Westinghouse Class 3

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SAFETY EVALUATION SUPPORTING A MORE NEGATIVE EOL MODERATOR TEMPERATURE COEFFICIENT TECHNICAL SPECIFICATION FOR THE MILLSTONE NUCLEAR POWER STATION UNIT 3

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R. J. Fetterman
M. G. Savage
J. V. Foley
P. W. Rosenthal

APPROVED: ______________________
M. Mutyala, Manager
Core Design

APPROVED: ______________________
P. A. Loftus, Manager
Nuclear Safety
Transient Analysis I

8810110251 881005
PDR ADOCK 05000423
P PDC

WESTINGHOUSE ELECTRIC CORPORATION
Commercial Nuclear Fuel Division
P. O. Box 3912
Pittsburgh, Pennsylvania 15230

ABSTRACT

This report proposes a relaxation of the Limiting Condition for Operation and Surveillance Requirements values of Moderator Temperature Coefficient for the end of cycle, rated thermal power condition. Relaxation is sought in order to improve plant availability and minimize disruptions to normal plant operation, while continuing to satisfy plant safety criteria. A methodology for establishing Technical Specification end of cycle Moderator Temperature Coefficient values that are consistent with the plant safety analyses is described herein. Specific application of the methodology to the Millstone Nuclear Power Station Unit 3 provides Technical Specification Moderator Temperature Coefficient values which are proposed to replace the existing values. This proposed Technical Specification EOL MTC Limiting Condition for Operation and 300 ppm Surveillance Requirements are applicable to both 4 Loop and 3 Loop (corrected to rated thermal power) operation.

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1.0 INTRODUCTION

1.1 Background

For FSAR accident analyses, the transient response of the plant is dependent on reactivity feedback effects, in particular, the moderator temperature coefficient (MTC) and the Doppler power coefficient. Because of the sensitivity of accident analyses results to the MTC value assumed, it is important that the actual core MTC remain within the bounds of the limiting values assumed in the FSAR accident analyses. While core neutronic analyses will have predicted that the MTC is within these bounds, the Technical Specifications require that the core MTC also be confirmed by measurement, as verification of the accuracy of the neutronic predictions. These MTC measurements are performed:

1. At beginning of cycle, prior to initial operation above 5% rated thermal power, and

2. Within 7 EFPD after reaching an equilibrium boron concentration of 300 ppm.

1.2 Basis of Current EOL MTC LCO and SR Values

In order to ensure a bounding accident analysis, the MTC is assumed to be at its most limiting value for the analysis conditions appropriate to each accident. Currently, the most negative MTC limiting value is based on EOL conditions (specifically with regards to fuel burnup and boron concentration), full power, with rods fully inserted.

Most accident analyses use a constant moderator density coefficient (MDC) designed to bound the MDC at this worst set of initial conditions (as well as at the most limiting set of transient conditions). This value for MDC forms the licensing basis for the FSAR accident analysis.

Converting the MDC used in the accident analyses to a MTC is a simple calculation which accounts for the rate of change of moderator density with temperature at the conditions of interest. In this report, the convention followed is to discuss the moderator feedback in terms of MTC, rather than MDC. Nevertheless, it is important to note that the accident analyses actually assume a constant MDC value, rather than making any explicit assumption on MTC.

Technical Specifications place both Limiting Condition for Operation (LCO) and Surveillance Requirements (SR) values on MTC, based on the accident analysis assumptions on MDC described above. The most positive MTC LCO limit applies to Modes 1 and 2, and requires that the MTC be less positive than the specified limit value. The most negative MTC LCO limit applies to Modes 1, 2, and 3, and requires that the MTC be less negative than the specified limit value for the all rods withdrawn, end of cycle life, rated thermal power condition.

The Technical Specification SR calls for measurement of the MTC at BOL of each cycle prior to initial operation above 5% rated thermal power, in order to demonstrate compliance with the most positive MTC LCO. Similarly, to demonstrate compliance with the most negative MTC LCO, the Technical Specification SR calls for measurement of the MTC prior to EOL (near 300 ppm equilibrium boron concentration). However, unlike the BOL situation, this 300 ppm SR MTC value differs from the EOL LCO limit value. Because the HFP MTC value will gradually become more negative with further core depletion and boron concentration reduction, a 300 ppm SR value of MTC should necessarily be less negative than the EOL LCO limit. The 300 ppm SR value is sufficiently less negative than the EOL LCO limit value to provide assurance that the LCO limit will be met when the 300 ppm surveillance criterion is met.

1.3 Operational Considerations: EOL MTC Tech Spec SR Value

It is becoming increasingly probable that reload cores will fail to meet the 300 ppm surveillance criterion associated with the EOL LCO limit. The primary factors causing more negative MTCs near EOL are higher core average operating temperature and higher discharge burnup. Failure to meet the surveillance criterion does not by itself imply a failure to meet the actual EOL MTC limit stated in the LCO, but invokes the requirement that the MTC continue to be measured at least once per 14 EFPD during the remainder of the fuel cycle. This repeated surveillance is performed to demonstrate that the actual LCO limit on EOL MTC is not violated.

The drawbacks to the current EOL MTC Technical Specification are:

1. The current and planned fuel management strategy is expected to yield MTC values which will be more negative than the existing 300 ppm surveillance criterion. This would result in repeated MTC measurements every 14 EFPD. In addition, the EOL HFP ARO MTC values for these anticipated designs will approach or possibly be more negative than the existing LCO limit.

2. If repeated measurements are necessary, they can require that load swings be performed, causing temperatures to deviate from the programmed reference temperature - situations which are never preferable to nominal steady state operation.

3. The repeated measurements require the resources of multiple operations personnel for roughly an entire shift, and require greater water processing for measurement via the boration/dilution method.

Westinghouse-designed PWRs which conform to Standard Technical Specification (STS) format generally feature a 300 ppm SR MTC value which is 9 pcm/°F less negative than the EOL LCO limit on MTC. Given the disadvantages of repeating the MTC plant measurements, it is logical to inquire if this difference between the SR value and the LCO value is overly large, and whether this conservatism would invoke repeated measurements that are unnecessary.

Examination of both plant-specific characteristics and fuel management effects on the difference between the 300 ppm HFP ARO predicted MTC and the EOL (0 ppm) HFP ARO predicted MTC indicates that the 9 pcm/°F difference applied to Westinghouse-designed STS plants is very conservative. This implies that a failure to satisfy the 300 ppm surveillance criteria can occur, yet the actual EOL MTC value could show margin to the LCO limit. It is concluded that relaxation of the difference between the SR limit value and the LCO limit value should be investigated, so as to preclude unnecessary MTC testing at full power conditions.

1.4 Operational Considerations: EOL MTC Tech Spec LCO Value

Relaxation of the SR limit value may provide only temporary relief from the repeated MTC measurement situation. With longer operating cycles and increased fuel discharge burnups, future reload core designs may eventually challenge the EOL MTC LCO limit. The reload core design process would detect the fact that the design value of EOL MTC could exceed the Tech Spec LCO limit long before a reload core were to begin operation, but the design measures that can be taken to produce a less negative EOL MTC negatively impact the desired energy production for the reload.

The FSAR accident analyses that form the plant's licensing basis have assumed a MDC value which, when converted to a MTC at full power pressure and temperature, translates to a HFP MTC value that is more negative than the LCO limit value of the Technical Specifications. The difference between the value of most negative MTC (most positive MDC) assumed in the accident analyses and that presented as the LCO of the Tech Specs is substantial, and offers a potential avenue for relaxation of the Tech Spec EOL MTC LCO value. The thrust of such an effort to relax the EOL MTC Tech Spec LCO limit must continue to bound the accident analysis assumptions, and should establish a reasonable basis for the difference between the safety analysis value of most negative MTC and the Tech Spec LCO value.

2.0 METHODOLOGY FOR MODIFYING MOST NEGATIVE MTC TECH SPEC VALUES

2.1 Conversion of Safety Analysis MDC to Tech Spec MTC

As stated previously, the FSAR accident analyses have assumed a bounding value of the moderator density coefficient (MDC) which ensures a conservative result for the transient analyzed. The process by which this accident analysis most positive MDC is transformed into the most negative MTC LCO value is stated in STS BASES section 3/4.1.1.3:

> "The most negative MTC value, equivalent to the most positive moderator density coefficient (MDC), was obtained by incrementally correcting the MDC used in the FSAR accident analyses to nominal operating conditions. These corrections involved subtracting the incremental change in the MDC associated with a condition of all rods inserted (most positive MDC) to an all rods withdrawn condition, and a conversion for the rate of change of moderator density with temperature at RATED THERMAL POWER conditions. This value of the MDC was then transformed into the limiting MTC value."

In the process of converting the accident analysis MDC into the Tech Spec MTC, the conversion for the rate of change of moderator density with temperature at rated thermal power conditions involves conventional thermodynamic properties and imposes no undue conservatism on the resulting MTC value. The additional conversion made is to correct the above MDC (MTC) value for the change associated with going from a condition of ARI to one of ARO. That is, the accident analysis MDC (MTC) assumes a coefficient determined for a condition of EOL HFP 0 ppm with all control and shutdown banks fully inserted. This accident analysis MDC (MTC) is corrected back to the ARO condition, in order to produce a Tech Spec limit which permits direct comparison against measured values. The effect of the presence of all control and shutdown banks is to make the MTC markedly more negative than a MTC at the ARO condition, hence this conversion has a substantial impact.

2.2 Conservatism of the ARI to ARO MTC Conversion

The use of a substantially negative MTC (positive MDC) value for the transient accident analyses is prudent, in that it produces a more severe result for the transient, which makes the analysis inherently conservative. The drawback to the ARI assumption is that when the conversion to the ARO condition is made, the resulting Tech Spec MTC value is dramatically less negative than the value corresponding to the transient safety calculations, and is even less negative than expected best estimate values of EOL MTC for high discharge burnup reload cores. In the worst case, maintaining the EOL MTC Tech Spec limit at its present value could result in requiring that the plant be placed in hot shutdown when, in fact, there exists substantial margin to the moderator coefficient assumed in the accident analyses. Such a situation is unnecessarily restrictive, and results primarily from the ARI to ARO adjustment made between the accident analysis MDC value and the Tech Spec MTC value.

In addition to being unnecessarily restrictive, the HFP ARI assumption is inconsistent with Tech Spec requirements for allowable operation, wherein shutdown banks are not permitted to be inserted during power operation and control banks must be maintained above their insertion limits.

2.3 Alternative MTC Conversion Approach

If the ARI to ARO basis for converting from the accident analysis MDC value to a Tech Spec LCO MTC value is overly restrictive, what would constitute a more meaningful, yet inherently conservative basis? The concept herein proposed as an alternative to the ARI to ARO conversion is termed the "Most Negative Feasible MTC" approach. This approach maintains the existing accident analysis assumption of a bounding value of moderator coefficient, but offers an alternative method for converting to the Tech Spec LCO MTC value.

