

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES

### 9.1. Shielding objectives (neutron and other limits at different important locations)

#### Experimental Fast Reactors

Plant	Shielding objectives (neutron and other limits at different important locations)			
	Reactor vessel (dpa)	Core support structure (dpa)	Above-core structure (dpa)	Activity of secondary sodium (Bq/kg)
Rapsodie (France)	-	-	-	-
KNK-II (Germany)	-	-	-	-
FBTR (India)	7.17x10 <sup>-9</sup> A/kg in accessible areas	-	-	-
PEC (Italy)	10 <sup>21</sup> nvt (E > 0.1 Mev)	-	-	-
JOYO (Japan)	below 2.10 <sup>-5</sup> Sv (γ and n) in accessible areas	-	-	-
DFR (UK)	-	-	-	-
BOR-60 (Russian Federation)	34 dpa	12x10 <sup>22</sup>	15x10 <sup>22</sup>	< 3.7x10 <sup>4</sup>
EBR-II (USA)	-	-	-	-
Fermi (USA)	-	-	-	-
FFTF (USA)	10% TE*	10% TE*	10% TE*	-
BR-10 (Russian Federation)	34 dpa (7x10 <sup>22</sup> E > 0.1 MeV)	-	-	-
CEFR (China)	0.5	3.4	0.1	7x10 <sup>4</sup>

#### Demonstration or Prototype Fast Reactors

Phenix (France)	-	2.0	0.1	10 <sup>5</sup>
SNR-300 (Germany)	-	-	-	-
PFBR (India)	<10 <sup>-10</sup>	< 0.001	< 0.001	62x10 <sup>3</sup>
MONJU (Japan)	-	-	-	-
PFR (UK)	1.8x10 <sup>-10</sup> A/kg above vessel roof and near secondary sodium pipes	-	-	-
CRBRP (USA)	10% TE*	-	10% TE*	-
BN-350 (Kazakhstan)	1.4x10 <sup>21</sup>	1.6x10 <sup>22</sup>	3x10 <sup>21</sup>	< 3.7x10 <sup>4</sup>
BN-600 (Russian Federation)	1.5x10 <sup>19</sup>	4.5x10 <sup>21</sup>	3.8x10 <sup>21</sup>	1.7x10 <sup>3</sup>
ALMR (USA)	4.1	4.1	4.1	-
KALIMER-150 (Republic of Korea)	to be decided			
SVBR-75/100 (Russian Federation)	10	0.22	0.6	no secondary circuit(s)
BREST-OD-300 (Russian Federation)	2.7x10 <sup>20</sup>	3.4x10 <sup>23</sup>	5x10 <sup>22</sup>	no secondary circuit(s)

\* total elongation

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.1. Shielding objectives (neutron and other limits at different important locations)

#### Commercial Size Reactors

Plant	Shielding objectives (neutron and other limits at different important locations)			
	Reactor vessel (dpa)	Core support structure (dpa)	Above-core structure (dpa)	Activity of secondary sodium (Bq/kg)
Super-Phenix 1 (France)	< 0.005	< 1.5		$2 \times 10^4$
Super-Phenix 2 (France)	not determined			
SNR 2 (Germany)	not determined			
DFBR (Japan)	-	-	-	$7.4 \times 10^{4**}$
CDFR (UK)	1/20 IAEA recommended limit			
BN-1600 (Russian Federation)	$1.9 \times 10^{17}$	$7.1 \times 10^{22}$	$6.9 \times 10^{22}$	$1.4 \times 10^4$
BN-800 (Russian Federation)	$4.5 \times 10^{17}$	$1.7 \times 10^{22}$ (6.7dpa)	$4.2 \times 10^{22}$ (16dpa)	$4.4 \times 10^4$
EFR	-	1	$1.9 \times 10^9$ n/cm <sup>2</sup> /s	$3 \times 10^4$
ALMR (USA)	not determined			
SVBR-75/100 (Russian Federation)	10	0.22	0.6	no secondary circuit(s)
BN-1800 (Russian Federation)	$1.2 \times 10^{11}$	$8 \times 10^{21}$	-	0.02
BREST-1200 (Russian Federation)	not determined			
JSFR-1500 (Japan)	to be determined	$5 \times 10^{21}$ n/cm <sup>2</sup>	$1 \times 10^{21}$ n/cm <sup>2</sup>	$7.4 \times 10^{4*}$

