UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO AMENDMENT NO. 111 TO

FACILITY OPERATING LICENSE NO. NPF-6

ENTERGY OPERATIONS, INC.

ARKANSAS NUCLEAR ONE, UNIT NO. 2

DOCKET NO. 50-368

A. INTRODUCTION

Pursuant to 10 CFR 50.90 and 50.91, Entergy Operations, Inc. (the licensee) proposes to amend Facility Operating License No. NPF-6 for Arkansas Nuclear One, Unit No. 2 (ANO-2) in its submittal dated November 21, 1990. The amendment would authorize operation of ANO-2 with rod-average fuel burnups up to 60 megawatt days per kilogram of uranium (MWd/kgM) and is based on a Combustion Engineering report as discussed below.

B. EVALUATION

1.0 Discussion

On July 20, 1989, the Arkansas Power and Light Company requested the U.S. Nuclear Regulatory Commission (NRC) to review the Combustion Engineering, Inc. (CE) report CEN-386-P to support Arkansas Nuclear One, Unit 2 (ANO-2) operation with rod-average fuel burnups up to 60 megawatt days per kilogram of uranium (MWd/kgM) for CE 16x16 fuel. The analysis used to demonstrate that the fuel design criteria are met are presented in References 1 and 2. It should be noted that Reference 2 is a topical report previously approved by NRC (Reference 3) that extended the burnup level of CE designed fuel to 52 MWd/kgM (rod-average). The difference between References 1 and 2 is the incremental increase in rod-average burnup from 52 to 60 MWd/kgM for the CE 16x16 fuel design.

Presented in this report is a review of the CE mechanical design criteria, analysis methods, and results for the ANO-2 fuel design application for CE 16x16 fuel. This review was conducted to assure that when the design criteria/limits are met they will prevent fuel damage or failure and maintain fuel coolability, as defined in the Standard Review Plan (SRP) (Reference 4) up to rod-average burnups of 60 MWd/kgM.

This review was based on the licensing requirements identified in Section 4.2 of the SRP (Reference 4). The objectives of this fuel system safety review, as described in Section 4.2 of the SRP, are to provide assurance that 1) the fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs), 2) the number of fuel rod failures is not underestimated for postulated accidents, 3) fuel system damage is never so severe as to prevent control rod insertion when it is required, and 4) coolability is always maintained. A "not damaged" fuel system is defined as one wherein fuel rods do not fail, fuel system dimensions remain within operation tolerances, and functional capabilities are not reduced below those assumed in the safety analyses. Objective 1 above is consistent with General Design Criterion (GDC) 10 (10 CFR Part 50, Appendix A) (Reference 5), and the design limits that accomplish this are called specified acceptable fuel design limits (SAFDLs).

"Fuel rod failure" (Objective 2) means that the fuel rod leaks and that the first fission product barrier (the cladding) has, therefore, been breached. Fuel rod failures must be accounted for in the dose analysis required by 10 CFR Part 100 (Reference 6) for postulated accidents. The general requirements to maintain control rod insertability (Objective 3) and core coolability (Objective 4) appear repeatedly in the GDC (e.g., GDC 27 and 35). Specific coolability requirements for the loss of coolant accident (LOCA) are given in 10 CFR 50.46 (Reference 7). "Coolability" which is sometimes termed "coolable geometry," means, in general, that the fuel assembly retains its rod-bundle geometrical configuration with adequate coolant channels to permit removal of residual heat even after a severe accident.

In order to assure that the above stated objectives are met and follow the format of Section 4.2 of the SRP, this review covers the following three major categories: 1) Fuel System Damage Mechanisms, which are most applicable to normal operation and AOOs, 2) Fuel Rod Failure Mechanisms, which apply to normal operation, AOOs, and postulated accidents, and 3) Fuel Coolability, which is applied to postulated accidents. Specific fuel damage or failure mechanisms are identified under each of these categories in Section 4.2 of the SRP and these individual mechanisms are addressed in this report. The design criteria, analysis methods, and results for the 16x16 fuel design, up to a rod-average burnup of 60 MWd/kgM, will be discussed in this report under each fuel damage or failure mechanism.