The Most Negative Feasible MTC approach seeks to determine the conditions for which a core will exhibit the most negative MTC value that is consistent with operation allowed by the Tech Specs. As an example, the Most Negative Feasible MTC approach would not require a conversion assumption that all rods be fully inserted at HFP conditions, but would require a conversion assumption that all control banks are inserted the maximum amount that Tech Specs permit, so as to make the calculated EOL HFP MTC more negative than it would be for an unrodded core.

The Most Negative Feasible MTC approach determines EOL MTC sensitivity to those design and operational parameters that directly impact MTC, and attempts to make this determination in a such a manner that the resulting sensitivity for one parameter is independent of the assumed values of the other parameters. As a result, parameters which are mutually exclusive but permissible according to the Tech Specs (such as an assumption of full power operation and an assumption of no xenon concentration in the core), and which serve to make MTC more negative, will have their incremental impacts on MTC combined to arrive at a conservative and bounding condition for the most negative feasible MTC. The parameters which are variable under normal operation, and which affect MTC are:

- soluble boron concentration in the coolant
- moderator temperature and pressure
- RCCA insertion
- axial flux (power) shape
- transient fission product (xenon) concentration

The Most Negative Feasible MTC approach examines each parameter separately, and assesses the impact of variation in that parameter on EOL MTC. The assessment is performed for multiple core designs that feature combinations of fuel design, discharge burnup, cycle length, and operating temperature expected to envelope future core designs of the plant of interest.

When the assessment is complete, the MTC sensitivity associated with each of the above parameters has been identified. One then determines the maximum deviation from "nominal" conditions (ARO, HFP, equilibrium xenon, Tavg on the reference temperature program) that the Tech Specs permit, and multiplies that deviation by the appropriate MTC sensitivity to arrive at a "delta MTC" factor associated with the parameter.

For example, suppose it is determined that MTC becomes 1 pcm/°F more negative for each 1°F increase in core average operating temperature above nominal (the MTC "sensitivity" is -1 pcm/°F/°F). If the Tech Specs permit a maximum increase in Tavg of 4°F above nominal core Tavg, then the moderator temperature "delta MTC" factor is:

$$(-1 \text{ pcm/°F/°F}) \times 4\text{°F} = -4 \text{ pcm/°F}.$$

Bounding "delta MTC" factors are determined in this way for each of the above parameters, and these factors are then added to arrive at an overall bounding "delta MTC" factor. This overall "delta MTC" factor states how much more negative the MTC can become, relative to the nominal EOL HFP ARO MTC value, for normal operation scenarios permitted by the current Tech Specs. The conditions of moderator temperature, rod insertion, xenon, etc., which defined the Most Negative Feasible MTC condition become the conversion proposed as a replacement for the ARI to ARO conversion of the current MTC Tech Spec. The conversion for the Most Negative Feasible MTC condition is applied in the same way that the current ARI-to-ARO conversion is applied, in order to arrive at an EOL ARO HFP MTC Tech Spec limit that remains based on the accident analysis MDC assumption.

2.4 Determining SR MTC from LCO MTC

Under the Most Negative Feasible MTC approach, the 300 ppm surveillance value is determined in the manner currently stated in the BASES for STS plant MTC Tech Specs:

> "The MTC surveillance value represents a conservative value (with corrections for burnup and soluble boron) at a core condition of 300 ppm equilibrium boron concentration and is obtained by making these corrections to the limiting MTC LCO value."

That is, the 300 ppm surveillance value is derived by making a conservative adjustment to the EOL ARO HFP MTC limit value that accounts for the change to MTC with soluble boron and burnup. Plant-specific examination of the difference between 300 ppm HFP MTC and EOL (0 ppm) HFP MTC suggests that a smaller correction is justified than the 9 pcm/°F which has historically been applied to Westinghouse-designed STS plants.

2.5 Benefits of the Alternative MTC Conversion Approach

The Most Negative Feasible MTC approach is considered to be superior to the ARI-to-ARO conversion specified by current STS plant Tech Specs for the following reasons:

1. The Most Negative Feasible MTC approach does not require an unduly positive 300 ppm surveillance value that would result in repeated MTC surveillance measurements. These repeated measurements are undesirable in that they entail perturbations to normal reactor operation.

2. The Most Negative Feasible MTC approach does not alter the FSAR transient accident analysis bases or assumptions, and hence, does not affect the accident analysis conclusions. It retains the concept of a conversion between the accident analysis MDC assumption and the Tech Spec LCO MTC value that assures that the plant cannot experience a MDC which is more severe than that assumed in the accident analyses.

3. The Most Negative Feasible MTC condition is a conservative but reasonable basis to assume for a MTC value of the reload core prior to a transient, and is consistent with operation as defined by other sections of the Tech Specs (whereas the ARI-to-ARO conversion is overly conservative and makes assumptions which are inconsistent with other sections of the Tech Specs).

Additionally, the Most Negative Feasible MTC approach retains the "built-in safeguard" of a requirement for a 300 ppm surveillance measurement to be performed in order to verify that the reactor is operating in a regime that is bounded by the accident analysis input assumptions.

3.0 MOST NEGATIVE FEASIBLE MTC APPROACH APPLIED TO MILLSTONE UNIT 3

3.1 Millstone Unit 3 Accident Analysis MDC Assumption

The FSAR accident analyses upon which the Tech Spec EOL HFP LCO MTC limit is based have assumed bounding values of moderator density coefficient in order to ensure a conservative simulation of plant transient response for the Millstone Nuclear Power Station Unit 3. For those transients for which analysis results are made more severe by assuming maximum moderator feedback, a moderator density coefficient (MDC) of 0.43 Δk/gm/cc has been assumed to exist throughout the transient.

When discussing the Tech Spec EOL LCO limit on moderator feedback, it is simpler to talk in terms of moderator temperature coefficient (MTC) than MDC. For this reason, the Millstone Unit 3 accident analysis MDC assumption of 0.43 Δk/gm/cc is converted to its equivalent MTC. This conversion depends on the density change-to-temperature change relationship which prevails for the conditions of interest. For this discussion, the conditions of interest are the core temperature and pressure (hence, density) experienced under normal operation at which the MDC assumes its most extreme (positive) value. These temperature and pressure conditions are the Millstone Unit 3 rated thermal power (RTP), full flow nominal operating conditions of 590.5°F and 2250 psia, respectively.

At these nominal RTP operating conditions, the accident analysis MDC value of 0.43 Δk/gm/cc is equivalent to a HFP MTC of -55.47 pcm/°F. For simplicity, this value of MTC will often be referred to as the "accident analysis MTC", in the discussion which follows. However, it should be remembered that the applicable accident analyses actually assume a constant MDC value of 0.43 Δk/gm/cc and make no explicit assumption about MTC.

3.2 Determination of Most Negative Feasible MTC Sensitivities

As stated previously, there are a limited number of core operational parameters that directly affect MTC and are variable under normal core operation. The list of parameters is as follows.

- soluble boron concentration in the coolant
- moderator temperature and pressure
- RCCA insertion
- axial flux (power) shape
- transient fission product (xenon) concentration

The radial flux (power) shape can also vary under normal core operation and will affect MTC. However, the operational activities that directly affect radial power shape do so through withdrawal or insertion of control rods and through xenon concentration; therefore, the impact of radial flux distribution variation on MTC will be an implicit part of the MTC sensitivity to these other parameters.

Soluble boron concentration is certainly variable under normal core operation. However, it [illegible] eliminated as a source of sensitivity for this analysis. This is because the EOL HFP ARO MTC Tech Spec limit value is assumed to be essentially a 0 ppm limit by virtue of the definition of EOL. The most negative MTC value will always occur at a boron concentration of 0 ppm, and therefore, a 0 ppm boron concentration is assumed as the basis of the EOL MTC Tech Spec limit under the Most Negative Feasible MTC approach.

For the remaining parameters, sensitivity analyses were performed by perturbing the parameter of interest in such a way as to induce a change from its nominal EOL value, and then performing a MTC determination with the parameter held in the perturbed state. A further perturbation was induced and the MTC calculation repeated. This sequence was repeated until sufficient MTC data values were generated to reliably determine the trend of MTC change with variation in the value of the independent parameter.

It should be noted that the discussion regarding the MTC sensitivities is based on 4 Loop operation unless specifically noted. It is shown in Sections 3.3 and A.5 that the proposed Technical Specification will be applicable to 3 Loop and 4 Loop operation. The LCO and SR values of most negative MTC are for the Rated Thermal Power, ARO condition; if a measurement is taken at a different condition, it should be adjusted to RTP, ARO conditions prior to comparison with the Technical Specification value.

In order to establish trends in MTC that are appropriate and bounding for the Millstone Unit 3 reload cores, these sensitivities were determined for five different reload cores. These cores exhibit design features that are expected to be incorporated in future Millstone Unit 3 reload cores (such as increased discharge burnup, longer cycles, and advanced fuel product features).

A brief description of the five reload core designs follows:

RELOAD A: This core is the currently operating reload (Cycle 2) of Millstone Unit 3. It utilizes the Westinghouse 17x17 standard rod diameter fuel design, feeds 84 assemblies in a low leakage loading pattern (L3P) and assumes a region average discharge burnup of 36000 MWD/MTU. This reload also has 448 pyrex glass BAs and a nominal cycle length of 15800 MWD/MTU. The control rod absorber material is hafnium. The nominal core average temperature assumed in this analysis is 590.5°F for 4 Loop operation and 582.7°F for 3 Loop operation. This is the first cycle for implementation of the revised Tech Spec.

RELOAD B: This is the proposed Cycle 3 reload design for Millstone Unit 3 using an L3P design feeding 76 assemblies with axial blankets, approximately 4500 part-length IFBA, high enrichments, and a region average discharge burnup of 45000 MWD/MTU. The cycle length is 16500 MWD/MTU and all other core operating parameters are assumed to be the same as Reload A.

RELOAD C: This reload is a conceptual equilibrium 24 month (21830 MWD/MTU) cycle design with advanced fuel product features including the features in RELOAD B plus Zr grids and Intermediate Flow Mixer (IFM) grids. A thimble plug removal analysis is also assumed which increases the core bypass flow and raises the core average moderator temperature to 591.3°F for 4 Loop operation and 583.5°F for 3 Loop operation.

RELOAD D: This reload core is an annual cycle L3P design using the Westinghouse 14 foot length 17x17 standard fuel rod diameter design. The discharge burnup for this design is necessarily low since this is the first reload core for this particular plant. This design has 416 pyrex glass BAs and uses hafnium as the control rod absorber material. The nominal core average moderator temperature of 596.5°F at full power.

RELOAD E: This reload core is a Westinghouse 4 loop plant with 17x17 standard diameter fuel. An L3P design is used for a cycle length of 17000 MWD/MTU and a region average discharge burnup of 38000 MWD/MTU. This design also feeds 84 assemblies and uses 1728 pyrex glass BAs. The control rod absorber material is silver-indium-cadmium. The nominal core average moderator temperature is 575.3°F.

