Over Temperature ΔT and Over Power ΔT Reactor Trip Functions and Setpoint Determination Process

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Abstract

This technical report describes Mitsubishi Heavy Industries' (MHI's) approach for determining the setpoints for the over temperature ΔT and the over power ΔT reactor trip protection functions to provide protection against departure from nucleate boiling (DNB) and fuel centerline melting. The US-APWR over temperature ΔT reactor trip method is expanded to provide independent protection of the core for both the DNB limit and the core exit boiling limit which provides additional operating margin compared to the traditional methodology. This document describes the design basis for core protection, the over temperature ΔT and the over power ΔT reactor trip protection functions, the analytical protection limit and setpoint determination process, and verification of the adequacy of the setpoints determined using this methodology in the Chapter 15 safety analysis.

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List of Acronyms

AOO	anticipated operational occurrence
DCD	Design Control Document
DNB	departure from nucleate boiling
DNBR	departure from nucleate boiling ratio
MHI	Mitsubishi Heavy Industries, Ltd
MSSV	main steam safety valve
PA	postulated accident
RCS	reactor coolant system
RCCA	rod cluster control assembly
RTD	resistance temperature detector
RTDP	revised thermal design procedure
RTP	rated thermal power

1. Introduction

This document describes the over temperature ΔT and the over power ΔT reactor trip protection functions and setpoint determination process.

In order to expand the operating margin, the US-APWR utilizes the expanded over temperature ΔT reactor trip method in lieu of the previous over temperature ΔT reactor trip method. The expanded over temperature ΔT reactor trip protects the core for both the Departure from Nucleate Boiling (DNB) limit and core exit boiling limit independently, as opposed to the conventional methodology which combines the two, thus expanding the operating margin.

2. Protection Purpose for the Over Temperature ΔT and Over Power ΔT Reactor Trips

2.1 Over Temperature ΔT Reactor Trip

The reactor trip is established so that it satisfies the following design conditions in order to protect the core:

a. DNB Protection

The DNB design criterion is established as a value where DNB will not occur at a 95 percent probability and a 95 percent confidence level on the fuel rod with the most severe thermal conditions in the reactor core during normal operation and anticipated operational occurrences (AOOs). This criterion maintains adequate heat transfer capabilities between the fuel cladding and core coolant, as well as prevents damage to the fuel cladding.

In order to satisfy this criterion, the minimum Departure from Nucleate Boiling Ratio (DNBR) calculated by the WRB-2 correlation should be greater than the safety analysis limit. The applicability of the WRB-2 correlation to the Mitsubishi fuel design has been verified as described in the US-APWR Thermal Design Methodology report, MUAP-07009 (Reference 1).

When the core axial power distribution distortion is large, the hot channel factor increases and the fuel temperature will be higher in the hot rod. Under these conditions, the reactor trip setpoint will be automatically lowered as a function of the axial power distribution. This penalty function is described in Section 8 of this document.

b. Core Exit Boiling Protection

The criterion is that the Reactor Coolant System (RCS) hot leg temperature does not reach the saturation temperature during normal operation and AOOs. Although the criterion is not a limit for physical core damage, RCS hot leg bulk boiling is not allowed since the over temperature ΔT and over power ΔT reactor trips are designed assuming that the reactor power is proportional to the RCS temperature difference (ΔT).

2.2 Over Power ΔT Reactor Trip

The over power ΔT reactor trip is established so that the fuel core temperature will not exceed the melting point during normal operation and AOOs which result in an increase in reactor power. The reactor will trip when the reactor power, as measured by ΔT, reaches the setpoint.

In addition, when the core axial power distribution distortion is large, the hot channel factor increases and the fuel temperature will be higher in the hot rod. As a result, the reactor trip function includes a penalty function that will automatically lower the setpoint dependent on the axial power distribution. This penalty function is described in Section 8 of this document.

3. Function

Due to the core protection design considerations explained in the previous section, operational limits are imposed on certain reactor operating parameters. The operational limit is related to some measurable parameters such as RCS average temperature (T_{avg}), RCS temperature difference (ΔT) as an indication of the reactor power, RCS pressure (P), and axial power imbalance (ΔI). The over temperature ΔT and over power ΔT reactor trips are designed to prevent the reactor core from unacceptable combinations of these operating parameters.

3.1 Over Temperature ΔT Reactor Trip

This reactor trip is established for DNB protection, including the hot channel exit quality limit, and core exit boiling protection.

Although DNB is a local parameter and hence cannot be directly measured, the minimum DNBR can be determined as a function of the reactor power, core inlet temperature, and RCS pressure, assuming the conservative design core power distribution and RCS flow rate. The effect of axial power distribution can also be accounted for by detecting the axial power imbalance (ΔI) via the ex-core detectors.

The parameter ranges, over which the core DNB limit should be available, are determined by other reactor trips, such as the over power ΔT reactor trip (for higher limit of power), the high and low pressurizer pressure trips (for pressure limits), and the main steam safety valve (MSSV) setpoint (for lower temperature limit). In addition, the hot channel exit quality is limited in order not to violate the applicable range of the DNB correlation. As described in the US-APWR Thermal Design Methodology report, MUAP-07009 (Reference 1), the upper limit of the applicable quality range of the WRB-2 DNB correlation is 30%. Limiting the hot channel exit quality to 30% ensures that the local quality at the point of minimum DNBR is within the range of applicability of the DNB correlation.

As explained above, the conditions corresponding to the minimum DNBR can be expressed as a function of the reactor power, core inlet temperature, and RCS pressure. The relationship between the limiting reactor power and core inlet temperature can be expressed in terms of the RCS temperature difference (ΔT) and the RCS average temperature (T_{avg}). Thus, the reactor power limit for DNB protection is established as ΔT_{limit}, which is a function of T_{avg}, P, and ΔI.

For the core exit boiling limit, the ΔT_{limit} can be expressed by T_{avg} and P.

For the US-APWR, the DNB limit and core exit boiling limit are protected by separate limit curves, respectively, in order to expand the operating margin. This method is different from NUREG-1431 (Reference 2) where a combined protection limit is used. The concept of this protection system is illustrated in Figure 3.1, which indicates the additional operating margin gained by this methodology. As a result of this methodology, the DNB protection and core exit boiling protection are described separately in Section 4 (Sections 4.1 and 4.2, respectively).

