D.1. PB1/1 instrumented fuel element.

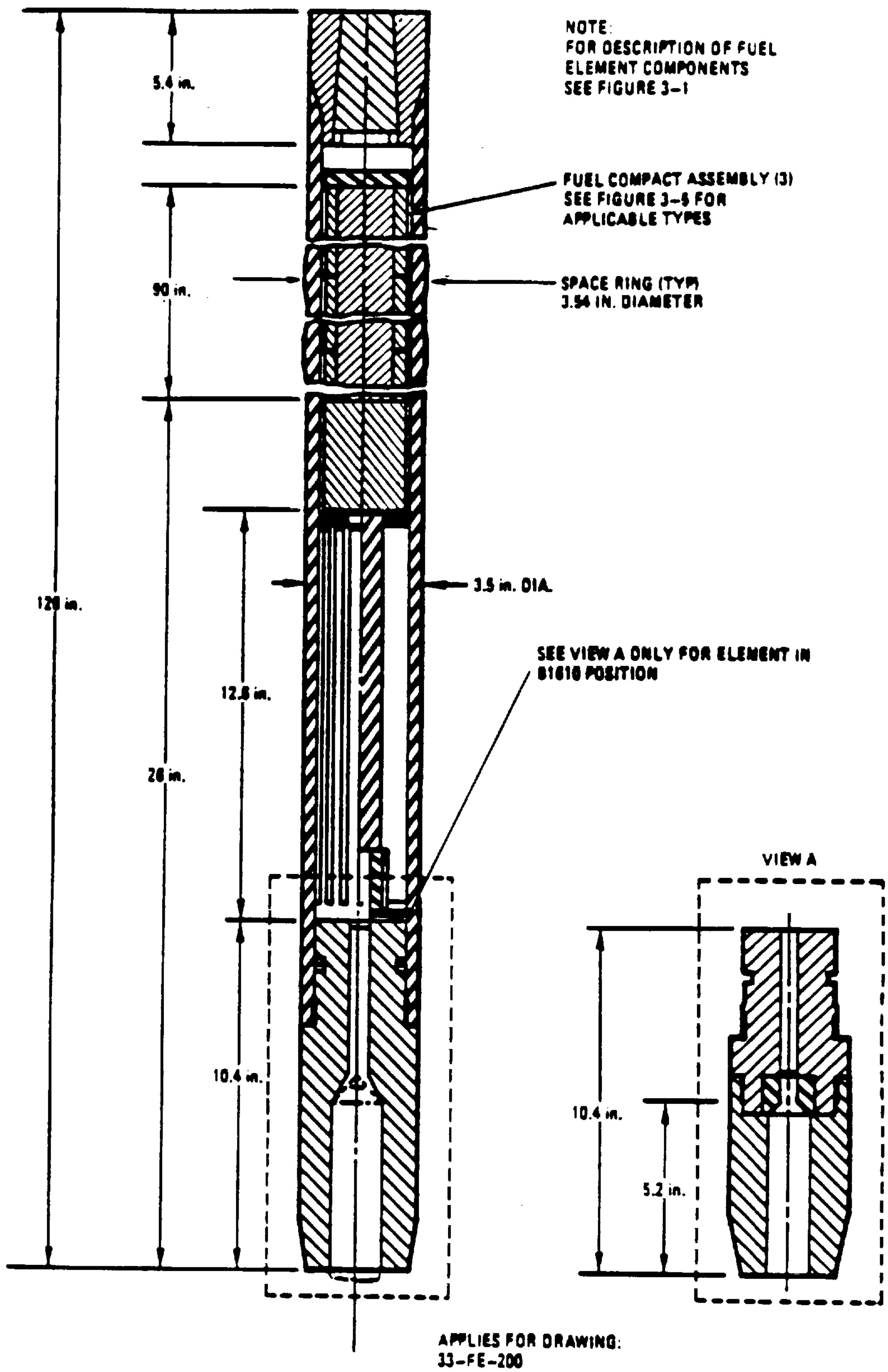


Fig. 4D.2. PB1/2 fuel element.

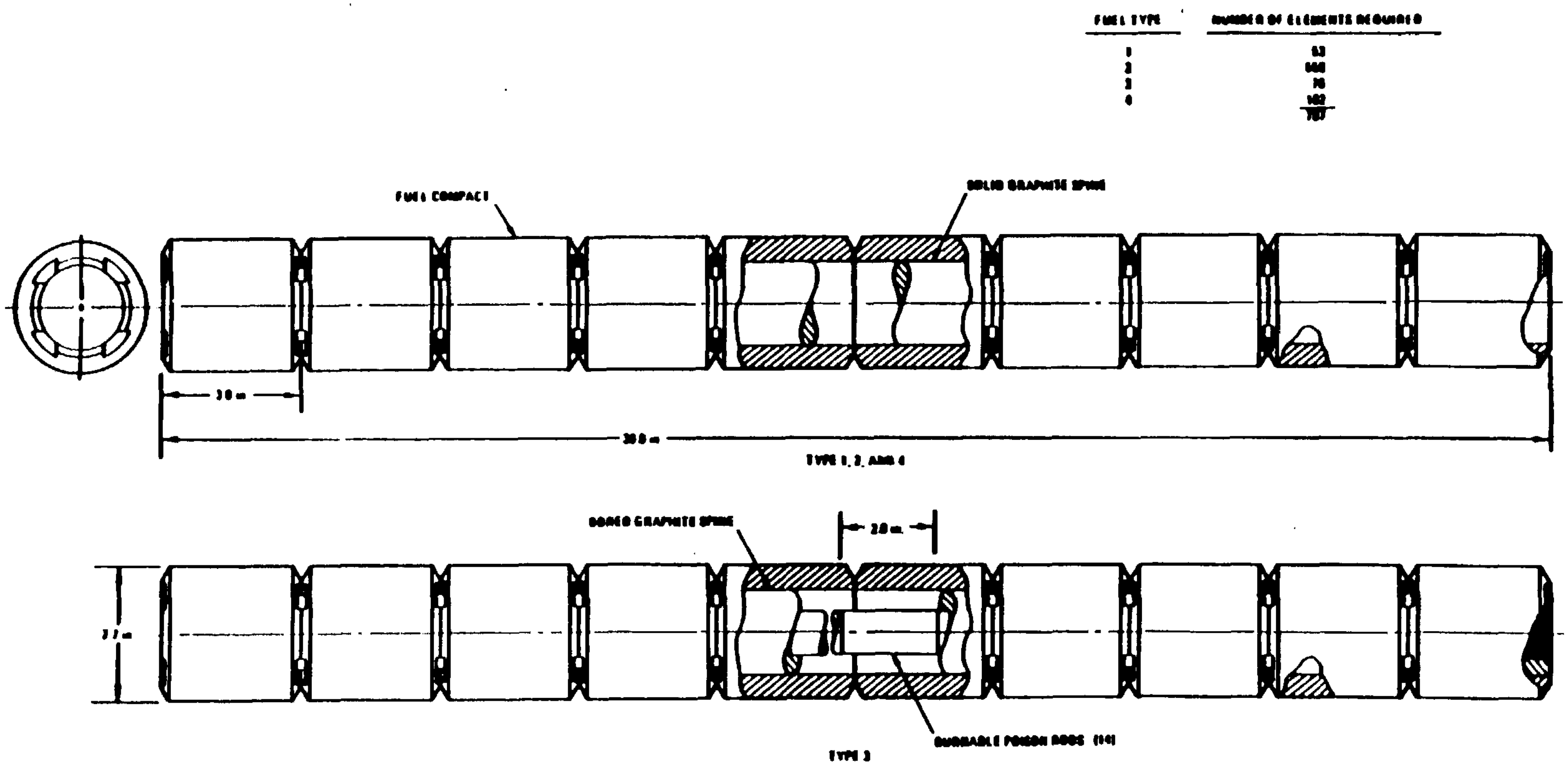


Fig. 4D.3. PB1/2 fuel compact assembly.

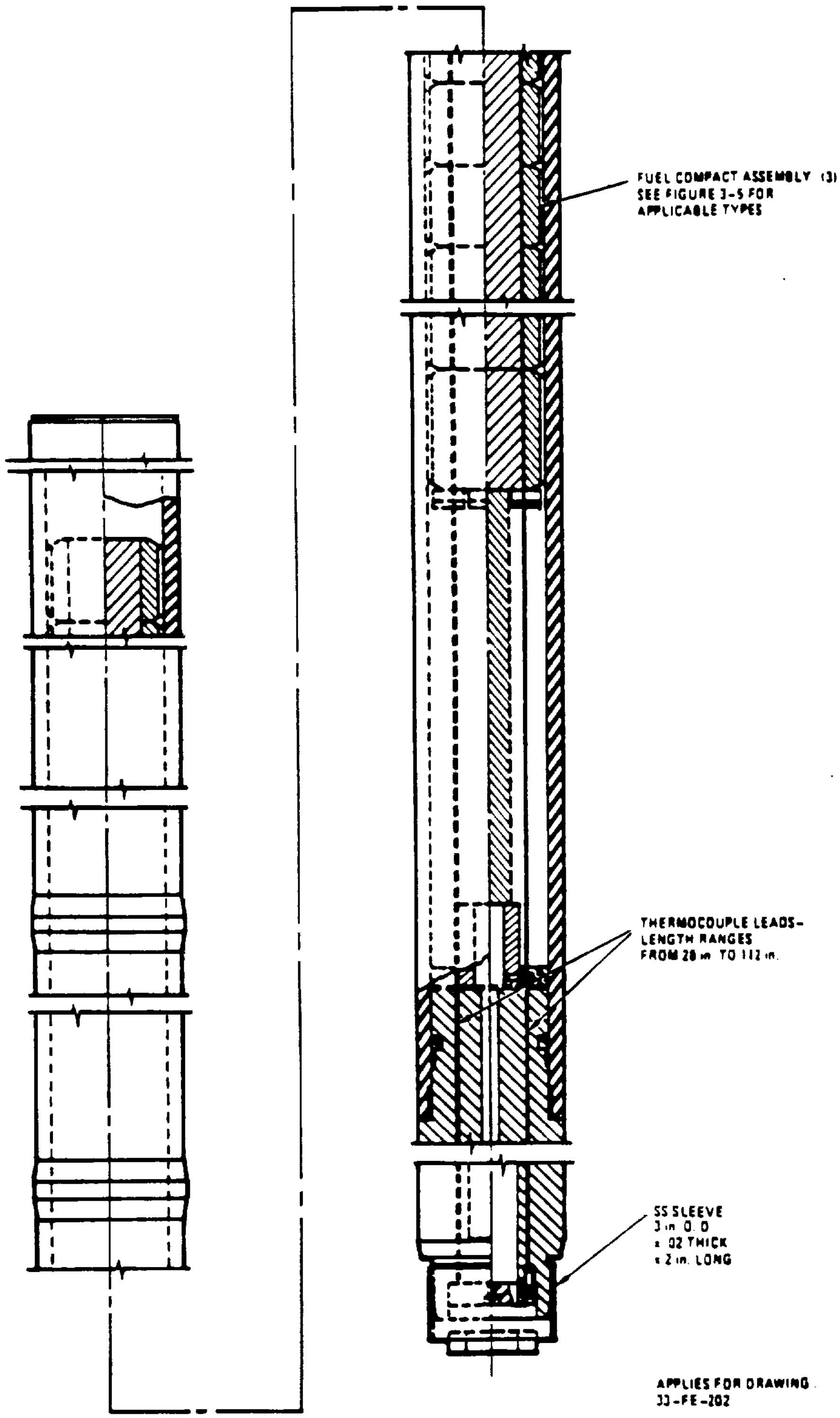
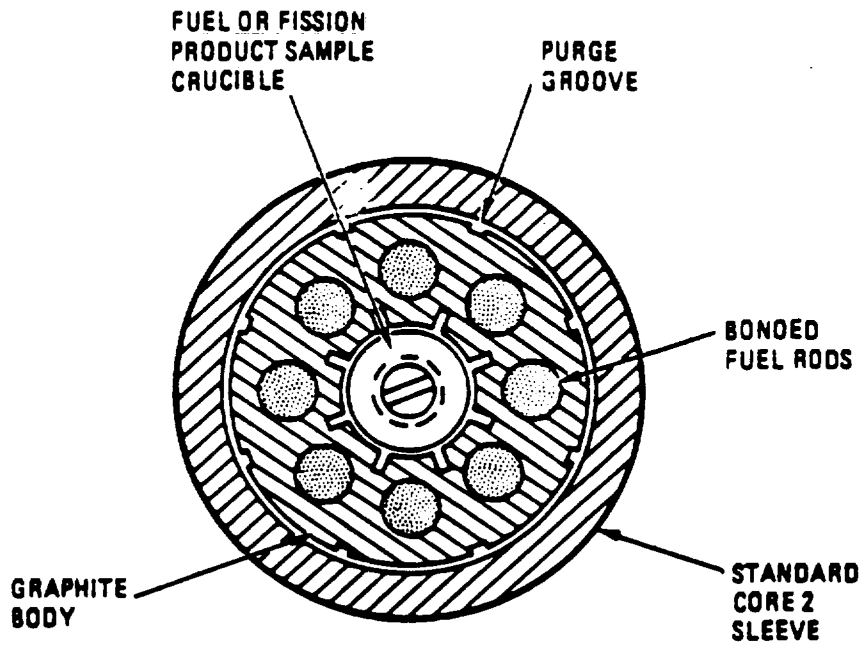
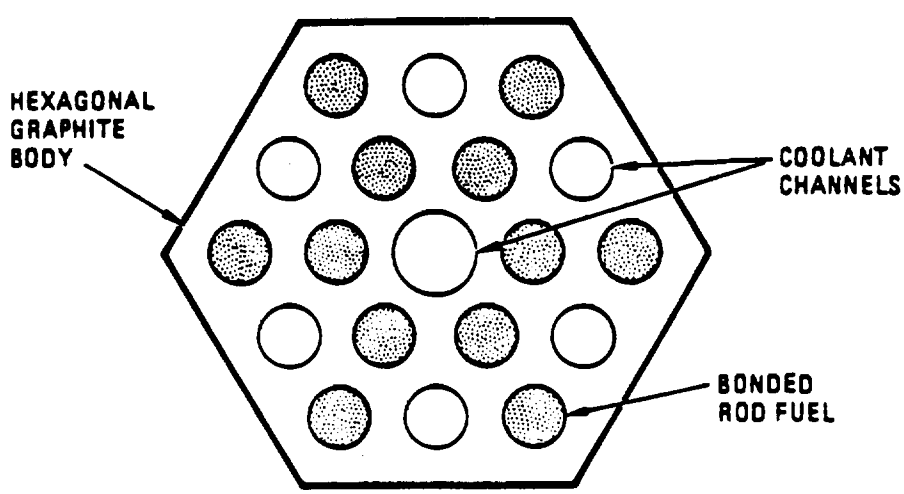


Fig. 4D.4. PB1/2 instrumented fuel element.