Reloads A, B, D, and E were used in the calculation of the sensitivities to the four parameters described previously. To provide additional information regarding the effect of extremely long cycles and high discharge burnups on the MTC sensitivity to moderator temperature and pressure and xenon concentration, Reload C was also used in the determination of those sensitivities. Given the nature of Reload C, it is expected that the impact on the sensitivities to RCCA insertion and axial flux shape would be bounded by the other reloads.

All five of these reload cores feature the same control bank configuration that will be used in Millstone Unit 3 reload cores, shown in Figure 3.1.

The core neutronic models of these five reload cores were derived using standard Westinghouse procedures and computer methods. The ARK code, which has evolved from the LEOPARD(1) and CINDER(2) codes, was used to perform the fast and thermal spectrum calculations and is the basis for all cross sections, depletion rates, and reactivity feedback models. ANC(3) and PALADON(4), nodal analysis theory codes used in two and three dimensions, were used for core neutronic calculations to determine MTC sensitivity for the five reload cores. APOLLO, an advanced version of PANDA(5), was used as an axial neutronic model of the reload cores to determine MTC sensitivity to varying axial flux shape.

The neutronic calculations and evaluations performed for the five reload core designs established MTC sensitivities for each of the parameters listed above. The detailed description and results of this analysis are provided in Appendix A.

3.3 Maximum Allowed Deviations from Nominal Operating Conditions

The concept of maximum allowed deviation from nominal operating conditions is employed to determine the extent to which reactor parameters can vary under normal operation so as to cause MTC to become more negative. This combination of parameter statepoints then defines the worst allowable initial condition for a transient that employs a most negative MTC (most positive MDC) assumption. It is also necessary to demonstrate that the parameter changes that occur throughout the transient do not result in a MTC value which is unbounded by the moderator coefficient assumption used in the accident analysis. The adequacy of the constant MDC accident analysis assumption to bound MTC values that occur throughout the transient is examined in Section 4.

The bases for the maximum allowed deviation from nominal operating conditions are Technical Specifications that limit the extent of moderator temperature increase, RCCA insertion, and axial power skewing. The deviations permitted by present Millstone Unit 3 Tech Specs and possible future perturbations to those Tech Specs values are discussed in the following sections:

Moderator Temperature and Pressure Deviations

Tech Spec 3.2.5 establishes the LCO values of the DNB parameters reactor coolant system Tavg and pressurizer pressure. For Millstone Unit 3, Tech Spec 3.2.5 states for 4 Loop operation a minimum allowable indicated pressurizer pressure of 2226 psia, and the maximum allowable indicated RCS average temperature of 591.2°F. These values have accounted for instrumentation uncertainties of 21 psi and 2°F. Therefore, the maximum allowable RCS temperature and the minimum allowable pressure assumed in the safety analysis are 593.2°F and 2205 psia, respectively. Because the current nominal design RCS temperature for the Millstone Unit 3 plant is 587.1°F, the 593.2°F safety analysis limit represents a 6.1°F maximum allowable Tavg increase over nominal conditions. The current nominal design pressure for the Millstone Unit 3 plant is 2250 psia; therefore, the 2205 psia safety analysis limit represents a 45 psi maximum reduction from nominal system pressure. Note that these pressure and temperature deviations from nominal HFP values match those deviations from nominal conditions which are assumed as initial conditions in the Millstone Unit 3 FSAR transient accident analyses.

Because Tech Spec 3.2.5 limits deviations from nominal condition RCS temperature and pressure to 6.1°F and 45 psi, respectively, it also indirectly places a limit on the maximum allowable deviation of RCS moderator density from nominal. Those maximum temperature and pressure deviations are applied to the MTC sensitivity to temperature and pressure, which is described in Appendix A, to obtain a "delta MTC" factor associated with RCS moderator temperature and pressure deviations from nominal. The resulting "delta MTC" is [$]^{+a,c}$ pcm/°F.

RCCA Insertion Deviation

The nominal condition assumption for RCCA placement is complete withdrawal (ARO). This assumption is underscored by the requirement in Tech Spec 3.1.1.3 that the LCO value of EOL MTC is for the "all rods withdrawn" condition. Because some RCCA insertion is allowed during full power operation, and because RCCA insertion will generally cause MTC to be more negative than it would be otherwise, the RCCA insertion deviation is simply that maximum allowable RCCA insertion permitted by the Tech Specs.

Tech Specs 3.1.3.5 and 3.1.3.6 place limits on allowable RCCA insertion. Tech Spec 3.1.3.5 precludes Shutdown RCCA insertion in Modes 1 and 2, and Tech Spec 3.1.3.6 limits Control Bank insertion via the Rod Insertion Limits (RILs).

Control rods can be inserted as a function of power level according to the RILs, and all RCCAs can be inserted at HZP coincident with reactor trip. With greater RCCA insertion, MTC becomes more negative relative to the ARO MTC, all other parameters being held equal. However, Tech Specs do not allow all other parameters to be held equal. With deeper RCCA insertion, power must be reduced and Tavg will be reduced accordingly. The reduction in Tavg serves to make the MTC more positive, and at EOL 0 ppm conditions, this positive Tavg effect will entirely offset the negative RCCA effect on MTC.

For example, for the Millstone Unit 3 first reload core, complete insertion of both Control Banks D and C at EOL 0 ppm HFP conditions (a condition not permissible under normal operation) will make the MTC [ ]$^{+a,c}$ pcm/°F more negative than the ARO MTC. However, in going from a nominal HFP Tavg to a nominal HZP Tavg at EOL and 0 ppm, the MTC for this same core becomes [ ]$^{+a,c}$ pcm/°F more positive. This [ ]$^{+a,c}$ pcm/°F more positive component of the MTC that results from the moderator temperature (density) change in going from HFP to HZP will not only compensate for the negative MTC component associated with RCCA insertion permitted by the RILS, but will also more than compensate for the negative MTC component that arises from total RCCA insertion with trip.

In this respect, the Millstone Unit 3 first reload core design is typical of reloads for Westinghouse-designed PWRs. Because the rate at which decreasing moderator temperature makes MTC positive exceeds the rate at which allowable RCCA insertion makes MTC negative, the most negative MTC situation will always exist at HFP Tavg with RCCAs inserted to the extent allowed by the HFP insertion limits. For this reason, the maximum RCCA deviation from nominal conditions allowable by the Tech Specs needs to be assessed at only the HFP condition.

Figure 3.2 shows the RCCA insertion limits to be used for Millstone Unit 3 reload cores. These are typical insertion limits for Westinghouse-designed 4 loop PWRs with the five control rod lead control bank of Figure 3.1. Figure 3.2 shows that at full power the lead control bank can be inserted to a depth of 164 steps withdrawn. However, strict application of these current RILs in determining the "delta MTC" factor associated with RCCA insertion may prove to be restrictive if minor changes to the RILs become necessary in the future. For this reason, the HFP RCCA insertion assumed for this analysis is [$]^{+a,c}$ steps withdrawn. This additional insertion is expected to bound minor RIL adjustment which may be necessary for optimizing core performance characteristics of future Millstone Unit 3 reloads. However, applicability of the ultimate EOL MTC LCO value derived from these sensitivities will be confirmed on a cycle-by-cycle basis as part of the reload design process, therefore, a RIL adjustment to lead control bank insertion beyond [$]^{+a,c}$ steps withdrawn will not necessarily invalidate the revised EOL MTC LCO value.

This limiting HFP RCCA insertion of [$]^{+a,c}$ steps withdrawn forms the basis of the determination of MTC sensitivity to HFP RCCA insertion, which is described in Appendix A. The resulting "delta MTC" factor associated with RCCA insertion was determined to be [$]^{+a,c}$pcm/°F.

Axial Flux (Power) Shape Deviation

As indicated earlier, MTC is affected by the axial flux shape which exists in the core, primarily as a result of the influence that the axial flux shape has on the rate at which the moderator is heated as it moves up the core. The detailed shape itself is not so important, but rather the "balance" of the flux shape, in terms of how much moderator heating occurs in the lower half of the core versus the upper half of the core. The influence which axial power shape has on MTC can, therefore, be captured by quantifying this axial flux "balance", and this balance is best quantified by the core's Axial Flux Difference (AFD).

The discussion of the MTC sensitivity to axial flux (power) shape presented in Appendix A establishes that the more negative the AFD becomes, the more negative the MTC will become. The axial flux (power) shape deviation is, therefore, determined by how negative the AFD is allowed to become under normal full power operating conditions.

The initial Millstone Unit 3 reload core employs a CAOC Tech Spec which sets the allowable full power AFD limits at +3% and -12%. To assign a "delta MTC" factor attributable to axial flux shape, one need only examine the MTC effect associated with the -12% "deviation" from a most negative expected target AFD value of approximately [ ]$^{+a,c}$%. However, to account for possible future changes in the most negative HFP AFD limit, an AFD value of [ ]$^{+a,c}$% is selected as the basis of the axial flux (power) shape deviation. This [ ]$^{+a,c}$% AFD deviation is applied to the MTC sensitivity to axial flux (power) shape, which is described in Appendix A, to obtain a "delta MTC" factor associated with AFD deviation from a perfectly balanced axial flux shape. The resulting "delta MTC" factor is [ ]$^{+a,c}$pcm/°F.

Transient Fission Product (Xenon) Concentration Deviation

Xenon is the most significant transient fission product in terms of effects on core reactivity and flux distribution; therefore, its possible impact on MTC are investigated to compute the final "delta MTC" factor to include in the Most Negative Feasible MTC approach. While Tech Specs place no limitations on either xenon distribution or overall concentration, the AFD limits discussed above, in effect, place a limitation on the amount of axial xenon skewing that can occur, and the physics of xenon buildup and decay place practical limits on the concentration.

Because axial xenon distribution directly impacts axial flux shape, this aspect of xenon effect on MTC is implicitly included in the axial flux (power) shape deviation discussed above. What remains to be quantified is the impact of the overall xenon concentration in the core.

Taking the EOL HFP ARO equilibrium xenon concentration to be the nominal xenon condition for the core, it was determined for low leakage core designs of the type anticipated for Millstone Unit 3 reloads, the MTC would become more negative with a reduced xenon concentration. Accordingly, the most negative MTC results when there is no xenon in the core.

It was established in the discussion on moderator temperature and pressure deviation and on RCCA insertion deviation, that the condition for the most negative MTC requires maximum allowable temperature (minimum allowable density) and, therefore, occurs at full power conditions. While the assumption of achieving full power operation with no xenon in the core is certainly a conservative assumption, the possibility of steady power escalation after an extended shutdown period presents a reasonable scenario for full power operation with a comparatively low xenon concentration in the core. For this reason, the "xenon deviation" to be used in conservatively determining the "delta MTC" factor attributable to transient fission product is a change from HFP ARO equilibrium xenon to no xenon in the core. The resulting "delta MTC" factor is [$]^{+a,c}$ pcm/°F.