The inputs of the setpoint equation (P, T_{avg} and ΔI) are measured in each train (corresponding to each of the 4 primary loops), and the calculated ΔT reactor trip setpoint is compared with the measured ΔT in each train. The reactor is tripped when the measured ΔT exceeds the setpoint in 2 or more trains. The logic diagram is shown in Figure 3.2. For the DNB protection limit, the reactor is tripped under the following conditions:

$$\Delta T_{SP1} \leq \frac{1+\tau_7 s}{1+\tau_8 s}\cdot\frac{1}{1+\tau_9 s}\ \Delta T \tag{3.1}$$

Where:

ΔT_{SP1} is the DNB protection setpoint.

ΔT is the measured RCS temperature difference (ΔT measured).

For the core exit boiling protection limit, the reactor is tripped under the following conditions:

$$\Delta T_{SP2} \leq \frac{1+\tau_7 s}{1+\tau_8 s}\cdot\frac{1}{1+\tau_9 s}\ \Delta T \tag{3.2}$$

Where:

ΔT_{SP2} is the core exit boiling protection setpoint.

As a countermeasure for fluctuations in the reactor vessel outlet hot leg coolant temperature observed in operating plants, a first order time lag or filter circuit (τ_9) is added to the ΔT measured. This reduces temperature fluctuations and enhances plant operating margin.

3.2 Over Power ΔT Reactor Trip

This reactor trip is established to limit the reactor power and prevent excess peak linear heat rate and fuel centerline temperature. The reactor power is correlated to ΔT considering the coolant density and specific heat. For this reason, the reactor power can be limited to below specific over power conditions by monitoring ΔT.

However, if there is significant core axial power distribution distortion, it is necessary to decrease the over power limit in order to prevent exceeding applicable fuel design limits for AOOs. Therefore, if the axial power imbalance (ΔI) becomes large, the reactor trip setpoint is reduced.

The reactor is tripped when the measured ΔT exceeds the reactor trip setpoint. The setpoint is conservatively developed as described in Section 4.3.

The inputs of the setpoint equation (T_{avg} and ΔI) are measured in each train (corresponding to each of the 4 primary loops), and the calculated ΔT reactor trip setpoint is compared with the measured ΔT in each train. The reactor is tripped when the measured ΔT exceeds the setpoint in 2 or more trains. The logic diagram is shown in Figure 3.2. Specifically, the reactor is tripped under the following conditions:

$$\Delta T_{SP3} \leq \frac{1+\tau_{13}s}{1+\tau_{14}s} \cdot \frac{1}{1+\tau_{15}s} \Delta T \tag{3.3}$$

As a countermeasure for fluctuations in the reactor vessel outlet hot leg coolant temperature observed in operating plants, a first order time lag or filter circuit (τ_{15}) is added to the ΔT measured value. This reduces temperature fluctuations and enhances plant operating margin.

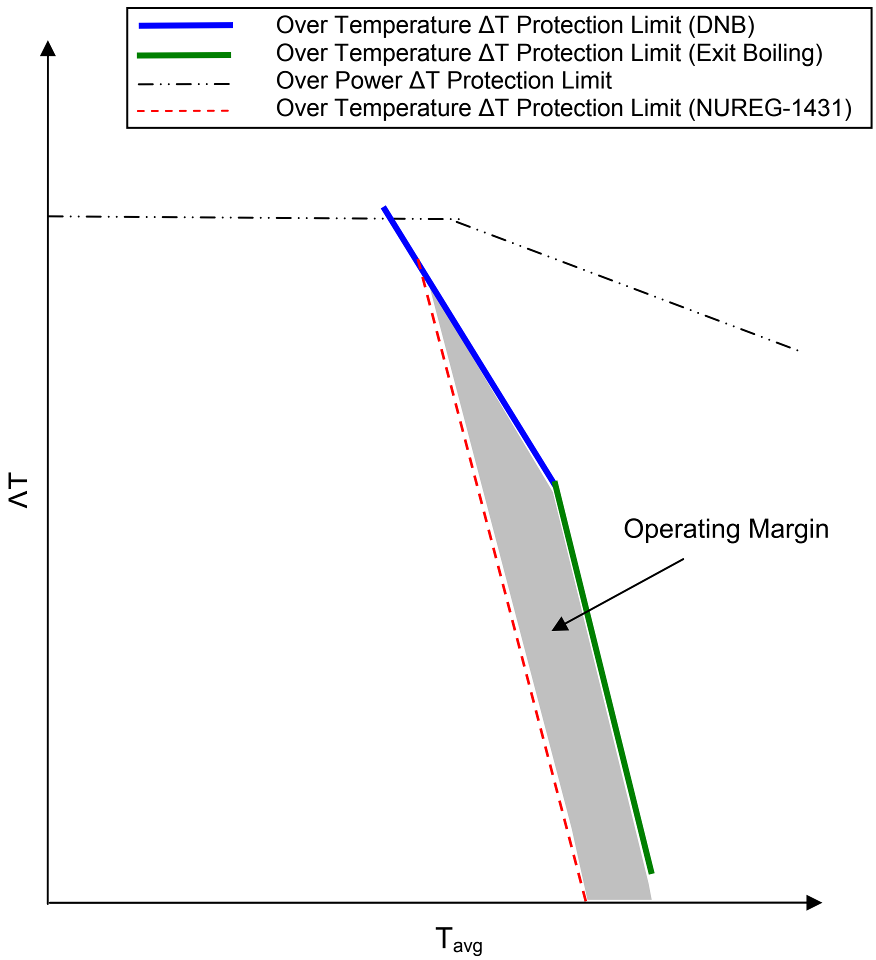

Figure 3.1 Protection Concept of Over Temperature ΔT and Over Power ΔT Reactor Trip

