Engineering Safeguards Systems

Reactor Protection System

Purpose: Prevent or mitigate fuel damage and release of radioactivity to environment.

- Trip Plant (shut down by control rod insertion)
- Initiate Safety Injection System (SIS)
- Initiate safeguards to assure primary (and secondary loops) and containment integrity.

Ex: PWR

Key Trip Functions
Description of Key Trip Functions

Power Range, Hi Neutron Flux

- Eight 5’ long uncompensated ion chambers
- Located in biological shield (see Figures IV-1.1&2)
- Core Power = (Top+Bottom) Detectors Signal
- Axial Power Shape: (Top-Bottom) Detectors ($\Delta I$ or $\Delta \Phi$) Signal

$\text{Core } P_{\text{Rel}} > (\text{Core } P_{\text{Rel}})_{\text{Setpoint}} \Rightarrow \text{Trip Plant}$

$(\text{Core } P_{\text{Rel}})_{\text{Setpoint}} \approx 1.06$

Protects against center line fuel melt.
FIGURE IV-1.1 - DETECTOR LOCATIONS
Over Temperature $\Delta T$ Trip

$$\Delta T_{\text{setpoint}} = \Delta T_{\text{rated}} (K_1 - K_2 (1 + \text{Rate of Change of } T_{\text{avg}}))(T_{\text{avg,actual}} - T_{\text{avg,rated}}) + K_3$$

$$\text{where } \Delta T_{\text{rated}} = \text{normal full power temperature rise in pressure vessel.}$$

- $T_{\text{avg}} = \text{average reactor coolant temperature (F)}$
- $P = \text{pressurizer pressure (psig)}$
- $K_1 = \text{setpoint bias(F)}$
- $K_2, K_3 = \text{constants based on the effect of temperature and pressure on the DNB limits, (F/F), F/psig)}$
- $f(\Delta \Phi) = \text{a function of the flux difference between upper and lower long ion chamber sections (F)}.$

$T_{\text{avg}}$ Signal – Obtained by averaging vessel inlet (cold leg) and outlet (hot leg) temperature signals from thermocouples.

$$\Delta T = T_{\text{Hot Leg}} - T_{\text{Cold Leg}} > \Delta T_{\text{Setpoint}} \Rightarrow \text{Trip}$$

Protects against DNB
Overpower $\Delta T$ Trip

$$\Delta T_{\text{setpoint}} = \Delta T_{\text{rated}} [K_4 - K_5 (\text{Rate of change of } T_{\text{avg}}) - K_6 (T_{\text{avg, actual}} - T_{\text{avg, rated}}) - f(\Delta \Phi)]$$

where

- $f(\Delta \Phi)$ = is a function of flux difference between upper and lower long ion chamber section (P)
- $K_4$ = a preset manually adjustable bias (F)
- $K_5$, $K_6$ = constants relating to the effect of $T_{\text{avg}}$ and rate of change of $T_{\text{avg}}$ on overpower limit
- $T_{\text{avg}}$ = average reactor coolant temperature (F)

Variables in brackets are individually low limited to zero.

$$\Delta T_{\text{Actual}} = T_{\text{Hot leg}} - T_{\text{Cold leg}} > \Delta T_{\text{setpoint}} \Rightarrow \text{Trip}$$

Why called Overpower $\Delta T$ Trip?

Core Power $=(h(T_{\text{Hot Leg}}\!-\!h(T_{\text{Cold Leg}})) \times \text{Mass Flow Rate}$

$\cong C_p(T_{\text{avg}})(T_{\text{Hot Leg}}-T_{\text{Cold Leg}}) \times \text{Mass Flow Rate}$

Assume flow rate fixed

$$\text{Core power} = T_{\text{Hot Leg}} - T_{\text{Cold Leg}} = \Delta T_{\text{Actual}}$$