\*\* dose rate below 6  $\mu$ Sv/h ( $\gamma = n$ ) in accessible areas

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.2. Shielding materials

#### Experimental Fast Reactors

Plant	Shielding materials	
	Radial shield within primary vessel	Radial (biological) shield outside primary vessel
Rapsodie (France)	stainless steel	concrete
KNK-II (Germany)	gray iron	high density concrete
FBTR (India)	stainless steel	concrete
PEC (Italy)	nikel reflector elements and B <sub>4</sub> C shield elements	high density concrete
JOYO (Japan)	stainless steel	graphite, concrete
DFR (UK)	steel and borated graphite, top plugs only borated graphite	concrete
BOR-60 (Russian Federation)	stainless steel	cast iron and high density concrete
EBR-II (USA)	graphite and borated graphite	borated graphite and reinforced concrete
Fermi (USA)	stainless steel	reinforced concrete
FFTF (USA)	stainless steel	high density concrete and B <sub>4</sub> C
BR-10 (Russian Federation)	-	cast iron, water concrete
CEFR (China)	SS + B <sub>4</sub> C covered by SS	reinforced concrete

#### Demonstration or Prototype Fast Reactors

Phénix (France)	graphite and stainless steel	concrete
SNR-300 (Germany)	stainless steel	serpentine concrete
PFBR (India)	SS & B <sub>4</sub> C	concrete
MONJU (Japan)	stainless steel	concrete and steel
PFR (UK)	graphite in steel	concrete and steel
CRBRP (USA)	SA-316	concrete
BN-350 (Kazakhstan)	stainless steel	concrete and steel
BN-600 (Russian Federation)	graphite and stainless steel	concrete
ALMR (USA)	304 + B <sub>4</sub> C	concrete
KALIMER-150 (Republic of Korea)	304 + B <sub>4</sub> C covered by SS	concrete
SVBR-75/100 (Russian Federation)	SS+ B <sub>4</sub> C +Pb-Bi	H <sub>2</sub> O+steel+ concrete
BREST-OD-300 (Russian Federation)	SS	high density concrete

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.2. Shielding materials

#### Commercial Size Reactors

Plant	Shielding materials	
	Radial shield within primary vessel	Radial (biological) shield outside primary vessel
Super-Phénix 1 (France)	stainless steel	concrete
Super-Phénix 2 (France)	SS + boron	concrete
SNR 2 (Germany)	steel	concrete and steel
DFBR (Japan)	SS + B <sub>4</sub> C	concrete and steel
CDFR (UK)	steel	concrete and steel
BN-1600 (Russian Federation)	stainless steel	concrete
BN-800 (Russian Federation)	SS+graphite and borated graphite	concrete
EFR	SS + B <sub>4</sub> C pins and blocks	concrete
ALMR (USA)	304 + B <sub>4</sub> C covered by SS	concrete
SVBR-75/100 (Russian Federation)	SS+ B <sub>4</sub> C +Pb-Bi	H <sub>2</sub> O+steel+ concrete
BN-1800 (Russian Federation)	SS+graphite and borated graphite	concrete
BREST-1200 (Russian Federation)	SS	high density concrete
JSFR-1500 (Japan)	SS + Zr-H	steel and concrete

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.2. Shielding materials

#### Experimental Fast Reactors

Plant	Shielding materials	
	Axial shield inside primary vessel	Axial shield in or above the reactor roof
Rapsodie (France)	-	-
KNK-II (Germany)	-	-
FBTR (India)	-	-
PEC (Italy)	-	-
JOYO (Japan)	-	-
DFR (UK)	-	-
BOR-60 (Russian Federation)	SS	SS, CS, graphite
EBR-II (USA)	-	-
Fermi (USA)	-	-
FFTF (USA)	-	-
BR-10 (Russian Federation)	SS, B <sub>4</sub> C	parafin, B <sub>4</sub> C, SS
CEFR (China)	SS	SS + reinforced concrete