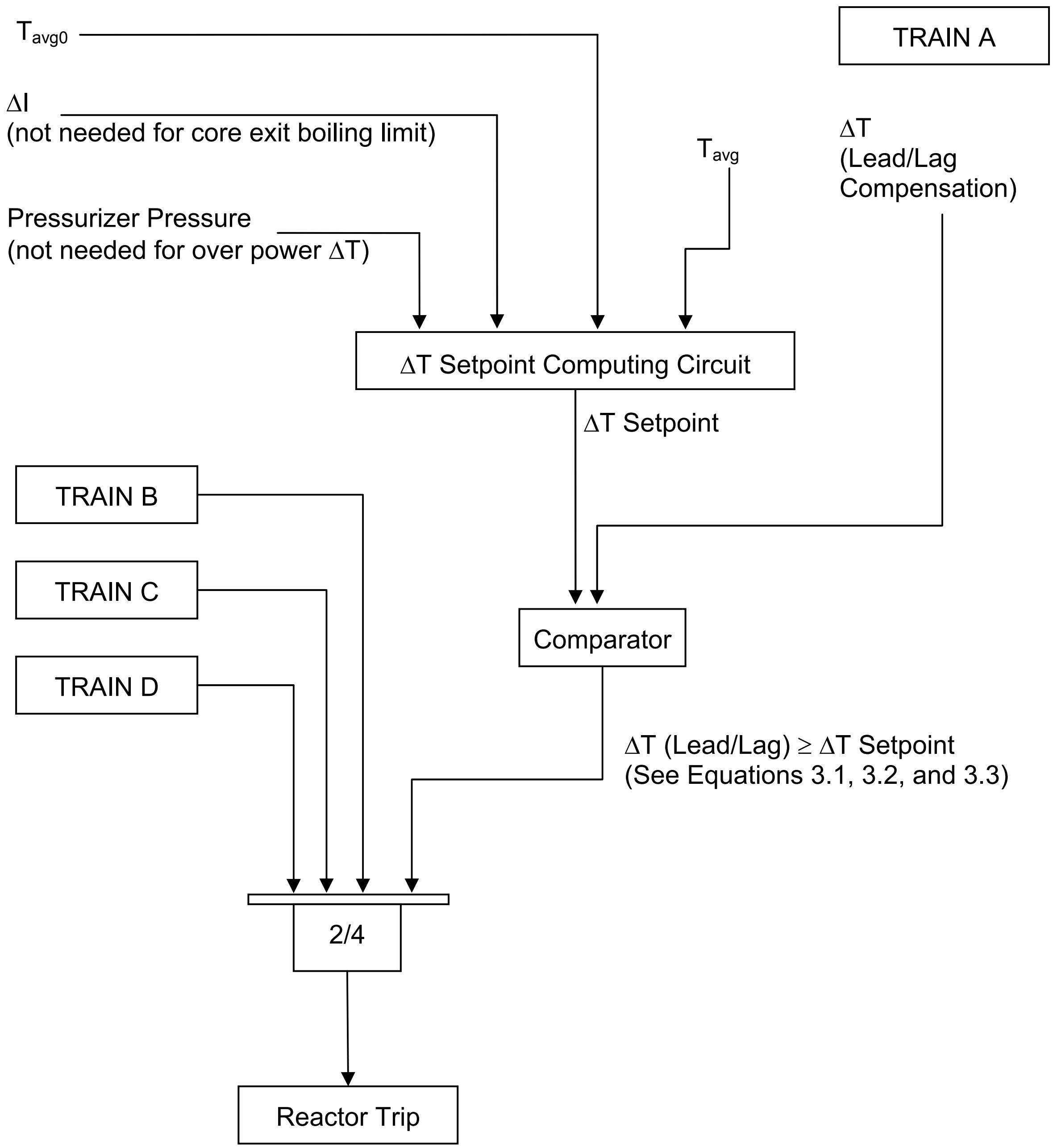

Figure 3.2 Over Temperature ΔT and Over Power ΔT Reactor Trip Logic Diagram

4. Determining Protection Limits

Protection against fuel melt is accomplished by ensuring that the core average thermal power does not exceed a pre-established limit. The core over power limit for fuel melt protection for the US-APWR is set at 120%. This value is used for determining the ΔT reactor trip setpoints in a manner that ensures operational margin is maintained.

If there is no significant core power distribution distortion and the average core power is limited to below 120%, then the fuel centerline temperature can be maintained below the melting point.

To determine the reactor trip setpoints for the three ΔT reactor trip equations, core protection limit curves are developed, excluding transient terms, to limit the average core power below 120% under static conditions.

The static conditions that are protected by the over temperature ΔT and the over power ΔT reactor trip can be expressed as shown in Figure 4.1. The reactor power operating limit curve is downward-sloping even though the core enthalpy increase is constant at 120% power. This is mainly due to the change in the specific heat as the result of temperature changes. For a DNBR equal to the limit value, the DNB operational limit curve is downward-sloping since DNBR will decrease if the T_{avg} increases. In addition, the DNB operational limit curve crosses the core exit boiling operational limit curve when the T_{avg} increases.

Figure 4.1 shows the thermal operational limit area surrounded by an over power limit curve, DNB limit curve and core exit boiling limit curve for a specific RCS pressure. Each of the operational limit curves is calculated for some specific RCS pressure. Since the RCS pressure is protected by the high pressurizer pressure reactor trip and low pressurizer pressure reactor trip, the range of the evaluated RCS pressures is between these two reactor trip setpoints.

The dotted lines in Figure 4.1 show the over temperature ΔT and over power ΔT protection limits. These protection limits are determined as linear limits in order to protect the thermal operational limits shown by the solid lines in Figure 4.1. The detailed method to determine these protection limits are presented in the following subsections.

4.1 Over Temperature ΔT Reactor Trip Setpoint (DNB Protection)

The equation of the over temperature ΔT protection setpoint (DNB protection) is provided in Design Control Document (DCD) Subsection 7.2.1.4.3.1 as follows:

$$\Delta T_{SP1} = \Delta T_0 \left(K_1 - K_2 \frac{(1+\tau_2 s)}{(1+\tau_3 s)} (T_{avg} - T_{avg0}) + K_3 (P - P_0) - f_1(\Delta I) \right) \tag{4.1}$$

Where:

ΔT_{SP1} is the DNB protection setpoint.
ΔT_0 is the indicated RCS ΔT at rated thermal power (RTP).

s is the Laplace transform operator.
T_{avg} is the measured RCS average temperature.
T_{avg0} is the nominal T_{avg} at RTP.
P is the measured pressurizer pressure.
P_0 is the nominal RCS operating pressure.
$f_1(\Delta I)$ is the penalty function of the axial power imbalance (ΔI) (see Section 8).
K_1, K_2, and K_3 are coefficient constants.

The above equation is simplified to the following equation by ignoring the time-dependent terms.

$$\Delta T_{SP1} = \Delta T_0 \left(K_1 - K_2 \ (T_{avg}^C - T_{avg0}) + K_3 \ (P - P_0) \right) \tag{4.2}$$

Where:
T_{avg}^C is the true RCS average temperature.

The over temperature ΔT setpoint is generated from the ΔT versus T_{avg} curves associated with the following operational limits:

a) Reactor power equals 120%
b) Minimum DNBR equal to the analytical limit
c) The hot leg temperature equal to the saturation temperature

These three operational limit curves are indicated by the solid lines in Figure 4.2.

The area that the over temperature ΔT and the over power ΔT reactor trip protect is limited to the area that is not protected by the low pressurizer pressure and high pressurizer pressure reactor trip functions. Therefore, these curves are calculated for the following pressures: 1775 psia (slightly lower than the low pressurizer pressure reactor trip protection limit; P_1), 2000 psia (intermediate value between the previous value and the nominal RCS pressure; P_2), 2250 psia (nominal RCS pressure; P_3), and 2470 psia (slightly higher than the high pressurizer pressure reactor trip protection limit; P_4). The intersection of operational limit curves a) and b) (defined above) is designated as point A and the intersection of operational limit curves b) and c) (defined above) is designated as point B, as indicated in Figure 4.2. Points A and B are then calculated for pressures P_1 through P_4 (A_1 through A_4 and B_1 though B_4, respectively).