Protects against Fuel Centerline Melt
Figure 9-2. Core Inlet Temperature versus Power for Minimum DNBR = 1.3
Figure 7-9. RPS Reactor Trip Actuation, Block Diagram
<table>
<thead>
<tr>
<th>Trip (1)</th>
<th>Accident (2)</th>
<th>Tech. Spec. (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtemperature ΔT Trip</td>
<td>1. Uncontrolled Rod Cluster Control Assembly Bank Withdrawal At Power (15.4.2)</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>2. Uncontrolled Boron Dilution (15.4.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Loss of External Electrical Load and/or Turbine Trip (15.2.2) (15.2.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Excessive Heat Removal Due to Feedwater System Malfunctions (15.1.1 &amp; 15.1.2)</td>
<td></td>
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<tr>
<td></td>
<td>5. Excessive Load Increase Incident (15.1.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Accidental Depressurization of the Reactor Coolant System (15.6.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Accidental Depressurization of the Main Steam System (15.1.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Loss of Reactor Coolant From Small Ruptured Pipes or From Cracks in Large Pipes Which Actuates ECCS (15.6.5)</td>
<td></td>
</tr>
<tr>
<td>Overpower ΔT Trip</td>
<td>1. Uncontrolled Rod Cluster Control Assembly Bank Withdrawal at Power (15.4.2)</td>
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</tr>
<tr>
<td></td>
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</tr>
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<td></td>
</tr>
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<td>4. Accidental Depressurization of The Main Steam System (15.1.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Major Secondary System Pipe Rupture (15.1.5)</td>
<td></td>
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</tbody>
</table>
### Table 7-4. Reactor Trip Correlation

<table>
<thead>
<tr>
<th>Trip (1)</th>
<th>Accident (2)</th>
<th>Tech. Spec. (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power-Range High Neutron Flux</td>
<td>1. Uncontrolled Rod Cluster Control Assembly Bank Withdrawal From A Subcritical</td>
<td>2.2</td>
</tr>
<tr>
<td>Trip (Low Setpoint)</td>
<td>Condition (15.4.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Excessive Heat Removal Due to Feedwater System Malfunctions (15.1.1 &amp; 15.1.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Rupture of a Control Rod Drive Mechanism Housing (15.4.8)</td>
<td></td>
</tr>
<tr>
<td>Power-Range High Neutron Flux</td>
<td>1. Uncontrolled Rod Cluster Control Assembly Bank Withdrawal From A Subcritical</td>
<td>2.2</td>
</tr>
<tr>
<td>Trip (High Setpoint)</td>
<td>Condition (15.4.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Uncontrolled Rod Cluster Control Assembly Bank Withdrawal at Power (15.4.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Startup of an Inactive Reactor Coolant Loop (15.4.4)</td>
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<td></td>
<td>4. Excessive Heat Removal Due to Feedwater System Malfunctions (15.1.1 &amp; 15.1.2)</td>
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<td>7. Major Secondary System Pipe Rupture (15.1.5)</td>
<td></td>
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<tr>
<td></td>
<td>8. Rupture of a Control Rod Drive Mechanism Housing (Rod Cluster Control Assembly Ejection) (15.4.8)</td>
<td></td>
</tr>
<tr>
<td>Intermediate-Range High Neutron</td>
<td>Uncontrolled Rod Cluster Control Assembly Bank Withdrawal From A Subcritical</td>
<td>see note 4</td>
</tr>
<tr>
<td>Flux Trip</td>
<td>Condition (15.4.1)</td>
<td></td>
</tr>
<tr>
<td>Source-Range High Neutron Flux</td>
<td>Uncontrolled Rod Cluster Control Assembly Bank Withdrawal From A Subcritical</td>
<td>see note 4</td>
</tr>
<tr>
<td>Trip</td>
<td>Condition (15.4.1)</td>
<td></td>
</tr>
<tr>
<td>Power-Range High Positive Neutron</td>
<td>Rupture of a Control Rod Drive Mechanism Housing (Rod Cluster Control Assembly Ejection) (15.4.8)</td>
<td>2.2</td>
</tr>
<tr>
<td>Flux Rate Trip</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(14 OCT 2000)
Safety Injection System (SIS) Actuation

Causes
- Reactor Trip
- SIS initiation

Protection: LOCA and SBA

Initiators:
1. Low pressurizer pressure
2. High containment pressure (2/4)
3. Low steam line pressure of one line compared to other three lines (High Differential Pressure) [Implies 4 loop plant]
4. High steam flow in two of four lines (1/2 measurements per line) (2/4 lines) in coincidence with low $T_{avg}$ or low steam line pressure (2/4). [Implies 4 loop plant]
Feedwater Isolation

Initiators: 2/3 Hi-Hi S/G Level  
SIS

Function: Stops & isolates main feedwater ⇒ Aux (safety) feedwater initiated.  
(2 electric + 1 steam pump)  
Trips turbine.

