Post Exam Comments on RO Question #61

Facility Comments

Upon review of the exam with the candidates, it was pointed out that for question #61, choice "D" is also a correct answer. To validate the possibility of two, and only two, correct answers for question #61, we ran a scenario on the simulator that effectively matches the conditions given in the stem of the question. We used Plant Process Computer (PPC) trends to track several points applicable to the parameters described in each of the question choices and the results are attached.

To further clarify the link between various parameters involved in question #61, we have included excerpts from the discussion section of normal operating procedure OP 2204, "Load Changes". Contained there is a detailed explanation of the relationship between steam generator pressure and T_{cold} during a power change in both directions (next to last paragraph, page 4 of 75) and the effects of not keeping temperature on program during a power change (following page).

Upon evaluation of the question and the attached information, we believe that choices "B" and "D" are clearly both correct for question #61.

Included in this report:

Page 1 – This page

Page 2 – Question #61 Detail Answer Key

Pages 3 & 4 – An explanation of the thermodynamic principals of question #61

Page 5 – Figure 1 Trends of #1 SG Pressure, Loop 1 T_{COLD}, RCS T_{AVG}

Page 6 – Figure 2: Trends of 15 Second Calorimetric, Loop 1 Delta-T, Reactor Power, MW Electric

Page 7 – Figure 3: RCS T_{COLD} Program Band

Page 8 – Figure 4: RCS T_{HOT}, T_{AVG} and T_{COLD} Training Drawing

Page 9 – Figure 5: ΔT vs. ΔT Power Training Drawing

Pages 10, 11 & 12 – General Physics explanation of Moderator Temperature Coefficient (MTC)

Page 13 & 14 – OP 2204, Rev. 24, Pages 4 & 5 (Discussion Section)

RO and SRO Exam Questions (No "Parents" Or "Originals")

Question #: 61 | Question ID: 1100029 | ☑ RO | ☐ SRO | ☐ Student Handout? | ☐ Lower Order?
Rev. 0 | ☑ Selected for Exam | Origin: New | ☐ Past NRC Exam?

Given the following conditions:

- The plant is at 95% power, starting up following a refueling outage.
- All systems are in a normal lineup to support 100% power operation.
- CONVEX orders an Emergency Generation Reduction to 580 MWe within the next 15 minutes.
- The crew initiates AOP 2557, "Emergency Generation Reduction"

While performing the Emergency Generation Reduction, Turbine load was lowered more quickly than the Operator on the Steam Dumps could respond. While attempting to stabilize the plant, the Operator on the Steam Dumps reported that S/G pressures were at 870 psia and rising. Steam and Feed flows were lowering.

Which of the following describes the impact on the stated parameter or calculated value, as compared to its value prior to the turbine load reduction?

☐ **A** Narrow Range Power will rise due to the lower density of the primary coolant.

☑ **B** Reactor Power will lower due to the rise in Reactor Coolant temperature.

☐ **C** Calorimetric power will rise due to the rise in Steam Generator Enthalpy.

☑ **D** Delta T Power will lower due to the rise in RCS Cold Leg temperature.

The attached simulator PPC trends demonstrate that Narrow Range Power and Calorimetric Power do NOT rise; therefore,choices "A" and "C" are NOT correct.

Choice "D" is ALSO correct due to the following:
1) Rise in SG pressure causes a rise in Tcold.
2) Rise in Tcold causes a drop in reactor power.
3) Thot does NOT rise proportionally with Tcold due to drop in Rx power and steam demand.
4) Tcold rising faster than Thot results in lower Delta-T Power (See plots next page).

Question Misc. Info: MP2"LOIT 2557, NRC-2011

Justification

B - CORRECT; Even though the core is at BOL conditions, at this power level MTC would still be negative. Therefore, rising S/G pressure and lowering Feed flow will result in rising RCS temperature, which will add negative reactivity causing power to lower.

D - <u>Also</u> CORRECT; Even though the reactor is at BOL conditions, at this power level, MTC would be negative. Therefore, as Tcold rises from the excessive "load reject", nuclear power will lower, resulting in Tcold rising faster than Thot (effectively - Delta-T lowers).
Plausible; Examinee may believe that because the core is at BOL conditions it would have a positive MTC. (MTC is positive at low power conditions BOL.)

A - WRONG; A rise in RCS temperature will cause primary coolant density to lower; however, the negative MTC will overshadow the effects of changing density.
Plausible; The examinee may remember that rising water temperature causes density to lower. The lower density will result in increased leakage to the neutron detectors.

C - WRONG; If S/G temperature rises, then S/G enthalpy will also rise; however, feed flow is the biggest contributor to the calorimetric.
Plausible; If S/G temperature and pressure rise, then S/G enthalpy will also rise.

