Modifications
to the
BWR Emergency Procedure Guidelines
to address
Reactor Core Instabilities

The BWR Owners' Group Emergency Procedures Committee (EPC) has developed modifications to the BWR Emergency Procedure Guidelines (EPGs) [Reference 1] to address potential reactor core thermal-hydraulic instabilities, specifically large irregular power oscillations.

Reactor core instabilities may occur when the reactor is operated at a relatively high power-to-flow ratio and core recirculation flow is reduced. Instabilities are manifested by oscillations in reactor power which, if the reactor cannot be shutdown, may increase in magnitude and, under certain circumstances, become sufficiently large and irregular to cause fuel damage. The initiation and growth of these oscillations is principally dependent upon the subcooling at the core inlet; the greater the subcooling, the more likely oscillations will commence and increase in magnitude [Reference 2].

The EPC has added two steps to the EPGs to prevent or mitigate the consequences of potential reactor instabilities:

1. If the reactor is not shutdown, RPV water level is lowered to two feet below the feedwater sparger and then maintained in a band below this level. The EPGs previously permitted this action, but it was not required. This places the feedwater sparger in the steam space so that any injection through the sparger will be heated by steam before it reaches the liquid surface in the downcomer. Heating the injected water reduces the core inlet subcooling, thereby preventing or mitigating the consequences of oscillations.

   Lowering RPV water level further than two feet below the feedwater sparger would result in increased steam heating of the injected water and thus reduced subcooling. However, lowering RPV water level also increases the likelihood of automatic MSIV closure and RPV isolation. Two feet below the sparger has been selected as the upper bound of the RPV water level control band for the following reasons:

   a. This water level is sufficiently low that steam heating of the injected water will be 65% to 75% complete (*i.e.*, the difference between the temperature of the injected water and the temperature of steam in the RPV will be reduced by 65% to 75%) [Reference 3].

This water level is sufficiently high that most plants without the capability to readily bypass the low RPV water level MSIV isolation should be able to control RPV water level with feedpumps to preclude the isolation. Table 1 illustrates the relationship between the top of the new RPV water level control band and the MSIV isolation setpoint for each domestic BWR.

2. Soluble boron is injected into the RPV whenever large oscillations are observed. The EPGs previously permitted this action, but it was not required. Injection of soluble boron mitigates the consequences of large irregular oscillations by limiting their duration.

   Permitting but not requiring boron injection prior to the observance of oscillations permits the operating crew to inject boron early if it is clearly necessary but does not require boron injection when this might unnecessarily increase the potential for a damaging reactivity excursion should RPV depressurization subsequently be required.

The EPC has also added or modified other EPG steps to reduce the likelihood of MSIV or RPV injection system isolation and to facilitate operator action under scram failure conditions:

1. Main steam line (MSL) and offgas high radiation interlocks are bypassed if necessary in order to open or preclude closing of MSIVs. Preserving the main condenser as a heat sink significantly reduces the energy which the primary containment must absorb, and any release through the MSLs will normally be held up in the offgas system until the reactor can be shutdown by injection of soluble boron.

2. Recirculation pumps are tripped before recirculation flow is run back only when all MSLs are isolated and no RPV injection system which may trip on high RPV water level is operating. This reduces the likelihood that the RPV may be isolated or an injection system tripped due to level swell following recirculation pump trip.

3. Interlocks are bypassed if necessary to prevent injection into the RPV in order to lower RPV water level.

4. MSL interlocks are bypassed immediately under all scram failure conditions if this capability exists.

5. RPV water level is controlled above the Minimum Steam Cooling RPV Water Level (MSCRWL) under all scram failure conditions. The EPGs previously required RPV water level to be controlled above the top of the active fuel under certain circumstances even though the core is adequately cooled whenever water level is above the MSCRWL. Permitting water level to drop to the MSCRWL increases the required water level control band and results in lower reactor power and containment heatup.

   The RPV water level control bands employed in the current EPGs and those which will result from the EPG modifications to address potential reactor instabilities are illustrated in Figure 1.

