

10. PROTECTION AND CONTROL

10.1. Main criteria for initiating automatic shutdown

Experimental Fast Reactors

Plant	Main criteria for initiating automatic shutdown
Rapsodie (France)	HF, FiL, HT, HRF, LCL, LEP, LPF, DND, EQ, TT, HIT
KNK-II (Germany)	HF, HRT, HT, LF, HRF
FBTR (India)	HF, FiL, HT, HRF, LNF, LEP, LSF, DND
PEC (Italy)	HF, LEP, HRF, HT, LPF, LSF, DND
JOYO (Japan)	HF, LPF, LCL, etc.
DFR (UK)	HF, HT, HRF, LEP, LPF
BOR-60 (Russian Federation)	HF, HT, HRF, LCL, LEP, LPF, LSF
EBR-II (USA)	HF, HT, EQ, LPF
Fermi (USA)	HF, LSF, HT, LPF, leakage in SG
FFTF (USA)	HF, HT, LPF, LSF, CFI
BR-10 (Russian Federation)	HF, FiL, HT, HRF, LCL, LEP, LSF
CEFR (China)	HF, HT, HRF, LCL, LEP, LPF, DND, EQ, HIT

HT	- High primary coolant outlet temperatures	HF	- High neutron flux (linear)
HRF	- High rate of flux change (reactivity)	FiL	- Failure of i loops
HRT	- High rate of coolant temperature change	LNF	- Low neutron flux indication
LPF	- Low ratio of primary coolant flow to core flux	LCL	- Low coolant level in reactor vessel
HPF	- High ratio of primary coolant flow to core flux	LEP	- Loss of electrical power
CFI	- Primary-to-secondary coolant flow imbalance	LSF	- Low secondary coolant flow
HIT	- High primary coolant inlet temperature	HRF1	- High rate-of-change of flow rate
HPSS	- High pressure in secondary coolant system	ABNS	- Acoustic boiling noise signal
HCE	- High coolant level in pipe enclosure	DND	- Delayed neutron detection signal
HCP	- High coolant level in primary pump tank	EQ	- Earthquake,
CI	- Containment isolation demand	HR	- High radiation in containment,
TT	- Turbine trip,	LCL	- Low coolant level in IHX
HD	- Hydrogen detection		

10. PROTECTION AND CONTROL (cont.)

10.1. Main criteria for initiating automatic shutdown

Demonstration or Prototype Fast Reactors

Plant	Main criteria for initiating automatic shutdown
Phénix (France)	HF,HRF,LEP,DND,EQ,HRT, in SG
SNR-300 (Germany)	HF,HRT,HT,HRF,LPF,LSF,CFI,DND,EQ,LCL
PFBR (India)	HF,HT,HRF,LNF,LPF,DND,HIT
MONJU (Japan)	HF,HRF,LCL,HT,LEP,LPF,LSF,DND,EQ
PFR (UK)	HF,HT,HRF,LNF,LCL,LEP,LPF,HRF1,DND
CRBRP (USA)	HF,HT,CFI,LPF,LCL
BN-350 (Kazakhstan)	HF,HT,HRF,LCL,LEP,LPF,F2L,DND
BN-600 (Russian Federation)	HF,HT,HRF,LCL,LEP,LPF,F2L,DND, EQ
ALMR (USA)	HF,DPF,LCL,HPSS,HIT*,HT*,HR*
KALIMER-150 (Republic of Korea)	HF,HRF,HT,LCL,LEP,HIT,HPSS
SVBR-75/100 (Russian Federation)	HF,FiL,HT,HRF,LEP,EQ,TT
BREST-OD-300 (Russian Federation)	HF,HT,LPF,LCL,LEF,EQ,HIT,HRF

Commercial Size Reactors

Super-Phénix 1 (France)	HF,LPF,HT,HRF,LEP,EQ,HD,DND,HIT,HR
Super-Phénix 2 (France)	LPF,HF,HT,HRF,LEP,EQ,HD,DND
SNR 2 (Germany)	HF,HT,LPF,DND
DFBR (Japan)	HF,HT,HRF,LCL,LEP,LPF,DND,EQ,LCL,LSF,
CDFR (UK)	HF,HT,HRT,LCL,LEP,HRF1,ABNS,DND,LPF
BN-1600 (Russian Federation)	HF,HT,HRF,LPF,F2L,EQ
BN-800 (Russian Federation)	HF,HT,HRF,LCL,LEP,LPF,EQ,F2L,DND
EFR	HF,HT,LPF,LSF,CFI,DND,EQ,HRF,ABNS,LEP
BN-1800 (Russian Federation)	HF,HT,HRF,LCL,LEP,LPF,EQ,F2L,DND
BREST-1200 (Russian Federation)	HF,HT,LPF,LCL,LEF,EQ,HIT,HRF
JSFR-1500 (Japan)	HF,HT,HRF,LCL,LEP,LPF,DND,EQ,HPSS,TT,HD