#### Demonstration or Prototype Fast Reactors

Phénix (France)	SS, B <sub>4</sub> C	concrete and steel (CS)
SNR-300 (Germany)	-	-
PFBR (India)	SS, B <sub>4</sub> C, graphite	heavy density concrete
MONJU (Japan)	SS	CS
PFR (UK)	-	-
CRBRP (USA)	-	-
BN-350 (Kazakhstan)	SS	SS, CS, graphite
BN-600 (Russian Federation)	SS	SS, CS, graphite
ALMR (USA)	steel	steel
KALIMER-150 (Republic of Korea)	SS	not determined
SVBR-75/100 (Russian Federation)	SS+ B <sub>4</sub> C +Pb-Bi	B <sub>4</sub> C +steel
BREST-OD-300 (Russian Federation)	SS, Pb	concrete, CS

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.2. Shielding materials

#### Commercial Size Reactors

Plant	Shielding materials	
	Axial shield inside primary vessel	Axial shield in or above the reactor roof
Super-Phénix 1 (France)	SS + B <sub>4</sub> C pins	CS
Super-Phénix 2 (France)	not determined	-
SNR 2 (Germany)	not determined	-
DFBR (Japan)	B <sub>4</sub> C	heavy concrete and steel
CDFR (UK)	not determined	-
BN-1600 (Russian Federation)	SS	SS, CS, graphite
BN-800 (Russian Federation)	SS	SS, CS, graphite
EFR	SS + B <sub>4</sub> C pins	850 mm solid steel roof
ALMR (USA)	not determined	-
SVBR-75/100 (Russian Federation)	SS+ B <sub>4</sub> C +Pb-Bi	B <sub>4</sub> C, steel
BN-1800 (Russian Federation)	SS	SS, CS, graphite
BREST-1200 (Russian Federation)	SS, Pb	concrete, CS
JSFR-1500 (Japan)	SS + B <sub>4</sub> C	steel and concrete

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.3. Containment

#### Experimental Fast Reactors

Plant	Containment		
	Geometry of secondary containment building	Material	Vented (V) or not vented (NV) to atmosphere through filters
Rapsodie (France)	cylindrical with dome	steel	-
KNK-II (Germany)	cylindrical with dome	steel	-
FBTR (India)	cylindrical with dome	concrete	-
PEC (Italy)	cylindrical with dome	carbon steel	-
JOYO (Japan)	cylindrical with dome	carbon steel	-
DFR (UK)	sphere	steel	NV
BOR-60 (Russian Federation)	rectangular building	concrete	-
EBR-II (USA)	cylindrical with dome	carbon steel	-
Fermi (USA)	cylindrical with dome	carbon steel	-
FFTF (USA)	cylindrical with dome	carbon steel	-
BR-10 (Russian Federation)	rectangular building	concrete	-
CEFR (China)	square with dome	concrete & steel	V

#### Demonstration or Prototype Fast Reactors

Phénix (France)	rectangular	concrete	NV
SNR-300 (Germany)	rectangular	-	steel and concrete
PFBR (India)	rectangular	reinforced concrete	NV
MONJU (Japan)	cylindrical with dome	carbon steel	NV
PFR (UK)	rectangular	concrete and steel	NV
CRBRP (USA)	cylindrical with dome	carbon steel	-
BN-350 (Kazakhstan)	ordinary rectangular bldg.	concrete	NV
BN-600 (Russian Federation)	ordinary rectangular bldg	concrete	NV
ALMR (USA)	cylindrical with dome	arbon steel	NV
KALIMER-150 (Republic of Korea)	cylindrical with dome	2.25Cr 1 Mo	NV
SVBR-75/100 (Russian Federation)	cylindrical with dome	concrete	V
BREST-OD-300 (Russian Federation)	rectangular building	concrete, CS	V