Plant	Isolation Bypass	Top of New Control Band to MSIV Isolation (in,)
A	Yes	-46
B	Yes	-45
C	No	12
D	Yes	10
E	No	11
F	No	18
G	No	18
H	No	3
I	Yes	29
J	No	37
K	No	48
L	No	44
M	No	44
N	No	74
O	No	97
P	No	81
Q	No	76
R	No	71
S	No	76
T	No	71
U	Planned	-9
V	No	70
W	Yes	82
X	No	86
Y	Yes	84
Z	No	87

Table 1. RPV Water Level Operating Range

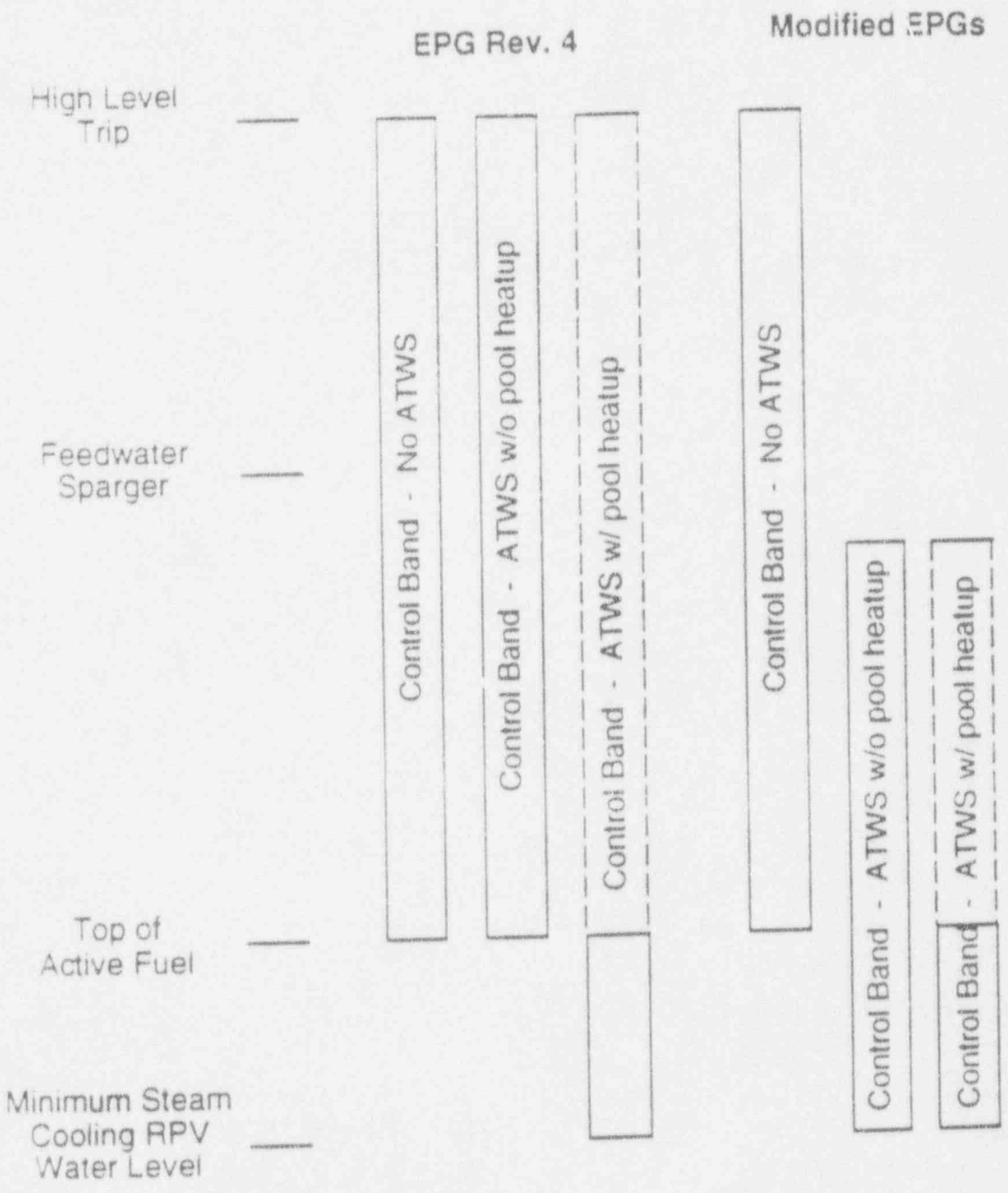


Figure 1. RPV Water Level Control Bands

The EPG modifications developed by the EPC have been evaluated and shown to be effective in reducing the magnitude of reactor power oscillations resulting from reactor core instabilities [Reference 4].