These eight intersection points (A_1 through A_4 and B_1 though B_4 in Figure 4.2) are used to determine the constants in Equation 4.2. The coefficient K_2 is a measure of the gradient of T_{avg} versus ΔT. It is determined by calculating the slope of the lines connecting A_1-B_1, A_2-B_2, A_3-B_3 and A_4-B_4 and then conservatively selecting the most negative (A_4-B_4 has most negative slope in Figure 4.2). The coefficient K_3 is a measure of the gradient of RCS pressure versus ΔT. It is determined by calculating the slope of the line connecting A_1-A_4 in the RCS pressure versus ΔT plane. Then the value is confirmed to ensure that A_2 and A_3 are protected by the setpoint equation determined by A_1 and A_4. The coefficient K_1 is an intercept of the equation and is determined considering instrument uncertainty and safety margin.

For each pressure, there is an area above point A that is not protected by the over temperature ΔT reactor trip setpoint. This area is protected by the over power ΔT reactor trip.

4.2 Over Temperature ΔT Reactor Trip Setpoint (Core Exit Boiling Protection)

The equation of the over temperature ΔT protection setpoint (core exit boiling protection) is provided in DCD Subsection 7.2.1.4.3.1 as follows:

$$\Delta T_{SP2} = \Delta T_0 \left(K_4 - K_5 \frac{(1+\tau_4 s)}{(1+\tau_5 s)} \left(T_{avg} - T_{avg0} \right) + K_6 \left(P - P_0 \right) \right) \tag{4.3}$$

Where:

ΔT_{SP2} is the core exit boiling protection setpoint.
ΔT_0 is the indicated RCS ΔT at RTP.
s is the Laplace transform operator.
T_{avg} is the measured RCS average temperature.
T_{avg0} is the nominal T_{avg} at RTP.
P is the measured pressurizer pressure.
P_0 is the nominal RCS operating pressure.
K_4, K_5, and K_6 are coefficient constants.

The above equation is simplified to the following equation by ignoring the time-dependent terms.

$$\Delta T_{SP2} = \Delta T_0 \left(K_4 - K_5 \ (T^{C}_{avg} - T_{avg0}) + K_6 \ (P - P_0) \right) \tag{4.4}$$

Where:

$T_{avg}{}^{C}$ is the true RCS average temperature.

The over temperature ΔT setpoint is generated from the ΔT versus T_{avg} curves associated with the following operational limits:

a) Minimum DNBR equal to the analytical limit
b) The hot leg temperature equal to the saturation temperature

These two operational limit curves are indicated by the solid lines in Figure 4.2.

Similar to the over temperature ΔT DNB protection setpoint process, these curves are calculated for 1775 psia, 2000 psia, 2250 psia and 2470 psia (P_1-P_4) and the intersections of these curves are also named in the same way (B_1-B_4) as indicated in Figure 4.2.

The four intersection points B_1 through B_4 are used to determine the constants in Equation 4.4. The coefficient K_6 is a measure of the gradient of RCS pressure versus T_{avg}. It is determined by calculating the slope of the line connecting B_1-B_4 in the pressure versus ΔT plane. Then the value is confirmed to ensure that B_2 and B_3 are protected by the setpoint equation determined by B_1 and B_4. The coefficient K_5 is the gradient of T_{avg}

versus ΔT and the value is always -2. This is because T_{hot} for core exit boiling operational limit is the saturation temperature corresponding to each specific pressure. Since the ΔT can be expressed by T_{avg} and T_{hot} using the definitions of T_{avg} and ΔT ($T_{avg}=(T_{hot}+T_{cold})/2$, $\Delta T=T_{hot}-T_{cold}$) as shown in the following equation, the slope is always -2 regardless of the pressure.

$$\Delta T = \left(T_{hot} - T_{cold}\right) = \left(T_{hot} - \left(2 \cdot T_{avg} - T_{hot}\right)\right)$$
$$= -2 \cdot \left(T_{avg} - T_{hot}\right)$$

The coefficient K_4 is an intercept of the equation and is determined considering instrument uncertainty and safety margin.

4.3 Over Power ΔT Reactor Setpoint

The equation of the over power protection setpoint is provided in DCD Subsection 7.2.1.4.3.2 as follows:

$$\Delta T_{SP3} = \Delta T_0 \left(K_7 - K_8 \frac{\tau_6 s}{1+\tau_6 s} T_{avg} - K_9 \left(T_{avg} - T_{avg0}\right) - f_2(\Delta I) \right) \quad (4.5)$$

Where:

ΔT_{SP3} is the over power protection setpoint.
ΔT_0 is the indicated RCS ΔT at RTP.
s is the Laplace transform operator.
T_{avg} is the measured RCS average temperature.
T_{avg0} is the nominal T_{avg} at RTP.
$f_2(\Delta I)$ is the penalty function of the axial power imbalance (ΔI) (see Section 8).
K_7, K_8, and K_9 are coefficient constants.

The above equation is simplified to the following equation by ignoring the time-dependent terms.

$$\Delta T_{SP3} = \Delta T_0 \left(K_7 - K_9 \left(T_{avg}^C - T_{avg0}\right)\right) \quad (4.6)$$

Where:

T_{avg}^C is the true RCS average temperature.

The over power ΔT setpoint is generated from the ΔT versus T_{avg} curves associated with the following operational limits:

a) Reactor power equals 120%
b) Minimum DNBR equal to the analytical limit

These two operational limit curves are indicated by the solid lines in Figure 4.3.

Similar to the over temperature ΔT reactor trip setpoint process, these curves are calculated for 1775 psia, 2000 psia, 2250 psia and 2470 psia (P_1-P_4) and the intersections of these curves are also named in the same way (A_1-A_4) as indicated in

Figure 4.3.

The over power ΔT reactor trip setpoint is function of T_{avg} and ΔT and does not depend on the pressure. Therefore, the setpoint is determined to be less than the enveloping curve generated by points A_1 through A_4. The actual process to determine the setpoint is as follows:

1) Determine the point E which is the intersection of the nominal T_{avg} and the line connecting A_2 and A_3
2) The ΔT value at point E is the protection limit when $T_{avg} \leq T_{avg0}$
3) The line E-A_3 or E-A_4 is the protection limit when $T_{avg} > T_{avg0}$ (The limiting case in Figure 4.3 is line E-A_4 since it has the most negative slope and hence bounds A_3.)