References

1. RE Curve and Data Book, Moderator Temperature Coefficient Versus Boron Concentration, RE-G-03
2. Reactivity Imbalances LP, RIB-01-C
3. Admin Controls: Reactivity Management, ADM-01-C

Comments and Question Modification History

01/06/11; Reworded the question statement in the stem to clarify what was being asked, per comment from Sandy Doboe.
07/25/11; Per NRC comments: Changed question stem to "Turbine load" vs. "Generator output. Reworded stem and question such that it clearly indicates an operation resulting a rise in RCS temperature. Reworded all the Choices to ensure plausibility. - RJA
09/02/11; per NRC comments, modified stem question statement to clarify what the parameter values stated in the choices are being compared with. - rlc
09/19/11; per Exam Validation, to eliminate confusion as to whether choices refer to "actual" values or "indicated" values <u>compared</u> to actual values, each choice was modified to remove the word "indicate" and made grammatically correct based on removing it. - rlc
10/17/2011; During the exam review, it was noted that Choice "D" is also a correct answer. Credit was given for 2 correct answers. Question Justification was edited for choice "D" being correct. Minor typographical errors were corrected in the stem. - rlc

NRC K/A System/E/A **System** 035 Steam Generator System (S/GS)

Number K5.01 **RO** 3.4 **SRO** 3.9 **CFR Link** (CFR: 41.5 / 45.7)

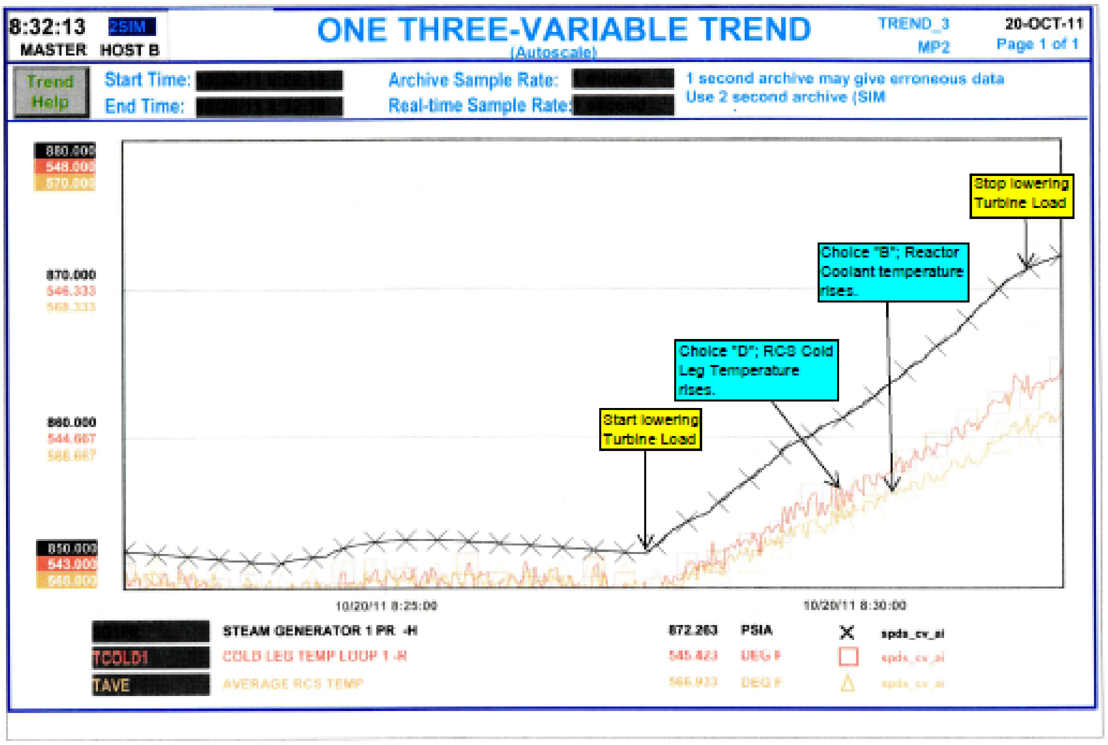
Knowledge of operational implications of the following concepts as the apply to the S/GS: Effect of secondary parameters, pressure, and temperature on reactivity