FTE CROSS SECTION



PTE CROSS SECTION

APPLIES FOR DRAWING:
90SK1972

Fig. 4D.5. Cross sections of PB1 test element classes.

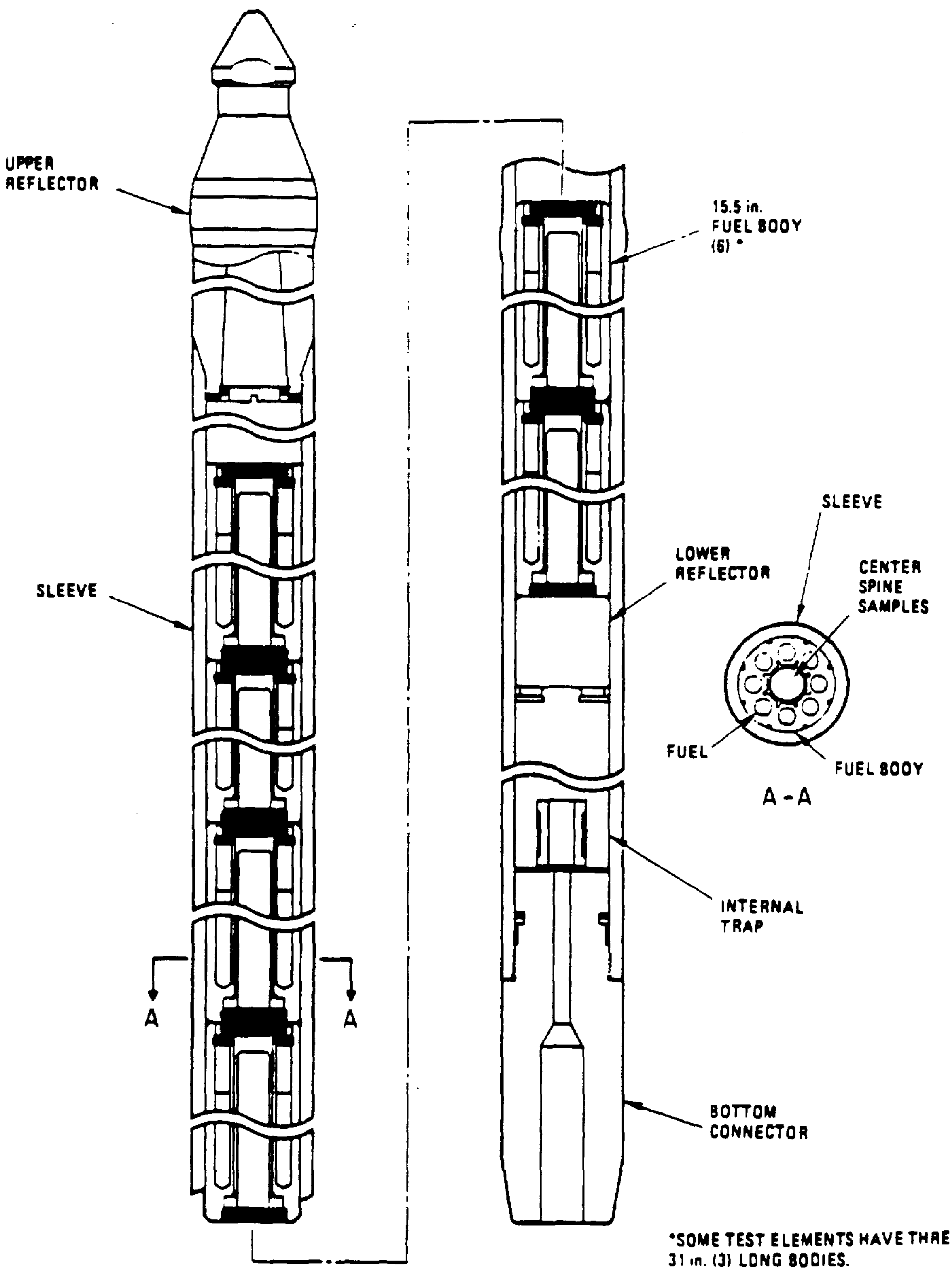
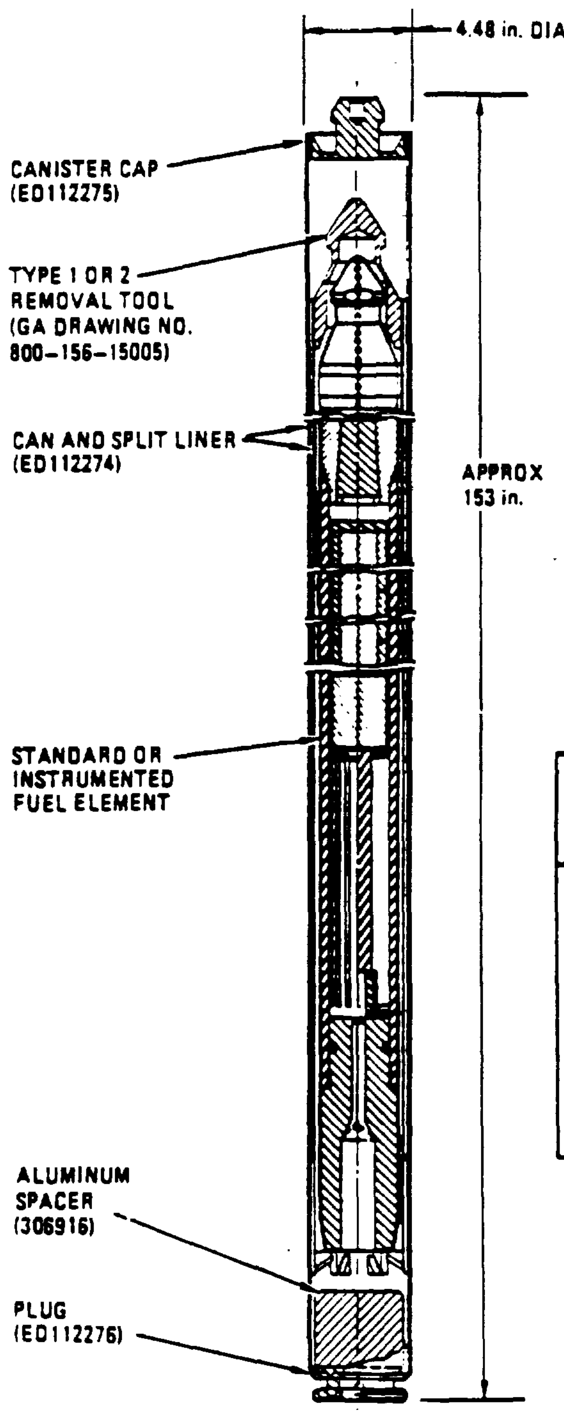
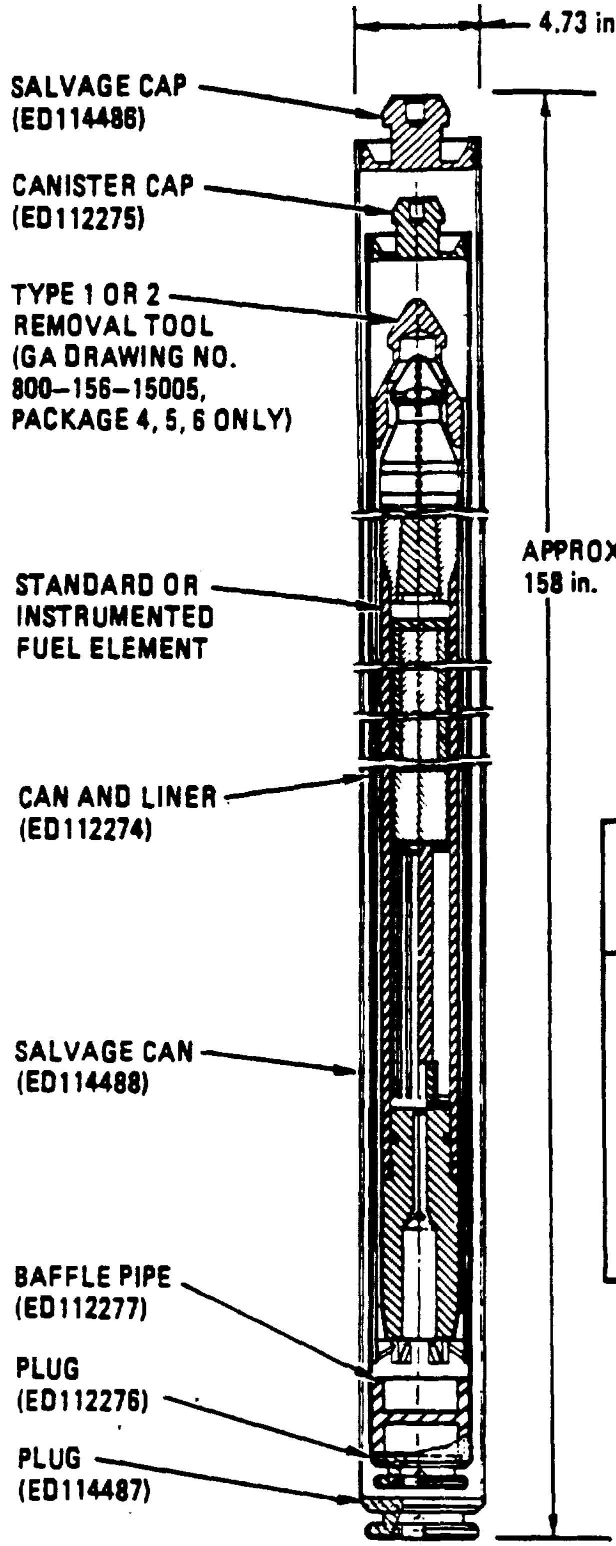


Fig. 4D.6. PB1 typical fuel test element assembly.



FUEL PACKAGE TYPE	NUMBER OF PACKAGES
2	58
3	7
10	8
11	1
13	1
15	5
16	1
19	3
	84

Fig. 4D.7. PB1/1 fuel element in storage canister with removal tool.



FUEL PACKAGE TYPE *	NUMBER OF PACKAGES
4	1
5	1
6	1
7	1
8	1
12	1
	6

* SEE TABLE 3–3

Fig. 4D.8. PB1/1 failed fuel element in storage canister with removal tool in salvage canister.

Table 4D.1. Uses of thermocouples in instrumented fuel elements

No. of instrumented fuel elements	Fuel loading type	Use of thermocouples	Reference drawing No.
8	1 and 2	Spine and sleeve temperature. Also acoustic thermometer at center, hot spot height	33-FE-10
3	1	Axial profile of center of core - spine temperature	33-FE-20
5	1, 2, 3, and 4	Radial profile - spine plus internal trap inlet temperature	33-FE-20
7	1, 2, and 3	Radial profile - both thermocouples for spine temperature	33-FE-20
3	2	Both thermocouples for spine temperature	33-FE-20
2	4	Low U loading - both thermocouples for spine temperature	33-FE-20
2	1 and 2	Internal trap inlet and outlet let temperature	33-FE-40
2	2 and 4	Standoff and bottom reflector temperature	33-FE-30
3	2	Axial profile at edge of core - spine temperature	33-FE-20
1	3	Boron loaded - both thermocouples for spine temperature	33-FE-20

Table 4D.2. Peach Bottom test elements irradiated in Core 2

Element	Phase[a]	Thermocouples	Fuel bed	Description/fuel type
PTE-2[b]	1	Yes	Rods[c]	Proof test element for FSV - rods
FBTE-1	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-2	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-3	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-4	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-5	1	No	Blended[d]	Fuel bed test element for LHTGRs - blended bed
FBTE-6	1	Yes	Blended	Fuel bed test element for LHTGRs - blended bed
FTE-1	1	Yes	Blended	Fuel test element for LHTGRs - blended bed
FTE-2	1	Yes	Blended	Fuel test element for LHTGRs - blended bed
FTE-5	1	Yes	Rods	Fuel test element for LHTGRs - bonded rods
RTE-2	1	No	Mixed	Recycle test element for ORNL - 1/2 beds, 1/2 rods
RTE-4	1	No	Mixed	Recycle test element for ORNL - 1/2 beds, 1/2 rods
RTE-5	1	No	Rods	Recycle test element for ORNL - bonded rods
RTE-6	1	No	Rods	Recycle test element for ORNL - bonded rods
RTE-7	1	No	Rods	Recycle test element for ORNL - bonded rods
RTE-8	1	No	Rods	Recycle test element for ORNL - 1/6 beds, 5/6 rods
FPTE-1	1	Yes	Compacts	Fuel pin test element for UKAEA - fuel pins
FTE-3	2	Yes	Rods	Fuel test element for LHTGRs
FTE-4	2	?	Rods	Fuel test element for LHTGRs
FTE-6	2	Yes	Rods	Fuel test element for LHTGRs
FTE-7	2	Yes	Rods	Fuel test element for LHTGRs
FTE-8	2	Yes	Rods	Fuel test element for LHTGRs
FTE-9	2	Yes	Rods	Fuel test element for LHTGRs
FTE-10	2	Yes	Rods	Proof test element for FSV
FTE-11	2	No	Rods	Recycle test element for ORNL
FTE-12	2	Yes	Rods	Fuel test element for LHTGRs
FPTE-3	2	Yes	Compacts	Fuel pin test element for UKAEA
FTE-13	3	Yes	Rods	Plutonium fuel test
FTE-14	3	Yes	Rods	Large HTGR fuel test
FTE-15	3	Yes	Rods	Large HTGR fuel test
FTE-16	3	Yes	Rods	FSV fuel proof test
FTE-17	3	Yes	Rods	FSV fuel proof test
FTE-18	3	Yes	Monolithic	HOBEG/KFA molded fuel body test

[a]Phase 1 loaded at 0 EFPD of Core 2, Phase 2 loaded at 252 EFPD of Core 2, and Phase 3 loaded at 385 of Core 2.