The modifications consist of changes in Sections RC/P and RC/Q and in Contingencies #4 and #5 of the EPGs. These EPG sections and contingencies, revised to reflect the changes, are contained in Attachment A. The changes are identified by a vertical bar in the right-hand margin. Text proposed for addition is underlined, and text proposed for deletion is lined out. Step number changes which are required to accommodate the modifications but which do not alter the sequence of steps are not identified.

References:

1. *BWR Owners' Group Emergency Procedure Guidelines, Revision 4*, GE Document 8390-4, January, 1987, NEDO-31331, March, 1987
2. *ATWS Rule Issues Relative to BWR Core Thermal-Hydraulic Stability*, NEDO-32047, February, 1992
3. *BWROG ATWS/Stability Mitigation Studies - Condensation Heat Transfer to Feedwater at Reduced Water Level*, DRF No. A13-00334/Section 26.1, November 30, 1992
4. *Mitigation of BWR Core Thermal-Hydraulic Instabilities in ATWS*, NEDO-32164, December, 1992

RC/P Monitor and control RPV pressure.

If while executing the following steps:

- A high drywell pressure ECCS initiation signal ([*2.0 psig (drywell pressure which initiates ECCS)*]) exists, prevent injection from those LPCS and LPCI pumps not required to assure adequate core cooling prior to depressurizing below their maximum injection pressures.

- Emergency RPV Depressurization is anticipated and either all control rods are inserted to or beyond position [02 (*Maximum Subcritical Banked Withdrawal Position*)] or it has been determined that the reactor will remain shutdown under all conditions without boron, rapidly depressurize the RPV with the main turbine bypass valves. ❷ ❻

- Emergency RPV Depressurization is required and less than [7 (*number of SRVs dedicated to ADS*)] SRVs are open, enter [procedure developed from Contingency #2].

- RPV water level cannot be determined and less than [7 (*number of SRVs dedicated to ADS*)] SRVs are open, enter [procedure developed from Contingency #2].

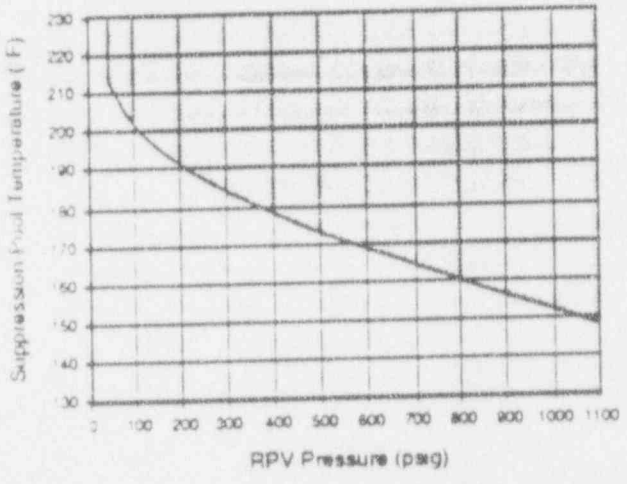
- RPV water level cannot be determined and at least [7 (*number of SRVs dedicated to ADS*)] SRVs are open, enter [procedure developed from Contingency #4].

RC/P-1 If any SRV is cycling, initiate IC and manually open SRVs until RPV pressure drops to [935 psig (*RPV pressure at which all turbine bypass valves are fully open*)].