Pacific Northwest Laboratory (PNL) has acted as a consultant to the NRC in this review. As a result of the review of the subject topical report by the NRC staff and their PNL consultants, a list of questions was sent by the NRC to the licensee (Reference 8) requesting further justification on why low measured cladding ductilities, greater cladding oxidation, guide wear, cladding collapse, and axial assembly growth are not limiting at the burnup level requested. The licensee has provided responses to these questions in References 9 and 10. The design criteria and analyses submitted for ANO-2 in support of this license submittal are those defined in CE reports (References 1 and 2) and, therefore, will be referred to as CE design criteria and analyses. The responses submitted by ANO-2 in this review were jointly developed by ANO-2 and CE staff and, therefore, will be referred to as ANO-2/CE responses.

The CE 16x16 design description is provided in Reference 11. The fuel damage and failure mechanisms and CE analyses of these mechanisms are addressed in Sections 2.0 and 3.0, respectively, while fuel coolability is addressed in Section 4.0.

2.0 FUEL SYSTEM DAMAGE

The design criteria presented in this section should not be exceeded during normal operation, including AOOs. Under each damage mechanism, there is an evaluation of the design criteria analysis methods and analyses used by CE to demonstrate that fuel damage does not occur for the 16x16 design during normal operation, including AOOs up to a rod-average burnup of 60 MWd/kgM.

(a) Stress

Bases/Criteria - In keeping with the GDC 10 SAFDLs, fuel damage criteria for stress should ensure that fuel system dimensions remain within operational tolerances for normal operation and AOOs, and that functional capabilities are not reduced below those assumed in the safety analysis. The CE design basis for fuel assembly, fuel rod, burnable poison rod, and upper-end fitting spring stresses is that the fuel system will be functional and will not be damaged due to excessive stresses (Reference 2).

The CE stress criteria for the fuel assembly components are provided in References 11 and 12. The design limit for fuel rod and burnable poison rod cladding is that the maximum primary tensile stress is less than two-thirds of the Zircaloy yield strength as affected by temperature.

The design limit of the Inconel X-750 upper-end fitting spring is that the calculated shear stress will be less than or equal to the minimum yield stress in shear.

Many of these bases and limits are used by the industry at large. CE has employed various conservatisms in the limits such as the use of unirradiated yield strengths for zirconium-based alloys. The NRC has concluded (Reference 3) that the fuel assembly, fuel rod, burnable poison rod, and upper-end fitting spring stress design bases and limits were acceptable for rod-average burnup levels up to 52 MWd/kgM. Extending the burnup level to 60 MWd/kgM does not reduce the applicability of these criteria, and thus, these criteria are found acceptable for use in the current ANO-2 applications for the CE 16x16 design.

Evaluation - CE has stated that the methods used to perform stress analyses will not change from those used and approved for previous applications. These analyses are performed using conventional engineering formulas from standard engineering mechanics textbooks and performed in accordance with ASME general guidelines for analyzing primary and secondary stresses. The NRC has concluded (Reference 3) that these stress analyses are acceptable for rod-average burnup levels up to 52 MWd/kgM. Extending the rod-average burnup level to 60 MWd/kgM does not reduce the applicability of these methods and thus these analysis methods are found to be acceptable for application to the CE 16x16 design up to a rod-average burnup of 60 MWd/kgM. As noted in Section 3.0(e), stress analyses at extended burnup levels must include the effects of cladding thinning due to cladding oxidation.

(b) Design Strain

Bases/Criteria - With regard to fuel assembly design strain, the CE design basis for normal operation and AOOs is that permanent fuel assembly deflections shall not result in control element assembly (CEA) insertion time beyond that allowable. This basis is satisfied by adherence to the stress criteria mentioned above and strain criterion yet to be discussed.

The submitted topical report provides a design criterion for fuel rod and burnable poison rod cladding uniform circumferential strain (elastic plus plastic) of one percent (1%) as a means of precluding excessive cladding deformation. This strain criterion is consistent with that given in Section 4.2 of the SRP.

The material property that could have a significant impact on the cladding strain criterion at the requested extended burnup levels is cladding ductility. The strain criterion could be impacted if cladding ductility were decreased, as a result of extended burnup operations, to a level that would allow cladding failure without the 1% cladding strain criterion being exceeded in the CE analyses.

Recent measured cladding and plastic cladding strain values from CE fuel rods (Reference 13) and other pressurized water reactor (PWR) fuel vendors (Reference 14) have shown a decrease in cladding ductilities when local burnups exceed 52 MWd/kgM. The cladding plastic strain values decreased to 0.03 from 0.11% when local burnups were between 55 and 63 MWd/kgM. ANO-2/CE was questioned on whether these significant reductions in cladding plastic ductilities justified a decrease in the 1% design criterion for total uniform strain (elastic plus lastic) for CE fuel with local burnups greater than 55 MWd/kgM (Reference 13).