The coefficient K_9 is determined by the slope of line E-A_4. The coefficient K_7 is an intercept of the equation and is determined considering instrument uncertainty and safety margin.

4.4 Combined Reactor Trip Setpoints

Figure 4.4 shows the combined protection limits of the over temperature ΔT and over power ΔT reactor trip. This figure shows that these protection limits protect the 120% reactor power operational limit, DNB operational limit, and core exit boiling operational limit at pressures between the low pressurizer pressure reactor trip protection limit and the high pressurizer pressure reactor trip protection limit. Note that the over temperature and over power ΔT reactor trip analytical limits and setpoints are determined based on these protection limits considering the instrument uncertainties and safety margins.

4.5 Validation of Protection Limit Curves During Transient Conditions

The protection limit determined by the aforementioned methods will be confirmed to ensure that the limit appropriately protects the reactor in various transient conditions considering the time constants discussed in Section 3. The coefficients K_1, K_4, and K_7 in the equations define the operating margins against the reactor trip. Therefore, the reactor will trip earlier if these constants are smaller.

The time constants also act to lower the ΔT reactor trip setpoint in accordance with the rate of increase in T_{avg} when RCS temperature increases and the operating condition approaches the reactor trip limit. These values are determined and validated through the analyses of AOOs, postulated accidents (PAs), and operational design transient analyses. This is discussed in Section 7.

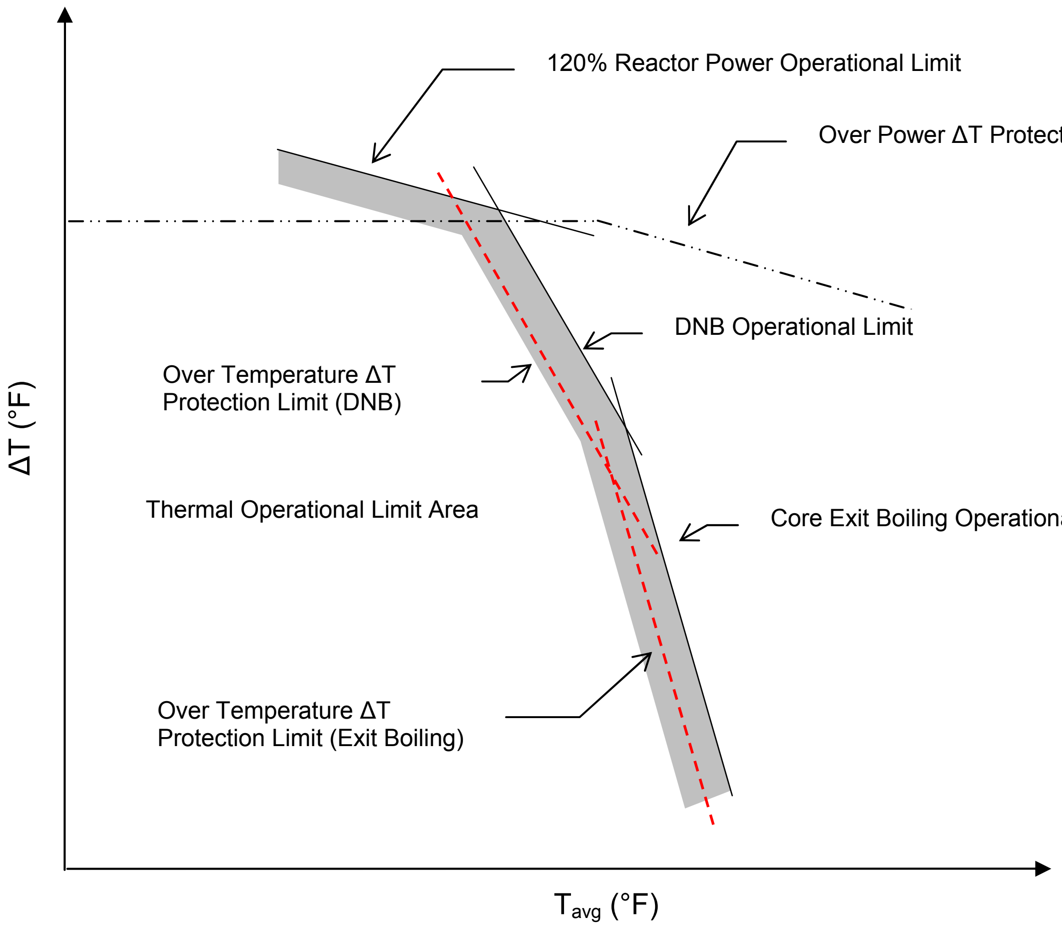

Figure 4.1 Over Temperature ΔT and Over Power ΔT Operational Limits and Protection Limits