If while executing the following steps:

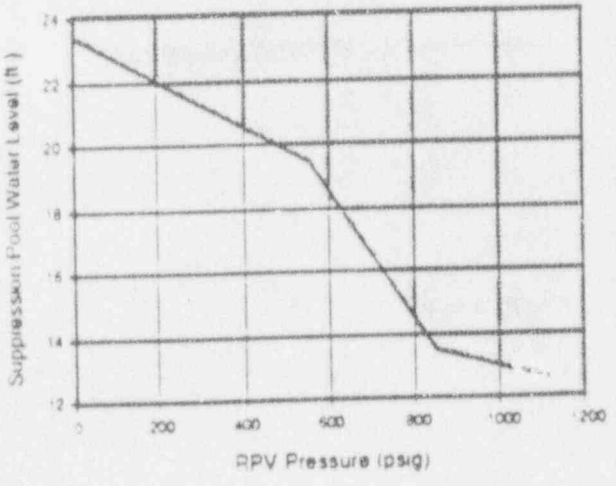
- Suppression pool temperature cannot be maintained below the Heat Capacity Temperature Limit, maintain RPV pressure below the Limit. ⑥

Heat Capacity Temperature Limit



- Suppression pool water level cannot be maintained below the SRV Tail Pipe Level Limit, maintain RPV pressure below the Limit. ⑥

SRV Tail Pipe Level Limit



- Steam Cooling is required, enter [procedure developed from Contingency #3].

if while executing the following steps:

- Boron injection is required, and
- The main condenser is available, and
- There has been no indication of ~~gross fuel failure or~~ a steam line break.

open MSIVs, bypassing MSL and offgas high radiation interlocks ~~pneumatic system~~ and low RPV water level ~~isolation~~ interlocks if necessary, to re-establish the main condenser as a heat sink.

RC/P-2 Stabilize RPV pressure at a pressure below [1045 psig (*high RPV pressure scram setpoint*)] with the main turbine bypass valves.

RPV pressure control may be augmented by one or more of the following systems:

- IC
- SRVs only when suppression pool water level is above [4 ft. 9 in. (*elevation of top of SRV discharge device*)]: open SRVs in the following sequence if possible: [M, B, G, F, D, L, K, C, A (*SRV opening sequence*)]; if the continuous SRV pneumatic supply is or becomes unavailable, place the control switch for each SRV in the [CLOSE or AUTO] position.
- HPCI with suction from the condensate storage tank. ❸
- RCIC with suction from the condensate storage tank. ❸ ❹
- [Other steam driven equipment]
- RWCU (*recirculation mode*), bypassing [regenerative heat exchangers and] filter/demineralizers and, if necessary, defeating SLC and other isolation interlocks.
- Main steam line drains
- RWCU (*blowdown mode*) if no boron has been injected into the RPV; refer to [sampling procedures] prior to initiating blowdown.

If while executing the following steps the reactor is not shutdown, return to [Step RC/P-2].

RC/P-3 When either:

- All control rods are inserted to or beyond position [02 (*Maximum Subcritical Banked Withdrawal Position*)], or
- It has been determined that the reactor will remain shutdown under all conditions without boron, or
- [700 pounds (*Cold Shutdown Boron Weight*)] of boron have been injected into the RPV, or
- The reactor is shutdown and no boron has been injected into the RPV,

depressurize the RPV and maintain cooldown rate below [100°F/hr (*RPV cooldown rate LCO*)].

If one or more SRVs are being used to depressurize the RPV and the continuous SRV pneumatic supply is or becomes unavailable, depressurize with sustained SRV opening.

RC/P-4 When the shutdown cooling RPV pressure interlock clears, initiate shutdown cooling [using only those RHR pumps not required to maintain RPV water level above [10 in. (*RPV water level shutdown cooling interlock*)] by operation in the LPCI mode].

If shutdown cooling cannot be established and further cooldown is required, continue to cool down using one or more of the systems used for depressurization.

RC/P-5 When either:

- All control rods are inserted to or beyond position [02 (*Maximum Subcritical Banked Withdrawal Position*)], or
- It has been determined that the reactor will remain shutdown under all conditions without boron, or
- [700 pounds (*Cold Shutdown Boron Weight*)] of boron have been injected into the RPV,

proceed to cold shutdown in accordance with [procedure for cooldown to cold shutdown conditions].

RC/Q Monitor and control reactor power.

If while executing the following steps:

- All control rods are inserted to or beyond position [02 (*Maximum Subcritical Banked Withdrawal Position*)] terminate boron injection and enter [scram procedure].
- It has been determined that the reactor will remain shutdown under all conditions without boron, terminate boron injection and enter [scram procedure].
- The reactor is shutdown and no boron has been injected into the RPV, enter [scram procedure].

RC/Q-1 [Confirm or place the reactor mode switch in SHUTDOWN.]