[b]PTE-2 was irradiated 152 EFPD in Core 1, prior to irradiation in Core 2.

[c]A fuel rod, as used here, is a close-packed assembly of coated fuel particles bonded together with a carbonaceous matrix.

[d]A blended bed, as used here, is a close-packed assembly of unbonded, coated fuel particles.

Table 4D.3. Peach Bottom Unit 1 - Core 1 spent fuel package types

Fuel package type	No. of elements	Description
1	528	Type I or II fuel element, regular can and liner
2	58	Type I or II fuel element, failed sleeve, normal can, split liner, spacer, type 2 removal tool
3	7	Fuel assembly type 2 with a type 1 removal tool
4	1	Type II fuel element (No. 263) broken and stored in 2 containers
		Upper portion of element with 21 compacts is in a salvage can with unmarked salvage cap with partial type 2 removal tool, special spacer, component canister, 4.25 in. spacer and 50 lb of steel shot
		Lower portion of element with 9 compacts is in a regular canister (cap No. 120) with a 3.25 in. spacer and a special GGA pulling tool
5	1	Type II fuel element (No. 451), failed sleeve, normal can, split liner, spacer, type 1 removal tool. Due to leaking canister, recanned in salvage canister with special vented cap, unmarked
6	1	Type II fuel element (No. 576), failed sleeve, type 2 removal tool, component canister and spacer in salvage canister, cap No. 8
7	1	Type 2 fuel assembly in a salvage canister (cap No. 851, fuel element No. 731).
8	1	Type 2 fuel element (No. 848) less upper reflector canned in salvage canister (component canister and 4 in. spacer inside). Salvage cap is unmarked
9	71	Type 3 fuel element, regular can and liner
10	8	Fuel assembly type 2 with a type 3 fuel element
11	1	Fuel assembly type 10 with a hollowed out cap (No. 90) due to a removal tool positioned too high (element No. 126)
12	1	Fuel assembly type 10 recanned in salvage canister with cap C5 (element No. 306)
13	1	Type 10 fuel assembly (element No. 870) in can No. 14 (cap unmarked) with type 1 removal tool
14	98	Type 4 fuel element, regular can and liner

Table 4D.3 (continued)

Fuel package type	No. of elements	Description
15	5	Type 2 fuel assembly with acoustic thermometer installed
16	1	Type 15 fuel assembly (fuel element No. 807) in can 01, cap unmarked, with a type 1 removal tool
17	1	Type 1 fuel assembly (fuel element No. 808 and cap No. 252R) with acoustic thermometer installed
18	18	Type 1 fuel assembly with thermocouple installed
19	3	Type 2 fuel assembly (element No. 848) with thermocouple installed
20	3	Type 9 fuel assembly with thermocouple installed
21	4	Type 14 fuel assembly with thermocouple installed

Table 4D.4. Peach Bottom Unit 1 - Core 1 inventory at INEL

Uranium, g	U-235, g	No. of elements
4853	3847	18
4662	3516	18
4761	3621	18
4857	3718	18
4960	3884	18
4719	3574	18
4972	3890	18
4919	3804	18
4823	3667	18
4705	3623	18
4804	3643	18
4777	3593	18
4822	3687	18
4939	3854	18
4814	3679	18
4794	3685	18
4749	3672	18
4835	3751	18
4957	3869	18
4884	3755	18
4840	3681	18
4865	3721	18
4519	3414	18
4776	3599	18
4309	3176	18
4335	3216	18
4823	3709	18
4919	3871	18
4780	3712	18
4253	3185	18
3442	2352	18
3480	2425	18
3482	2444	18
2805	1754	18
3785	2721	18
4874	3738	18
4836	3680	18
4099	2950	18
2932	1869	18
4687	3546	18
4744	3624	18
4702	3612	18
4923	3848	18
4879	3760	18
4815	3738	18
1084	842	4
Total		814

Table 4D.5. Peach Bottom Unit 1 - Core 2 inventory at INEL

Uranium, g	U-235, g	No. of elements
3053	618	18
2355	657	18
1854	678	18
1855	680	18
2470	623	18
3184	468	18
2446	570	18
2508	562	18
2449	570	18
2657	565	18
2441	548	17
2722	562	18
2833	539	18
2790	567	18
2919	551	18
2995	594	18
2997	610	18
3004	610	18
3001	609	18
3027	605	18
3038	610	18
3017	614	18
3033	617	18
3091	617	18
3009	611	18
3034	615	18
3099	620	18
3136	624	18
3037	604	18
3046	584	18
2977	580	18
2983	540	18
2978	548	18
2975	580	18
2958	582	18
2972	607	18
2948	607	18
2975	595	18
2971	594	18
2971	594	18
2976	578	18
2978	578	18
2152	373	13
2787	496	17
Total		785

Table 4D.6. Peach Bottom Unit 1 - Core 1 summary of postirradiation uranium loadings by fuel assembly package type

Package type	No. of elements	Total U Average (g) Maximum (g)	U-232 Average (μg) Maximum (μg)	U-233 Average (g) Maximum (g)	U-234 Average (g) Maximum (g)	U-235 Average (g) Maximum (g)	U-236 Average (g) Maximum (g)	U-238 Average (g) Maximum (g)
1	528	268.68	1645	23.99	3.71	206.46	18.46	16.06
		303.81	2081	27.10	3.89	268.84	20.76	17.10
2	58	267.46	1697	24.39	3.73	204.46	18.84	16.04
		283.83	2081	27.10	3.89	226.93	20.76	16.27
3	7	279.24	883	17.94	3.47	227.35	14.08	16.39
		282.79	960	19.04	3.49	230.81	14.52	16.50
4	1	256.77	1584	20.42	3.71	197.31	19.06	16.27
		256.77	1584	20.42	3.71	197.31	19.06	16.27
5	1	280.85	820	18.24	3.44	229.11	13.75	16.31
		280.85	820	18.24	3.44	229.11	13.75	16.31
6	1	255.80	1699	21.36	3.75	194.85	19.62	16.21
		255.80	1699	21.36	3.75	194.85	19.62	16.21
7	1	278.49	1191	22.71	3.53	219.86	16.25	16.14
		278.49	1191	22.71	3.53	219.86	16.25	16.14
8	1	297.20	285	11.00	3.36	257.31	8.60	16.93
		297.20	285	11.00	3.36	257.31	8.60	16.93
9	71	269.79	1594	23.67	3.68	208.20	18.15	16.08
		295.62	2050	27.04	3.86	258.37	20.33	16.71
10	8	268.25	1836	25.70	3.77	203.54	19.27	15.96
		274.76	2050	27.04	3.86	213.19	20.33	16.05
11	1	272.57	1646	25.21	3.69	209.35	18.31	16.00
		272.57	1646	25.21	3.69	209.35	18.31	16.00
12	1	274.64	1498	24.36	3.63	212.99	17.61	16.05
		274.64	1498	24.36	3.63	212.99	17.61	16.05
13	1	285.85	749	17.82	3.42	235.34	12.87	16.40
		285.85	749	17.82	3.42	235.34	12.87	16.40
14	98	150.41	3009	34.81	3.19	91.69	11.90	8.81
		155.48	3262	36.28	3.34	96.02	12.33	8.86
15	5	268.15	1715	24.53	3.73	205.07	18.79	16.03
		277.75	2013	25.57	3.84	218.51	20.25	16.13
16	1	288.17	651	16.82	3.40	239.07	12.35	16.53
		288.17	651	16.82	3.40	239.07	12.35	16.53
17	1	277.75	1279	23.04	3.55	218.51	16.51	16.13
		277.75	1279	23.04	3.55	218.51	16.51	16.13
18	18	270.69	1550	23.62	3.66	209.37	17.95	16.09
		283.63	2013	25.61	3.84	226.63	20.25	16.24
19	3	277.57	1228	22.79	3.54	218.63	16.46	16.14
		278.54	1297	23.00	3.57	219.94	16.90	16.14
20	3	268.61	1378	21.33	3.61	210.09	17.35	16.23
		284.63	1559	22.54	3.68	227.42	18.55	16.26
21	4	150.60	2933	34.56	3.16	92.24	11.81	8.82
		155.48	3240	36.17	3.18	96.02	11.96	8.83

Table 4D.7. Peach Bottom Unit 1 – Core 2 test element initial heavy metal loadings

Test element No.	Thorium, g	Uranium,[a] g
PTE-2	2152.62	450.0
FBTE-1	1263.6	215.9
FBTE-2	566.6	235.0
FBTE-3	762.2	194.2
FBTE-4	943.7	235.7
FBTE-5	1518.1	194.4
FBTE-6	1667.7	181.0
FTE-1	1537.8	206.1
FTE-2	1639.5	184.4
FTE-5	1082.4	203.3
RTE-2	804.0	211.9
RTE-4	1093.2	177.4
RTE-5	1083.5	186.6
RTE-6	928.2	190.6
RTE-7	1250.0	185.5
RTE-8	881.1	185.7
FPTE-1	0	1477.5[b]
FTE-3	996.80	205.9
FTE-4	1027.63	188.42
FTE-6	855.43	222.94
FTE-7	1396.08	223.44
FTE-8	519.15	182.44
FTE-9	1114.5	179.76
FTE-10	685.1	171.81
FTE-11	891.02	224.14
FTE-12	1338.6	191.52
FPTE-3	0	1592.39[c]
FTE-13[d]	1352.03	99.94
FTE-14	1922.6	191.5
FTE-15	1883.7	191.85
FTE-16	1045.0	144.93
FTE-17	907.2	100.8
FTE-18	736.2	168.0[e]

[a]93.15% enriched, except as noted.
[b]9.15% enriched.
[c]14.08% enriched.
[d]This element contained 18.77 g total Pu (16.65 g Pu-239).
[e]86.46% enriched.

Table 4D.8. Peach Bottom Unit 1 - Core 2 test element postirradiation heavy metal loadings[a]

Element No.	Th-232	Pa-231	U-232	U-233[b]	U-234	U-235	U-236	U-238	Pu-239[c]	Pu-240	Pu-241	Pu-242	Np-237
PTE-2	2120.76	0.010	0.003	26.34	5.14	316.77	24.34	23.65	0.80	0.17	0.10	0.009	0.93
FBTE-1	1211.22	0.007	0.008	30.03	4.96	83.11	23.83	8.93	0.26	0.09	0.14	0.060	2.03
FBTE-2	526.21	0.003	0.004	16.88	4.00	87.36	26.26	9.76	0.25	0.09	0.14	0.069	2.14
FBTE-3	727.09	0.004	0.005	19.00	3.93	67.71	22.03	8.12	0.19	0.06	0.11	0.058	1.73
FBTE-4	932.78	0.003	d	9.64	3.44	179.16	9.78	10.97	0.28	0.05	0.02	0.001	0.26
FBTE-5	1457.91	0.008	0.011	32.04	5.39	65.95	22.64	7.98	0.20	0.07	0.12	0.066	1.99
FBTE-6	1650.59	0.005	0.001	14.67	2.92	131.30	8.53	8.41	0.20	0.04	0.02	0.002	0.23
FTE-1	1522.48	0.005	0.001	13.40	3.21	150.84	9.49	9.58	0.23	0.05	0.02	0.002	0.26
FTE-2	1614.40	0.007	0.003	20.36	3.24	120.73	11.44	8.37	0.25	0.06	0.04	0.005	0.46
FTE-5	1039.43	0.005	0.007	23.36	4.47	72.43	22.85	8.52	0.20	0.07	0.11	0.059	1.77
RTE-2	773.80	0.004	0.004	19.43	3.75	98.30	20.55	9.07	0.27	0.09	0.12	0.036	1.43
RTE-4	1072.56	0.005	0.002	16.10	2.95	110.60	11.97	8.00	0.23	0.06	0.05	0.007	0.52
RTE-5	1022.46	0.006	0.008	25.16	4.61	61.57	21.90	7.65	0.19	0.07	0.11	0.065	1.94
RTE-6	882.06	0.005	0.007	23.66	4.57	60.31	22.70	7.78	0.19	0.07	0.12	0.069	2.05
RTE-7	1235.16	0.004	0.001	12.78	2.89	135.34	8.71	8.60	0.22	0.04	0.02	0.002	0.25
RTE-8	837.34	0.005	0.007	22.51	4.38	58.99	22.09	7.58	0.19	0.06	0.11	0.067	1.99
FPTE-1	0	0	0	0	0	107.64	5.65	1330.60	6.65	1.18	0.58	0.041	1.13
FTE-3	990.41	0.002	d	6.00	1.54	170.22	5.13	11.75	0.20	0.02	0.005	d	0.08
FTE-4	1006.65	0.004	0.003	15.51	2.00	107.05	13.84	10.21	0.25	0.07	0.08	0.015	0.60
FTE-6	825.61	0.004	0.004	18.93	2.70	99.77	21.47	11.53	0.32	0.10	0.15	0.049	1.43
FTE-7	1359.43	0.006	0.006	23.34	3.07	100.27	21.05	11.74	0.27	0.09	0.13	0.044	1.23
FTE-8	499.05	0.002	0.002	12.67	2.02	80.83	17.31	9.58	0.22	0.07	0.10	0.037	1.01
FTE-9	1080.01	0.006	0.005	22.36	2.67	83.79	16.80	9.34	0.26	0.08	0.12	0.036	1.08
FTE-10	658.36	0.003	0.003	16.89	2.29	76.55	16.58	8.89	0.24	0.08	0.11	0.038	1.10
FTE-11	858.50	0.004	0.005	19.79	2.93	93.23	22.56	11.55	0.29	0.10	0.15	0.057	1.54
FTE-12	1301.92	0.007	0.006	23.94	2.83	90.26	17.75	9.96	0.28	0.09	0.12	0.037	1.13
FPTE-3	0	0	0	0	0	112.59	21.18	1337.45	7.15	2.26	3.05	0.933	1.19
FTE-13	1317.24	0.006	0.005	23.69	2.16	50.05	8.81	4.36	1.08	2.03	1.92	1.002	0.47
FTE-14	1889.32	0.007	0.002	27.83	3.51	132.15	10.45	8.69	0.23	0.05	0.03	0.003	0.35
FTE-15	1834.43	0.008	0.005	34.63	4.46	104.64	15.51	8.45	0.20	0.06	0.08	0.017	0.73
FTE-16	1018.51	0.005	0.003	18.45	2.88	75.85	12.35	6.31	0.17	0.05	0.06	0.015	0.67
FTE-17	881.11	0.004	0.003	17.70	2.41	50.00	9.01	4.37	0.11	0.04	0.05	0.012	0.51
FTE-18	712.83	0.003	0.003	15.54	4.91	75.75	15.12	14.48	0.37	0.12	0.16	0.046	0.91

[a]Assuming all test elements stay in Core 2 until Core-2 end-of-life (EOL). Loadings are given in grams.
[b]Includes Pa-233.
[c]Includes Np-239.
[d]Less than 0.001.