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.3. Containment

#### Commercial Size Reactors

Plant	Containment		
	Geometry of secondary Containment building	Material	Vented (V) or not vented (NV) to atmosphere through filters
Super-Phénix 1 (France)	cylindrical with dome	concrete	NV
Super-Phénix 2 (France)	rectangular bldg	concrete	-
SNR 2 (Germany)	cylindrical	concrete	-
DFBR (Japan)	rectangular building	steel and concrete	NV
CDFR (UK)	cylindrical with dome	steel and concrete	-
BN-1600 (Russian Federation)	cylindrical building	concrete	-
BN-800 (Russian Federation)	rectangular building	concrete	NV
EFR	cylindrical building	reinforced concrete	V
ALMR (USA)	cylindrical with dome	carbon steel	NV
SVBR-75/100 (Russian Federation)	cylindrical with dome	concrete	V
BN-1800 (Russian Federation)	rectangular building	concrete	NV
BREST-1200 (Russian Federation)	rectangular building	concrete, CS	V
JSFR-1500 (Japan)	rectangular	concrete and steel	V

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURE (cont.)

### 9.3. Containment

#### Experimental Fast Reactors

Plant	Containment	
	Gross volume (m <sup>3</sup> )	Maximum design pressure (MPa)
Rapsodie (France)	15000	0.235
KNK-II (Germany)	5000	0.25
FBTR (India)	15000	0.025
PEC (Italy)	18000	0.15
JOYO (Japan)	18600	0.15
DFR (UK)	11500	0.125
BOR-60 (Russian Federation)	-	-
EBR-II (USA)	14000	0.166
Fermi (USA)	7900	0.32
FFTF (USA)	64100	0.067
BR-10 (Russian Federation)	-	-
CEFR (China)	17000	0.1

#### Demonstration or Prototype Fast Reactors

Phénix (France)	31000	0.040
SNR-300 (Germany)	323000	0.024
PFBR (India)	87000	0.25
MONJU (Japan)	130000	0.03
PFR (UK)	74000	0.005
CRBRP (USA)	170000	0.170
BN-350 (Kazakhstan)	-	-
BN-600 (Russian Federation)	-	-
ALMR (USA)	112	0.172
KALIMER-150 (Republic of Korea)	1036	0.254
SVBR-75/100 (Russian Federation)	2000	0.03
BREST-OD-300 (Russian Federation)	-	-

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURE (cont.)

### 9.3. Containment

#### Commercial Size Reactors

Plant	Containment	
	Gross volume (m <sup>3</sup> )	Maximum design pressure (MPa)
Super-Phénix 1 (France)	dome - 6500 containment - 170000	dome -0.3 containment - 0.004
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	180000	*
DFBR (Japan)	27000	0.05
CDFR (UK)	40200	0.1
BN-1600 (Russian Federation)	not defined	
BN-800 (Russian Federation)	-	-
EFR	136000	0.05
ALMR (USA)	-	-
SVBR-75/100 (Russian Federation)	80000	0.03
BN-1800 (Russian Federation)	to be defined	
BREST-1200 (Russian Federation)	to be defined	
JSFR-1500 (Japan)	20000	0.18

\* structures are determined by large airplane crash considerations

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.3. Containment

#### Experimental Fast Reactors

Plant	Containment	
	Seismic acceleration (designed) (g)	
	Horizontal	Vertical
Rapsodie (France)	0.10-0.20	0.20-0.50
KNK-II (Germany)	-	-
FBTR (India)	0.1	0.05
PEC (Italy)	0.30	0.10
JOYO (Japan)	0.15	0.075
DFR (UK)	-	-
BOR-60 (Russian Federation)	0.1	0.07
EBR-II (USA)	containment designed in accordance with Uniform Building Code, in its contemporary version	
Fermi (USA)	0.1	-
FFTF (USA)	0.250	0.166
BR-10 (Russian Federation)	0.1	0.07
CEFR (China)	0.107	0.071

#### Demonstration or Prototype Fast Reactors

Phénix (France)	0.15-0.30	0.30-0.60
SNR-300 (Germany)	0.044	0.005
PFBR (India)	0.078 OBE (PGA) 0.156 SSE (PGA)	0.052 OBE (PGA) 0.104 SSE (PGA)
MONJU (Japan)	-	-
PFR (UK)	-	-
CRBRP (USA)	0.125	0.125
BN-350 (Kazakhstan)	-	-
BN-600 (Russian Federation)	0.1	0.07
ALMR (USA)	0.3-0.5	0.3-0.5
KALIMER-150 (Republic of Korea)	0.3	0.2
SVBR-75/100 (Russian Federation)	0.24-0.38	1.0
BREST-OD-300 (Russian Federation)	0.1	0.07