Three Loop Operation

For this report, unless otherwise stated, the maximum 3 Loop power level assumed is 75% rated thermal power (RTP). This is conservative since the current Tech Specs limit 3 Loop operation to 65% RTP and, as discussed earlier, a reduction in core power will make the MTC more positive. For a corresponding nominal operating condition of 582.7°F and 2250 psia, the accident analysis MDC of 0.43 Δk/g/cc is equivalent to an MTC of -52.46 pcm/°F, or a change of 3.01 pcm/°F from the equivalent 4 Loop safety analysis MTC. It has been observed for Reload A that the EOL 3 Loop 75% RTP ARO MTC is [$]^{+a,c}$ pcm/°F more positive than the corresponding EOL 4 Loop HFP ARO

MTC. The [ ]$^{+a,c}$pcm/°F change in the calculated MTCs between 3 Loop and 4 Loop is larger than the [ ]$^{+a,c}$pcm/°F reduction of the safety analysis MTC. Therefore, demonstrating that the 4 Loop total "delta-MTC" is applicable to 3 Loop operation will in turn imply that the Tech Spec determined for 4 Loop operation is also applicable to 3 Loop operation.

The change in MTC due to moderator temperature and pressure deviations for 3 Loop operation will be smaller than the corresponding 4 Loop derivative. This is because the nominal 3 Loop core average moderator temperature is lower than the 4 Loop core average moderator temperature and the lower moderator temperature provides a smaller change in moderator density for a given change in temperature.

The 3 Loop change in MTC as a function of the xenon concentration will be smaller than the corresponding 4 Loop change due to a reduction in the equilibrium xenon concentration during 3 Loop operation. This reduction in the change of the MTC is on the order of [ ]$^{+a,c}$% as discussed in Section A.5 of this report.

The change in MTC due to RCCA insertion to the RIL will be larger for 3 Loop operation than for 4 Loop operation. This is due to the deeper D bank insertion allowed by the 3 Loop RIL and amounts to the 3 Loop delta-MTC due RCCA insertion being about [ ]$^{+a,c}$ pcm/°F more negative than the N Loop value.

The delta-MTC as a function of axial offset (AO) for 3 Loop operation is smaller than the 4 Loop value. The calculated value for reload A Loop operation is about [ ]$^{+a,c}$ of the 4 Loop delta-MTC used in setting the Tech Spec LCO, or about [ ]$^{+a,c}$ pcm/°F. This is because the 3 Loop total temperature rise is less than the 4 Loop temperature rise.

In summary, the 3 Loop delta-MTC due to RCCA insertion is more negative than the 4 Loop delta-MTC by [ ]$^{+a,c}$ pcm/°F, but the 3 Loop delta-MTC as a function of axial offset is more positive than the 4 Loop delta-MTC by [ ]$^{+a,c}$ pcm/°F. Also the delta-MTCs due to xenon and moderator density will also be slightly more positive for 3 Loop operation. Therefore the 3 Loop total delta-MTC is more positive than the 4 Loop total delta-MTC and is therefore bounded by the 4 Loop value.

3.4 Overall "Delta MTC" Factor for Millstone Unit 3 Reloads

The preceding section has concluded that the most adverse operation possible, in terms of achieving the most negative EOL MTC under current and proposed Millstone Unit 3 Tech Specs, would feature the following values of key parameters:

- Core Moderator Temperature: 6.1°F above HFP nominal
- Core Moderator Pressure: 2205 psia
- HFP RCCA insertion: [ ]$^{+a,c}$ steps withdrawn
- HFP most negative AO: [ ]$^{+a,c}$ %
- HFP xenon concentration: 0 %

When these maximum allowable deviations from a nominal condition of EOL HFP ARO, with equilibrium xenon, and 0 ppm boron are applied to the individual parameter sensitivities discussed in Appendix A, the overall "delta MTC" factor is determined. This overall factor for Millstone Unit 3 is computed as follows:

- Core Moderator Temperature and Pressure Factor: [ ]$^{+a,c}$ pcm/°F
- HFP RCCA Insertion Factor: [ ]$^{+a,c}$ pcm/°F
- Axial Flux (Power) Shape Factor: [ ]$^{+a,c}$ pcm/°F
- Xenon Concentration Factor: [ ]$^{+a,c}$ pcm/°F

Overall "Delta MTC" Factor: [ ]$^{+a,c}$ pcm/°F

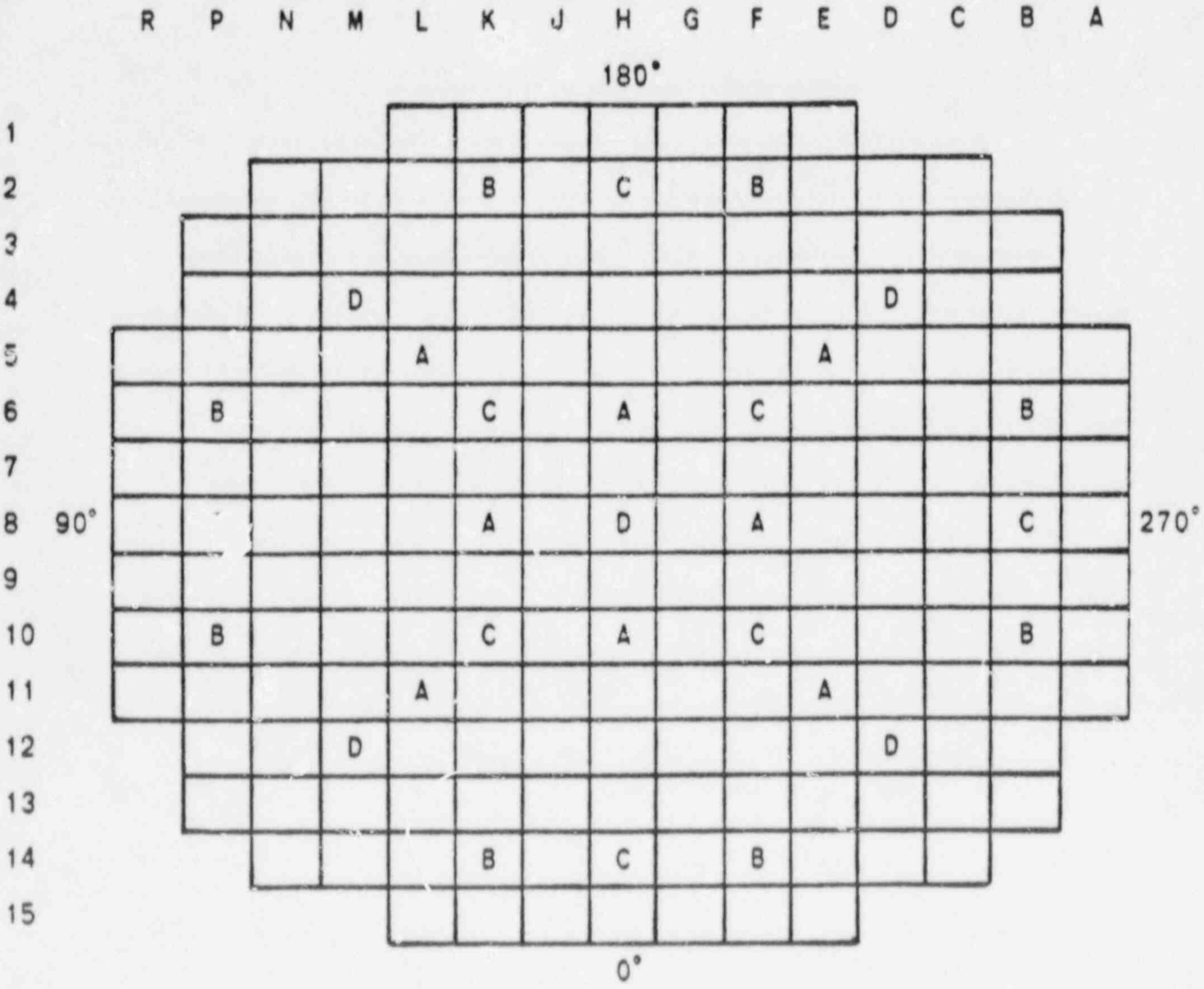
The interpretation of this overall "delta MTC" factor is as follows. The Tech Spec LCO value of EOL MTC is based on the explicit conditions of unrodded full power operation. This is an appropriate condition for performing a MTC experiment and obtaining results that can be meaningfully compared to design predictions. It is not, however, the condition under which the MTC can achieve its most negative value under normal operation scenarios permitted by the Tech Specs. The conservative "delta MTC" formulation has concluded that the actual core MTC can be as much as [$]^{+a,c}$ pcm/°F more negative than the EOL MTC LCO value defined by the Tech Specs.

The individual components of this [$]^{+a,c}$ pcm/°F overall "delta MTC" factor have been determined on a conservative basis and are expected to bound the values predicted for Millstone Unit 3 reload cores in the future. While an individual component could conceivably exceed the value cited above, such an occurrence would not invalidate the Most Negative Feasible MTC approach, as long as the total of all the components remains bound by the [$]^{+a,c}$ pcm/°F overall "delta MTC factor. Implementation of a revised EOL MTC Tech Spec based on the Most Negative Feasible MTC approach will require that any reload core's overall "delta MTC" factor be demonstrated to be bounded by the licensing basis value, rather than specifically addressing the individual components. Such validation of the Most Negative Feasible MTC approach on a cycle-specific basis would be performed as part of the reload core design process described in Reference 6.

3.5 Proposed Millstone Unit 3 Tech Spec EOL MTC LCO Value

As was pointed out in Section 3.1, Millstone Unit 3 FSAR accident analyses have assumed a MDC value which, when converted to a MTC at nominal HFP conditions, is equivalent to a MTC of -55.47 pcm/°F. At no time may the actual core be allowed to experience a MTC more negative than -55.47 pcm/°F, as this would invalidate an assumption of the accident analyses. The Most Negative Feasible MTC approach guarantees that such a situation will not occur by subtracting from this -55.47 pcm/°F MTC value the [$]^{+a,c}$ pcm/°F "delta MTC" factor determined for Millstone Unit 3. The resulting value of [$]^{+a,c}$ pcm/°F is the Tech Spec EOL LCO value of MTC under the Most Negative Feasible MTC approach. As an additional measure of conservatism, this value is further increased to -47.5 pcm/°F, and proposed as the EOL HFP ARO Tech Spec MTC LCO value for Millstone Unit 3 reload cores, replacing the current LCO value of -40 pcm/°F.

The -47.5 pcm/°F proposed limit provides relief over the -40 pcm/°F limit associated with the current Tech Spec ARO-to-ARI conversion requirement, yet still represents a conservative formulation. The scenario of deep RCCA insertion, coupled with high Tavg, low system pressure, and no xenon, represents a compounding of worst case events which can be considered independent, yet are not treated as such in the Most Negative Feasible MTC formulation. Determination that the core MTC is less negative than -47.5 pcm/°F at EOL HFP ARO conditions provides assurance that the assumption on initial condition MTC made in the plant accident analyses remains bounding. Additional assurance that the MTC (MDC) will not become more limiting at any time during a transient is also needed, in order to demonstrate that the accident analysis conclusions remain valid. This additional assurance is the primary subject of Section 4.0.