APPENDIX 4E. SUPPLEMENTAL DATA FOR FAST FLUX TEST FACILITY

APPENDIX 4E. SUPPLEMENTAL DATA FOR FAST FLUX TEST FACILITY

4E.1 INTRODUCTION

The purpose of this appendix is to provide data on the physical and radiological properties of the spent fuel and other assemblies discharged from the Fast Flux Test Facility and on the quantities of such materials discharged to date and projected to be discharged by the year 2020. The principal source document is a letter report prepared by Battelle Pacific Northwest Laboratories for Oak Ridge National Laboratory (Luksic and Love, 1988).

4E.2 FACILITY DESCRIPTION

The Fast Flux Test Facility (FFTF) is a 400-MWt sodium-cooled research reactor located in Hanford, Washington. The purpose of the FFTF is to provide a test facility in which fuels and materials can be subjected to fast flux conditions in order to evaluate the effects of high-energy irradiation, thus providing engineering knowledge that can be used in the design of fast reactors. Initial criticality of the FFTF was achieved in 1980.

The FFTF has seven major types of in-core assemblies:

1. driver fuel assemblies,
2. movable and fixed control rod assemblies,
3. in-core shim assemblies,
4. reflector assemblies,
5. materials open test assemblies,
6. fuels open test assemblies, and
7. core demonstration experiment assemblies.

The driver fuel assemblies are the fuel source for the reactor. Reactor control is provided by the movable and fixed control rod assemblies, as well as in-core shim assemblies. Radial neutron reflection is provided by reflector assemblies that surround the fueled section of the core. Special test assemblies include Materials Open Test Assemblies (MOTAs), Fuels Open Test Assemblies (FOTAs), and Core Demonstration Experiment (CDE) assemblies.

The design core arrangement of these assemblies is shown in Fig. 4E.1. Weights of each type of assembly are shown in Table 4E.1. More detailed descriptions of the various assembly types are given in the following sections.

4E.2.1 DRIVER FUEL ASSEMBLY

The 74 driver fuel assemblies contain the fuel that drive the reactor. The driver assemblies are 12 ft long and consist of 217 fuel pins surrounded by a hexagonal duct tube, plus lower and upper end hardware. A typical driver fuel pin is shown in Fig. 4E.2. The fuel pellets and reflector materials are surrounded by a stainless steel cladding tube. A 0.056 in. diam wire is helically wrapped around the outside of the clad in order to maintain spacing between the fuel pins in the assembly. The material compositions and weights of the driver assembly and fuel pin hardware are shown in Table 4E.2.

4E.2.2 CONTROL ASSEMBLIES

The movable control rod and control rod fixed shim assemblies (Figs. 4E.3, 4E.4, 4E.6) are 12 ft long and consist of 61 absorber pins surrounded by a duct tube, plus upper and lower hardware. The duct is similar to that of the driver fuel. Absorber pins are shown in Figs. 4E.5 and 4E.7. The absorber material in the pin is natural boron carbide (20% B-10). The cladding material is stainless steel. A wire is wrapped helically around the pin cladding to maintain spacing in the control assembly. The material compositions and weights of the movable control assembly and absorber pin hardware are shown in Table 4E.3.

4E.2.3 IN-CORE SHIM ASSEMBLY

The in-core shim assembly (Fig. 4E.8) is basically a 12-ft-long, stainless steel hexagonal component. The assembly is similar to the driver fuel assembly, except that it is a non-fueled component. It is essentially a stainless steel duct surrounding solid stainless steel pins. The material compositions and weight of the major components of the in-core shim assembly are shown in Table 4E.4. The in-core shims substitute for operational fuel or test assemblies during operation.

4E.2.4 RADIAL REFLECTOR ASSEMBLIES

There are two different sizes of radial reflector assemblies. Inner core assemblies (Row 8A) are 12 ft long and rest directly in the core basket. Outer assemblies (Rows 8B and 9) are about 11 ft in length. The reflector region (Inconel 600) and the upper and lower shields (stainless steel) consist of blocks stacked on vertical arrays of parallel coolant and structure tubes. The major hardware difference between the inner and outer assemblies is in the number and size of these tubes (Figs. 4E.9 and 4E.10). The inner reflectors have 37 small-diameter cooling tubes, while the outer reflectors have seven-large diameter flow tubes surrounding a structural stainless steel rod, creating a coolant flow annulus. The component materials are shown in Table 4E.5. The weights of the major reflector assembly components are shown in Table 4E.6.

4E.2.5 MATERIALS OPEN TEST ASSEMBLY

A Materials Open Test Assembly (MOTA) is a 40-ft-long assembly with 48 small canisters attached to the main structure. When in place in the reactor, 18 of the canisters will remain above the core and 30 will be in the core region. The structure of the MOTA includes an instrument train to house the instrumentation that runs through the assembly. Like most of the other assemblies, the in-core section is surrounded by a duct similar to that of a driver fuel assembly. The major MOTA component materials and weights are shown in Table 4E.7.

4E2.6 FUELS OPEN TEST ASSEMBLY

A Fuels Open Test Assembly (FOTA) (Figs. 4E.11-4E.12) is one assembly used to test specimens of fuel. The assembly is 40 ft long, with test specimens inserted into the bottom 12 ft and instrumentation in the top 28 ft. When irradiation of a FOTA is completed, the FOTA design allows the assembly to be sheared apart at the 12-ft point. This produces a 28-ft instrument stalk and a 12-ft section that contains the tested fuel. The fuel section of the assembly is the same as the standard driver fuel assembly. The weights and material compositions of the major FOTA components are shown in Table 4E.8.

4E2.7 CORE DEMONSTRATION EXPERIMENT (CDE) ASSEMBLIES

There are two different types of CDE assemblies: fuel and blanket. The basic structures of the two types (Figs. 4E.13 and 4E.14) are similar to the driver fuel assemblies. The material compositions and weights of the major components are shown in Table 4E.9.

4E.3 MATERIAL DISCHARGE AND DISPOSAL

On the average, 42 driver fuel elements have been discharged from the FFTF core per year. After discharge, the spent fuel is placed in the spent fuel pool.

The fuel test assemblies are handled in a different manner. The test pins are removed from the elements and placed in pin containers. A pin container is a cylindrical carbon-steel container that can hold up to 217 pins, but a typical container currently holds between 120 and 160 pins. When full, the containers are stored in the spent fuel pool.

The pin containers are new hardware before they are employed to store the spent fuel pins. When full, the tops of the containers are welded shut and they are placed in the spent fuel pool for storage. The pin containers are unirradiated except for a small neutron flux from the spent fuel, so there will be little activation of the materials composing the pin container itself.

Other in-core hardware is discharged at a much slower rate. The hardware and containers from experiments have been discharged at a rate of about six per year. Reflector elements are not discharged at a regular rate. Several may be discharged one year, then there may be none discharged for several more years. An overall average discharge rate would be approximately two assemblies per 100 reactor days.

It is unclear what the ultimate control rod discharge rate will be. A number of elements have been discharged thus far, but it has been found that the predicted design life of 300 full-power days was an underestimate of their useful life. There is a high probability that many of the assemblies that have already been discharged will be reused in the future.

The MOTAs are removed from the core at a rate of one per year. They are currently being stored in a 40-ft-tall vault, but the long-term plan is to cut them into 12-ft lengths and bury them in burial casks. One MOTA will fill approximately two-thirds of a burial cask of the type now being used at FFTF.

There have been only two FOTA assemblies irradiated in the FFTF core to date. After the FOTA has been sheared apart, the lower 12-ft section is treated in the same manner as a used driver fuel assembly. The upper 28-ft section is removed from the core and stored.

There are a total of 12 CDE Fuel and 6 CDE Blanket assemblies that are being used in FFTF. All of these assemblies are to be discharged by the end of cycle 12.

When the non-fuel elements are removed from the core, they are left intact and stored in the spent fuel pool.

The burial casks that are currently being used at FFTF for disposal of core hardware are approximately 13 ft tall and contain compartments. Each compartment is large enough to hold one in-core assembly. The current plan is to dispose of all non-fuel assemblies in these burial casks.

Table 4E.10 tabulates the amount of spent fuel and non-fuel components that have been discharged from FFTF as of early 1988. Projections for the total discharged quantities are also included, based on the best information available to us. It is difficult to estimate more precisely due to uncertainties in the future operation and changing mission of FFTF.

4E.4 REFERENCES

Luksic and Love 1988. A. T. Luksic and E. F. Love, *FFTF Characterization Report*, letter report to Oak Ridge National Laboratory, October 1988.

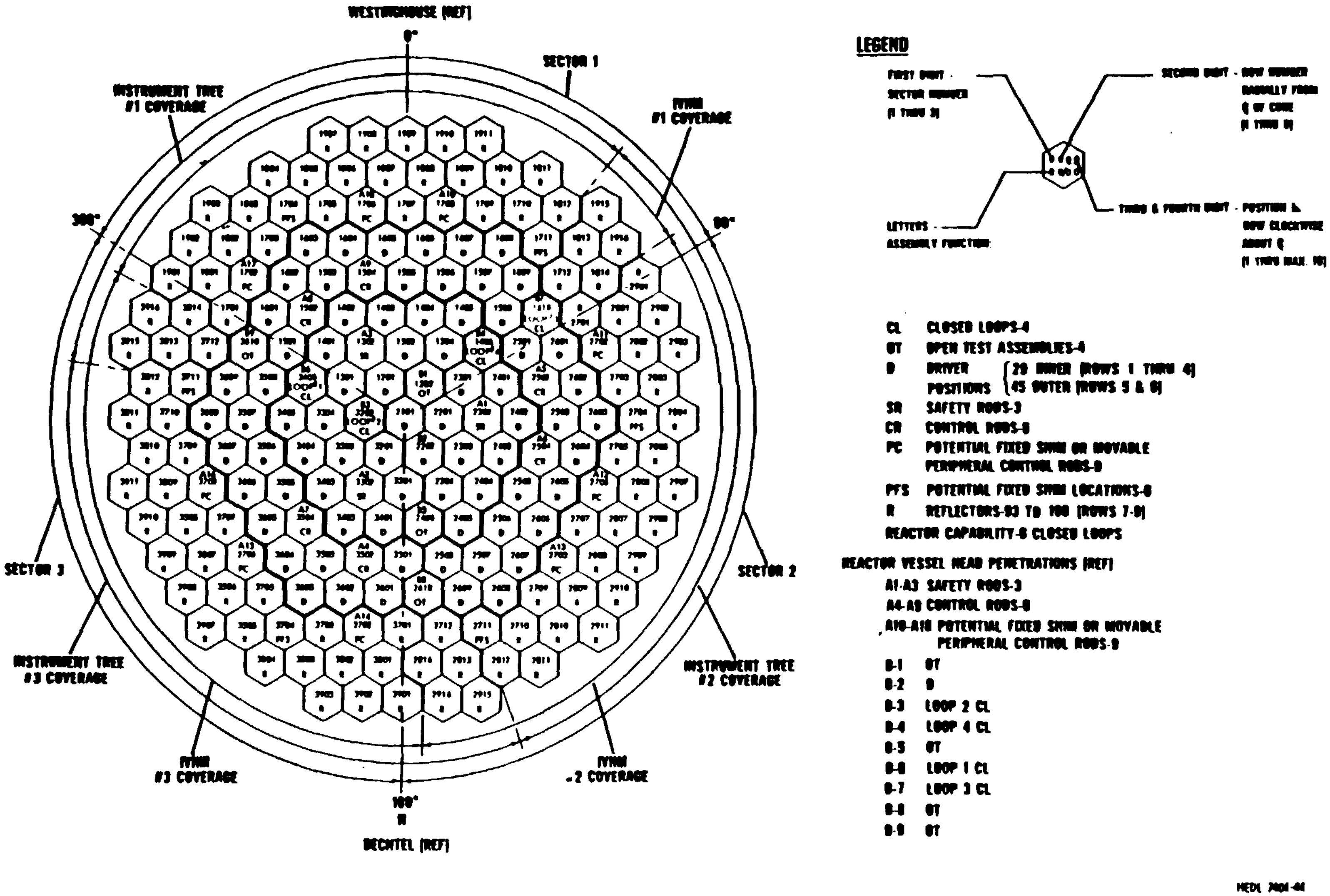


Fig. 4E.1. FFTF core map.