An explanation of the thermodynamic principles of question #61	
T_{AVG} is the mathematical average of the Reactor Coolant System (RCS) hot and cold legs; $T_{AVG} = (T_H + T_C)/2$. It is important to note, however, that although RCS T_{AVG} is an important parameter that is often monitored and utilized, it is not what operators focus on controlling during a planned power change. Instead, the operators closely monitor T_{COLD} when controlling the plant during a transient condition. T_{COLD} is procedurally required to be maintained at a specific value that varies with power because numerous plant design criteria are based on T_{COLD} being at a specific value for a given power level. RCS T_{AVG} remains proportional to T_{COLD} as power level is changed, and it is because the two temperatures are so directly related that they are often <u>both</u> referred to as simply "RCS temperature".	See Figure 4 See Figure 3
The following explanation uses basic thermodynamics to describe how Steam Generator (SG) pressure and RCS temperatures respond to changes in Turbine Load, as it pertains to question #61.	
<u>Consider these formulas</u>: <u>First Equation</u>:	
$\dot{Q}_{RX} = \dot{m} c_P \Delta T_{RCS}$, Where:	
$\dot{Q}_{RX}$ = Energy transfer from the reactor to the RCS (directly related to reactor power)	
$\dot{m}$ = RCS mass flow rate (This is constant if reactor power is > 0%)	
c_P = Constant of Proportionality for water (This is constant for this purpose)	
$\Delta T_{RCS} = T_H - T_C$, Where:	
T_H = T_{Hot}, or the RCS Hot Leg temperature	
T_C = T_{Cold}, or the RCS Cold Leg temperature	
RCS ΔT is calculated and displayed by the Reactor Protection System (RPS) as **Delta-T Power.** *The PPC does <u>not</u> calculate or monitor Delta-T Power.*	See Figure 5
Because $\dot{m}$, c_P are both constant, the <u>first</u> equation becomes: $\dot{Q}_{RX} \propto \Delta T_{RCS}$ or $\dot{Q}_{RX} \propto T_H - T_C$	
<u>Second Equation</u>	
$\dot{Q}_{SG} = UA \Delta T_{RCS-SG}$, Where:	
$\dot{Q}_{SG}$ = Rate of energy transfer from the RCS to the SG (related to rate of energy entering the RCS and leaving the SG)	
UA = SG tube heat transfer coefficient and SG heat transfer area (these quantities are constant)	

$\Delta T_{RCS-SG} = T_C - T_{STM}$ Where:	
T_C = T_{cold}, or the RCS Cold Leg temperature	
T_{STM} = Temperature of the steam in the SG	
Because U and A are both constant, the <u>second</u> equation becomes: $\dot{Q}_{SG} \propto \Delta T_{RCS-SG}$ or $\dot{Q}_{SG} \propto T_C - T_{STM}$	
For the plant to remain stable at a specific power level, The rate and quantity of energy transfer from the reactor to the turbine must be equal. Therefore, $\dot{Q}_{RX}$ and $\dot{Q}_{SG}$ must be equal.	
Question #61 began with the operators shifting turbine load to the Steam Dump Valves, by slowly opening the steam dumps while simultaneously closing the turbine control valves. If done correctly, there would be no change in the energy coming into or leaving the SG. However, the question went on to state that turbine load (energy from the SG to the turbine) was reduced faster than the steam dumps were opened. Effectively, energy leaving the SG was reduced too fast, resulting in more energy entering the SG from the RCS than is now leaving. This would cause an energy "build-up" in the SG and the RCS and result in a rise in RCS temperature. However, because of the manner in which the energy build-up occurred, RCS T_{COLD} will rise faster than RCS T_{HOT}, causing an overall drop in RCS ΔT.	See Figure 1
The energy contained in water and steam is often referred to as *enthalpy*. As the SG is a saturated system, a rise in the enthalpy of the SG water and steam would require a rise in SG *temperature* (T_{STM}) and, therefore, a rise in SG *pressure*, based on the generally accepted properties of steam and water.	See Figure 1
Although the rise in SG enthalpy would tend to cause a rise in the secondary Calorimetric, the drop in turbine load would result in a proportional drop in SG feed flow. Because SG feed flow has a mathematically higher affect on the secondary Calorimetric calculation, this drop would lower the *calorimetric value*.	See Figure 2 Calorimetric *lowers* (Choice "C" is <u>wrong</u>)
Assuming the rate of energy entering the RCS has not *yet* changed, a rising T_{STM} would have the following effect in the <u>second</u> equation:	
$\dot{Q}_{SG} = T_C\uparrow - T_{STM}\uparrow$ [With $\dot{Q}_{Stm}$ constant, if $T_{STM}\uparrow$, then $T_C\uparrow$]	
Again, assuming the rate of energy transfer has not *yet* changed, the initial rise in T_C would have the following effect in the <u>first</u> equation:	
$\dot{Q}_{RX} = T_H\uparrow - T_C\uparrow$ [With $\dot{Q}_{RX}$ constant, if $T_C\uparrow$, then $T_H\uparrow$]	
Rising RCS temperature (T_C) would result in a negative reactivity addition to the reactor due to the presence of a negative Moderator Temperature Coefficient (MTC) [1]. This would quickly cause power produced by the reactor to begin lowering, which would limit the rise in T_H.	See Figure 2 Reactor Power *lowers* (Choice "B" is <u>correct</u>)
This drop in reactor power production would be seen as a drop in nuclear power on the RPS *Narrow Range* (Safety) Channels.	Narrow Range lowers (Choice "A" is <u>wrong</u>)
Using the <u>first</u> equation again, T_C rising faster than T_H causes ΔT_{RCS} to drop. $T_H\uparrow - T_C\Uparrow = \Delta T_{RCS}\downarrow$ Which means, by definition, **ΔT Power** goes down.	See Figure 2 **ΔT Power** *lowers* (Choice "D" is <u>correct</u>)