	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1															
2						B		C		B					
3															
4				D								D			
5					A						A				
6		B				C		A		C				B	
7															
8						A		D		A				C	
9															
10		B				C		A		C				B	
11					A						A				
12				D								D			
13															
14						B		C		B					
15															

FIGURE 3.1

4 LOOP CONTROL ROD LOCATIONS

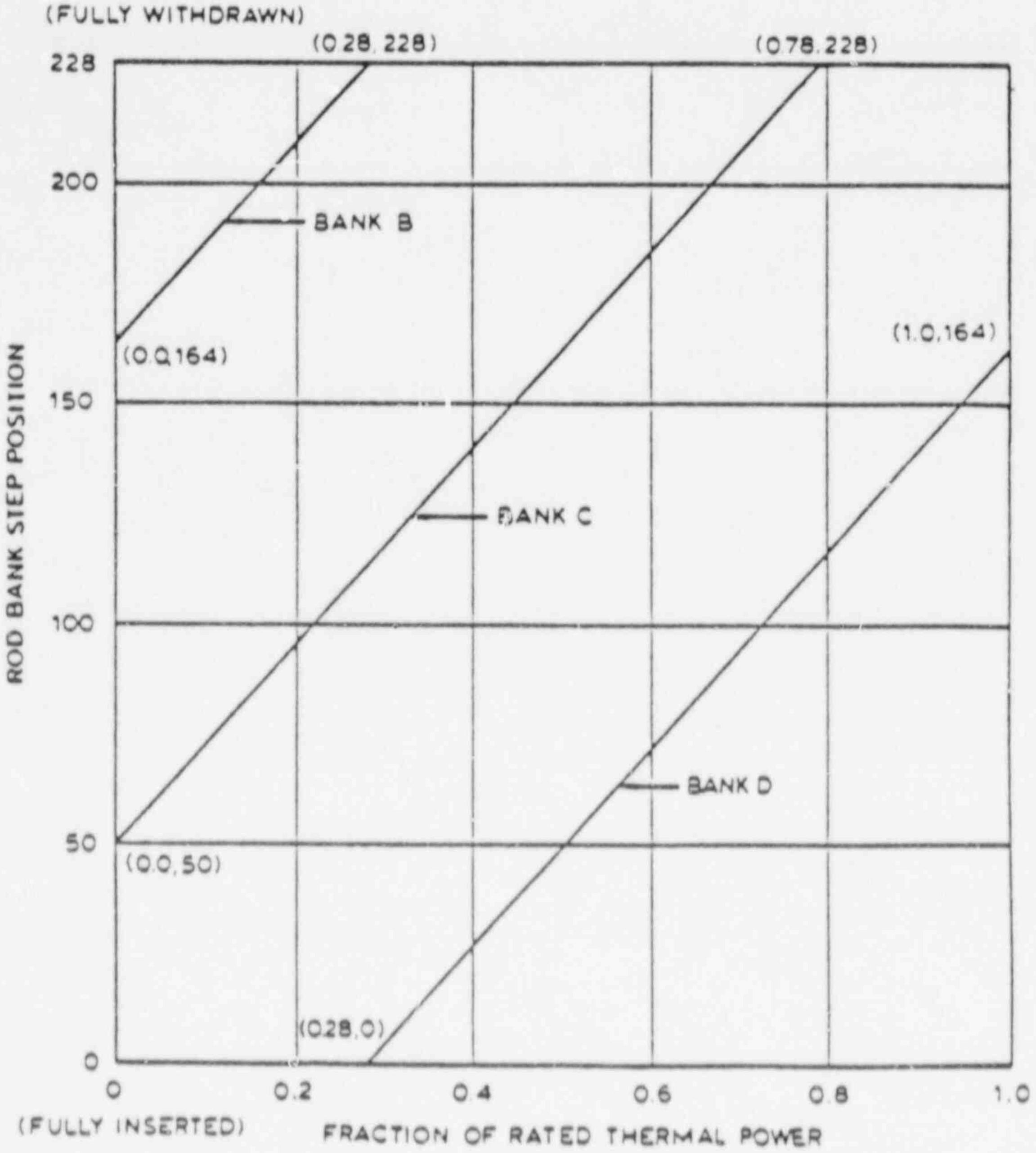


FIGURE 3.2

EXPECTED RCCA INSERTION LIMITS FOR MILLSTONE UNIT 3 RELOAD CORES

4.0 SAFETY ANALYSIS IMPACT OF MOST NEGATIVE FEASIBLE MTC APPROACH

The accident analyses conservatively model the various reactivity coefficients to produce a bounding analysis. As discussed in Section 3.1, the applicable analyses assume a constant MDC of 0.43 Δk/gm/cc to bound the predicted moderator reactivity insertion. The events which assume this value for EOL MDC are listed in Table 4.[illegible]ould be noted that the Millstone Unit 3 FSAR accident analyses include consideration of both 4 loop and 3 loop operating conditions.

The Most Negative Feasible MTC approach determines the conditions for which a core will exhibit the most negative MTC value that is consistent with operation allowed by the Tech Specs. Thus, the value for the Most Negative Feasible MTC provides the basis for a conservative initial condition assumption.

Changes in the parameters identified in Section 2.3 could take place during a transient in such a way as to make the MTC more negative than that allowed under normal operation. However, the most adverse conditions seen in these events will not result in a reactivity insertion that would invalidate the conclusions of the FSAR accident analyses. Therefore, the 0.43 Δk/gm/cc assumption used as the basis for the Most Negative Feasible MTC Tech Spec will not change.

As discussed in Reference 6, the reactivity coefficients assumed can have a strong influence on accident analysis results. Since the moderator coefficient can be affected by a reload, the conservative nature of the accident analysis assumption must be confirmed on a cycle-specific basis using the methodology discussed in Reference 6. This includes verification that the most adverse accident conditions discussed above do not invalidate the conservative nature of the accident analysis assumption. This process ensures the ability to verify that the applicable safety limits are met for each reload design and, consequently, that the Tech Specs are met.

TABLE 4.1

FSAR Chapter 15 Events That Assume A Constant 0.43Δk/gm/cc Value of MDC

15.1.1	Feedwater System Malfunctions that Result in a Decrease in Feedwater Temperature
15.1.2	Feedwater System Malfunctions that Result in an Increase in Feedwater Flow
15.1.3	Excessive Increase in Secondary Steam Flow
15.2.2	External Loss of Electrical Load
15.2.3	Turbine Trip
15.2.8	Feedwater System Pipe Break
15.4.2	Uncontrolled Rod Cluster Control Assembly Bank Withdrawal at Power
15.4.4	Startup of an Inactive Reactor Coolant Pump at an Incorrect Temperature

5.0 DETERMINATION OF MOST NEGATIVE FEASIBLE MTC SURVEILLANCE VALUE

Section 1.3 pointed out the potential conservatism in the separation of 9 pcm/°F between the Tech Spec 300 ppm MTC SR value and the EOL HFP ARO MTC LCO value. Typical 17x17 reload designs exhibit a predicted difference between the 300 ppm HFP design MTC and the EOL HFP ARO design MTC which is much less than 9 pcm/°F. However, in order to justify the use of a value which is smaller than 9 pcm/°F for a given plant, the specific design predictions of the plant must be examined.

Design predictions for the initial Millstone Unit 3 reload core were reviewed in order to determine the difference between the predicted 300 ppm HFP MTC and the predicted EOL HFP MTC. The difference was found to be [$]^{+a,c}$ pcm/°F.

In reviewing the differences between predicted 300 ppm and EOL MTC values for the reload cores of 4 loop plants which are similar to Millstone Unit 3, an important trend was discerned. It was observed that the higher core average enrichments associated with increasing discharge burnup tend to decrease the magnitude of MTC difference. As the Millstone Unit 3 reload cores will necessarily increase fuel discharge burnup levels beyond that of Cycle 2, it is anticipated that the difference between the HFP 300 ppm MTC and the HFP EOL MTC will become less in the future. This [$]^{+a,c}$ pcm/°F should, therefore, bound the 300 ppm MTC-to-EOL MTC differences for future Millstone Unit 3 reload cores.

The proposed Tech Spec SR value for Millstone Unit 3 reload cores is -40.0 pcm/°F. This value is 7.50 pcm/°F less negative than the EOL LCO MTC value proposed in Section 3.5. The 7.50 pcm/°F was chosen to bound the maximum [$]^{+a,c}$ pcm/°F difference predicted for the Millstone Unit 3 Cycle 2 reload core, yet afford relief from the 9 pcm/°F difference applied by the current Tech Specs. While the -40.0 pcm/°F 300 ppm Tech Spec SR value is expected to be bounding for future Millstone Unit 3 fuel management, the validity of this SR value will be confirmed on a cycle-by-cycle basis, as part of the reload core design process described in Reference 6.

6.0 CONCLUSIONS

The present Millstone Unit 3 Technical Specification values of -40 pcm/°F for the EOL HFP ARO MTC LCO and -31 pcm/°F for the 300 ppm HFP ARO SR conservatively reflect the FSAR accident analysis MDC assumption, but are considered to be overly restrictive by potentially requiring repeated deviation from nominal plant operation. An alternative adjustment procedure is proposed which is based on a conservative determination of the extent to which a nominal EOL HFP ARO MTC value can be made more negative under the most extreme values of certain operational parameters that are permitted by other Tech Specs. This Most Negative Feasible MTC approach assumes that these largely independent extreme situations occur simultaneously, and in the worst case, serve to make the EOL HFP MTC [$]^{+a,c}$ pcm/°F more negative than it would be at nominal conditions. When this value is subtracted from the MTC equivalent of the accident analysis assumed MDC value, the resulting MTC is [$]^{+a,c}$ pcm/°F. The slightly more conservative value of -47.5 pcm/°F is, proposed as the EOL HFP MTC Tech Spec LCO limit under the Most Negative Feasible MTC approach.

Examination of the difference between the 300 ppm HFP equilibrium boron concentration MTC value and the EOL HFP MTC values concluded that a bounding expected difference between these two MTC values for Millstone Unit 3 reload cores is -7.50 pcm/°F. This difference is subtracted from the proposed -47.5 pcm/°F EOL HFP MTC Tech Spec limit to arrive at a proposed Tech Spec 300 ppm HFP MTC SR value of -40.0 pcm/°F.

It is concluded that the Tech Spec EOL MTC LCO and 300 ppm SR values proposed under the Most Negative Feasible MTC approach do not impact conclusions of FSAR accident analyses, because they do not affect the accident analysis assumption of MDC. In addition, the validity of the above-stated LCO and SR MTC values, as well as the plant's ability to comply with them, will be examined for each reload cycle as part of the normal reload design process. This proposed Tech Spec EOL MTC LCO and 300 ppm SR values are applicable to both 4 Loop and 3 Loop (corrected to rated thermal power) operation.

The new EOL MTC LCO and 300 ppm SR MTC values and the revised basis for adjustment overcome the problems inherent with the present version of Tech Spec 3/4.1.1.3, yet still afford protection. Tech Spec 3/4.1.1.3 continues to require that surveillance be performed, so that any deviations between the operating core and design predictions that might threaten the validity of accident analysis assumptions can be detected, and continued surveillance and appropriate action undertaken.

