

4. FUEL DESIGN AND PERFORMANCE

- 4.1. Number of fuel pins per subassembly
 4.1.1. Core
 4.1.2. Blanket

Experimental Fast Reactors

Plant	4.1.1.	4.1.2.
Rapsodie (France)	61	7
KNK-II (Germany)	169/211*	121
FBTR (India)	61	7
PEC (Italy)	91	
JOYO (Japan)	127**	**
DFR (UK)	1	1
BOR-60 (Russia)	37	
EBR-II (USA)	91	19
Fermi (USA)	140	25
FFTF (USA)	217	
BR-10 (Russia)	7	
CEFR (China)	61	19

Demonstration or Prototype Fast Reactors

Phénix (France)	217	61
SNR-300 (Germany)	127	61
PFBR (India)	217	61
MONJU (Japan)	169	61
PFR (UK)	325/265/169***	85
CRBRP (USA)	217	61
BN-350 (Kazakhstan)	127	37
BN-600 (Russia)	127	37
ALMR (USA)	271	

Commercial Size Reactors

Super-Phénix 1 (France)	271	91
Super-Phénix 2 (France)	271	127
SNR 2 (Germany)	271	127
DFBR (Japan)	217	127
CDFR (UK)	325	85
BN-1600 (Russia)	331	91
BN-800 (Russia)	127	37
EFR	331	169
ALMR (USA)	271	127

* test zone

** MK II; (91, 19, respectively, in MK-I)

*** dependent on pin diameter (see 4.2.1).

FUEL DESIGN AND PERFORMANCE

<u>4.2.</u>	Core fuel pin dimensions (mm) and fuel density
4.2.1.	Outer diameter
4.2.2.	Thickness of cladding
4.2.3.	Overall length of fuel pin

Experimental Fast Reactors

Plant	4.2.1.	4.2.2.	4.2.3.
Rapsodie (France)	5.1	0.37	320
KNK-II (Germany)	6*/8.2**	0.38	1540
FBTR (India)	5.1	0.37	531.5
PEC (Italy)	6.7	0.45	1935
JOYO (Japan)	5.5***	0.35***	1533***
DFR (UK)	20	2.3	1228
BOR-60 (Russia)	6	0.3	1100
EBR-II (USA)	4.42	0.305	343
Fermi (USA)	4.01	0.127	833
FFTF (USA)	5.84	0.38	2380
BR-10 (Russia)	8.4	0.4	615
CEFR (China)	6.00	0.40	1622

Demonstration or Prototype Fast Reactors

Phénix (France)	6.6	0.45	850
SNR-300 (Germany)	7.6	0.38	2475
PFBR (India)	6.6	0.45	2580
MONJU (Japan)	6.5	0.47	2800
PFR (UK)	5.8/6.6/8.5	0.38	2250
CRBRP (USA)	5.84	0.38	2906
BN-350 (Kazakhstan)	6.9	0.4	2445
BN-600 (Russia)	6.9	0.4	2445
ALMR (USA)	7.44	0.56	3842

Commercial Size Reactors

Super-Phénix 1 (France)	8.5	0.56	2700
Super-Phénix 2 (France)	8.5	0.56	2690
SNR 2 (Germany)	8.5	0.565	2900
DFBR (Japan)	8.5	0.5	3100
CDFR (UK)	6.6	0.52	2500
BN-1600 (Russia)	8.5	0.55	2410
BN-800 (Russia)	6.6	0.4	2000
EFR	8.2	0.52	2645
ALMR (USA)	7.44	0.56	3842

* test zone

** driver

*** MK-II; (6.3, 0.35, 1900, respectively, in MK-I)

FUEL DESIGN AND PERFORMANCE

4.2. Core fuel pin dimensions (mm) and fuel density (% TD)

4.2.4. Intrinsic density of fuel pellet

4.2.5. Smear density of fuel with fuel assumed to occupy whole space inside the cladding tube

Experimental Fast Reactors

Plant	4.2.4.	4.2.5.
Rapsodie (France)	92.0*	88.0*
KNK-II (Germany)	86.5	80.0
FBTR (India)	11.7 (86)	10.7 (78)
PEC (Italy)	95.0	87.6
JOYO (Japan)	94.0	87.0
DFR (UK)	19.0*	18.0*
BOR-60 (Russia)	8.8-9.0*	
EBR-II (USA)	17.7*	75.0
Fermi (USA)	100	100
FFTF (USA)	90.4	85.5
BR-10 (Russia)	12.9*	11.7*
CEFR (China)	90.0	86.6

Demonstration or Prototype Fast Reactors

Phénix (France)	95.0	85.0
SNR-300 (Germany)	86.5	80.0
PFBR (India)	90.0	85.0
MONJU (Japan)	85.0	
PFR (UK)	10.8*	8.6*
CRBRP (USA)	91.3	83.2
BN-350 (Kazakhstan)	10.4*	8.6*
BN-600 (Russia)	10.4*	8.6*
ALMR (USA)	100	75.0