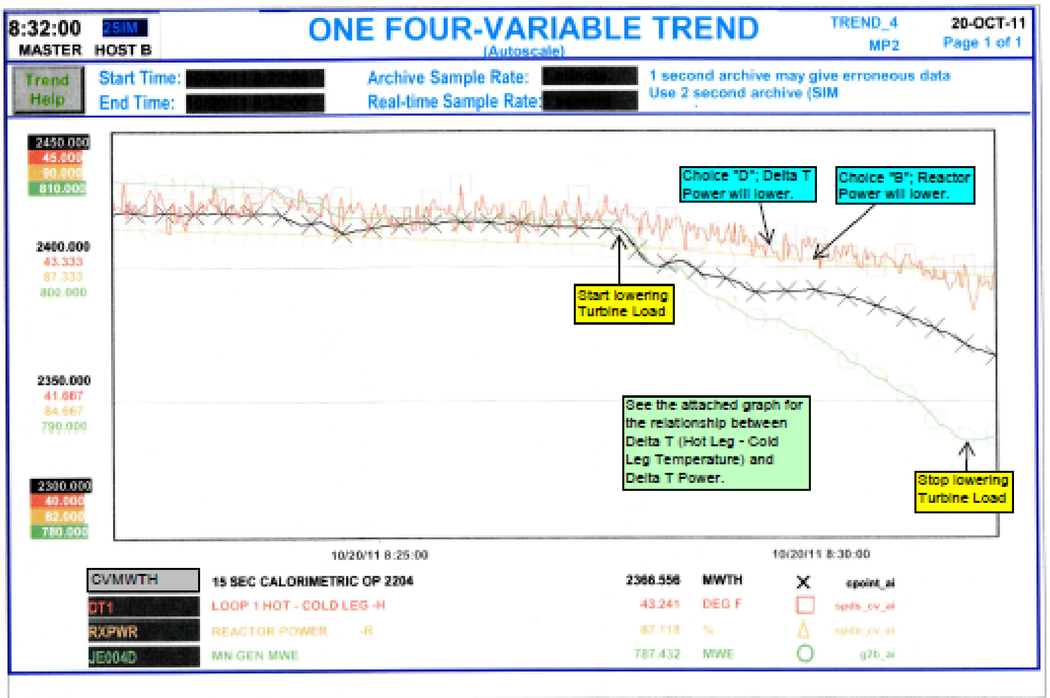
Note 1: An explanation of MTC follows.

Figure 1



These trends were generated from data obtained on the Unit 2 Simulator. The changes in the displayed parameters are caused by lowering Turbine Load without any other operator actions, similar to the event described in Question #61. The main difference in this case is that initial Reactor power is 89% vs. 95% power described in Question #61. Turbine load was lowered to obtain 870 psia in the Steam Generators, as in Question #61. The objective of this display is to show the response of the parameters listed in the various choices of Question #61 and to show that both Choices "B" and "D" are correct.