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APPENDIX A

DETERMINATION OF MOST NEGATIVE FEASIBLE MTC SENSITIVITIES

Investigation of the sensitivity of MTC to core operational parameters that are variable under normal core operation is a fundamental requirement of the Most Negative Feasible MTC approach. Of the parameters discussed in Section 3.2, those that required detailed evaluation are:

- moderator temperature and pressure
- RCCA insertion
- axial flux (power) shape
- transient fission product (xenon) concentration

For each of these parameters, the sensitivity analyses were performed by perturbing the parameter in such a way as to induce a change from its nominal EOL value, and then performing a MTC determination with the parameter held in the perturbed state. A further perturbation was induced and the MTC calculation repeated. This sequence was repeated until sufficient data was obtained to reliably determine the trend of MTC change with variation in the value of the parameter.

In order to establish trends in MTC that are appropriate and bounding for the reload core type of interest, the sensitivity calculations were performed for five different reload cores. These cores exhibit a spectrum of design features (such as cycle length, fuel lattice design, etc.) that permit the MTC sensitivity results to have broad application for Westinghouse-designed 17x17 4-loop cores. A brief description of the five reload core designs follows:

RELOAD A: This core is the currently operating reload (Cycle 2) of Millstone Unit 3. It utilizes the Westinghouse 17x17 standard rod diameter fuel design, feeds 84 assemblies in a low leakage loading pattern (L3P) and assumes a region average discharge burnup of 36000 MWD/MTU. This reload also has 448 pyrex glass BAs and a nominal cycle length of 15800 MWD/MTU. The control rod absorber material is hafnium. The nominal core average temperature assumed in this analysis is 590.5°F for 4 Loop operation and 582.7°F for 3 Loop operation. This is the first cycle for implementation of the revised Tech Spec.

RELOAD B: This is the proposed Cycle 3 reload design for Millstone Unit 3 using an L3P design feeding 76 assemblies with axial blankets, approximately 4500 part-length IFBA, high enrichments, and a region average discharge burnup of 45000 MWD/MTU. The cycle length is 16500 MWD/MTU and all other core operating parameters are assumed to be the same as Reload A.

RELOAD C: This reload is a conceptual equilibrium 24 month (21830 MWD/MTU) cycle design with advanced fuel product features including the features in RELOAD B plus Zr grids and Intermediate Flow Mixer (IFM) grids. A thimble plug removal analysis is also assumed which increases the core bypass flow and raises the core average moderator temperature to 591.3°F for 4 Loop operation and 583.5°F for 3 Loop operation.

RELOAD D: This reload core is an annual cycle L3P design using the Westinghouse 14 foot length, 17x17 standard fuel rod diameter design. The discharge burnup for this design is necessarily low since this is the first reload core for this particular plant. This design has 416 pyrex glass BAs and uses hafnium as the control rod absorber material. The nominal core average moderator temperature of 596.5°F at full power.

RELOAD E: This reload core is a Westinghouse 4 loop plant with 17x17 standard diameter fuel. An L3P design is used for a cycle length of 17000 MWD/MTU and a region average discharge burnup of 38000 MWD/MTU. This design also feeds 84 assemblies and uses 1728 pyrex glass BAs. The control rod absorber material is silver-indium-cadmium. The nominal core average moderator temperature is 575.3°F.

As stated in Section 3.2, all of these core designs feature the control bank configuration that will be used in Millstone Unit 3 reload cores, which is shown in Figure 3.1.

The core neutronic models of these five reload cores were derived using standard Westinghouse design procedures and computer methods. The ARK code, which evolved from the LEOPARD(1) and CINDER(2) codes, was used to perform the fast and thermal spectrum calculations and is the basis for all cross sections, depletion rates, and reactivity feedback models. ANC(3) and PALADON(4), nodal analysis theory codes used in two and three dimensions, were used for core neutronic calculations to determine MTC sensitivity for the five reload cores. APOLLO, an advanced version of PANDA(5), was used as an axial neutronic model of the reload cores to determine MTC sensitivity to varying axial flux shape.

The neutronic calculations and evaluations performed for the five reload core designs established MTC sensitivities for each of the parameters listed above. The sections which follow provide details of the calculations performed and the MTC sensitivity results obtained.

A.1 MTC Sensitivity to Moderator Temperature and Pressure Variation

The decrease in moderator density which accompanies moderator heatup has the effect of reducing neutron moderation. With a low soluble boron concentration in the moderator, this results in a negative moderator temperature coefficient. An increase in coolant temperature, keeping density constant, leads to a hardened neutron spectrum and results in an increase in resonance absorption in U238, Pu240, and other isotopes. The hardened spectrum also causes a decrease in the fission-to-capture ratio in U235 and Pu239. Both of these effects make the MTC more negative. In addition, the hardened neutron spectrum results in a larger fast-to-thermal flux ratio which increases the leakage of the core. Again, the effect of higher leakage is to make the MTC more negative.

Since water density changes more rapidly with increasing temperature, and because of the spectrum hardening effects mentioned above, the MTC becomes progressively more negative with increasing temperature. The sensitivity of MTC to increasing temperature was determined for each of the three reload cores by increasing core reference moderator temperature slightly above the nominal HFP value, while holding pressure constant at 2250 psia, and then performing a MTC calculation that induced small changes in core K-effective via changes in moderator temperature and density about the reference values. The effects of changes in moderator temperature and density were considered together. After the MTC value was computed, core reference moderator temperature was further increased, and another MTC calculation performed. This process was repeated until the trend of MTC with increasing core reference moderator temperature was clearly established.

Results were recorded for the five reload cores in terms of change in MTC from the nominal HFP MTC as a function of increase in reference moderator temperature above the nominal HFP moderator temperature. The results are shown in Figure A.1. As expected, Reload D exhibits the strongest sensitivity of MTC to increases in moderator temperature, due to its higher nominal HFP reference temperature. A curve which conservatively bounds the MTC sensitivity results of the five reloads is also shown in Figure A.1. This bounding curve is used in determining the "delta MTC" factor.

To use the bounding MTC sensitivity information of Figure A.1, the maximum allowable temperature and pressure (and, therefore, density) deviations permissible under operation that complies with Tech Specs must also be determined. These deviation values, presented in Section 3.3, are combined with the sensitivity data to arrive at a "delta MTC" factor associated with moderator temperature and pressure (and, therefore, density). For the 6.1°F temperature deviation cited in Section 3.3, Figure A.1 indicates that the corresponding "delta MTC" due to temperature increase is [$]^{+a,c}$ pcm/°F. The "delta MTC" due to the 45 psi pressure deviation cited in Section 3.3 was conservatively determined to not exceed [$]^{+a,c}$ pcm/°F. The combined "delta MTC" factor is, therefore, [$]^{+a,c}$ pcm/°F.

A.2 MTC Sensitivity to RCCA Insertion

With constant moderator temperature, pressure, and boron concentration, insertion of control rods makes MTC more negative. This trend in MTC arises from three effects. The first is that RCCA insertion makes the overall flux spectrum slightly harder, which makes MTC more negative, as discussed in Section A.1. The second effect is that RCCA insertion will increase core leakage, which again makes MTC more negative. The third effect arises from the impact of RCCA insertion on axial flux (power) shape. This effect is treated separately in Section A.3.

Control rods can be inserted as a function of power level according to the RCCA insertion limits (RILs), and all RCCAs can be inserted at HZP coincident with reactor trip. With greater RCCA insertion, MTC becomes more negative relative to the ARO MTC, all other parameters being held equal. However, Tech Specs do not allow all other parameters to be held equal. With deeper RCCA insertion, power must be reduced and Tavg will be reduced accordingly. The reduction in Tavg serves to make the MTC more positive, and at EOL 0 ppm conditions, this positive Tavg effect will entirely offset the negative RCCA effect on MTC. The overall result is that the most negative MTC that can exist in the core occurs at HFP; therefore, the MTC sensitivity to RCCA insertion need only be determined at HFP conditions for HFP allowed RCCA insertion.

To calculate the EOL HFP MTC sensitivity to RCCA insertion, four of the reload core models had the lead control bank inserted the maximum applicable amount determined from Section 3.3 ([$]^{+a,c}$ steps withdrawn), at HFP, with no soluble boron in the core. The MTC value for this condition was then determined by inducing small changes in core K-effective via changes in moderator temperature and density about their reference values. This MTC value was compared to the MTC determined at the same conditions, but with all RCCAs removed from the core.

Of the four reload cores analyzed, it was determined that the maximum change to the EOL 0 ppm HFP ARO MTC which occurred as a result of HFP RCCA insertion to a depth of [$]^{+a,c}$ steps withdrawn was [$]^{+a,c}$ pcm/°F. Because some minor adjustment to RILs may be desirable for optimization of future core designs, it was considered prudent to further increase this MTC sensitivity factor. An increase of [$]^{+a,c}$% is considered sufficient to bound HFP RCCA worth changes that would accompany anticipated RIL changes, therefore, the bounding "delta MTC" factor associated with allowable HFP RCCA insertion becomes [$]^{+a,c}$ pcm/°F.

A.3 Sensitivity to Axial Flux (Power) Shape

MTC is not so much directly affected by axial flux distribution itself, but is affected via the impact which the axial flux distribution has on the rate at which the moderator is heated as it moves up the core, and via the importance weighting which the axial flux shape imparts to different regions of the core.

In general, the accumulated burnup in the bottom half of the core exceeds that in the top half of the core, as indicated in Figure A.2 for EOL of Reload A. Other things being equal, higher burnup results in a more negative MTC as a result of isotopic impacts on flux spectrum. A more negative axial flux (power) shape allocates a greater "importance weighting" to the lower regions of the core where burnups are greater, thereby accentuating this effect.

A greater effect is the impact which axial flux (power) shape has on heating rate of the moderator as a function of axial elevation. Figure A.3 shows, in the top diagram, three distinct axial power shapes - one which is skewed toward the bottom of the core, one which is skewed toward the top of the core, and one which is balanced, with an axial offset near zero. The lower diagram in Figure A.3 shows the core moderator temperature as a function of core height for these three different axial power distributions. While the same temperature rise through the core occurs for all three power shapes, it is evident that a more bottom-skewed axial power distribution will give rise to a higher average moderator temperature. This results from the greater heating of the moderator in the lower core elevations for the bottom-skewed case. As energy is added to the moderator at higher elevations, the temperature still remains highest for the bottom-skewed power case because of its initial "head start" in the lower elevations. The temperature differences gradually decrease as a result of the differing heating rates occurring in the upper core regions among the three shapes.

Both the importance weighting effect and the moderator axial heating rate effect indicate that a more bottom-skewed flux shape (more negative Axial Flux Difference) will result in a more negative MTC. This effect was investigated for four of the reload cores at EOL HFP 0 ppm conditions with no xenon in the core (xenon was removed so as to not complicate flux skewing strategy). A specific axial flux shape was induced and then, holding this flux shape approximately constant, the MTC was determined by observing the small changes in core K-effective which resulted from variation in moderator temperature and density about their reference values. A different axial flux shape was induced, and the MTC calculation repeated. This process was repeated until the behavior of MTC with variation in axial flux shape (as quantified by Axial Flux Difference) was clearly identified.