Commercial Size Reactors

Super-Phénix 1 (France)	95.5	82.6
Super-Phénix 2 (France)	95.5	
SNR 2 (Germany)	93.0	87.0
DFBR (Japan)	95.0	83.7
CDFR (UK)	10.8*	8.6*
BN-1600 (Russia)	10.4*	9.0*
BN-800 (Russia)	10.4*	8.6*
EFR	96.0	82.7
ALMR (USA)	100	75.0

* g/cm³

FUEL DESIGN AND PERFORMANCE

4.3. Blanket fuel pin dimensions (mm) and density (% TD) of fertile column

4.3.1. Outer diameter

4.3.2. Thickness of cladding

4.3.3. Length

4.3.4. Intrinsic density of pellets

4.3.5. Smear density, with fuel assumed to occupy whole space inside the cladding tube

Experimental Fast Reactors

Plant	4.3.1.	4.3.2.	4.3.3.	4.3.4.	4.3.5.
Rapsodie (France)	16.5	0.5	1079	10.5*	10.0*
KNK-II (Germany)	9.15	0.5	1363	94	89
FBTR (India)	16.5	0.5	1079	95	90
PEC (Italy)					
JOYO (Japan)	**	**	**		
DFR (UK)	34***	0.9***	2490***		
BOR-60 (Russia)					
EBR-II (USA)	12.5	0.457	1397	17.7*	90
Fermi (USA)	11.3	0.25	1650	100	98
FFTF (USA)					
BR-10 (Russia)					
CEFR (China)	11.1	0.50	1100	95.0	91.3

Demonstration or Prototype Fast Reactors

Phénix (France)	13.4	0.45	1668		
SNR-300 (Germany)	11.6	0.55	2475	95	91
PFBR (India)	14.33	0.6	1960	92	90
MONJU (Japan)	12.0	0.5	2800	93	
PFR (UK)	13.5	1.0	1900	10.7*	10.0*
CRBRP (USA)	12.85	0.38	2959	95.6	93.2
BN-350 (Kazakhstan)	14.0	0.4	1980	93	90
BN-600 (Russia)	14.0	0.4	1980	93	90
ALMR (USA)					

Commercial Size Reactors

Super-Phénix 1 (France)	15.8	0.57	1944	95.5	91.6
Super-Phénix 2 (France)	13.6	0.57	2480		
SNR 2 (Germany)	15.8	0.6	2900	96	90
DFBR (Japan)	11.3	0.4	3100	95	
CDFR (UK)	13.5	0.5	2000	10.8*	9.7*
BN-1600 (Russia)	17.5	0.5	2000	10.6*	10.0*
BN-800 (Russia)	14.0	0.4	1980	10.6*	9.7*
EFR	11.5	0.6	2645	96	89
ALMR (USA)	12.0	0.54	3842	15.7*	85

* g/cm³

** MK II; (15, 0.6, 1900, respectively, in MK-I)

*** nickel reflector pins

FUEL DESIGN AND PERFORMANCE

4.4. Cladding material (type of steel)

4.4.1. Core

4.4.2. Blanket

4.5. Wrapper material

Experimental Fast Reactors

Plant	4.4.1.	4.4.2.	4.5.
Rapsodie (France)	316	316	
KNK-II (Germany)	1.4970	1.4981	
FBTR (India)	316 (CW)	316	316 L (CW)
PEC (Italy)	316 (15%-20% CW)		
JOYO (Japan)	316 (20% CW)	**	316 (20% CW)
DFR (UK)	niobium	18/8/1	
BOR-60 (Russia)	Cr16 Ni15 Mo3 Nb	Cr16 Ni15 Mo3 Nb	
EBR-II (USA)	316	304 L	
Fermi (USA)	Zr	304	
FFTF (USA)	316 (20% CW)		
BR-10 (Russia)	Cr16 Ni15 Mo3 Nb		Cr16 Ni 15 Mo3 Nb
CEFR (China)	316 Ti (20% CW)	316 Ti (20% CW)	316 Ti (20% CW)

Demonstration or Prototype Fast Reactors

Phénix (France)	Cr 17 Ni 13 Mo 2.5 Mn 1.5 Ti Si		
SNR-300 (Germany)	X10 Cr Ni Mo Ti B1515	1.4970	
PFBR (India)	15Cr 15Ni MoTi (CW)	15Cr 15Ni MoTi (CW)	15Cr 15Ti MoTi
MONJU (Japan)	mod 316	mod 316	mod 316
PFR (UK)	*	316	PE16/FV448
CRBRP (USA)	316 (20% CW)	316 (20% CW)	
BN-350 (Kazakhstan)	Cr16 Ni15 Mo2 MnTiSi (CW)	Cr16 Ni15 Mo2 MnTiSi (CW)	Cr13 Mn Nb
BN-600 (Russia)	Cr16 Ni15 Mo2 MnTiSi (CW)	Cr16 Ni15 Mo2 MnTiSi (CW)	Cr13 Mn Nb
ALMR (USA)	HT9		HT9