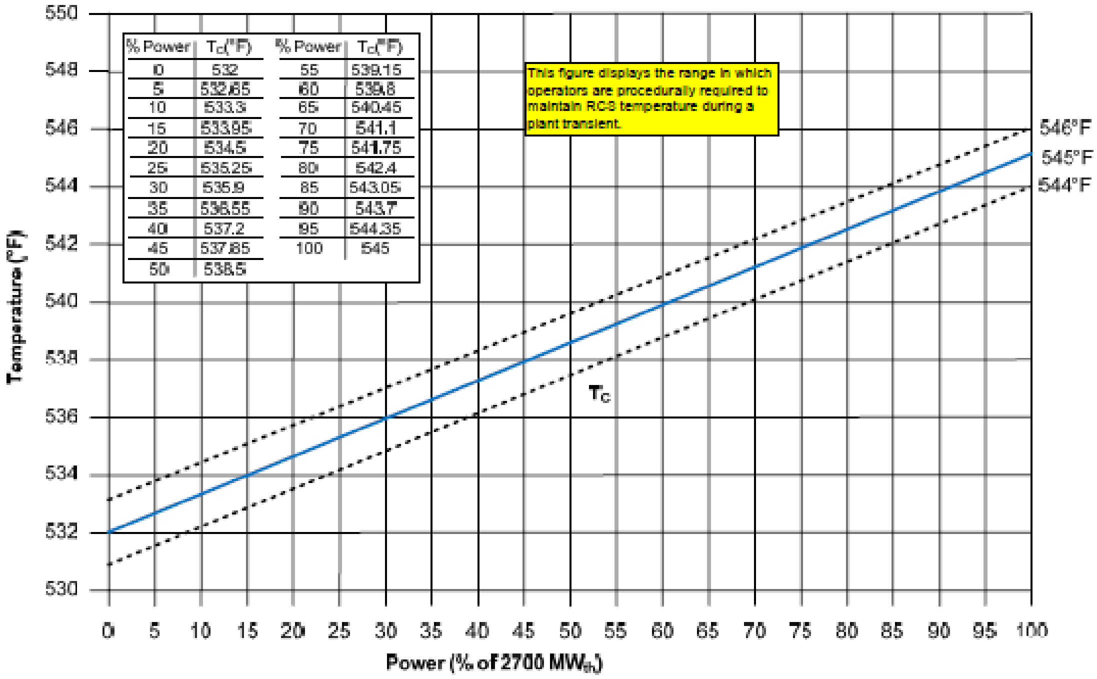
Figure 2



These trends were generated from data obtained on the Unit 2 Simulator. The changes in the displayed parameters are caused by lowering Turbine Load without any other operator actions, similar to the event described in Question #61. The main difference in this case is that initial Reactor power is 89% vs. 95% power described in Question #61. Turbine load was lowered to obtain 870 psia in the Steam Generators, as in Question #61. The objective of this display is to show the response of the parameters listed in the various choices of Question #61 and to show that both Choices "B" and "D" are correct.