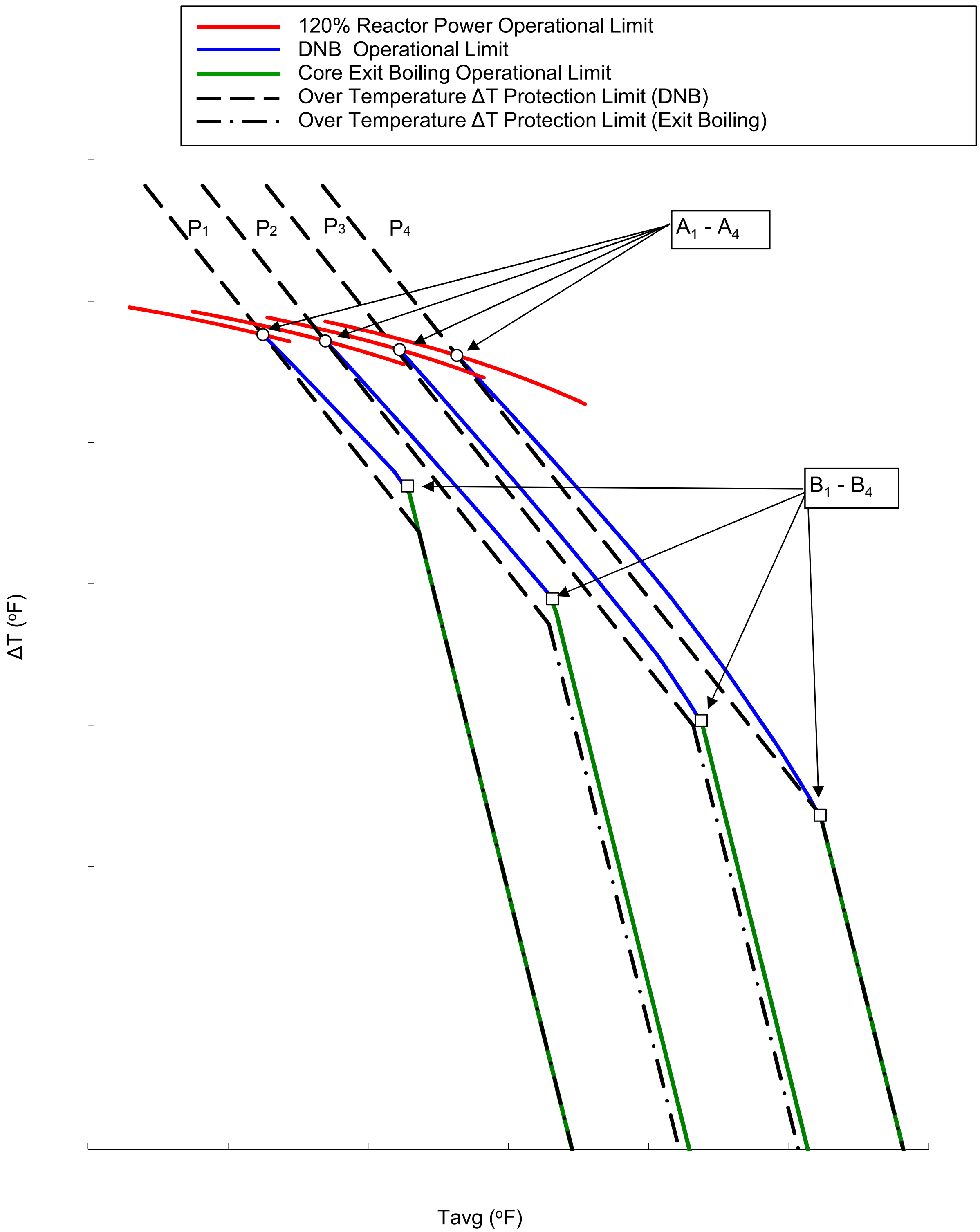

Figure 4.2 Process of Determining the Over Temperature ΔT Reactor Trip Setpoint

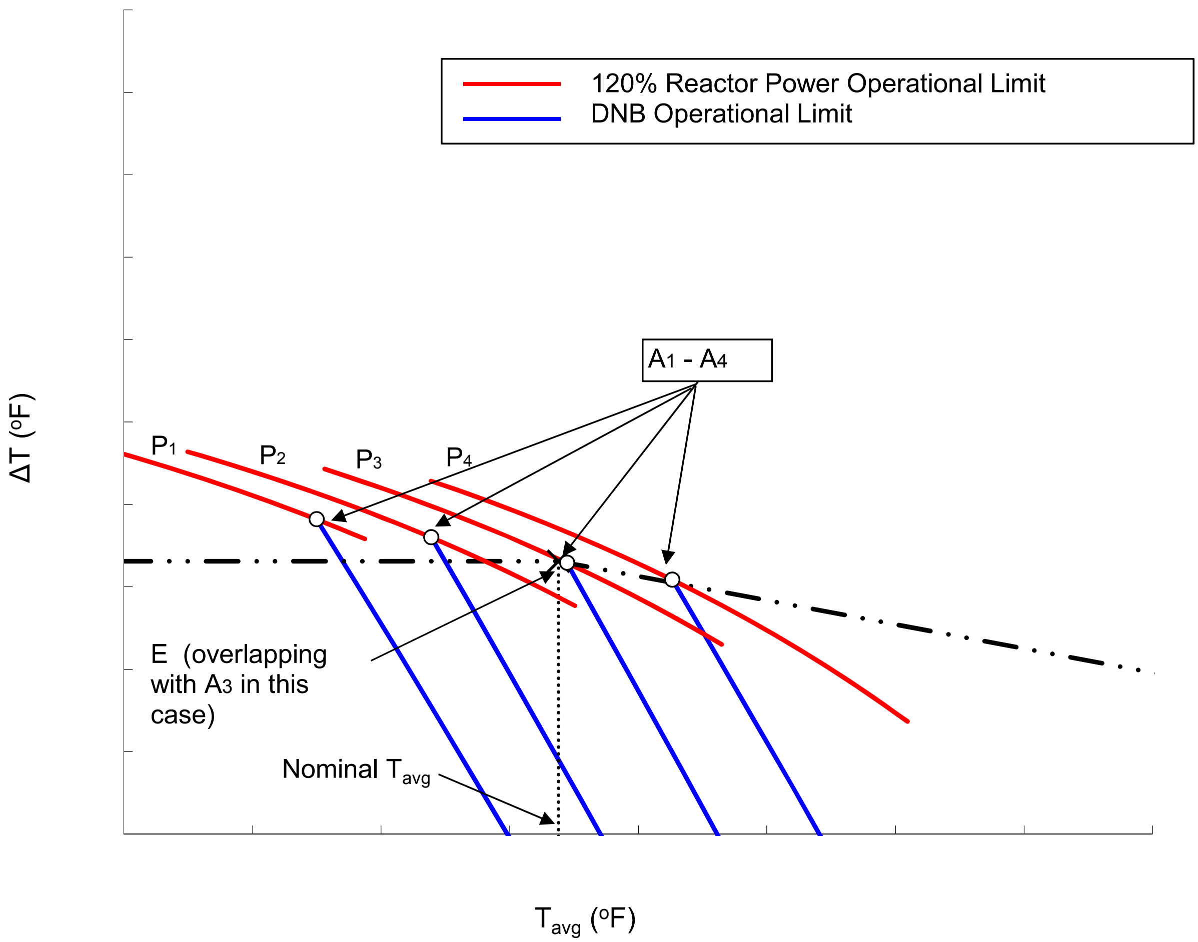

Figure 4.3 Process of Determining the Over Power ΔT Reactor Trip Setpoint

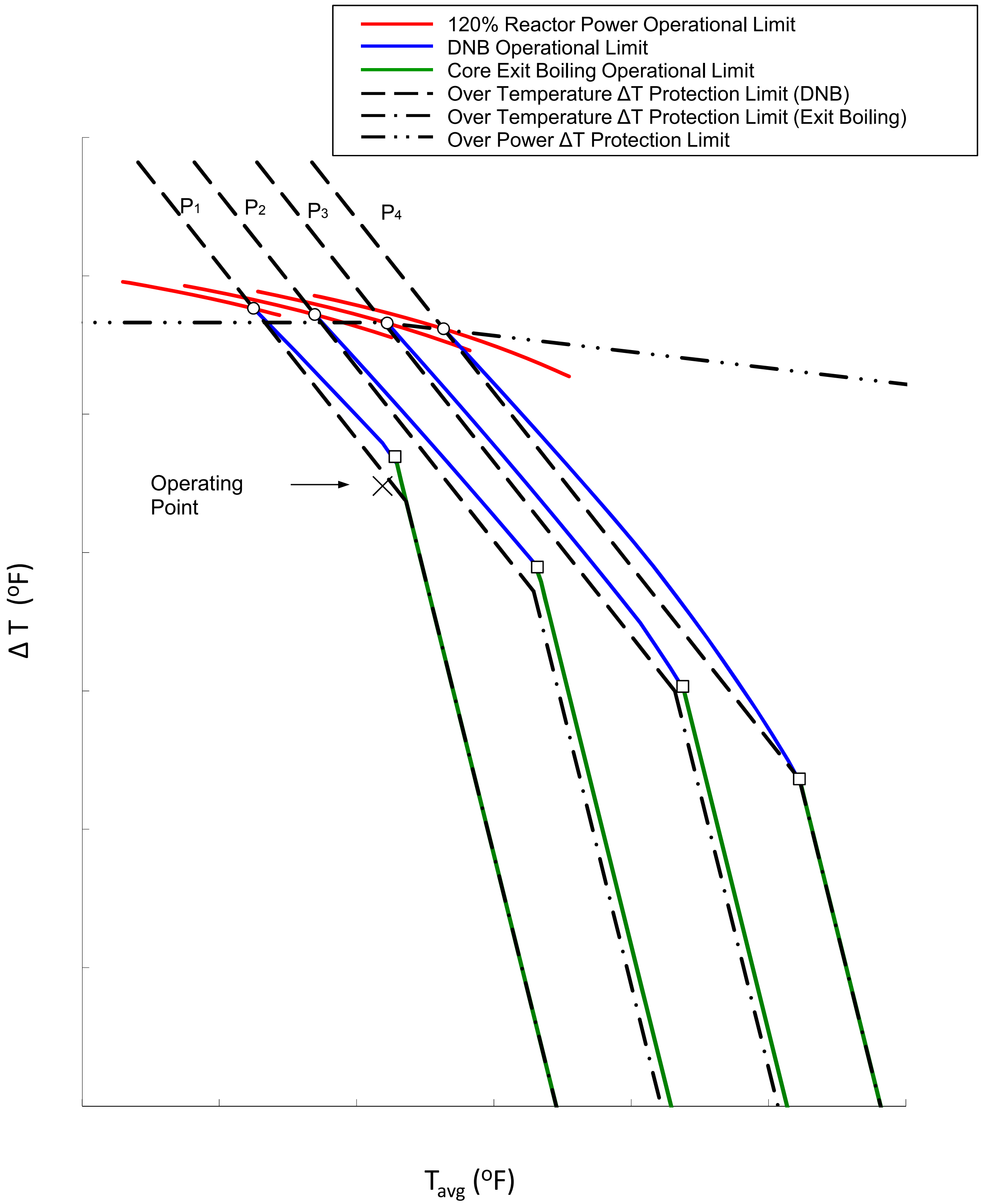

Figure 4.4 Over Temperature ΔT and Over Power ΔT Reactor Trip Protection Limits

5. Determining Reactor Trip Setpoints

The over temperature ΔT and over power ΔT reactor trip setpoints are determined by considering instrumentation error and operating margin (if necessary) on the protection limits. The setpoints are determined in accordance with the US-APWR Instrument Setpoint Methodology report, MUAP-09022 (Reference 3).

6. Protection Limits and Setpoints

The protection limit and setpoint are determined using the methodology described in Section 4. Table 6.1 shows preliminary values of the constants, time constants and parameters. These values are managed by the Setpoint Control Program and determined by the US-APWR Instrument Setpoint Methodology report, MUAP-09022 (Reference 3). Both the protection limit (P.L.) and the setpoint values are shown in Table 6.1. The protection limits generated by the values in Table 6.1 are shown in Figure 6.1.