* used by protection system only if control system directed runback fails

HT - High primary coolant outlet temperatures	HF - High neutron flux (linear)
HRF - High rate of flux change (reactivity)	FiL - Failure of i loops
HRT - High rate of coolant temperature change	LNF - Low neutron flux indication
LPF - Low ratio of primary coolant flow to core flux	LCL - Low coolant level in reactor vessel
HPF - High ratio of primary coolant flow to core flux	LEP - Loss of electrical power
CFI - Primary-to-secondary coolant flow imbalance	LSF - Low secondary coolant flow
HIT - High primary coolant inlet temperature	HRF1 - High rate-of-change of flow rate
HPSS - High pressure in secondary coolant system	ABNS - Acoustic boiling noise signal
HCE - High coolant level in pipe enclosure	DND - Delayed neutron detection signal
HCP - High coolant level in primary pump tank	EQ - Earthquake,
CI - Containment isolation demand	HR - High radiation in containment,
TT - Turbine trip,	LCL - Low coolant level in IHX
HD - Hydrogen detection	

10. PROTECTION AND CONTROL (cont.)

10.2. Principal shutdown systems

Experimental Fast Reactors

Plant	Principal shutdown systems
Rapsodie (France)	6 control rods (CR)
KNK-II (Germany)	2 CR
FBTR (India)	6 CR*
PEC (Italy)	11 CR* comprising 2 CIRS**
JOYO (Japan)	safety CR
DFR (UK)	12 bottom-entry fuel rods and 3 top entry boron shut-off rods
BOR-60 (Russian Federation)	safety and regulating control rods
EBR-II (USA)	drive-out of CR containing fuel
Fermi (USA)	safety rods
FFTF (USA)	3 primary and 6 secondary CR* comprising 2 CIRS**
BR-10 (Russian Federation)	bottom-entry Ni-reflector
CEFR (China)	5 CR (primary) and 23 safety rods (secondary)

Demonstration or Prototype Fast Reactors

Phenix (France)	6 CR
SNR-300 (Germany)	2 redundant diverse systems
PFBR (India)	12 CR* comprising 2 CIRS**
MONJU (Japan)	main CR and back up CR
PFR (UK)	5 control and 5 shut-off rods held by 2 guard lines
CRBRP (USA)	two independent and diverse systems; primary system has 9 rods; secondary system has 6 rods
BN-350 (Kazakhstan)	safety and regulating CR
BN-600 (Russian Federation)	safety and regulating CR
ALMR (USA)	9 CR with diverse shutdown systems
KALIMER-150 (Republic of Korea)	6 CR with diverse shutdown systems
SVBR-75/100 (Russian Federation)	safety and regulating CR
BREST-OD-300 (Russian Federation)	2 CIRS

* CR - control rods

** CIRS - completely independent reactor shut-down systems

10. PROTECTION AND CONTROL (cont.)

10.2. Principal shutdown systems

Commercial Size Reactors

Plant	Principal shutdown systems
Super-Phenix 1 (France)	2 redundant systems
Super-Phenix 2 (France)	2 redundant systems
SNR 2 (Germany)	2 redundant diverse systems
DFBR (Japan)	2 redundant diverse systems
CDFR (UK)	18 regulating rods and 6 shut-off rods and 6 alternative shut-down rods held by 2 guard-lines
BN-1600 (Russian Federation)	safety and regulating CR
BN-800 (Russian Federation)	safety and regulating CR
EFR	2 redundant diverse systems
ALMR (USA)	9 control rods with diverse shutdown systems
SVBR-75/100 (Russian Federation)	safety and regulating CR
BN-1800 (Russian Federation)	to be defined
BREST-1200 (Russian Federation)	2 CIRS
JSFR-1500 (Japan)	2 redundant diverse systems

* CR - control rods

** CIRS - completely independent reactor shut-down systems

10. PROTECTION AND CONTROL (cont.)

10.3. Reactor power control

Experimental Fast Reactors

Plant	Reactor power control
Rapsodie (France)	manual
KNK-II (Germany)	load following
FBTR (India)	manual
PEC (Italy)	manual
JOYO (Japan)	manual
DFR (UK)	steady operation at full power
BOR-60 (Russian Federation)	automatic and manual
EBR-II (USA)	manual or automatic*
Fermi (USA)	automatic
FFTF (USA)	manual
BR-10 (Russian Federation)	automatic and manual
CEFR (China)	manual or automatic