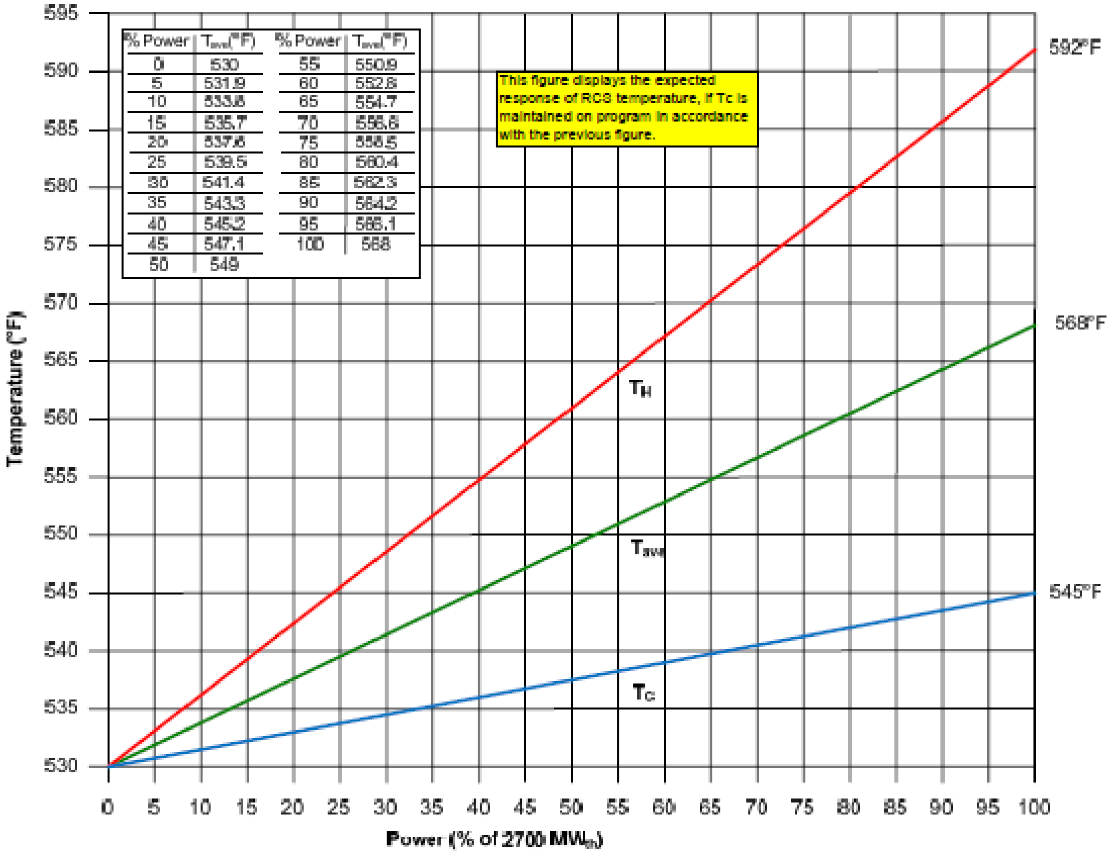
Figure 3

Tc Program Band

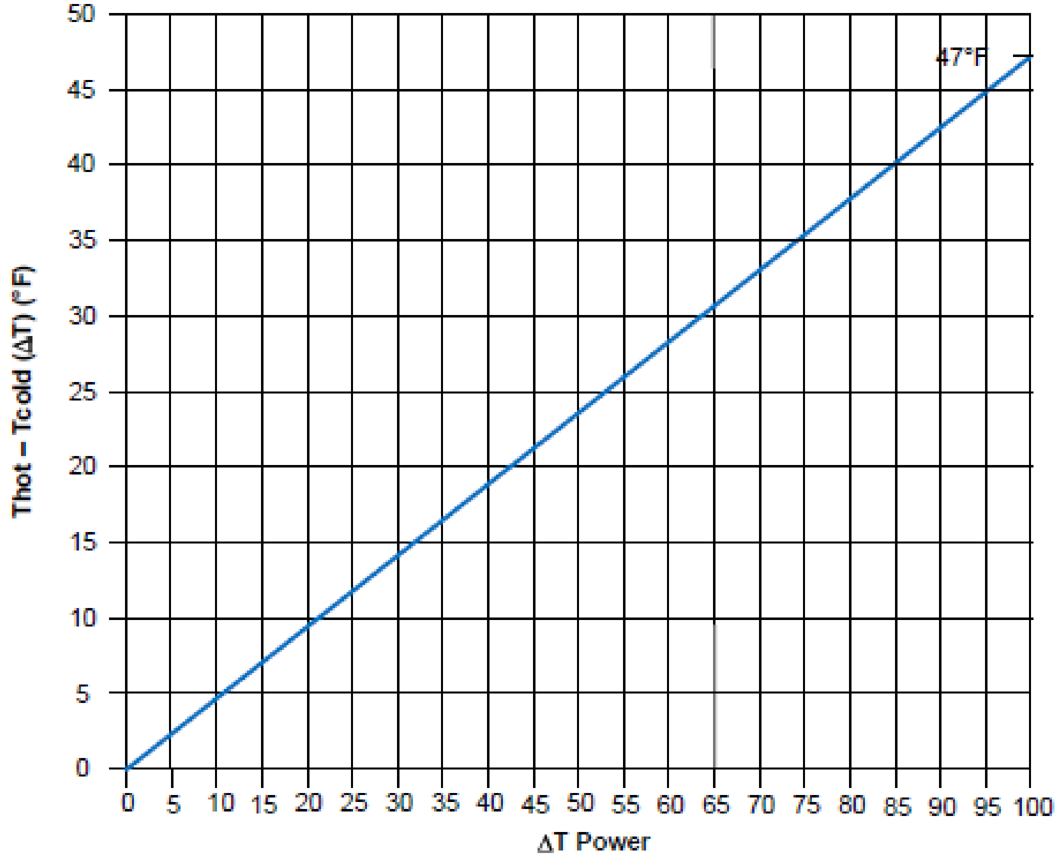


% Power	T_C(°F)	% Power	T_C(°F)
0	532	55	539.15
5	532.65	60	539.8
10	533.3	65	540.45
15	533.95	70	541.1
20	534.5	75	541.75
25	535.25	80	542.4
30	535.9	85	543.05
35	536.55	90	543.7
40	537.2	95	544.35
45	537.85	100	545
50	538.5		

Figure 4



% Power	T_{ave} (°F)	% Power	T_{ave} (°F)
0	530	55	550.9
5	531.9	60	552.8
10	533.8	65	554.7
15	535.7	70	556.6
20	537.6	75	558.5
25	539.5	80	560.4
30	541.4	85	562.3
35	543.3	90	564.2
40	545.2	95	566.1
45	547.1	100	568
50	549		



ΔT vs. ΔT Power

MODERATOR TEMPERATURE COEFFICIENT (α_M)

The moderator temperature coefficient (MTC) predicts changes in reactivity resulting from changes in moderator temperature. MTC is defined as the change in reactivity per unit change in the temperature (°F) of the moderator.

$$\alpha_m = \frac{\Delta\rho}{\Delta T_{mod}}$$

$$\alpha_m = \left(\frac{\Delta\rho}{\Delta T_{mod}}\right) = \frac{\rho_{final} - \rho_{initial}}{T_{modfinal} - T_{modinitial}}$$

Where:

α_m = moderator temperature coefficient (MTC)($\Delta k/k$/°F)

$\Delta\rho$ = change in reactivity associated with change in moderator temperature ($\Delta k/k$)

ΔT_{mod} = change in moderator temperature (°F)

Equation 4-4

The symbol α_m or α_T is also used to represent the moderator temperature coefficient (MTC). The symbol α_m will be used in this text.

A reactor operating at 530°F has a k_{eff} = 1.000. The moderator temperature is increased to 540°F and k_{eff} decreases to 0.999. What is the value of the moderator temperature coefficient?

Solution:

Example 4-1

A good approximation for the average value of α_m is $-1\times10^{-4}\Delta k/k$/°F for the normal range of moderator temperature at power.

© 2007 GENERAL PHYSICS CORPORATION

Click to go to the next page in the document

For the moderator (water), an increase in temperature results in a decrease in density. As shown in Figure 4-1, the magnitude of the density change for a given temperature change gets larger with increasing temperatures.

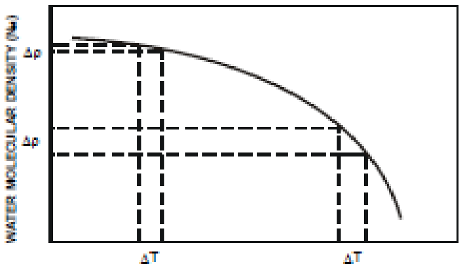


Figure 4-1 Moderator Temperature and Density Changes (at Power)

This can be more accurately seen with numerical values from the steam tables.