RC/Q-2 If ARI has not initiated, initiate ARI.

RC/Q-3 If the main turbine-generator is on-line [and ~~the MSIVs are open~~ an MSL is not isolated,] [or if any of the following systems are operating:

- Feedwater
- HPCI
- RCIC]

confirm or initiate recirculation flow runback to minimum.

RC/Q-4 If reactor power is above [3% (*APRM downscale trip*)] or cannot be determined, trip the recirculation pumps.

RC/Q-5 If ARI has not initiated, initiate ARI.

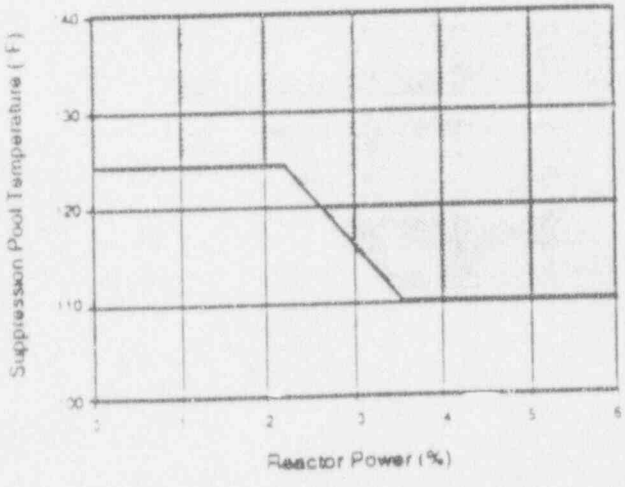
Execute [Steps RC/Q-6 and RC/Q-7] concurrently.

RC/Q-6 Either:

- When periodic neutron flux oscillations in excess of 125% (*Large Oscillation Threshold*) peak-to-peak commence and continue, or
- Before suppression pool temperature reaches (the Boron Injection Initiation Temperature) ~~but only if the reactor cannot be shut down.~~

BORON INJECTION IS REQUIRED: Inject boron into the RPV with SLC and prevent automatic initiation of ADS.

Boron Injection Initiation Temperature



If boron cannot be injected with SLC, inject boron into the RPV by one or more of the following alternate methods:

- CRD
- HPCS
- RWCU
- Feedwater
- HPCI
- RCIC
- Hydro pump

> If while executing the following steps SLC tank water level drops to [0% (*low SLC tank water level trip*)], confirm automatic trip of or manually trip the SLC pumps.

RC/Q-6.1 If boron is not being injected into the RPV by RWCU and RWCU is not isolated, bypass [regenerative heat exchangers and] filter/demineralizers.

RC/Q-6.2 Continue to inject boron until [700 pounds (*Cold Shutdown Boron Weight*)] of boron have been injected into the RPV.

RC/Q-6.3 Enter [scram procedure].

RC/Q-7 Insert control rods as follows:

RC/Q-7.1 Reset ARI, defeating ARI logic trips if necessary.

RC/Q-7.2 Insert control rods with one or more of the following methods:

- De-energize scram solenoids
- Vent the scram air header
- Reset the scram, defeating RPS logic trips if necessary, drain the scram discharge volume, and initiate a manual scram
- Open individual scram test switches
- Increase CRD cooling water differential pressure
- Drive control rods, defeating RSCS and RWM interlocks if necessary
- Vent control rod drive overpiston volumes

C4-1 If any control rod cannot be determined to be inserted to or beyond position [02 (*Maximum Subcritical Banked Withdrawal Position*)] and it has not been determined that the reactor will remain shutdown under all conditions without boron, flood the RPV as follows:

> If while executing the following steps either all control rods are inserted to or beyond position [02 (*Maximum Subcritical Banked Withdrawal Position*)] or it has been determined that the reactor will remain shutdown under all conditions without boron but RPV water level cannot be determined, continue in this procedure at [Step C4-2].

C4-1.1 Terminate and prevent all injection into the RPV except from boron injection systems and CRD, defeating interlocks as required, until RPV pressure is below the Minimum Alternate RPV Flooding Pressure.