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.3. Containment

#### Commercial Size Reactors

Plant	Containment	
	Seismic acceleration (designed) (g)	
	Horizontal	Vertical
Super-Phénix 1 (France)	0.1-0.2	0.07-0.14
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	-	-
CDFR (UK)	0.25	0.17
BN-1600 (Russian Federation)	-	-
BN-800 (Russian Federation)	0.1	0.07
EFR	0.25/0.2*	0.17/0.13*
SVBR-75/100 (Russian Federation)	0.24-0.38	1.0
BN-1800 (Russian Federation)	0.1	0.07
BREST-1200 (Russian Federation)	0.1	0.07
JSFR-1500 (Japan)	-	equivalent M7.1

\* using UK/USNRC soil response spectr

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.4. Additional safety features

#### Experimental Fast Reactors

Plant	Additional safety features
Rapsodie (France)	DW, TGV
KNK-II (Germany)	EP
FBTR (India)	DW
PEC (Italy)	EP, DW
JOYO (Japan)	DW, CI
DFR (UK)	DW
BOR-60 (Russian Federation)	TPGV*
EBR-II (USA)	blast shield, isolation system with containment building
Fermi (USA)	DW, CI, TGV, EC, meltdown pan
FFTF (USA)	EP, EC
BR-10 (Russian Federation)	TPGV
CEFR (China)	CI, TGV, EC, NP, PC

#### Demonstration or Prototype Fast Reactors

Phénix (France)	TGV
SNR-300 (Germany)	TGV, EC, NP, CI, PC
PFBR (India)	CI, TGV, EC, NP, PC
MONJU (Japan)	EP, CI, TEV, EC
PFR (UK)	NP, leak jacket which would contain sodium above core level
CRBRP (USA)	EP, CI, TGV
BN-350 (Kazakhstan)	TPGV
BN-600 (Russian Federation)	TGV, NP
ALMR (USA)	DW, CI, TGV, EC, NP, PC
KALIMER-150 (Republic of Korea)	TGV, EC, NP, PC
SVBR-75/100 (Russian Federation)	TGV, EC, NP
BREST-OD-300 (Russian Federation)	DW, TGV

\* on parts of the primary loops to limit effect of pipe rupture

- EP - elevated piping guard vessel to limit effect of pipe rupture
- DW - double walls of primary loops
- CI - containment isolation on increased radiation
- TGV - reactor tank guard vessel
- TPGV - tank and piping guard vessels
- EC - elevations of the core, IHX dump HX to ensure natural convection cooling
- NP - no penetrations below sodium level
- PC - provision for collecting and cooling core debris following core meltdown or partial meltdown

## 9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

### 9.4. Additional safety features

#### Commercial Size Reactors

Plant	Additional safety features
Super-Phénix 1 (France)	CI, TGV, PC
Super-Phénix 2 (France)	CI, TGV
SNR 2 (Germany)	CI, TGV, EC, NP
DFBR (Japan)	EP, DW, CI, TGV, NP
CDFR (UK)	TGV
BN-1600 (Russian Federation)	TGV, NP
BN-800 (Russian Federation)	TGV, NP, PC
EFR	CI, TGV, EC, NP, PC
ALMR (USA)	to be defined
SVBR-75/100 (Russian Federation)	TGV, EC, NP
BN-1800 (Russian Federation)	to be defined
BREST-1200 (Russian Federation)	DW, TGV
JSFR-1500 (Japan)	DW, CI, TGV, TPGV, EC, NP, PC

- EP - elevated piping guard vessel to limit effect of pipe rupture
- DW - double walls of primary loops
- CI - containment isolation on increased radiation
- TGV - reactor tank guard vessel
- TPGV - tank and piping guard vessels
- EC - elevations of the core, IHX dump HX to ensure natural convection cooling
- NP - no penetrations below sodium level
- PC - provision for collecting and cooling core debris following core meltdown or partial meltdown