Table 4-1 Density Change for 4°F Temperature Change

From Steam Tables		
Temperature (°F)	Density (lb_m/ft^3)	
92	62.09252	
96	62.04629	
4°F temperature	Change in density	-0.046231
192	60.29545	
196	60.20107	
4°F temperature	Change in density	-0.094376
292	57.5374	
296	57.43825	
4°F temperature	Change in density	-0.099145
392	53.96654	
396	53.82131	
4°F temperature	Change in density	-0.145228
492	49.35834	
496	49.16421	
4°F temperature	Change in density	-0.194133
592	42.95533	
596	42.64392	
4°F temperature	Change in density	-0.311403
T↑		ρ↓

This results in the magnitude of the moderator temperature coefficient being larger (more negative) at higher temperatures. The moderator temperature coefficient for a one degree change at a high temperature (499 to 500°F) is more negative than the moderator temperature coefficient at a low temperature (99 to 100°F).

Since reactivity is defined in terms of the effective multiplication factor, k_{eff}, it is necessary to examine how moderator temperature changes affect the effective multiplication factor or, more specifically, the six factors. Recall:

$$k_{eff} = \varepsilon L_f \, p \, L_{th} \, f \, \eta$$

Equation 4-5

We have shown that an increase in moderator temperature results in a decrease in water density. This causes an accompanying increase in slowing down and thermal diffusion lengths. This is expected since the moderator atoms are farther apart, requiring neutrons to travel farther between collisions.

Increasing the slowing down length increases the probability that a neutron may reach the fuel while still at resonance energy. Since the slowing down length increases, the slowing down time also increases. This means that the neutrons spend more time at resonance energy levels. The probability of a neutron escaping resonance capture is reduced; therefore the resonance escape probability (p) decreases. This effect is shown on the plot for p in Figure 4-2.

© 2007 GENERAL PHYSICS CORPORATION

GF@gpworldwide.com

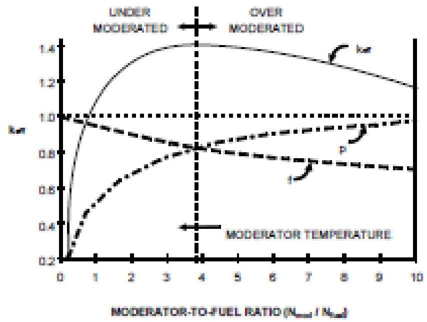


Figure 4-2 k_{eff} vs. Moderator-to-Fuel Ratio

A decrease in the moderator density also causes the thermal neutron absorption in the moderator to decrease due to fewer moderator atoms in the core area. This increases the probability of thermal neutron absorption in the fuel, and thermal utilization factor (f) increases slightly (Figure 4-2).

Recall from Chapter 2 the equation:

$$f = \frac{\Sigma_a^{fuel}}{\Sigma_a^{fuel} + \Sigma_a^{mod} + \Sigma_a^{other}}$$

Equation 4-6

This can be rewritten as:

$$f = \frac{\sigma_a^{fuel}}{\sigma_a^{fuel} + \frac{N_{mod}}{N_{fuel}}(\sigma_a^{mod}) + \frac{N_{other}}{N_{fuel}}(\sigma_a^{other})}$$

Equation 4-7

As the temperature increases, the concentration of moderator atoms (N_{mod}) decreases, so the thermal utilization factor increases.

Decreasing moderator density increases the migration length of the neutrons, which leads to an increase in the fraction of neutrons that leak out of the core, therefore decreasing the non-leakage factors (ℓ_f and ℓ_{th}). For large commercial power reactors neutron leakage is insignificant.

The fast fission factor (ε) increases slightly due to increased slowing down length, but the effect is very small.

The reproduction factor (η) is not dependent on moderator density, so the reproduction factor does not change significantly as moderator temperature changes.

As Figure 4-2 shows, moderator temperature changes result in essentially two competing processes, the resonance escape probability (p) and the thermal utilization factor (f). The resonance escape probability has the dominant effect, causing k_{eff} and reactor power to decrease as moderator temperature increases. Since increasing moderator temperature (decreasing the moderator to fuel ratio) decreases k_{eff}, the moderator temperature coefficient is negative.

The region to the left of the maximum effective neutron multiplication factor is called the under-moderated region. Note that in this region, an increase in temperature results in a reduction of the effective neutron multiplication factor. This results in a negative moderator temperature coefficient. Operating in the under-moderated region is very important in terms of reactor control. If reactor power suddenly increases, the moderator temperature will rise, inserting negative reactivity into the system and thus limiting the power excursion. Commercial reactors are designed with a moderator-to-fuel ratio such that the moderator temperature coefficient is negative.