Minimum Alternate RPV Flooding Pressure

Number Of Open SRVs	RPV Pressure (psig)
7 or more	94
6	112
5	137
4	175
3	238
2	364
1	743

If less than [1 (*minimum number of SRVs for which the Minimum Alternate RPV Flooding Pressure is below the lowest SRV lifting pressure*)] SRV[s] can be opened, continue in this procedure.

C4-1.2 If at least [4 (*Minimum Number of SRVs Required for Emergency Depressurization*)] SRVs can be opened, close the MSIVs, main steam line drain valves, and IC, RCIC, and RHR steam condensing isolation valves.

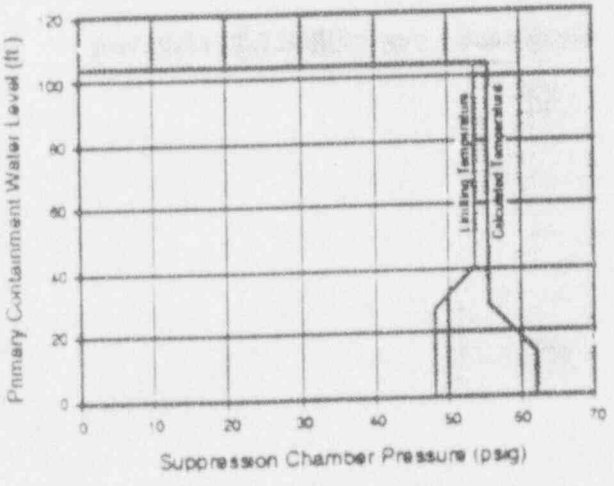
CONTINGENCY #5

LEVEL/POWER CONTROL

If while executing the following steps:

- RPV water level cannot be determined, enter [procedure developed from Contingency #4].
- All control rods are inserted to or beyond position [02 (*Maximum Subcritical Banked Withdrawal Position*)] or it has been determined that the reactor will remain shutdown under all conditions without boron, enter [procedure developed from the RPV Control Guideline] at [Step RC/L].
- Primary containment water level and suppression chamber pressure cannot be maintained below the Maximum Primary Containment Water Level Limit, then irrespective of whether adequate core cooling is assured terminate injection into the RPV from sources external to the primary containment until primary containment water level and suppression chamber pressure can be maintained below the Maximum Primary Containment Water Level Limit.

Maximum Primary Containment Water Level Limit



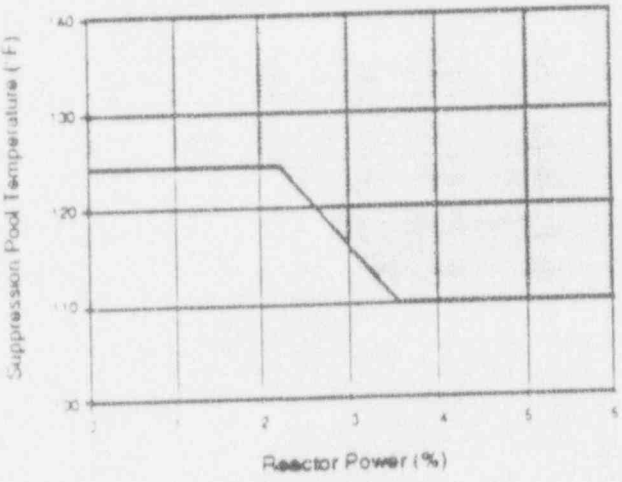
C5-1 Prevent automatic initiation of ADS.

C5-2 If any MSL is not isolated, bypass [MSL and offgas high radiation interlocks] [and] [low RPV water level interlocks] to maintain the main condenser as a heat sink.

C5-3 If:

- Reactor power is above [3% *(APRM downscale trip)*] or cannot be determined, and
- Suppression pool temperature is above [the Boron Injection Initiation Temperature], and

Boron Injection Initiation Temperature



- Either an SRV is open or opens or drywell pressure is above [2.0 psig *(high drywell pressure scram setpoint)*].