Commercial Size Reactors

Super-Phénix 1 (France)	Cr 17 Ni 13 Mo 2.5 Mn 1.5 Ti Si		
Super-Phénix 2 (France)			
SNR 2 (Germany)	1.4970	1.4970	
DFBR (Japan)	Advanced austentic	Advanced austenitic	Advanced austenitic
CDFR (UK)	PE16	PE10	
BN-1600 (Russia)	Cr16Ni15Mo2MnTiSi(CW)	Cr16Ni15Mo2MnTiSi(CW)	Cr13MnNb
BN-800 (Russia)	Cr16Ni15Mo2MnTiSi(CW)	Cr16Ni15Mo2MnTiSi(CW)	Cr13MnNb
EFR	AIM1 or PE16	AIM1 or PE16	EM10 or Euralloy
ALMR (USA)	HT 9	HT 9	HT 9

* various materials including Nimonic PE16

** Mk-II (316 (20% CW) in Mk-I)

FUEL DESIGN AND PERFORMANCE

<u>4.6.</u>	Mechanical separation of pins	<u>4.7.</u>	Linear power (kW/m)
4.6.1.	Core fuel	4.7.1.	Maximum, fuel, at start of life
4.6.2.	Blanket fuel	4.7.2.	Maximum, blanket, at end of life
	W - wire wrapped	4.7.3.	Average core
	G - grids		
	F - fins on pin cladding		

Experimental Fast Reactors

Plant	4.6.1.	4.6.2.	4.7.1.	4.7.2.	4.7.3.
Rapsodie (France)	W	W	43		31
KNK-II (Germany)	G	W	45	5	24
FBTR (India)	W	W	35		27
PEC (Italy)	W		36.5	2.1	24.5
JOYO (Japan)	W		40*		22*
DFR (UK)	F	F	370		250
BOR-60 (Russia)	W		44		33
EBR-II (USA)			34.8	4.9	23
Fermi (USA)	G	W	28	14	17
FFTF (USA)	W		41.3		23.4
BR-10 (Russia)	W		44		32
CEFR (China)	W	W	43		26.1

Demonstration or Prototype Fast Reactors

Phénix (France)	W	W	45	41	27
SNR-300 (Germany)	G	W	36	23	23
PFBR (India)	W	W	45	45-50	28
MONJU (Japan)	W	W	36	27	21
PFR (UK)	G	G	48	50	27.0
CRBRP (USA)	W	W	40.3	54.1	26.7
BN-350 (Kazakhstan)	W	W	40	48	24
BN-600 (Russia)	W	W	47	48	28
ALMR (USA)	W		34		22

Commercial Size Reactors

Super-Phénix 1 (France)	W	W	48	48	30
Super-Phénix 2 (France)	W	W	48	48	30
SNR 2 (Germany)	G	W	45		
DFBR (Japan)	W	W	41		25
CDFR (UK)	G	W	43	63	28
BN-1600 (Russia)	W	W	48.7	39.6	30
BN-800 (Russia)	W	W	48	48	31
EFR	W	W	52	41	26
ALMR (USA)	W	W	31	34	19

* MK II; (32, 22, respectively, in MK-I, 75 MWt)

FUEL DESIGN AND PERFORMANCE

4.8. Maximum cladding surface temperature of core fuel pin (°C)

4.9. Fission product (FP) gas volume per pin (cm³)

4.9.1. Core fuel pin

4.9.2. Blanket fuel pin

Experimental Fast Reactors

Plant	4.8.	4.9.1.	4.9.2.
Rapsodie (France)	635**	2.5	2
KNK-II (Germany)	600**	16	16
FBTR (India)	600**	1.9	
PEC (Italy)	700	15.6	
JOYO (Japan)	650*	10*	
DFR (UK)	400	0	0
BOR-60 (Russia)	710	7.3	
EBR-II (USA)	580	2.4	12.8
Fermi (USA)	566	0	
FFTF (USA)	680	19.0	
BR-10 (Russia)	565	4.8	
CEFR (China)	620**	10.0***	7

Demonstration or Prototype Fast Reactors

Phénix (France)	650**	13	12
SNR-300 (Germany)	600**	25	58
PFBR (India)	625**	18.1	27.1
MONJU (Japan)	675****		
PFR (UK)	670	14	34
CRBRP (USA)	732	21.1	133
BN-350 (Kazakhstan)	600	20.6	46
BN-600 (Russia)	695	20.6	46
ALMR (USA)	609	31.6	