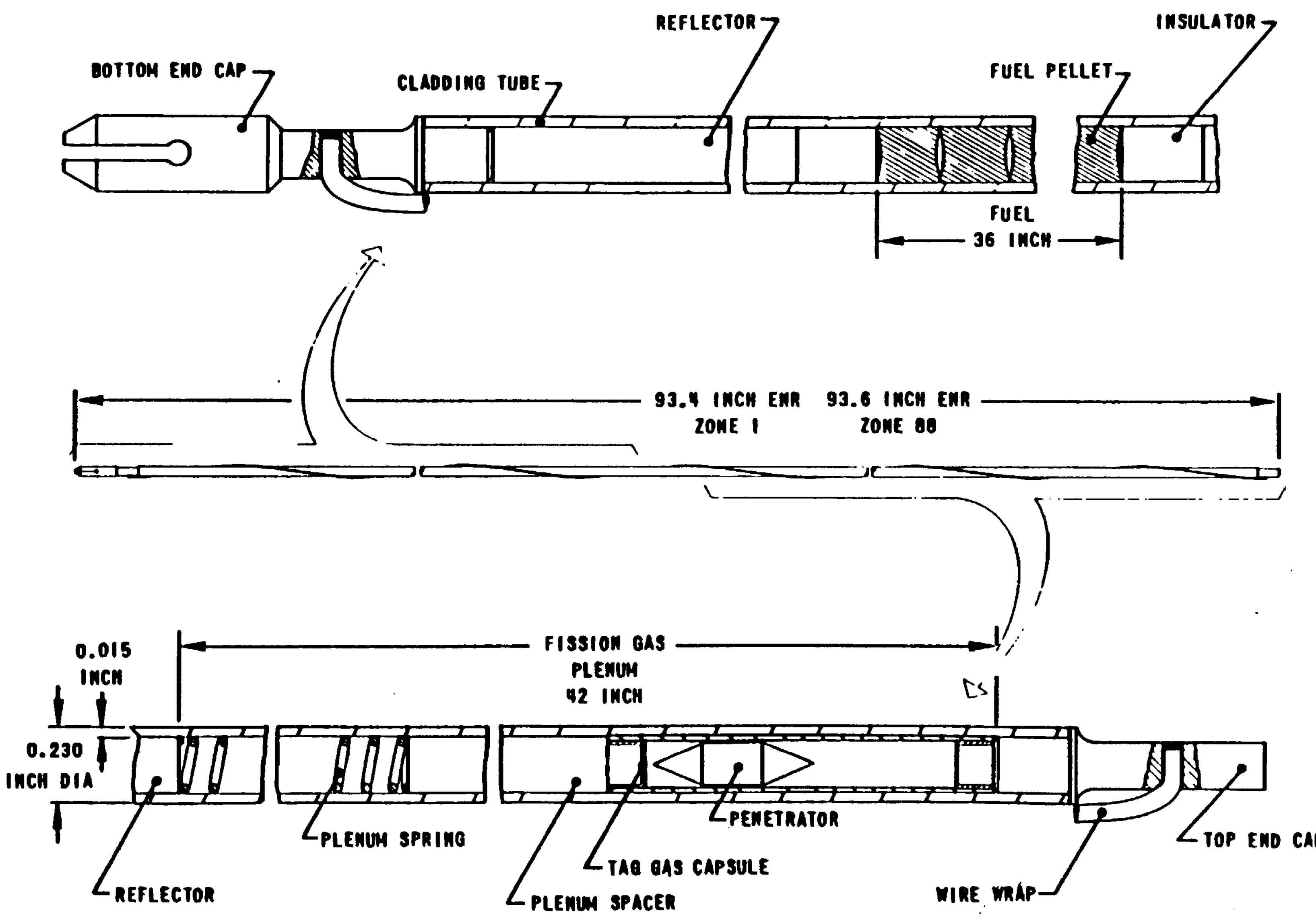


Fig. 4E.2. FFTF driver fuel pin.

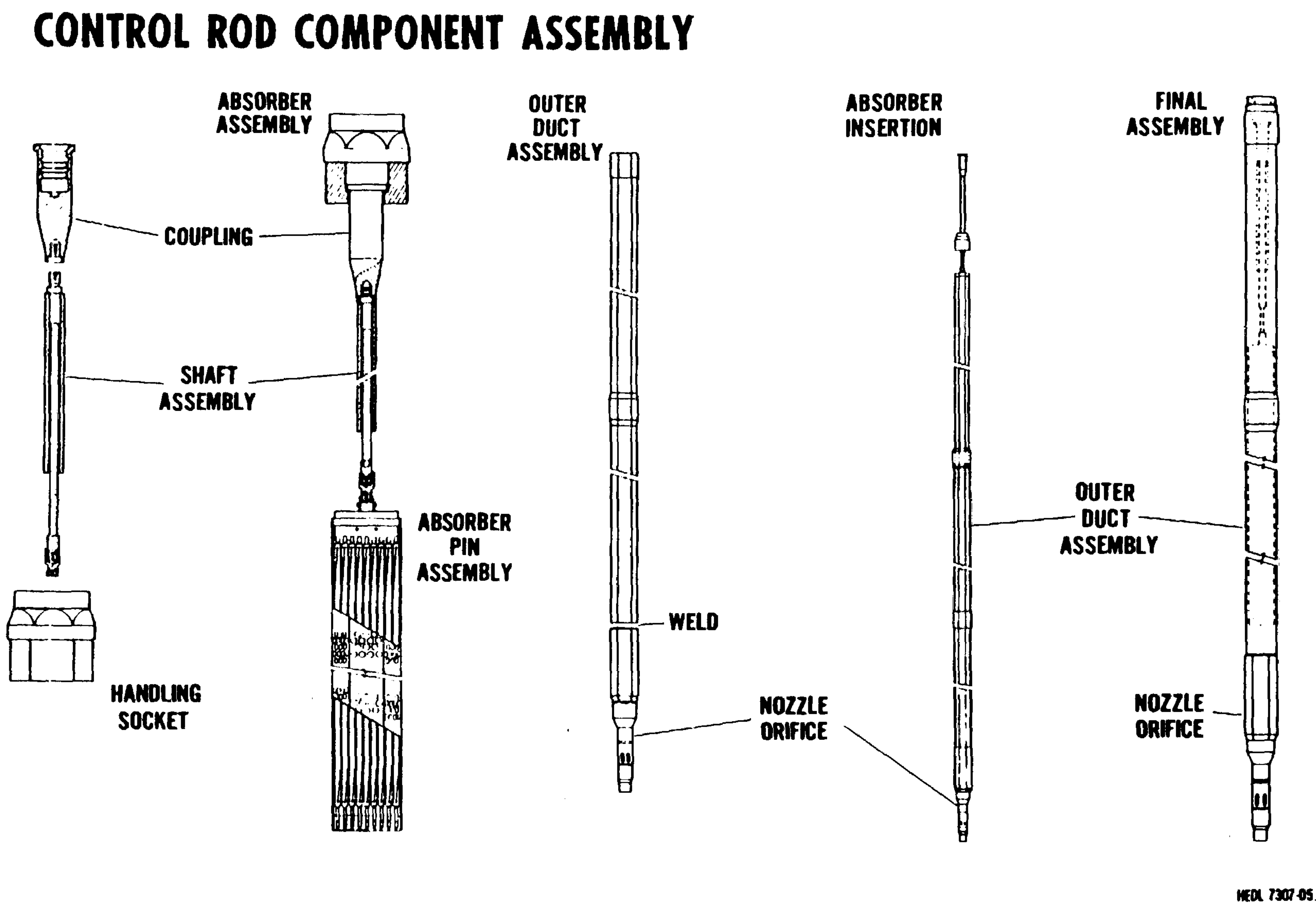


Fig. 4E.3. FFTF control rod component assembly.

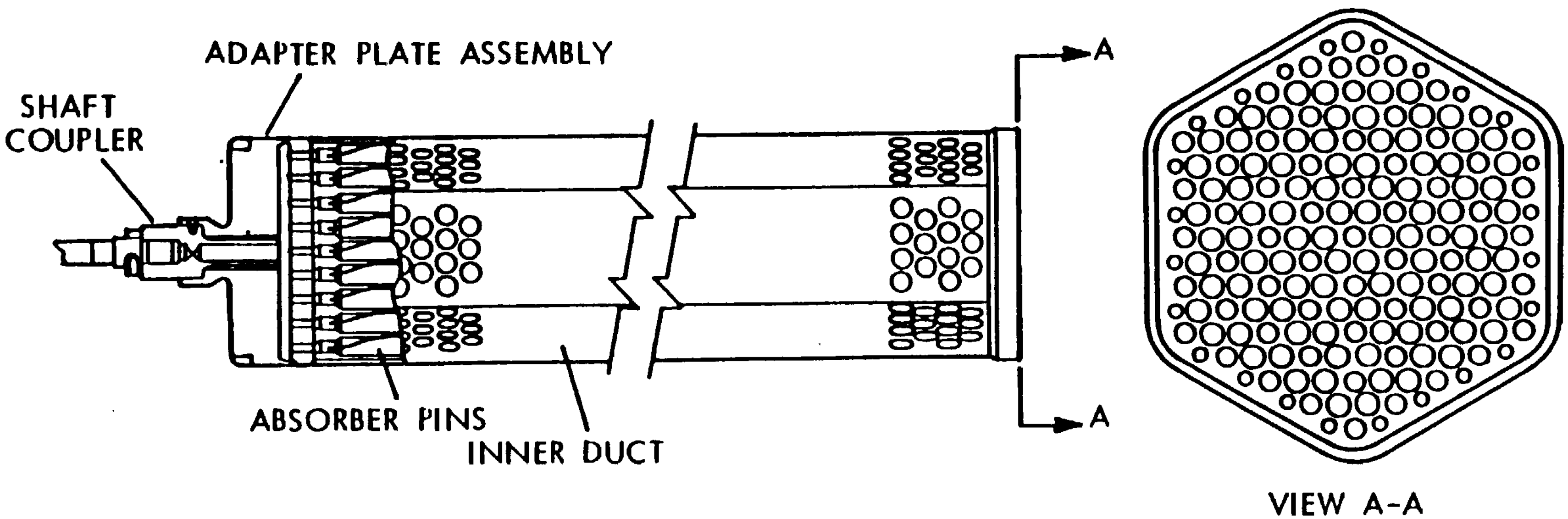


Fig. 4E.4. FFTF control rod absorber assembly.

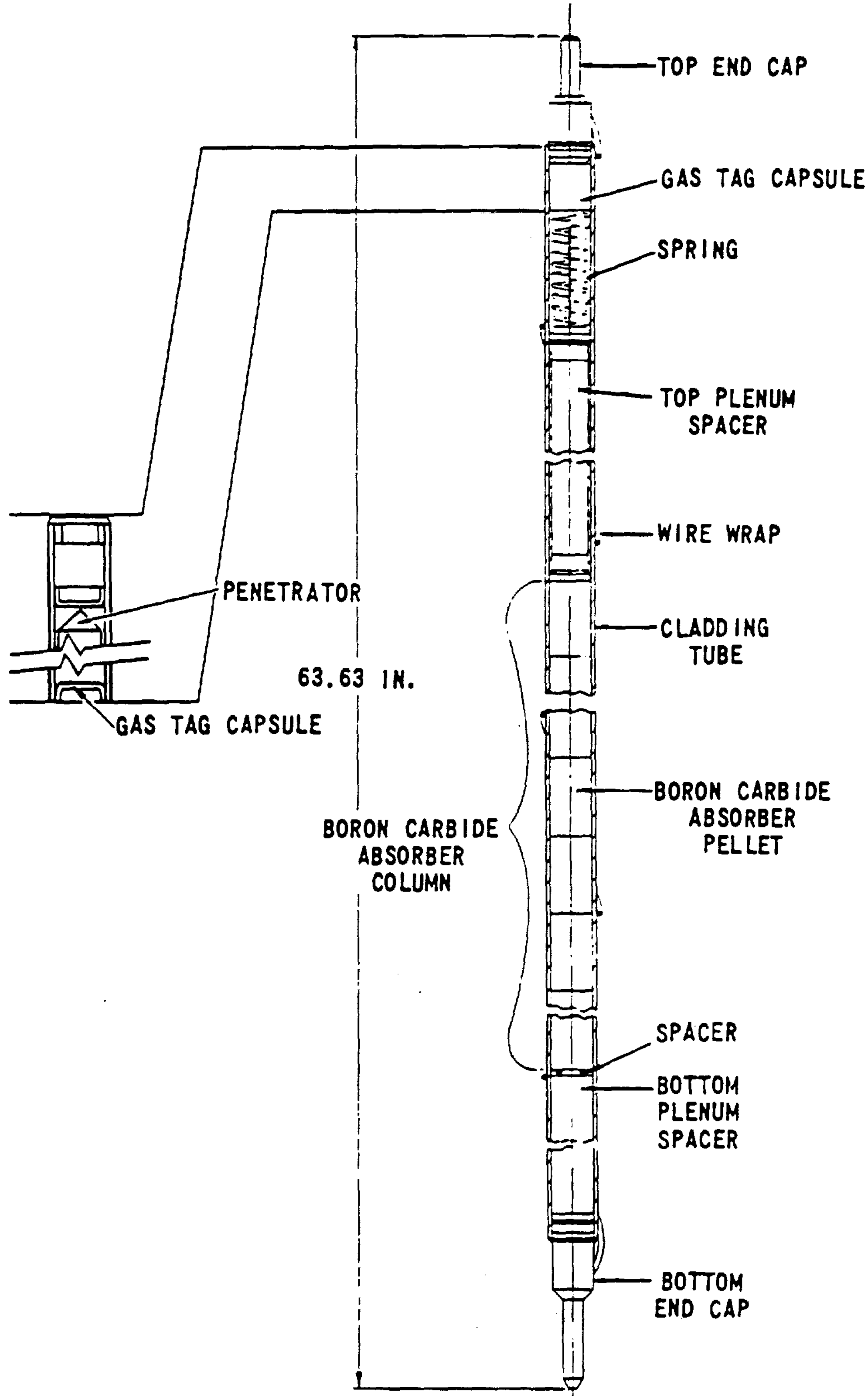


Fig. 4E.5. FFTF control rod absorber pin assembly.