Then:

- If any ~~MSIV~~ MSL is ~~open~~ not isolated, bypass [MSL and offgas high radiation interlocks] [and] [low RPV water level ~~pneumatic system and MSIV isolation~~ interlocks] ~~and restore the pneumatic supply [to the containment]~~ to maintain the main condenser as a heat sink and

- Lower RPV water level, irrespective of any ~~consequent~~ reactor power or RPV water level oscillations, by terminating and preventing all injection into the RPV except from boron injection systems, RCIC, and CRD, defeating interlocks as necessary, until either:
  - Reactor power drops below [3% *(APRM downscale trip)*], or
  - RPV water level reaches [-164 in. *(top of active fuel)*], or
  - All SRVs remain closed and drywell pressure remains below [2.0 psig *(high drywell pressure scram setpoint)*].

> If while executing the following steps Emergency RPV Depressurization is required, continue in this procedure at [Step C5-5.1].

C5.4 If RPV water level is above [-58 in. (24 inches below the feedwater sparger nozzles)] and the reactor is not shutdown:

- If any MSL is not isolated, bypass [MSL and offgas high radiation interlocks] [and] [low RPV water level interlocks] to maintain the main condenser as a heat sink and

- Lower RPV water level to below [-58 in. (24 inches below the feedwater sparger nozzles)] by terminating and preventing all injection into the RPV except from boron injection systems, RCIC, and CRD, defeating interlocks as necessary.

If while executing the following step:

- Reactor power is above [3% *(APRM downscale trip)*] or cannot be determined, and
- RPV water level is above [-164 in. *(top of active fuel)*], and
- Suppression pool temperature is above [the Boron Injection Initiation Temperature], and
- Either an SRV is open or opens or drywell pressure is above [2.0 psig *(high drywell pressure scram setpoint)*].

return to [Step C5-4].

C5-5 Maintain RPV water level between [-195 in. *(Minimum Steam Cooling RPV Water Level)*] and either: ❼

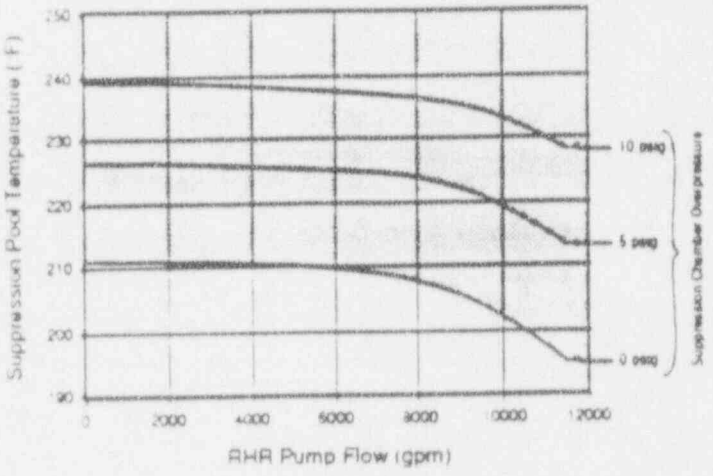
- If RPV water level was deliberately lowered in [Step C5-3 or C5-4], ~~between [-195 in. *(Minimum Steam Cooling RPV Water Level)*] and~~ the level to which it was lowered, or
- If RPV water level was not deliberately lowered in [Step C5-3 or C5-4], ~~between [-164 in. *(top of active fuel)*] and~~ [+58 in. (high level trip setpoint)].

with the following systems:

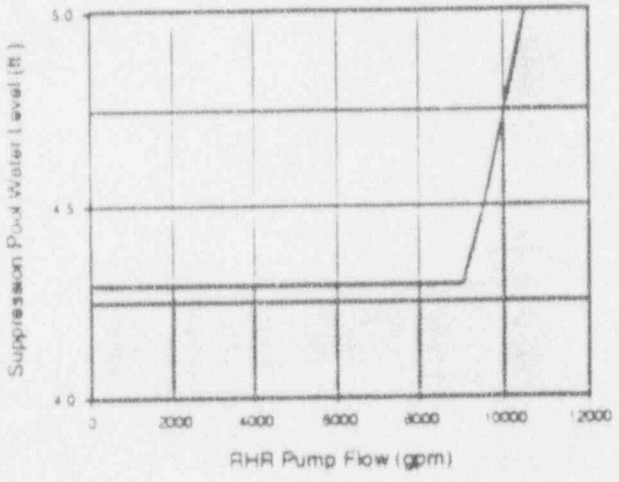
- Condensate/feedwater
- CRD
- RCIC with suction from the condensate storage tank, defeating low RPV pressure isolation interlocks and high suppression pool water level suction transfer logic if necessary. ❸ ❹
- HPCI with suction from the condensate storage tank, defeating high suppression pool water level suction transfer logic if necessary. ❸

- LPCI with injection through the heat exchangers as soon as possible: control and maintain pump flow less than the RHR Pump NPSH Limit and [the RHR Vortex Limit].