Table 6.1 Over Temperature ΔT and Over Power ΔT Reactor Trip Preliminary Setpoints

Over Temperature ΔT (DNB Limit)		
Constants	K_1 (P.L.)	1.154
	K_1 (Setpoint)	1.098
	K_2 (1/°F)	0.009685
	K_3 (1/psi)	0.0003529
T_{avg} (Lead/Lag)	τ_2/τ_3 (sec)	25 / 3
ΔT (Lead/Lag)	τ_7/τ_8 (sec)	8 / 3
First order delay	τ_9 (sec)	2
Over Temperature ΔT (Core Exit Boiling Limit)		
Constants	K_4 (P.L.)	2.055
	K_4 (Setpoint)	1.959
	K_5 (1/°F)	0.03086
	K_6 (1/psi)	0.002098
T_{avg} (Lead/Lag)	τ_4/τ_5 (sec)	12 /3
ΔT (Lead/Lag)	τ_7/τ_8 (sec)	8 / 3
First order delay	τ_9 (sec)	2
Over Power ΔT		
Constants	K_7 (P.L.)	1.162
	K_7 (Setpoint)	1.106
	K_8 (1/°F)	0.0278
	K_9 (1/°F)	0.0009029
T_{avg} (Rate/Lag)	τ_6 (sec)	3
ΔT (Lead/Lag)	τ_{13}/τ_{14} (sec)	9/3
First order delay	τ_{15} (sec)	2
Other Parameters		
Reactor Parameters	Nominal T_{avg} (°F)	583.3
	Nominal ΔT (°F)	64.8
DNBR Methodology	Thermal Design Methodology	RTDP
	Analytical Limit	1.45