Curves of "delta MTC" as a function of Axial Flux Difference (AFD) for the four reload cores are shown in Figure A.4. Note that a zero AFD is taken as the reference point, therefore, "delta MTC" is fixed at zero for an AFD of zero. Because more negative AFD values result from RCCA insertion, this axial flux shape MTC sensitivity implicitly captures part of the RCCA MTC sensitivity not included in the "delta MTC" factor of the previous section.

Section 3.2 concludes that a negative value of HFP AFD that is expected to bound future Millstone Unit 3 reload cores is [ ]$^{+a,c}$%. Using a value which bounds the most conservative trend of Figure A.4, the "delta MTC" factor corresponding to [ ]$^{+a,c}$% AFD is [ ]$^{+a,c}$ pcm/°F.

Figure A.3 indicates that for a markedly negative AFD, the core average moderator temperature could be as much as [ ]$^{+a,c}$°F higher than that seen for a core with a balanced axial power shape (AFD near 0). Recalling the MTC sensitivity to moderator temperature of Figure A.1, one would expect a much greater MTC sensitivity to AFD than is indicated by Figure A.4. While the volume-weighted moderator temperature for a very negative AFD may increase significantly above that of the balanced flux shape case, the power-weighted moderator temperature increase will be very modest, and this will result in rather weak MTC sensitivity to AFD.

To further illustrate this point, examination of Figure A.3 shows that the very negative AFD power shape imparts a significant "importance weighting" to the bottom portion of the core where moderator temperature is lowest, but in the top portion of the core, where moderator temperature is greatest, the relative importance weighting is low. This power "importance weighting" aspect serves to negate a great deal of the "volume-weighted" temperature effect described above, and makes the "effective" moderator temperature increase for very bottom-skewed power shape rather small. Again, this causes the MTC sensitivity to extremes of flux (power) shape to be rather weak.

A.4 Sensitivity to Transient Fission Product (Xenon) Concentration

Xenon is the most significant transient fission product in terms of effects on core reactivity and flux distribution, therefore, its possible impacts on MTC were investigated to compute the final "delta MTC" factor to include in the Most Negative Feasible MTC approach. While Tech Specs place no limitations on either xenon distribution or overall concentration, the AFD limits discussed in Section 3.3, in effect, place a limitation on the amount of axial xenon skewing that can occur, and the physics of xenon buildup and decay place practical limits on the concentration.

Because axial xenon distribution directly impacts axial flux shape, this aspect of xenon effect on MTC is implicitly included in the Axial Flux Shape "delta MTC" factor discussed in Section A.3. What remains to be determined is the sensitivity to overall xenon concentration in the core. Calculations to determine this sensitivity were performed with the ANC(4) and PALADON(5) codes, taking the EOL HFP ARO 0 ppm MTC value with an equilibrium concentration of xenon as the reference value of MTC. A number of differing xenon concentration scenarios were modeled, and the MTC value associated with each scenario was determined.

For all five reload cores, the most negative MTC resulted when all xenon was removed from the core. The largest "delta" from the reference (equilibrium xenon) MTC that occurred when all xenon was removed was [ ]$^{+a,c}$ pcm/°F. This value becomes the final "delta MTC" factor attributable to xenon. No further uncertainty is added, simply because the scenario of operating at full power with no xenon in the core is itself sufficiently conservative as to be bounding.

A.5 Three Loop Operation

As discussed in Section 3.3, the change in the MTC corresponding to the safety analysis MDC is less than the change in the calculated MTCs at the nominal core conditions for 4 and 3 Loop operation. The following table is summarizes the EOL MTCs based on the differences discussed in Section 3.3. Note that both 4 and 3 Loop safety analysis MTC limits assume the same MDC of 0.43 Δk/g/cc but at different core average moderator temperatures.

	Tech Spec (100% RTP Values)	Corresponding 3 Loop (75% RTP)
300 PPM Surv.	-40.0 pcm/°F	[ ]$^{+a,c}$ pcm/°F
0 PPM Tech Spec (T.S.)	-47.5 pcm/°F	[ ]$^{+a,c}$ pcm/°F
Safety Analysis Limit (S.A.)	-55.47 pcm/°F	-52.46 pcm/°F
Delta (S.A. - T.S.)	- 7.97 pcm/°F	[ ]$^{+a,c}$ pcm/°F

The [ ]$^{+a,c}$pcm/°F change in the calculated MTCs between 3 Loop and 4 Loop is larger than the [ ]$^{+a,c}$pcm/°F reduction of the safety analysis MTC. Therefore, demonstrating that the 4 Loop total "delta-MTC" is applicable to 3 Loop operation will in turn imply that the Tech Spec determined for 4 Loop operation is also applicable to 3 Loop operation.

The 3 Loop MTC sensitivity will be less than the 4 Loop MTC sensitivity for the same deviations in the moderator temperature and pressure conditions. This is because during 3 Loop operation the core is at a lower average moderator temperature, and the change in moderator density for a 1°F change in moderator temperature will be smaller at the lower core average temperature. This in turn will make the change in the MTC for a 1°F change in temperature smaller for the 3 Loop core conditions. The 3 Loop MTC sensitivity to changes in the moderator temperature and pressure will be approximately [ ]$^{+a,c}$% less than the 4 Loop sensitivity, or approximately [ ]$^{+a,c}$ pcm/F.

The 3 Loop MTC sensitivity to RCCA insertion will be larger than the 4 loop sensitivity due to the increased D bank insertion allowed by the 3 Loop rod insertion limits (RIL) in the Tech Spec versus the 4 Loop RIL at HFP (132 steps withdrawn for 3 Loop versus 164 steps withdrawn for 4 Loop). The increased D bank insertion is expected to make the 3 Loop MTC sensitivity to RCCA insertion approximately [ ]$^{+a,c}$ pcm/°F more negative than 4 Loop value, or approximately [ ]$^{+a,c}$ pcm/°F.

The 3 Loop sensitivity to the axial flux (power) shape was calculated for Reload A and found to be [ ]$^{+a,c}$ pcm/°F for a [ ]$^{+a,c}$% Axial Offset (AO). Section A.3 reports a bounding 4 Loop value of [ ]$^{+a,c}$ pcm/°F for a [ ]$^{+a,c}$% AO, however the actual calculated 4 Loop value for Reload A was [ ]$^{+a,c}$ pcm/°F. If the 3 Loop sensitivity is scaled up by the same amount as the 4 Loop value, then the 3 Loop bounding MTC sensitivity to the axial flux (power) shape is [ ]$^{+a,c}$ pcm/°F.

The 3 Loop MTC sensitivity to the transient fission product (xenon) concentration is also less limiting than the 4 Loop sensitivity. This is due to the reduction in the 3 Loop xenon concentration compared to the N Loop HFP equilibrium concentration. The 3 Loop equilibrium xenon worth is approximately [ ]$^{+a,c}$% less than the 4 Loop equilibrium worth at HFP, EOL core conditions. Then an approximate value of the 3 Loop sensitivity to the transient fission product concentration is [ ]$^{+a,c}$% of the 4 Loop value given in Section A.4, or [ ]$^{+a,c}$ pcm/°F.

Finally, an estimate of the overall "delta-MTC" factor for 3 Loop operation for Millstone Unit 3 reloads is given by:

- Core Moderator Temperature and Pressure FActor: [ ]$^{+a,c}$ pcm/°F
- RIL RCCA Insertion Factor: [ ]$^{+a,c}$ pcm/°F
- Axial Flux (Power) Factor: [ ]$^{+a,c}$ pcm/°F
- Xenon Concentration Factor: [ ]$^{+a,c}$ pcm/°F

Overall 3 Loop Delta-MTC Factor: [ ]$^{+a,c}$ pcm/°F

If this value is further increased by [ ]$^{+a,c}$% for additional conservatism, the resulting 3 Loop "Delta-MTC" of [ ]$^{+a,c}$pcm/°F is still less than the 4 Loop "Delta-MTC" of [ ]$^{+a,c}$pcm/°F given in Sections 3.4 and 3.5. Therefore the safety analysis MDC of 0.43 Δk/g/cc is met for 3 Loop operation for Millstone Unit 3 reload cores and furthermore the 4 Loop Tech Spec is also applicable to 3 Loop operation.