RHR Pump NPSH Limit



RHR Vortex Limit



~~If RPV water level was not deliberately lowered [,] [Step C5-2] and RPV water level cannot be maintained above [-161] in. *[top of active fuel]*, maintain RPV water level between [-185 in. *[Minimum Steam Cooling RPV Water Level]* and [+58 in. *[high level trip setpoint]*.~~

If any MSL is not isolated, bypass [MSL and offgas high radiation interlocks] [and] [low RPV water level interlocks] to maintain the main condenser as a heat sink.

If RPV water level cannot be restored and maintained above [-195 in. *Minimum Steam Cooling RPV Water Level*], EMERGENCY RPV DEPRESSURIZATION IS REQUIRED:

C5-5.1 Terminate and prevent all injection into the RPV except from boron injection systems, CRD, and RCIC, defeating interlocks as necessary, until RPV pressure is below the Minimum Alternate RPV Flooding Pressure.

Minimum Alternate RPV Flooding Pressure

Number Of Open SRVs	RPV Pressure (psig)
7 or more	94
6	112
5	137
4	175
3	238
2	364
1	743

If less than [1 *(minimum number of SRVs for which the Minimum Alternate RPV Flooding Pressure is below the lowest SRV lifting pressure)*] SRV[s] can be opened, continue in this procedure.

C5-5.2 Commence and, irrespective of pump NPSH and vortex limits, slowly increase injection into the RPV with the following systems to restore and maintain RPV water level above ~~[-164 in. (top of active fuel)]~~ [-195 in. *(Minimum Steam Cooling RPV Water Level)*]:

- Condensate/feedwater
- CRD
- RCIC with suction from the condensate storage tank, defeating low RPV pressure isolation interlocks and high suppression pool water level suction transfer logic if necessary.
- HPCI with suction from the condensate storage tank, defeating high suppression pool water level suction transfer logic if necessary.]

- LPCI with injection through the heat exchangers as soon as possible.]

~~[If RPV water level cannot be restored and maintained above [-164 in. *(top of active fuel)*], restore and maintain RPV water level above [-195 in. *(Minimum Steam Cooling RPV Water Level)*].~~

[If RPV water level cannot be restored and maintained above [-195 in. *(Minimum Steam Cooling RPV Water Level)*], commence and, irrespective of pump NPSH and vortex limits, slowly increase injection into the RPV with the following systems to restore and maintain RPV water level above [-195 in. *(Minimum Steam Cooling RPV Water Level)*]:

- HPCS
- LPCS
- RHR service water crosstie
- Fire System
- Interconnections with other units
- ECCS keep-full systems

If RPV water level cannot be restored and maintained above [-195 in. *(Minimum Steam Cooling RPV Water Level)*], enter [procedure developed from Contingency #6].

C5-5.3 When RPV water level can be maintained above [-195 in. *(Minimum Steam Cooling RPV Water Level)*], return to [Step C5-5].

If while executing the following step reactor power commences and continues to increase, return to [Step C5-3].

C5-6 When [364 pounds *[Hot Shutdown Boron Weight]*] of boron have been injected, restore and maintain RPV water level between [+12 in. *[low level scram setpoint]*] and [+58 in. *[high level trip setpoint]*].

If RPV water level cannot be restored and maintained above [+12 in. *[low level scram setpoint]*], maintain RPV water level above [-164 in. *[top of active fuel]*].

If RPV water level cannot be restored and maintained above [-164 in. *[top of active fuel]*], EMERGENCY RPV DEPRESSURIZATION IS REQUIRED; return to [Step C5-5.1].

C5-7 When [procedure for cooldown to cold shutdown conditions] is entered from [procedure developed from the RPV Control Guideline] at [Step RC/P-5], proceed to cold shutdown in accordance with [procedure for cooldown to cold shutdown conditions].