Protection: Excessive Feedwater Accident  
Mitigates cooldown of primary  
Protects turbine from moisture carryover  
Steamline Break Accident
Steam Line Isolation

Initiators:
- High containment pressure
- [High steam line flow (two out of four steam lines) and low steam line pressure (two out of four steamlines)] or [high steam line flow (two out of four steam lines) and low-low $T_{AVG}$ (two out of four loops)]. These signals also produce safety injection; however, a small steam break could actuate the pressurizer signals to produce safety injection, but not produce steam line isolation.

Function: Closes main steamline isolation valve (MSIV) in each loop

Protection: Large Steamline Break Accident
- Mitigates cooldown of primary
- Mitigates containment pressurization

Containment Protection
Protection: Mitigates containment overpressurization

<table>
<thead>
<tr>
<th>Signal</th>
<th>Setpoint*</th>
<th>Logic</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hi</td>
<td>10%</td>
<td>2/3</td>
<td>Initiate SIS</td>
</tr>
<tr>
<td>Hi-2</td>
<td>33%</td>
<td>2/3</td>
<td>Close Steamline Isolation Valves</td>
</tr>
<tr>
<td>Hi-3</td>
<td>50%</td>
<td>2/4</td>
<td>Actuate Containment Spray</td>
</tr>
</tbody>
</table>

*% of containment design pressure limit.
Power Source Protection

Power to plant equipment comes from plant turbine generator

Trip Plant ⇒ Loss Onsite Power ⇒ Automatic Switch to Offsite Power

Loss Offsite Power ⇒ Automatic switch to Batteries (DC) and two or three emergency Diesels (AC)

Diesels cannot power reactor coolant pumps ⇒ RCP coastdown and other non-essential equipment isolation.
Reactor Protection System

Ex: BWR

Key Trip Functions
- Manual
- High Pr. in Drywell
- Low RPV Level
- High Pr. in RPV
- High $\frac{1}{n}$ Flux
- High Scram Discharge Tank Water Level
- Turbine Trip
- Main Steam Line Isolation
- Main Steam Line High Radiation Activity

Description of Key Trip Functions

Power Range, High Neutron Flux
- Fixed “point” in-core ion chambers
  [Linear Power Range Monitors (LPRM)].
- Located between 4 F/A clusters @ 4 core elevations.
- Core Power = Sum of subset of ion chambers.

\[ \text{Core } P_{\text{Rel}}> (\text{Core } P_{\text{Rel}})_{\text{Setpoint}} \Rightarrow \text{Trip} \]

Protects against fuel center-line melt.

\[ \text{Low RPV Level} \}
\[ \text{High } \frac{1}{n} \text{ Flux} \}
Both Protect against dryout. (CHF)

Safety Injection System (SIS) Activation

Causes
- Reactor Trip
- SIS Initiation

Initiators
- High Pr. in Drywell
- Low RPV Level
- Manual
Steam Line Isolation/ F/W Isolation

Causes
- Steam to be contained within containment via closing steam line valves and redirecting steam to suppression pool
- HPCI initiated
  ⇒ Reactor Core Isolation Cooling System.

Initiators
- SIS Initiators
- Main Steam Line High Radiation Activity
- Leak Detection [sensed by flow, temperature, pressure, drain flows, and radiation levels]
- Turbine Inlet Low Pressure

Automatic Depressurization System Activation

Causes
- Safety and relief valves to blow steam to suppression pool
- Low prz core spray and/or safety injection flow

Initiators
- High Pr in RPV
- High Pr. in Drywell and Low RPV Level

Containment Protection

Provided by suppression pool, which is part of SIS and Depr. System, and Reactor Bldg. Sprays.

Power Source Protection

Basically same as PWR but perhaps more use of steam turbine driven pumps.