Commercial Size Reactors

Super-Phénix 1 (France)	620**	43	40
Super-Phénix 2 (France)	627**		
SNR 2 (Germany)	570**	52	150
DFBR (Japan)	700****		
CDFR (UK)	670		
BN-1600 (Russia)	675	50	
BN-800 (Russia)	693	18	46
EFR	635**	47	100
ALMR (USA)	609	31.6	

* MK-II; (620, 15, 60, respectively, in MK-I)

** Best estimate; without hot-spot factors

*** Not including the gas volume incorporated press spring

**** Midwall

FUEL DESIGN AND PERFORMANCE

- 4.10. Pressure of F.P.-gas in fuel pin (MPa) at operating temperature and maximum burn-up
 4.11. Method of detecting failed pins
 4.11.1. DM-Delayed neutron detection (main primary circuit pipes)
 4.11.2. DB-Delayed neutron detection (bypass pipes)
 4.11.3. DS-Delayed neutron detection (special pipework)
 4.11.4. CGM-Cover gas monitoring system

Experimental Fast Reactors

Plant	4.10.	4.11.1.	4.11.2.	4.11.3.	4.11.4.
Rapsodie (France)	12.8		DB	DS	
KNK-II (Germany)	2.6	DM			CGM
FBTR (India)	6.0	DM			CGM
PEC (Italy)	5.0	DM*	DB		CGM
JOYO (Japan)	7.3	DM			CGM
DFR (UK)			DB		CGM
BOR-60 (Russia)	4.0	DM			CGM
EBR-II (USA)	12.4	DM			CGM
Fermi (USA)	0.0				CGM
FFTF (USA)	4.28				CGM
BR-10 (Russia)	5.0	DM			CGM
CEFR (China)	3.46		DB		CGM

Demonstration or Prototype Fast Reactors

Phénix (France)		DM	DB	DS	CGM
SNR-300 (Germany)	3.1	DM			CGM
PFBR (India)	5.7	DM			CGM
MONJU (Japan)	6.9	DM			CGM
PFR (UK)	5.6		DB	DS	CGM
CRBRP (USA)	4.93	DM			
BN-350 (Kazakhstan)	4.4	DM			CGM
BN-600 (Russia)	5	DM	DB		CGM
ALMR (USA)	6.7				

Commercial Size Reactors

Super-Phénix 1 (France)	4.0			DS	CGM
Super-Phénix 2 (France)				DS**	CGM
SNR 2 (Germany)	5.0				
DFBR (Japan)				DS	CGM
CDFR (UK)			DB	DS	CGM
BN-1600 (Russia)		DM	DB		CGM
BN-800 (Russia)	5.0	DM	DB		CGM
EFR	6.2	DM			
ALMR (USA)	6.7				CGM

* test channel

** - in-vessel instrumentation

FUEL DESIGN AND PERFORMANCE

- 4.12. Methods of locating failed pins
 4.12.1. SSm-Sodium sampling to allow transfer and monitoring of delayed neutron precursors
 4.12.2. GT-Gas tagging with selected isotopes in pin
 4.12.3. DSp-Dry sipping method to induce release of fission products
 4.12.4. WSp-Wet sipping method to induce release of fission products

Experimental Fast Reactors

Plant	4.12.1.	4.12.2.	4.12.3.	4.12.4.
Rapsodie (France)	SSm	GT	DSp	
KNK-II (Germany)	SSm		DSp	WSp
FBTR (India)				
PEC (Italy)	SSm (SSm*)			
JOYO (Japan)				WSp
DFR (UK)		GT**		
BOR-60 (Russia)			DSp	WSp
EBR-II (USA)		GT		
Fermi (USA)				
FFTF (USA)		GT (Kr, Xe)		
BR-10 (Russia)			DSp	
CEFR (China)			DSp	WSp

Demonstration or Prototype Fast Reactors

Phénix (France)	SSm			
SNR-300 (Germany)	SSm			WSp
PFBR (India)	SSm			
MONJU (Japan)		GT		
PFR (UK)	SSm	GT		
CRBRP (USA)		GT	DSp	
BN-600 (Russia)			DSp	
ALMR (USA)	SSm	GT		

Commercial Size Reactors

Super-Phénix 1 (France)	SSm			
Super-Phénix 2 (France)	SSm			
SNR 2 (Germany)				
DFBR (Japan)	SSm		DSp	
CDFR (UK)	SSm			
BN-1600 (Russia)	to be determined			
BN-800 (Russia)	***		DSp	
EFR	SSm			
ALMR (USA)	SSm	GT		

* test channel

** a few experimental pins only

*** locating of section with failed pins