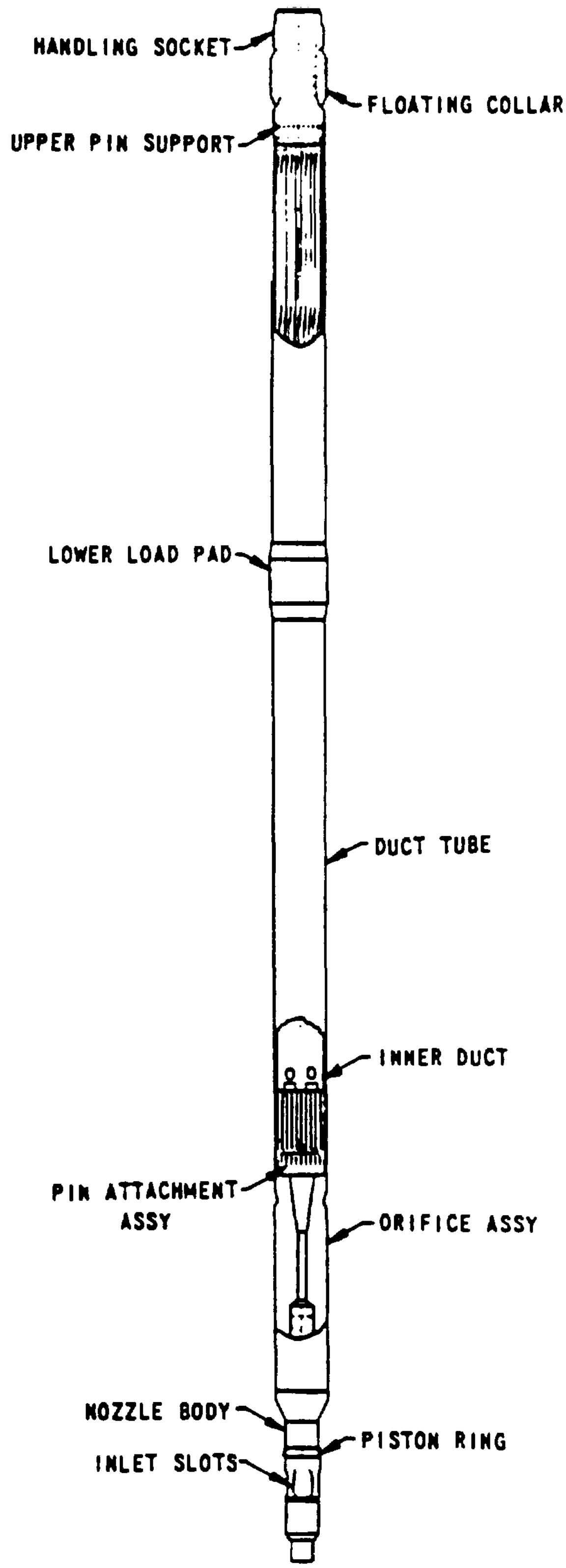


Fig. 4E.6. FFTF control rod fixed shim assembly.

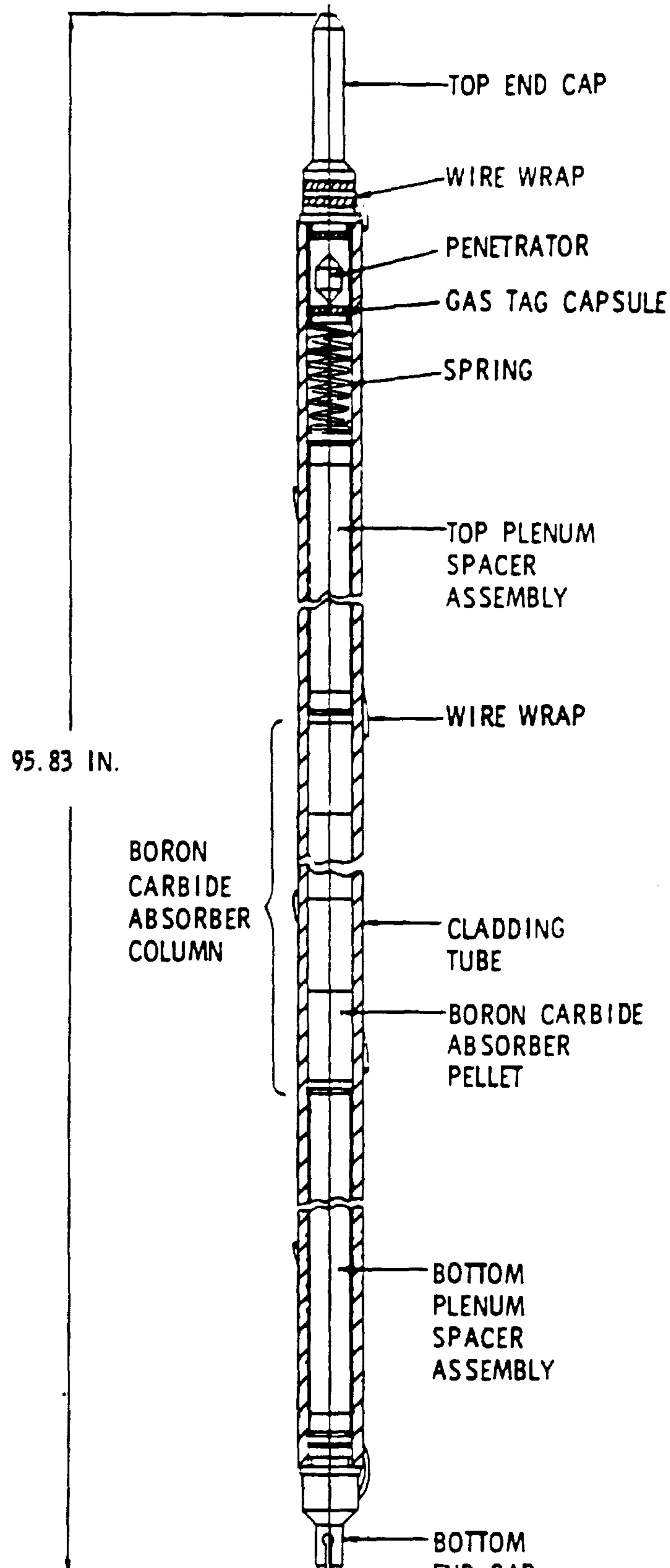


Fig. 4E.7. FFTF control rod fixed shim pin assembly.

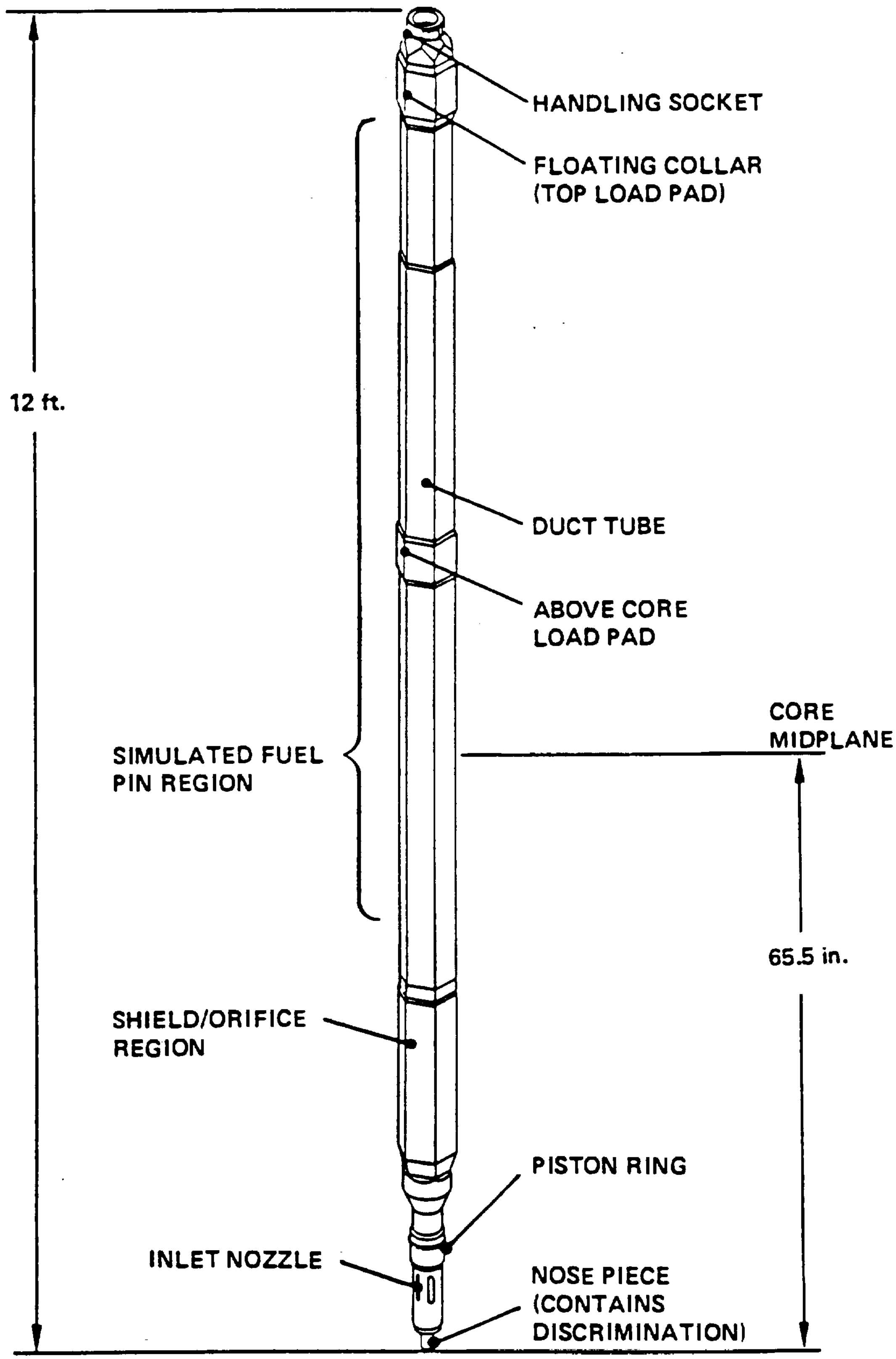


Fig. 4E.8. FFTF in-core shim assembly.

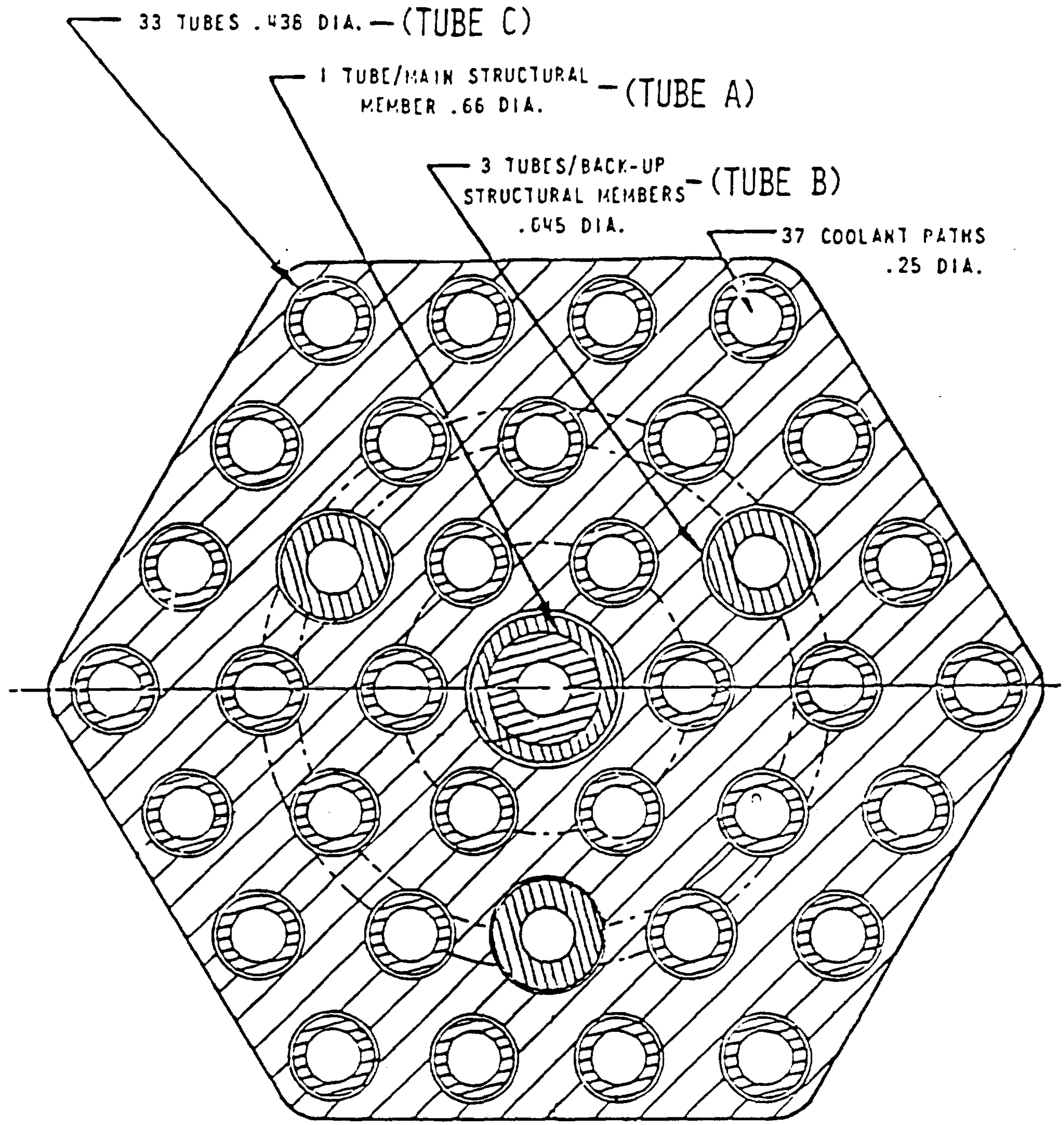


Fig. 4E.9. FFTF inner radial reflector.

