

## 10. PROTECTION AND CONTROL

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

### Experimental Fast Reactors

Plant	10.1.
Rapsodie (France)	HF,HT,LEP,LPF,DND,EQ
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 (Russia)	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 (Russia)	HF, F1L, HT, HRF, LCL, LEP, LSF
CEFR (China)	HF, HT, HRF, LCL, LEP, LPF, DND, EQ, HIT

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### Demonstration or Prototype Fast Reactors

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,FIL,HT,HRF,LNF,LEP,LPF,LSF,EQ
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 (Russia)	HF,HT,HRF,LCL,LEP,LPF,F2L,DND, EQ
ALMR (USA)	HF,DPF,LCL,HPSS,HIT*,HT*,HR*

### 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,LCI,LSF, HCE,CI,HPF,HCP,TT
CDFR (UK)	HF,HT,HRT,LCL,LEP,HRF1,ABNS,DND,LPF
BN-1600 (Russia)	HF,HT,HRF,LPF,F2L,EQ
BN-800 (Russia)	HF,HT,HRF,LCL,LEP,LPF,EQ,F2L,DND
EFR	HF,HT,LPF,LSF,CFI,DND,EQ,HRF,ABNS,LEP
ALMR (USA)	

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

## PROTECTION AND CONTROL

### 10.2. Principal shutdown systems (see also Section V)

#### Experimental Fast Reactors

Plant	10.2.
Rapsodie (France)	6 control rods
KNK-II (Germany)	2
FBTR (India)	6 CR*
PEC (Italy)	11 CR* comprising 2 CIRS**
JOYO (Japan)	safety control rods
DFR (UK)	12 bottom-entry fuel rods and 3 top entry boron shut-off rods
BOR-60 (Russia)	safety and regulating control rods
EBR-II (USA)	drive-out of control rods containing fuel
Fermi (USA)	safety rods
FFTF (USA)	3 primary and 6 secondary CR* comprising 2 CIRS**
BR-10 (Russia)	bottom-entry Ni-reflector
CEFR (China)	6 control rods (primary) and 2 safety rods (secondary)

#### Demonstration or Prototype Fast Reactors

Phenix (France)	6 control rods
SNR-300 (Germany)	2 redundant diverse systems
PFBR (India)	12 CR* comprising 2 CIRS**
MONJU (Japan)	main control rods and back up control rods
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 control rods
BN-600 (Russia)	safety and regulating control rods
ALMR (USA)	9 control rods with diverse shutdown systems

#### Commercial Size Reactors

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 (Russia)	safety and regulating control rods
BN-800 (Russia)	safety and regulating control rods
EFR	2 redundant diverse systems
ALMR (USA)	9 control rods with diverse shutdown systems

\* CR - control rods;

\*\* CIRS - completely independent reactor shut-down systems

## PROTECTION AND CONTROL

- 10.3. Reactor power control
- 10.3.1. Method of controlling reactor power

### Experimental Fast Reactors

Plant	10.3.1.
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 (Russia)	automatic and manual
EBR-II (USA)	manual or automatic*
Fermi (USA)	automatic
FFTF (USA)	manual
BR-10 (Russia)	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 (Russia)	automatic power control on outlet Na and steam T
ALMR (USA)	grid following/automatic or manual

### Commercial Size Reactors

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 (Russia)	automatic power control on outlet Na and steam T
BN-800 (Russia)	automatic power control on outlet Na and steam T
EFR	grid following, automatic
ALMR (USA)	grid following/automatic or manual

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

## PROTECTION AND CONTROL

- 10.3. Reactor power control
- 10.3.2. Main parameter used for control

### Experimental Fast Reactors

Plant	10.3.2.
Rapsodie (France)	manual
KNK-II (Germany)	constant coolant $\Delta T$
FBTR (India)	constant primary flow and cool. 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 $\Delta P$ through core
BOR-60 (Russia)	manual
Fermi (USA)	constant flow rate
FFTF (USA)	manual
BR-10 (Russia)	constant coolant, $\Delta T$
CEFR (China)	constant coolant $\Delta T$

### Demonstration or Prototype Fast Reactors

Phénix (France)	control $\Delta T$ of each subassembly
SNR-300 (Germany)	constant coolant $\Delta T$
PFBR (India)	not yet finalized
MONJU (Japan)	program control (proportional to the reactor power) for nominally constant coolant $\Delta T$ or manual
PFR (UK)	manual or constant steam pressure
CRBRP (USA)	automatic; load following
BN-350 (Kazakhstan)	constant flow rate
BN-600 (Russia)	constant coolant $\Delta T$
ALMR (USA)	core outlet temperature with flux trim

### Commercial Size Reactors

Super-Phénix 1 (France)	core outlet temperature
Super-Phénix 2 (France)	control $\Delta T$ of each instrumented subassembly
SNR 2 (Germany)	core outlet T control, variable flow, constant coolant $\Delta T$
DFBR (Japan)	outlet T control, variable flow, variable coolant $\Delta T$ following pre-set power
CDFR (UK)	automatic control, following pre set power and core outlet temperature
BN-1600 (Russia)	constant coolant $\Delta T$
BN-800 (Russia)	constant coolant $\Delta T$
EFR	constant reactor inlet temperature
ALMR (USA)	core outlet temperature with flux trim

## PROTECTION AND CONTROL

- 10.3. Reactor power control
- 10.3.3. Plant response designed to cope with seizure or stopping of a primary pump

### Experimental Fast Reactors

Plant	10.3.3.
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 (Russia)	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 (Russia)	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 (Russia)	automatic scram
ALMR (USA)	automatic scram, pony motors operate available pumps, DHR system available

### Commercial Size Reactors

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 (Russia)	automatic scram
BN-800 (Russia)	automatic scram
EFR	automatic scram
ALMR (USA)	automatic scram, pony motors operate available pumps, DHR system available

## PROTECTION AND CONTROL

10.4. Method of detection of sodium leaks

10.4.1. Type of detector

### Experimental Fast Reactors

Plant	10.4.1.
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 (Russia)	electrical contact
EBR-II (USA)	electrical contact
Fermi (USA)	H <sub>2</sub> detectors, sodium level indicators
FFTF (USA)	electrical contact and aerosol detector
BR-10 (Russia)	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 (Russia)	electrical contact, radiation, aerosol detectors
ALMR (USA)	electrical contact and aerosol detectors

### Commercial Size Reactors

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 (Russia)	electrical contact, radiation, aerosol detectors
BN-800 (Russia)	electrical contact, radiation, aerosol detectors
EFR	electrical contact, thermocouples, smoke and aerosol detectors
ALMR (USA)	electrical contact and aerosol detectors