FIGURE A.1

CHANGE IN MTC WITH INCREASE IN T-AVERAGE ABOVE NOMINAL T-AVERAGE

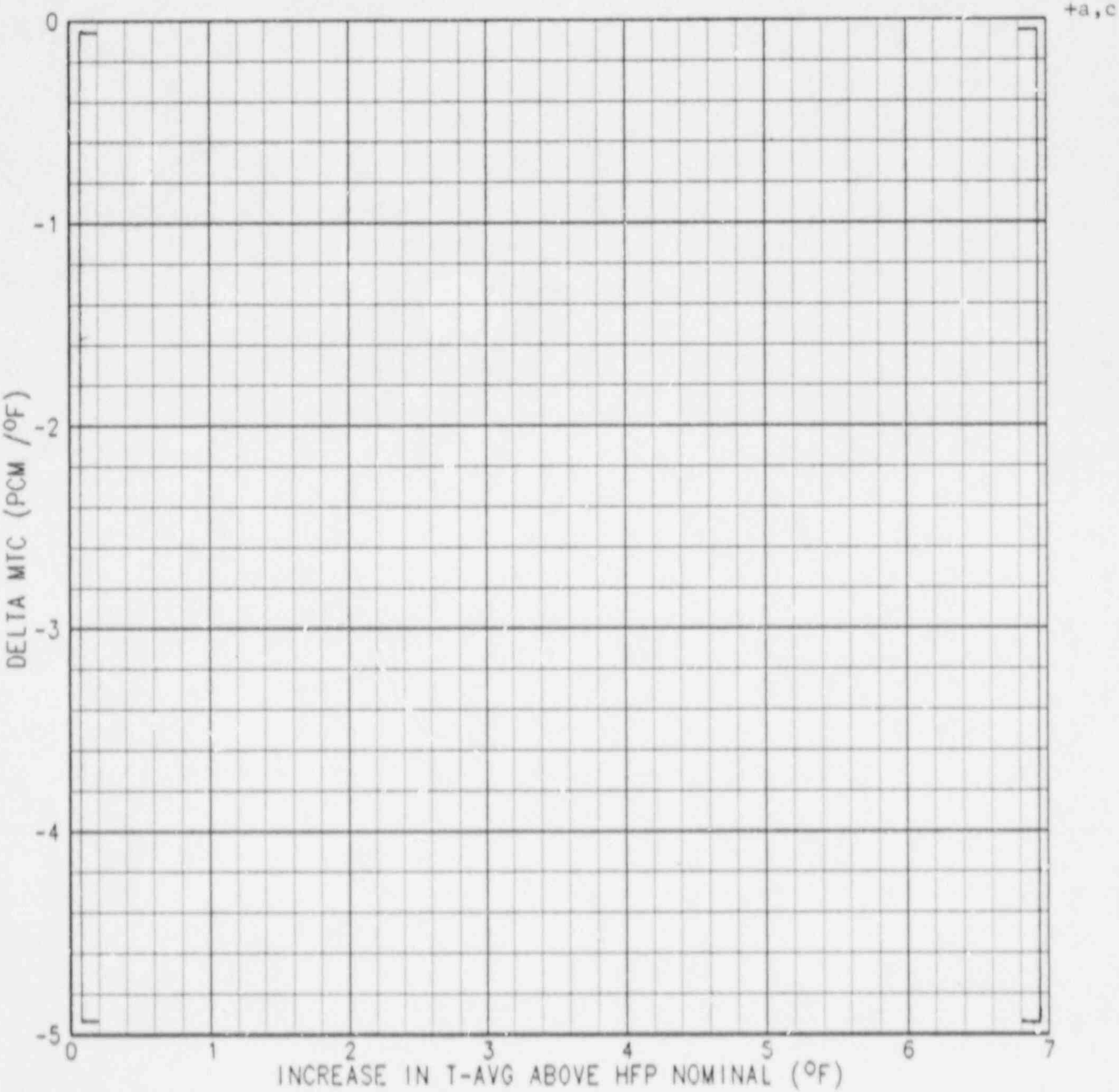


FIGURE A.2

CORE AVERAGE AXIAL BURNUP VERSUS CORE HEIGHT AT EOL

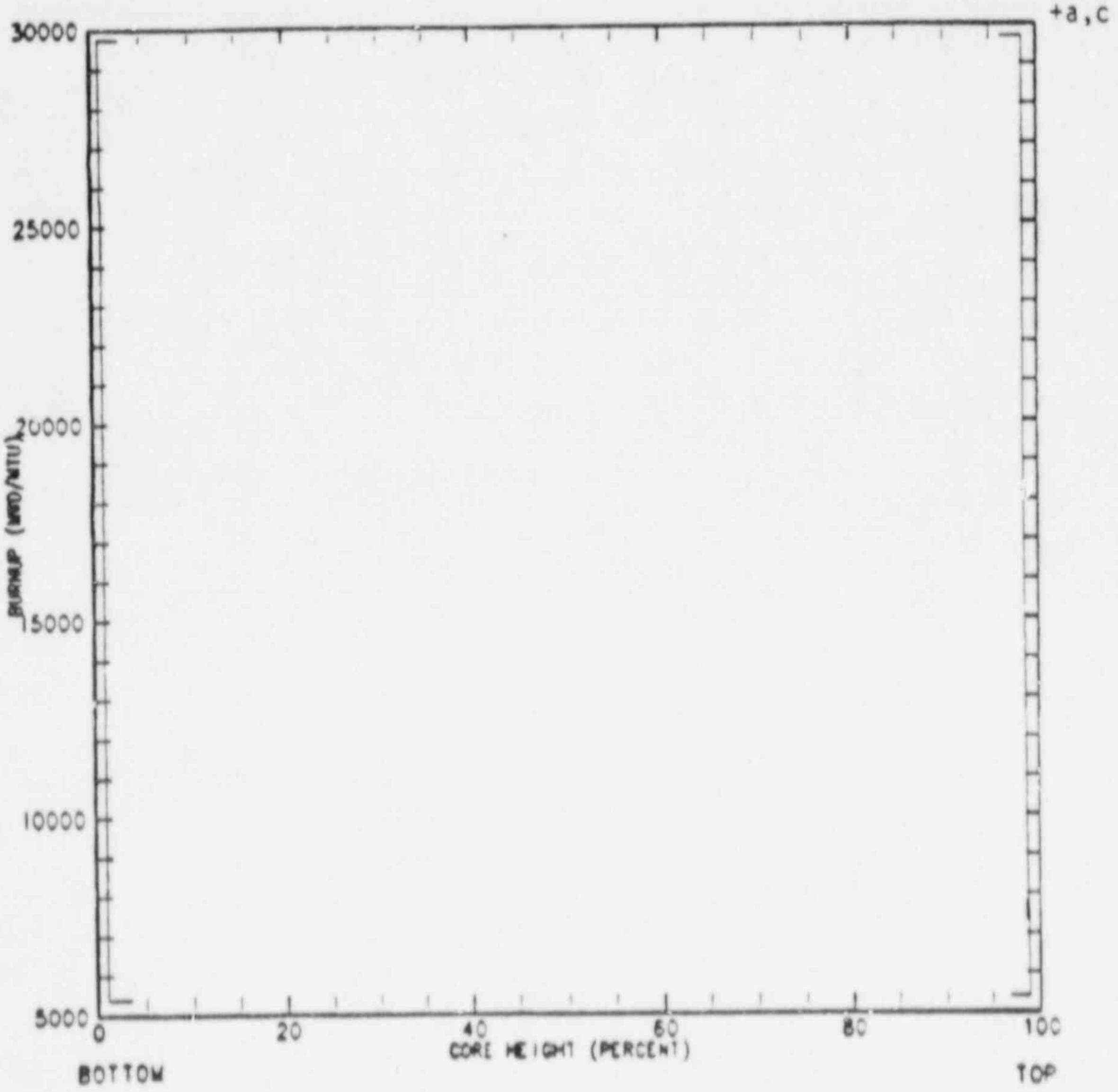
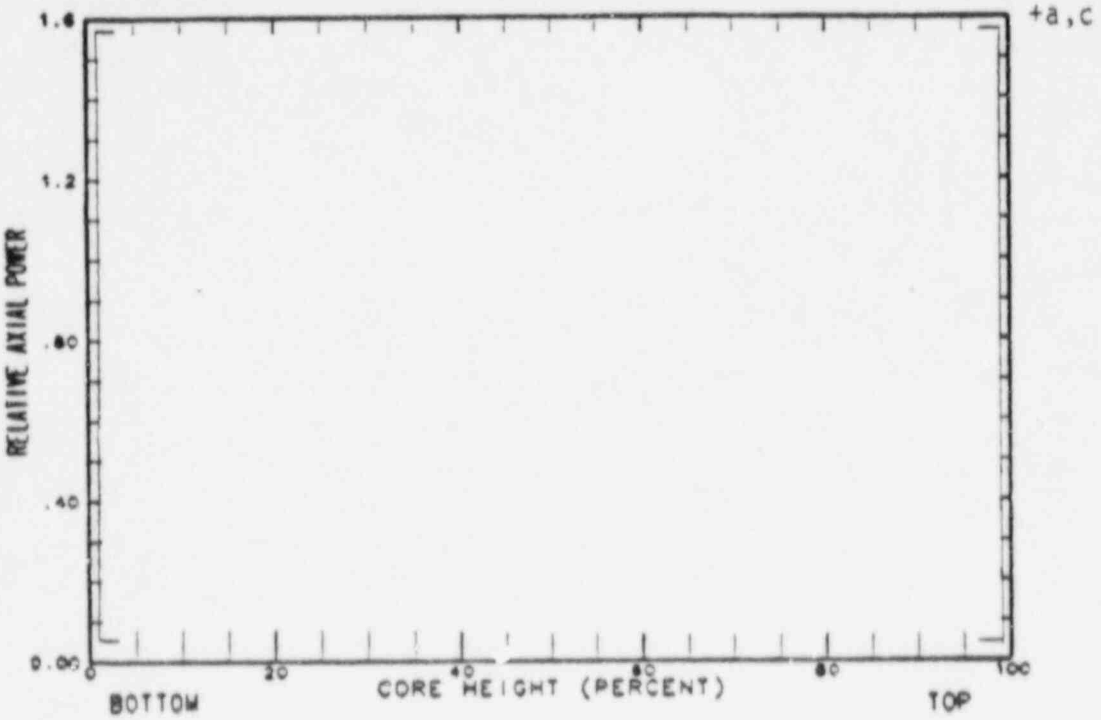


FIGURE A.3

AXIAL POWER AND MODERATOR TEMPERATURE VERSUS CORE HEIGHT

RELATIVE AXIAL POWER VERSUS CORE HEIGHT



MODERATOR TEMPERATURE VERSUS CORE HEIGHT

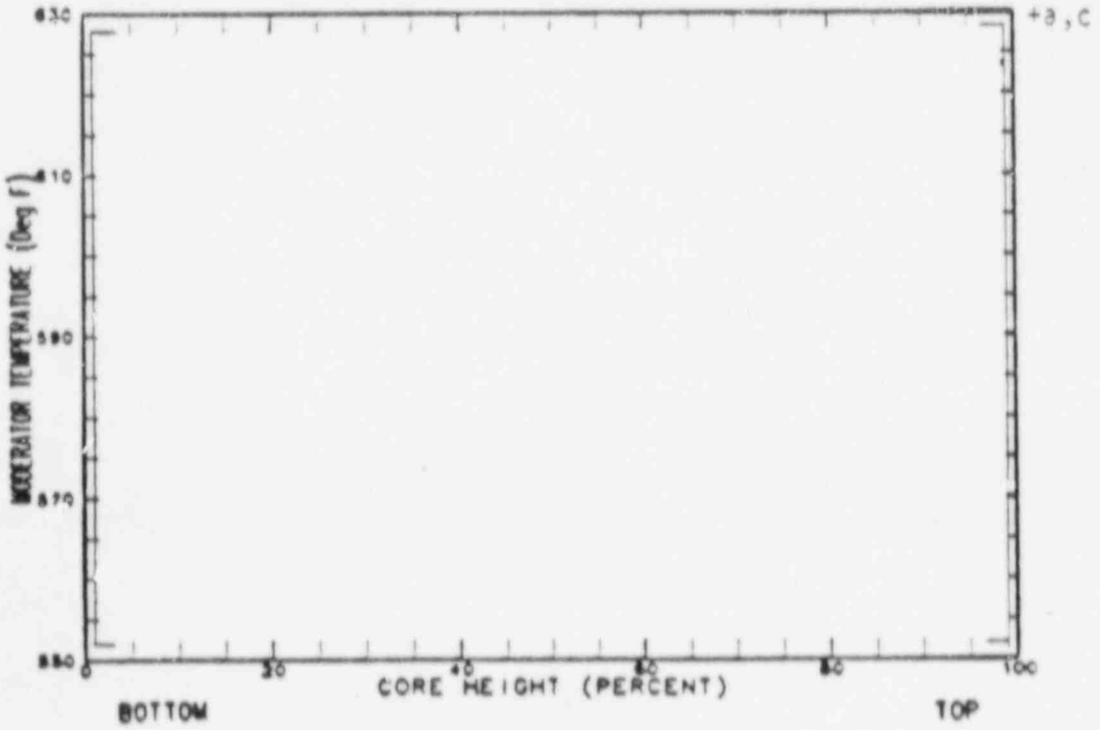


FIGURE A.4

DELTA MTC VERSUS AXIAL FLUX DIFFERENCE
AT EOL, HFP, ARO