Demonstration or Prototype Fast Reactors

Phénix (France)	primarily manual
SNR-300 (Germany)	grid following/automatic or manual
PFBR (India)	manual
MONJU (Japan)	power control on outlet temperature or manual
PFR (UK)	manual or power control on outlet temperature
CRBRP (USA)	automatic; load following
BN-350 (Kazakhstan)	automatic power control
BN-600 (Russian Federation)	automatic power control on outlet Na and steam temperature
ALMR (USA)	grid following/automatic or manual
KALIMER-150 (Republic of Korea)	manual/automatic
SVBR-75/100 (Russian Federation)	manual and automatic
BREST-OD-300 (Russian Federation)	automatic and manual

* also in transient as well as steady-state mode of operation

10. PROTECTION AND CONTROL (cont.)

10.3. Reactor power control

Commercial Size Reactors

Plant	Reactor power control
Super-Phénix 1 (France)	base load operation
Super-Phénix 2 (France)	grid following
SNR 2 (Germany)	grid following, automatic
DFBR (Japan)	base load operation
CDFR (UK)	grid following
BN-1600 (Russian Federation)	automatic power control on outlet Na and steam T
BN-800 (Russian Federation)	automatic power control on outlet Na and steam T
EFR	grid following, automatic
ALMR (USA)	grid following/automatic or manual
SVBR-75/100 (Russian Federation)	manual and automatic
BN-1800 (Russian Federation)	automatic power control on outlet Na and steam T
BREST-1200 (Russian Federation)	automatic and manual
JSFR-1500 (Japan)	automatic

10. PROTECTION AND CONTROL (cont.)

10.3. Reactor power control

Experimental Fast Reactors

Plant	Reactor power control
Rapsodie (France)	manual
KNK-II (Germany)	constant coolant ΔT
FBTR (India)	constant primary flow and coolant inlet temperature
PEC (Italy)	manual
JOYO (Japan)	constant coolant inlet temperature and flow rate
DFR (UK)	steady operation at full flow required to maintain specified ΔP through core
BOR-60 (Russian Federation)	manual
Fermi (USA)	constant flow rate
FFTF (USA)	manual
BR-10 (Russian Federation)	constant coolant, ΔT
CEFR (China)	constant coolant ΔT

Demonstration or Prototype Fast Reactors

Phénix (France)	control coolant ΔT of each subassembly
SNR-300 (Germany)	constant coolant ΔT
PFBR (India)	period, reactivity and reactor power
MONJU (Japan)	programme control (proportional to the reactor power) for nominally constant coolant ΔT or manual
PFR (UK)	manual or constant steam pressure
CRBRP (USA)	automatic; load following
BN-350 (Kazakhstan)	constant flow rate
BN-600 (Russian Federation)	constant coolant ΔT
ALMR (USA)	core outlet temperature with flux trim
KALIMER-150 (Republic of Korea)	to be defined
SVBR-75/100 (Russian Federation)	level of coolant in separator, power level
BREST-OD-300 (Russian Federation)	coolant outlet temperature of each subassembly in inner core, coolant level, coolant inlet temperature

10. PROTECTION AND CONTROL (cont.)

10.3. Reactor power control

Commercial Size Reactors

Plant	Reactor power control
Super-Phénix 1 (France)	core coolant outlet temperature
Super-Phénix 2 (France)	control ΔT of each instrumented subassembly
SNR 2 (Germany)	core coolant outlet T control, variable flow, constant coolant ΔT
DFBR (Japan)	outlet T control, variable flow, variable coolant ΔT following pre-set power
CDFR (UK)	automatic control, following pre set power and core core coolant outlet temperature
BN-1600 (Russian Federation)	constant coolant ΔT
BN-800 (Russian Federation)	constant coolant ΔT
EFR	constant reactor coolant inlet temperature
ALMR (USA)	core outlet temperature with flux trim
SVBR-75/100(Russian Federation)	level of coolant in separator, power level
BN-1800 (Russian Federation)	constant coolant ΔT
BREST-1200 (Russian Federation)	coolant outlet temperature of each subassembly in inner core, coolant level, coolant inlet temperature
JSFR-1500 (Japan)	constant coolant inlet ,outlet temperature and flow rate

10. PROTECTION AND CONTROL (cont.)

10.3. Reactor power control

Experimental Fast Reactors

	Reactor power control
Plant	Plant response designed to cope with seizure or stopping of a primary pump
Rapsodie (France)	automatic scram by low flow
KNK-II (Germany)	automatic scram
FBTR (India)	automatic scram
PEC (Italy)	automatic scram and all pumps operate with pony motors
JOYO (Japan)	automatic scram by auxiliary relay of motor power supply or pump outlet flow
DFR (UK)	diesel generator electric supply to primary EM pony
BOR-60 (Russian Federation)	automatic scram
EBR-II (USA)	auxiliary EM pump with battery power supply
Fermi (USA)	power set back to 67%, secondary pump in same loop stopped
FFTF (USA)	automatic scram and all pumps operate with pony motors
BR-10 (Russian Federation)	automatic scram, pumps with battery power supply
CEFR (China)	automatic scram and all pumps operate with pony motors