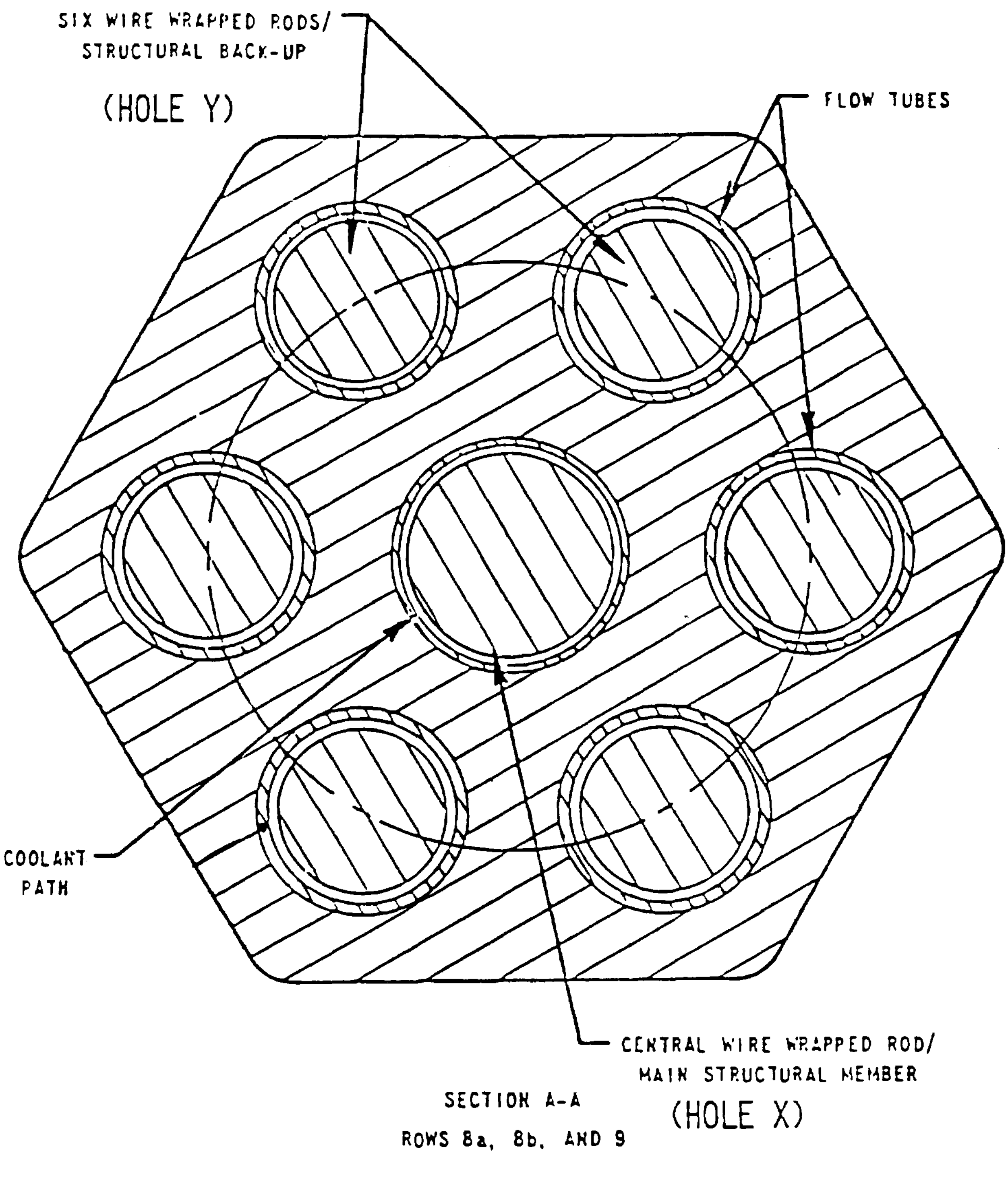


Fig. 4E.10. FFTF outer radial reflector.

FUELS OPEN TEST ASSEMBLY (FOTA)

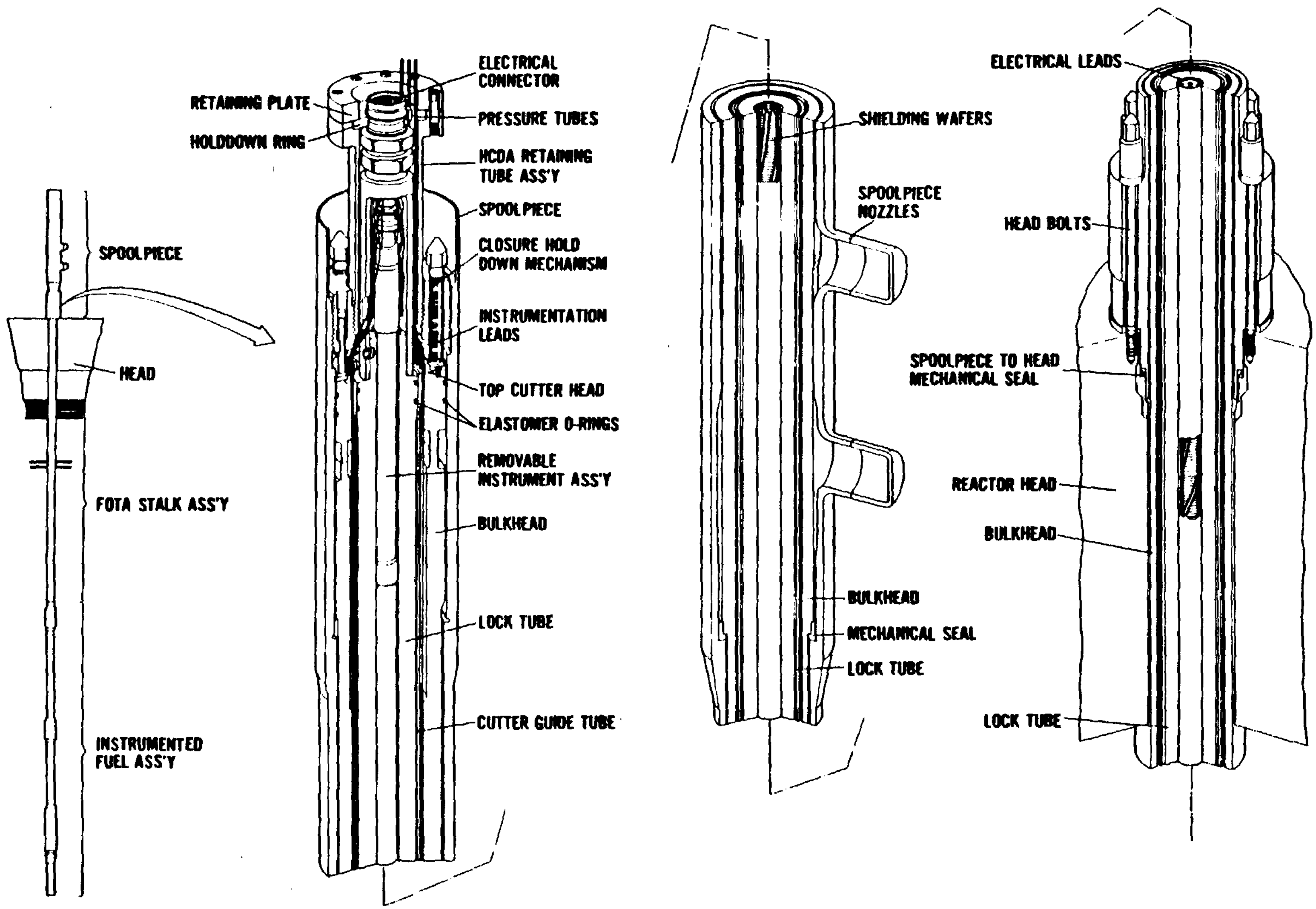


Fig. 4E.11. FFTF fuels open test assembly (FOTA).

HEDL 7400-50.1

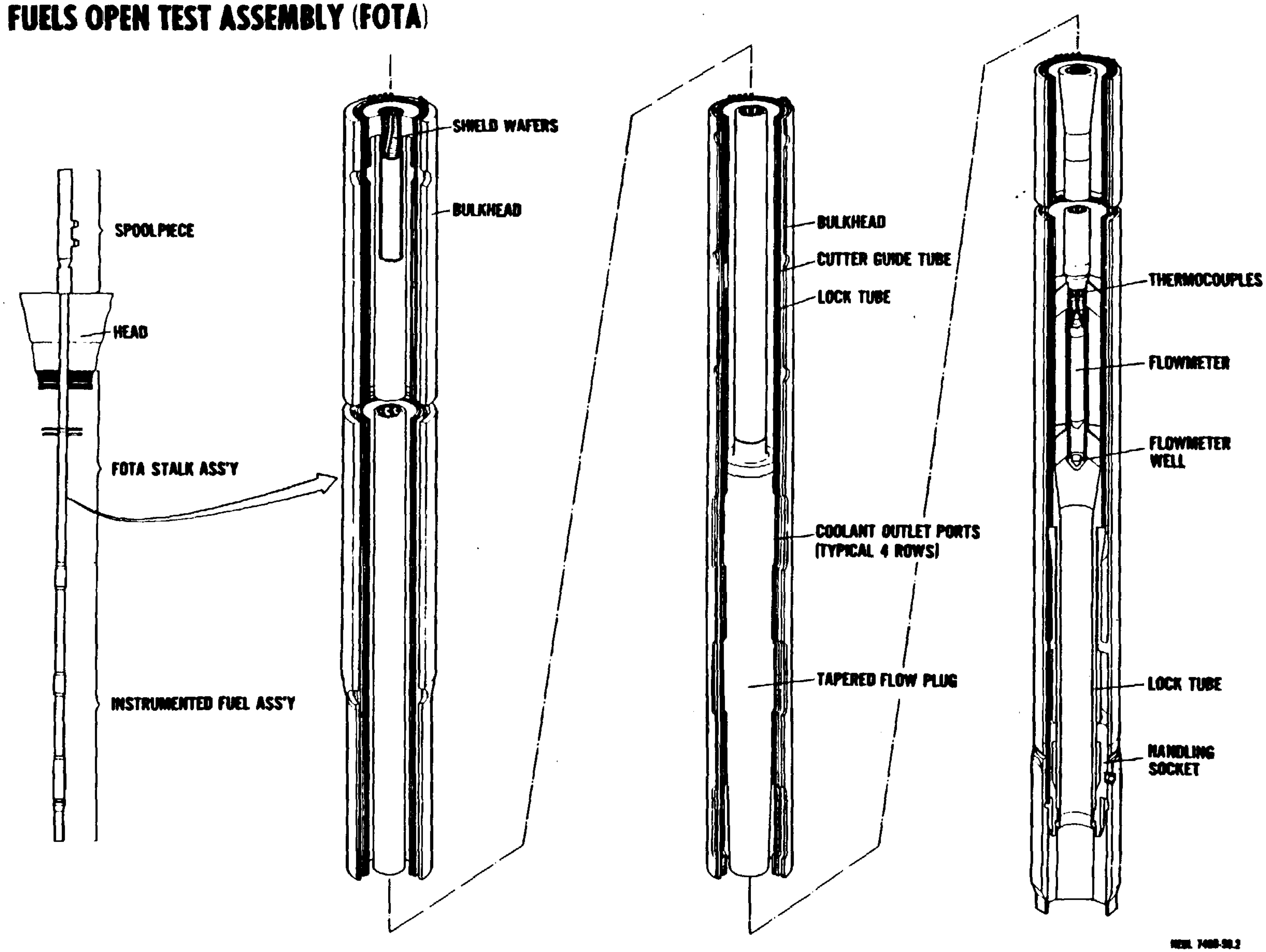


Fig. 4E.12. FFTF fuels open test assembly (FOTA).