© 2007 GENERAL PHYSICS CORPORATION

Steam Generator Feed Pump speed is adjusted to minimize the vibration on both SGFP's when in service. This is accomplished through the changing of a constant to the Woodward controller computer. The speed differential is adjusted to between zero and 200 rpm. The differential is established by the System Engineer with advice from the CBM and manual operation of the SGFP speeds. When the constant is determined, the speed of one of the SGFP's is greater than the determined setpoint and the other is less. The setpoint displayed on C−05 is the final setpoint including the bias.

The SGFP discharge check valves (2−FW−1A and 1B) have had the disc retaining pins disengaged during operation more than once (CR−02−08189). This caused plant transients including plant trip. The procedure uses the discharge MOV to minimize the effect of the failure but does not eliminate it. If during the startup or shutdown of a SGFP, a SG level transient occurs, closing the associated MOV should stop the transient.

When operating at steady state 100% power for extended periods, FRV position can be expected to exceed 80% open, which will generate a PPC alarm. This condition is expected during an operating cycle due to changes in SGFP suction pressure, SG pressure, Condenser vacuum, and Condensate System temperature. The suction pressure of the SGFP can change as much as five psig from summer to winter. This causes a change in SGFP speed and can result in FRV DPs going outside of their optimal operating parameters. Due to the line losses in the Feed and Steam systems, the #2 FRV is more susceptible to exceeding limits. When this occurs, the SGFP control system constants (SG pressure constant, SGFP speed offset, or both) must be adjusted to maintain FRV optimal criteria and system parameters stable. An assessment is performed to determine which constant needs to be adjusted. Prior to making changes in SGFP constants, the reason for a need to make an adjustment must be understood and verified by Engineering. Adjustments are made by I&C.

The optimum value of the SG pressure constant is 2−10 psi above the average pressure in the SG with the highest pressure. During steady state operations, actual SG pressure is dependent on steam load and RCS temperature. With steady state Reactor power, raising T_{cold} by 0.2 °F will raise actual SG pressure by about three psi. Conversely, lowering T_{cold} by 0.2 °F will lower SG pressure by about three psi, as long as Reactor Power is maintained stable.

Every psi change in Steam Generator pressure equates to about one psi change in Feed Regulating Valve differential pressure.

Raising or lowering RCS temperature at a faster or slower rate than the optimum dictated by the Temperature v. Power Program, while maintaining their relationship within the allowable band, can buffer or exacerbate the effects of SG pressure changes due to a power change.

Because FRVs are much further closed at low power (less than 20%) and the unit is *not* operated there for extended periods of time, high differential pressures are *not* as much of a concern during this time (control band 40 – 150) and the SGFP constants do *not* require adjustment.

This procedure is written assuming initial conditions of either 20 or 100% power and final conditions of 100 or 20% power. If the initial or final conditions are *not* as stated, the SM or US must initial and date those steps that apply and "N/A" those steps that do *not* apply, as well as document reasons in Section 5.

Steps in this procedure may be performed in parallel, provided the SM or US reviews the applicable steps and determines that *no* plant conditions or system alignments established by any preceding steps are required, prior to commencing these steps.

Items specified on Attachment 1, "Load Change Parameters," and Attachment 2, "Load Change Conditional Actions," apply to this procedure and should be referred to as necessary during load changes.

As a guide in determining boric acid addition, Attachment for, "Reactivity Thumb Rules," of OP 2208, "Reactivity Calculations" may be used.

The SGFP Control System utilizes Main Steam flow and SGFP suction pressure to determine the appropriate SGFP speed. When SGFP suction pressure is less than 325 PSIG, SGFP suction pressure can oscillate. These oscillations occur due to interactions between the Condensate and Heater Drains systems. These are in turn magnified by the SGFP Control System. The oscillations can be eliminated by starting an additional Condensate pump or placing the SGFP Control System in Manual.

A difference in temperature between Pressurizer steam space, T109, and Pressurizer water space, T101, may indicate a non–condensible gas bubble has formed in the top of the Pressurizer. The non–condensible gas bubble will insulate Pressurizer steam space, T109. When the gas bubble is removed, Pressurizer steam space, T109, may indicate Pressurizer heatup limits have been exceeded. A non–condensible gas bubble may also prevent steam from entering the Pressurizer level reference leg condensing pot. This causes a higher than actual Pressurizer level to be indicated. [♣Ref. 6.12]

NRC Response

The NRC agrees with the proposed change. RO Question #61 has TWO correct answers. Both Answers B and D will be accepted as correct.

A pressurized water reactor operating in its power range responds via temperature feedback mechanisms to a change in steam demand on the secondary plant. When operating with a negative moderator temperature coefficient, the feedback causes reactor power changes that trend toward restoring equilibrium between heat added to the reactor coolant system and heat removed from the reactor coolant system. Question #61 describes a situation where secondary steam demand is reduced. The reduced steam demand will raise SG pressure. RCS cold leg temperature and average coolant temperature will both increase. The higher temperature water passing through the reactor vessel will add negative reactivity, lowering reactor power generation, as indicated on nuclear instruments and also on delta-T power instruments, where delta-T power is proportional to the difference between hot and cold leg temperatures.