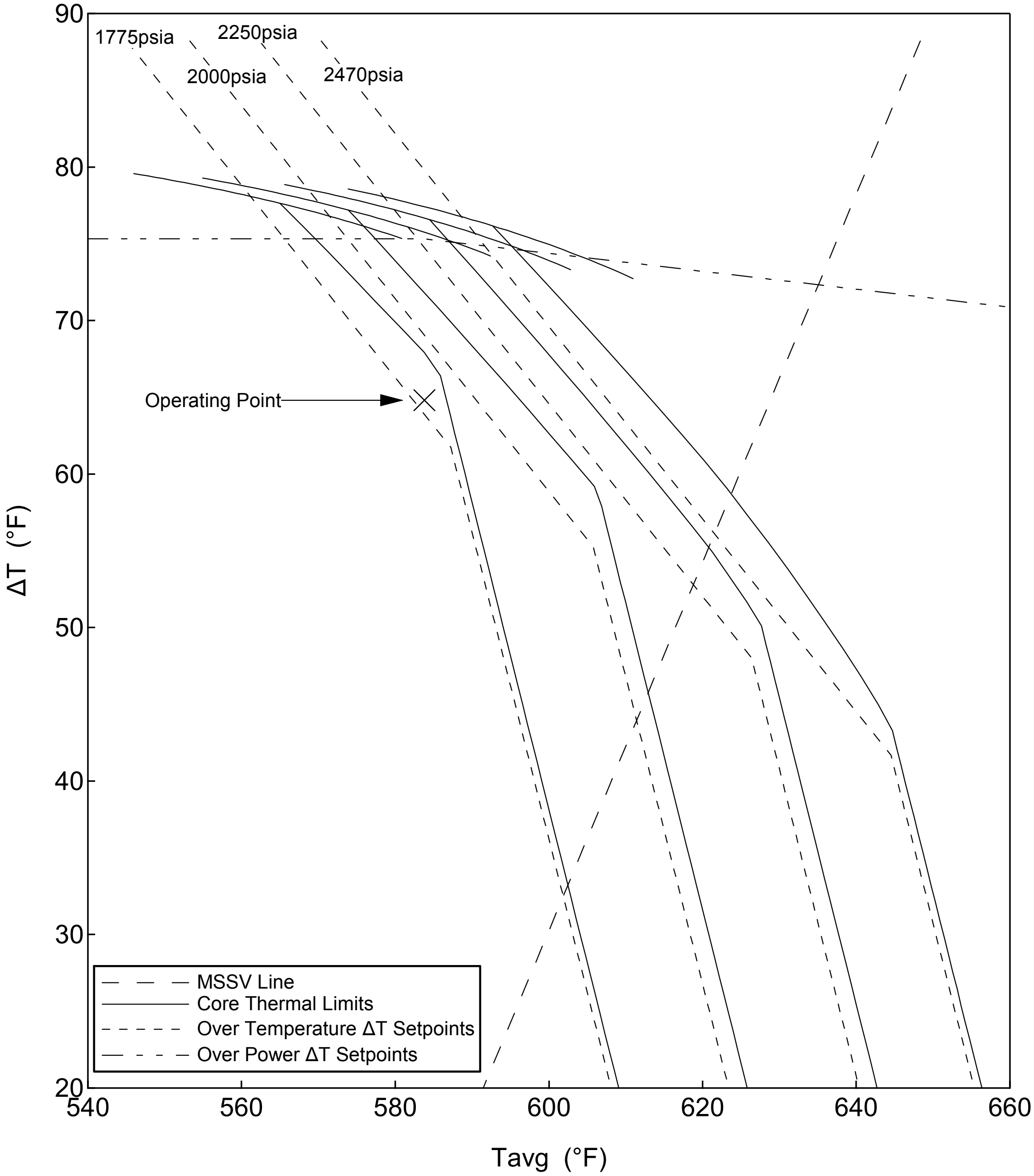

Figure 6.1 US-APWR Over Temperature ΔT and Over Power ΔT Reactor Trip Protection Limits

7. Time Constants

The time constants in the equations described in Sections 3 and 4 are determined such that the reactor trip function works appropriately during transient conditions. The time constants in Equations 4.1, 4.3, and 4.5 act to lower the ΔT setpoint in accordance with the rate of increase in T_{avg} when RCS temperature increases and the operational condition approaches the reactor trip limit. These values are determined in order to compensate the resistance temperature detector (RTD) measurement for the temperature delay between the primary coolant in the core, the hot leg, and the cold leg.

7.1 Removal of Lead/Lag Compensation

For the measurement of primary coolant temperature, the lag processing of the measured RCS average temperature is deleted since the US-APWR will utilize a well-type RTD instead of the RTD with bypass-line used in some operating plants. Lag processing, which is included in the equations in NUREG-1431 (T_6 in Table 3.3.1-1 Notes 1 and 2 of Reference 2), for the measured RCS average temperature was previously used for noise filtering because the RTD with bypass-line responds relatively quickly to changes in temperature. On the other hand, lag processing for noise filtering of the measured RCS average temperature in the US-APWR is no longer necessary because the installed RTD responds slower due to the thermal mass associated with the RTD enclosure. Therefore, Equations 4.1, 4.3, and 4.5 contain no lag processing of the RCS average temperature measurement since this processing is not necessary for the US-APWR primary coolant temperature measurement system.

7.2 Safety Analysis Validation of Time Constants

The numerical values of the time constants presented in Table 6.1 are validated by confirming that the acceptance criteria are met in the safety analysis and by confirming that spurious reactor trips do not occur in operational design transients.

The safety analyses of AOOs and PAs rely on various reactor trips to prevent the violation of acceptance criteria. For certain events, the over temperature ΔT and over power ΔT reactor trips provide this protection. The time constants used in the over temperature ΔT and over power ΔT reactor trip setpoints are validated by performing the safety analysis for the applicable events. Appropriate time constant values will ensure that the applicable acceptance criteria are met for all events analyzed in the safety analysis that credit the over temperature ΔT and over power ΔT reactor trips.

Note that most events are protected by multiple reactor trips. The reactor trip that provides protection for a particular event depends on event-specific conditions. For example, the rod cluster control assembly (RCCA) withdrawal at power event is protected by the high power range neutron flux reactor trip when the reactivity insertion rate is large and the increase in the neutron flux is rapid. However, this reactor trip function cannot protect when the reactivity insertion rate is small and therefore the over temperature ΔT reactor trip protects the reactor in these cases. As a result, the safety analysis carefully considers the various combinations of initial conditions and event-specific characteristics that could require the protection of the over temperature ΔT and over power ΔT reactor trips.

8. Penalty Functions

The terms $f_1(\Delta I)$ and $f_2(\Delta I)$ in Equations 4.1 and 4.5 are the penalty functions of the axial power imbalance (ΔI) which is calculated from neutron flux difference between the upper and lower portion of the power range neutron flux detectors. When there is significant core axial power distribution distortion, these penalty functions reduce the over temperature ΔT reactor trip (DNB protection) setpoint and/or the over power ΔT reactor trip setpoint in order to prevent exceeding applicable fuel design limits for AOOs. The functions are determined as part of the design process for each core design.

9. References

This section provides the references discussed within this technical report.

1. Thermal Design Methodology, MUAP-07009-P (Proprietary) and MUAP-07009-NP (Non-Proprietary), May 2007.

2. Standard Technical Specifications Westinghouse Plants, NUREG-1431, Rev. 2, April 2001.

3. US-APWR Instrument Setpoint Methodology, MUAP-09022-P Rev.2 (Proprietary) and MUAP-09022-NP Rev.2 (Non-Proprietary), May 2011.