Demonstration or Prototype Fast Reactors

Phénix (France)	automatic scram
SNR-300 (Germany)	automatic scram, pony motors operate pumps for decay heat removal
PFBR (India)	automatic scram
MONJU (Japan)	automatic scram by pump outlet flow or turning speed
PFR (UK)	automatic engagement of battery backed pony motors on primary pumps (10% flow) and automatic scram
CRBRP (USA)	automatic scram; pony motors operate available pumps; steam drum is vented to air-cooled condenser
BN-350 (Kazakhstan)	automatic scram
BN-600 (Russian Federation)	automatic scram
ALMR (USA)	automatic scram, pony motors operate available pumps, DHR system available
KALIMER-150 (Republic of Korea)	automatic scram, pony pumps are activated
SVBR-75/100 (Russian Federation)	automatic scram
BREST-OD-300 (Russian Federation)	automatic scram

10. PROTECTION AND CONTROL (cont.)

10.3. Reactor power control

Commercial Size Reactors

	Reactor power control
Plant	Plant response designed to cope with seizure or stopping of a primary pump
Super-Phénix 1 (France)	automatic scram
Super-Phénix 2 (France)	power reduction and shutdown
SNR 2 (Germany)	automatic scram
DFBR (Japan)	automatic scram with pony motor pump operation
CDFR (UK)	automatic engagement of battery- backed pony motors on primary pumps (10% flow)
BN-1600 (Russian Federation)	automatic scram
BN-800 (Russian Federation)	automatic scram
EFR	automatic scram
ALMR (USA)	automatic scram, pony motors operate available pumps, DHR system available
SVBR-75/100 (Russian Federation)	automatic scram
BN-1800 (Russian Federation)	automatic scram
BREST-1200 (Russian Federation)	automatic scram
JSFR-1500 (Japan)	automatic scram and natural circulation DHR

10. PROTECTION AND CONTROL (cont.)

10.4. Method of detection of coolant leaks

Experimental Fast Reactors

Method of detection of coolant leaks	
Plant	Type of detector
Rapsodie (France)	conductivity and aerosol detectors
KNK-II (Germany)	electrical contact
FBTR (India)	conductivity and aerosol detectors
PEC (Italy)	continuity and aerosol detector
JOYO (Japan)	direct contact type (and aerosol type)
DFR (UK)	conductivity detectors
BOR-60 (Russian Federation)	electrical contact
EBR-II (USA)	electrical contact
Fermi (USA)	H ₂ detectors, sodium level indicators
FFTF (USA)	electrical contact and aerosol detector
BR-10 (Russian Federation)	electrical contact and aerosol detectors
CEFR (China)	electrical contact, smoke and aerosol detectors

Demonstration or Prototype Fast Reactors

Phénix (France)	electrical contact, aerosol detectors
SNR-300 (Germany)	electrical contact, radiation and sodium fire detectors
PFBR (India)	electrical contact and aerosol detectors
MONJU (Japan)	gas sampling type and contact type
PFR (UK)	electrical contact and sodium fire detectors
CRBRP (USA)	radiation, aerosol detectors and electrical contact
BN-350 (Kazakhstan)	electrical contact, radiation, aerosol detectors
BN-600 (Russian Federation)	electrical contact, radiation, aerosol detectors
ALMR (USA)	electrical contact and aerosol detectors
KALIMER-150 (Republic of Korea)	electrical contact and aerosol detectors
SVBR-75/100 (Russian Federation)	to be defined
BREST-OD-300 (Russian Federation)	control coolant level and concrete temperature

10. PROTECTION AND CONTROL (cont.)

10.4. Method of detection of coolant leaks

Commercial Size Reactors

	Method of detection of coolant leaks
Plant	Type of detector
Super-Phénix 1 (France)	electrical contact, aerosol detectors
Super-Phénix 2 (France)	electrical contact, aerosol detectors
SNR 2 (Germany)	electrical contact, smoke detectors
DFBR (Japan)	electrical contact, aerosol detectors, sodium-ion and smoke detectors
CDFR (UK)	various conductivity detectors
BN-1600 (Russian Federation)	electrical contact, radiation, aerosol detectors
BN-800 (Russian Federation)	electrical contact, radiation, aerosol detectors
EFR	electrical contact, thermocouples, smoke and aerosol detectors
ALMR (USA)	electrical contact and aerosol detectors
SVBR-75/100 (Russian Federation)	to be defined
BN-1800 (Russian Federation)	electrical contact, radiation, aerosol detectors
BREST-1200 (Russian Federation)	control coolant level and concrete temperature
JSFR-1500 (Japan)	sodium ion detector (laser type)