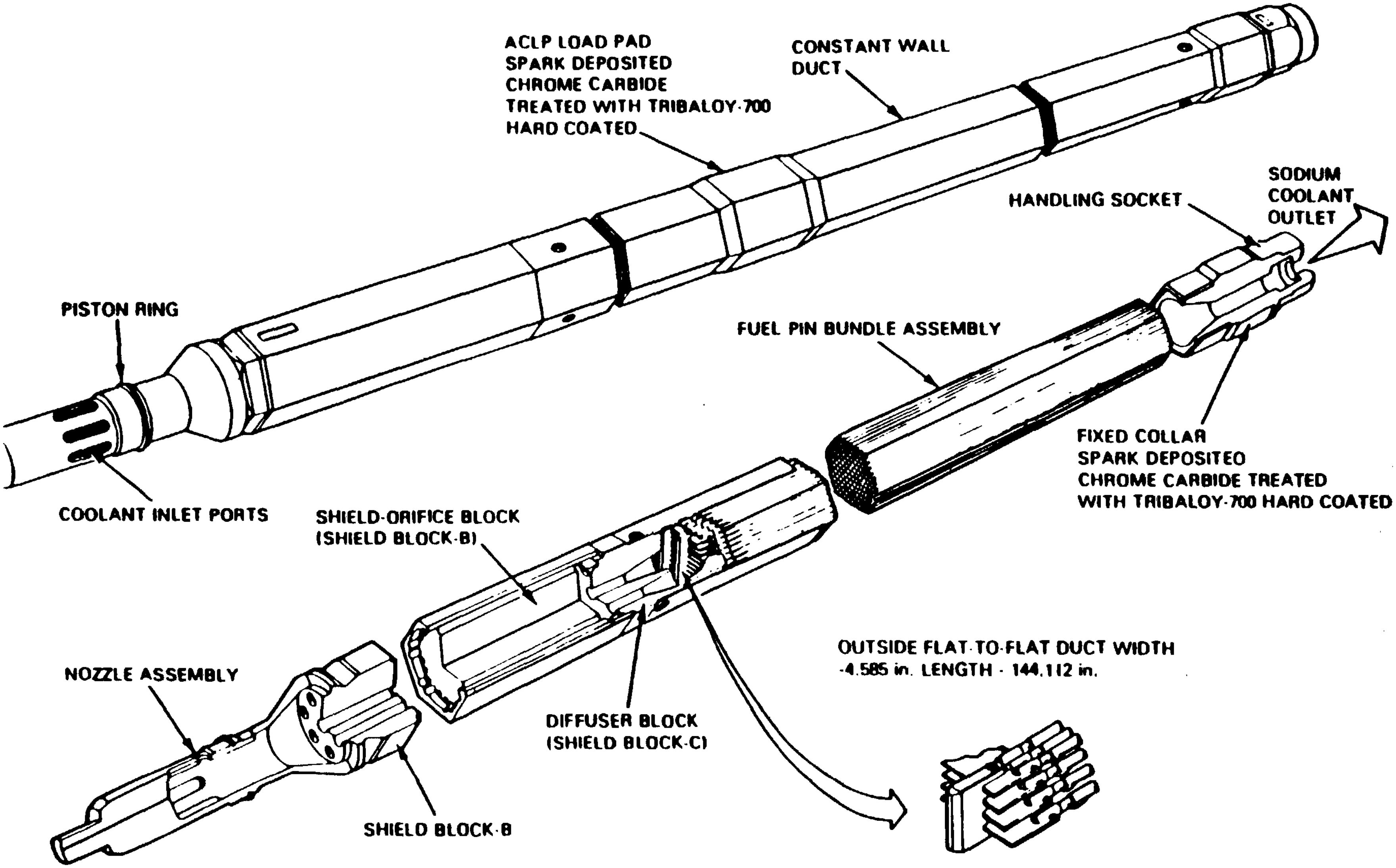


Fig. 4E.13. FFTF core demonstration experiment fuel assembly.

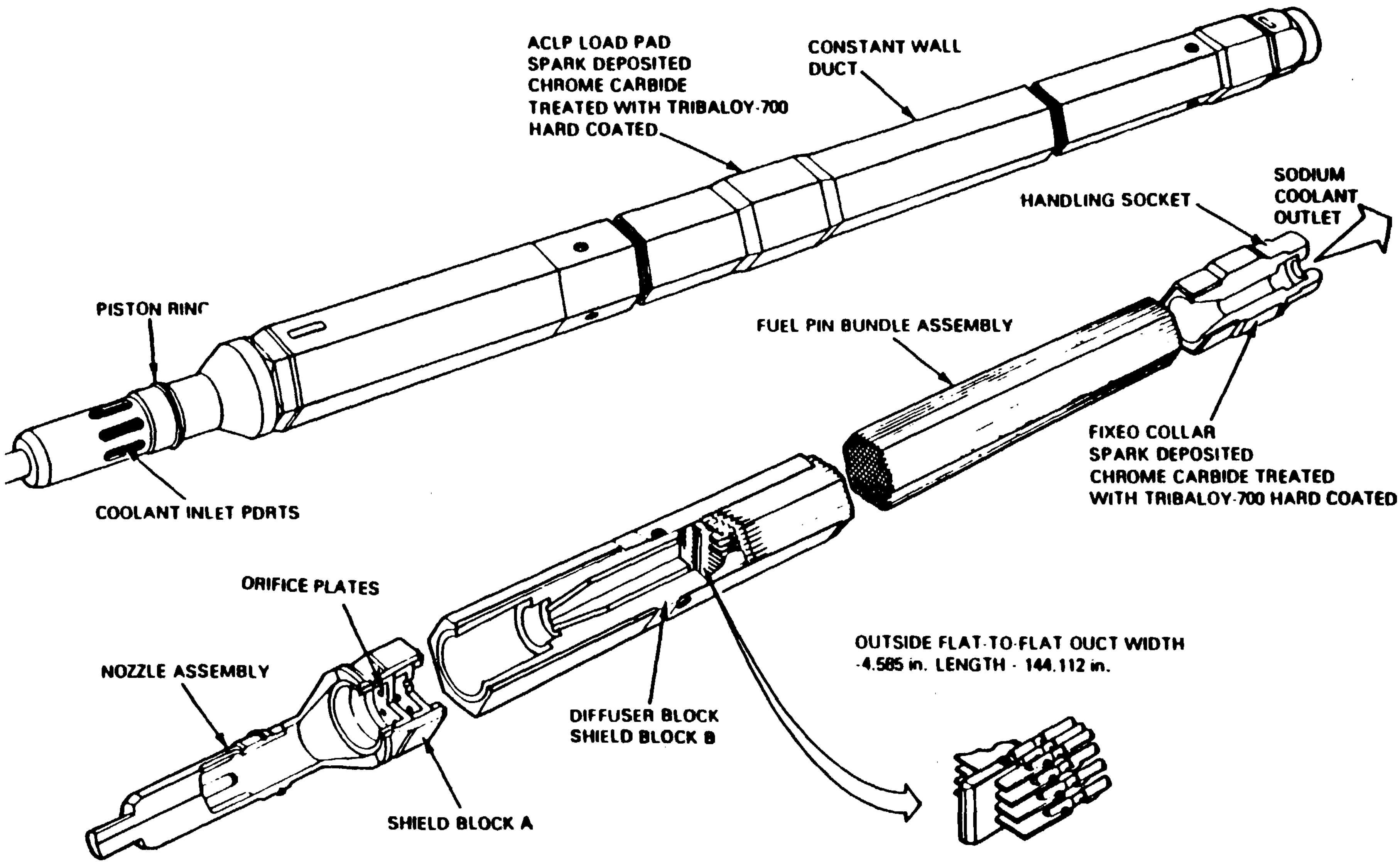


Fig. 4E.14. FFTF core demonstration experiment blanket assembly.

Table 4E.1. FFTF assembly weight summary

Component	Approximate weight per assembly (kg)
Driver fuel assembly	175.1
Control assemblies	
Series 1	136.1
Series 2	133.8
In-core shim assembly	201.8
Reflector assemblies	
Row 7	274.0
Row 8A	289.8
Rows 8B and 9	273.4
Materials open test assembly	612.2
Fuels open test assembly	905.2
Core demonstration experiment assemblies	
Fuel assembly	181.0
Blanket assembly	189.9

Table 4E.2. Driver fuel assembly component materials and weights[a]

Component	Material	Approximate weight per assembly (kg)
Duct tube	20% CW 316 SS	25.4
Load pad hard surface coating	Chromium carbide	
Handling socket	316 SS	11.1
Collar	316 SS	
Transition ring	316 SS	
Pin	316 SS	
Ring and collar coatings	Chromium carbide	
Attachment rail	316 SS (annealed or CW, 20% max)	0.3
Driver fuel pins		
Top end cap	20% CW 316 SS	
Bottom end cap	20% CW 316 SS	
Cladding tube	20% CW 316 SS	
Wire wrap	17% CW 316 SS	
Reflector	Inconel 600	
Plenum spacer	20% CW 316 SS	
Insulator pellet	Natural UO_2	
Fuel	PuO_2, UO_2	34.4[b]
Top gas driver assembly		
Capsule tube	20% CW 316 SS	
Penetrator	410 SS	
Rupture cup	316 SS (annealed)	
Bottom closure cup	316 SS (annealed)	
Subtotal		41.0
Shield and inlet assembly		
Shield blocks A, B, C	316 SS (annealed)	
Orifice ring	316 SS (annealed)	
Nozzle body	316 SS (annealed)	7.7
Chrome plate	Chrome	
Subtotal		48.8
Fuel support can	316 SS (annealed)	
Pin support bar	316 SS (annealed)	
Locking bar	Inconel 718	0.54
Piston rings	Inconel 718	0.05
Total driver fuel assembly[b]		175.1

[a]Not all component weights are available, so the total driver fuel assembly weight is greater than the sum of the weights listed.

[b]Plutonium + uranium.

Table 4E.3. Control assembly component materials and weights[a]

Component	Material	Approximate weight per assembly (kg)
Absorber pin assembly		49.7
Absorber	Natural B4C	
Clad	316 SS	
Pin assembly wear bands	Inconel 718	0.1
Duct tube	20% CW 316 SS	25.4
Load pad hard surface coating	Chromium carbide	
Handling socket	316 SS	3.7
Support can	316 SS (annealed)	
Pin support bar	316 SS (annealed)	
Locking bar	Inconel 718	0.54
Piston ring	Inconel 718	0.05
Nozzle body	316 SS (annealed)	7.7
Control rod coupling, shaft assembly	Inconel 718	4.9

[a]Total control assembly weights are approximately 136.1 kg for Series 1 and 133.8 kg for Series 2.

Table 4E.4. In-core shim component materials and weights[a]

Component	Material	Approximate weight per assembly (kg)
Duct tube	20% CW 316 SS	25.4
Load pad hard surface coating	Chromium carbide	
Handling socket	316 SS	11.1
Collar	316 SS	
Transition ring	316 SS	
Pin	316 SS	
Ring and collar coatings	Chromium carbide	
Attachment rail	316 SS (annealed or CW, 20% max)	0.3
Solid pins	316 SS	116.6
Shield and inlet assembly		48.8
Shield blocks A, B, C	316 SS (annealed)	
Orifice ring	316 SS (annealed)	
Nozzle body	316 SS (annealed)	
Chrome plate	Chrome	
Support can	316 SS (annealed)	
Pin support bar	316 SS (annealed)	
Locking bar	Inconel 718	0.54
Piston rings	Inconel 718	0.05

[a]Total driver fuel assembly weight is approximately 201.8 kg.

Table 4E.5. Reflector assembly component materials

Component	Material
Reflector plates (12)	Inconel 500
Upper shield region	316 SS
Nozzle	316 SS
Orifice	316 SS
Handling socket	316 SS
Upper adapter block	316 SS
Load pad	316 SS
Row 7 tubular main structural members	316 SS
Row 8a, 8b, and 9 flow tubes and main structural member rods	316 SS

Table 4E.6. Reflector assemblies: major component weights per assembly

Component	Row 7 (kg)	Row 8a (kg)	Rows 8b and 9 (kg)
Reflector plates (12)	79.9	72.1	72.1
Shield plates (5)	73.3	55.2	55.2
Nozzle	7.9	7.9	8.1
Orifice block	47.7	47.7	31.0
Handling socket	12.9	9.4	9.4
Adapters	5.7	11.7	11.7
Load pad	5.9	6.2	6.2
Tubes	40.7	79.8	79.8
Total assembly weight	274.0	289.8	273.4

Table 4E.7. Materials open test assembly: major component materials and weights

Component	Material	Approximate weight per assembly (kg)
Thermocouples	304 SS	
PIOTA stalk	316 SS[a]	453.5
Test train	316 SS	56.7
Duct/nozzle assembly/orifice assembly	316 SS	102.0
Total assembly weight		612.2

[a]Future PIOTA assemblies will be fabricated from 304 SS.

Table 4E.8. Fuels open test assembly: major component materials and weights

Component	Material	Approximate weight per assembly (kg)
Support housing	SS 316	212.7
Bulkhead	SS 316	34.6
Guide tube assembly	SS 316	32.4
Tapered flow plug	SS 316	31.2
Bulkhead extension tube	SS 316	42.9
Flowmeter guide	SS 316	47.5
Flow plug extension	SS 316	11.4
Support tube (lower section)	SS 316	9.0
Flowmeter sleeve assembly	SS 316	2.1
Flowmeter well assembly	SS 316	0.7
Removable instrument assembly	SS 316	30.8
Instrument tubing (T/C, etc.)	SS 316	13.4
Bulkhead cap	SS 316	11.5
FOTA holddown parts	SS 316	25.4
Spoolpiece	SS 316	124.7
Fuel driver assembly	a	172.3
Total assembly weight		905.2

[a]See Table 4E.2.

Table 4E.9. Core demonstration experiment assembly: major component materials and weights

Component	Material	Approximate weights, kg	
		Fuel assembly	Blanket assembly
Shield/inlet nozzle assembly	316 SS	48.4	46.1
Attachment rails	316 SS	0.3	0.4
Duct tube	HT9	26.6	26.6
Handling socket	316 SS	10.4	10.4
Fuel pin hardware	316 SS	12.3	9.1
Fuel pin end caps and cladding	Tube HT9	37.4	28.3
Piston ring	Inconel 718	0.1	0.1
Locking bars	Inconel 718	0.5	0.5
Fuel (CDE fuel assembly)	PuO_2 Depleted UO_2	35.1 9.9	0.0 0.0
Blanket (CDE blanket assembly)	Depleted UO_2	0.4	68.4
Total assembly weight		181.4	189.9

Table 4E.10. Historical and projected discharges from FFTF

Assembly type	Number of assemblies discharged	
	To date[a]	20-year design life
Driver fuel	~300	840
Reflectors	24	120
Control	10	40
Materials open test assemblies	5	20
Fuel open test assemblies	2	8
Core demonstration experiments	18	18
Fuel pin containers	23	92
In-core shim	--	10
Approximate total	382	1,148

[a]As of October 1988.

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