ANO-2/CE has responded (Reference 9) that because of the increase in the yield strength and the corresponding increase in elastic strain of the cladding due to irradiation, the typical elastic strains were above 1% using nominal values for irradiated yield strength and Young's modulus at burnups greater than 55 MWd/kgM. ANO-2/CE was further questioned about the probability that the combined elastic plus plastic strains between 55 and 63 MWd/kgM would fall below the 1% strain criterion. ANO-2/CE presented (Reference 10) a statistical analysis of their measured yield strength data from cladding with local burnups greater than 55 MWd/kgM and calculated a two-sided tolerance limit about the mean value for yield strength. They also calculated a two-sided tolerance limit about the mean value for Young's modulus using data from the open literature. Using the lower bound tolerance limit for yield strength and the upper bound tolerance limit for Young's modulus, plus the range of plastic strain, they calculated that there is a 9% probability that cladding strain would fall below the 1% total limit for a strain limit.

This reviewer has performed an independent simplified statistical analysis at a 5% probability level that total uniform strain will fall below 1% using a one-sided lower tolerance limit of the measured yield strengths at burnups greater than 55 MWd/kgM and a one-sided upper tolerance limit of the measured values for Young's modulus. This analysis has demonstrated that there is slightly less than a 5% probability that cladding strain will fall below the 1% total uniform strain limit. The 5% probability of falling below the 1% strain limit calculated by this reviewer is conservative because this simplified approach has assumed that combining the yield strength and Young's modulus tolerance limits will result in an equivalent plastic strain tolerance limit. Hall and Sampson (Reference 15) have provided a more exact analytical procedure for determining either one-sided or two-sided tolerance limits for the distribution of the quotient (e.g., plastic strain) of two independent normal variables (e.g., yield strength and Young's modulus) for this application.

Therefore, because 1) there is a very low probability of total uniform strain falling below 1% in the CE 16x16 fuel cladding, 2) histories are used in the CE strain analysis, and 3) no fuel failures have been observed on fuel rods irradiated with rod-average burnups to 63 MWd/kgM, we conclude that the 1% total uniform strain limit remains applicable for the ANO-2 use of the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM. However, it should be stressed that future requests to extend the rod-average burnup limit beyond 60 MWd/kgM should be accompanied with measured cladding strain, yield, and fracture strength data at the extended burnup levels requested. This data is necessary to demonstrate that the total uniform strain criterion of 1% remains applicable at these higher burnups and that fuel cladding brittle fracture will not occur during normal operation and AOOs at these higher burnups.

Evaluation - CE utilizes the FATES3B (Reference 16) computer code to predict cladding strain and other fuel performance phenomena at high burnup levels. This code has been approved by the NRC for fuel performance analyses up to rod-average burnups of 60 MWd/kgM (Reference 17). The FATES3B code will take the place of the earlier FATES3 code (Reference 18). The use of the FATES3B code for calculating cladding strain is acceptable for rod-average burnups up to 60 MWd/kgM.

(c) Strain Fatigue

Bases/Criteria - The ANO-2/CE strain fatigue criterion is different from those described in Section 4.2 of the SRP, viz., a safety factor of 2 on stress amplitude or of 20 on the number of cycles using the methods of O'Donnell and Langer (Reference 19). Instead, CE has proposed in the past that the cumulative strain cycling usage (i.e., the sum of the ratios of the number of cycles in a given effective strain range to the permitted number in that range) will not exceed 0.8. For Zircaloy cladding, the design limit curve has been adjusted to provide a strain margin for the effects of uncertainty and irradiation. The resulting curve given in References 2 and 11 bounds all of the data used in the development of the criterion that is discussed in the SRP. The NRC has previously concluded that the proposed criterion was acceptable for current burnup levels (Reference 3).

The material property that could have a significant effect on the strain fatigue criterion is cladding ductility. As discussed in the above section for design strain, extended burnup operation above local burnups of 55 MWd/kgM has demonstrated a significant reduction in cladding ductilities. However, as also discussed herein, there is a low probability that cladding ductility will fall below the acceptable limit for total uniform strain at a rod-average burnup of 60 MWd/kgM. In addition, there is a considerable amount of conservatism in the ANO-2/CE strain fatigue calculation. Therefore, we conclude that the strain fatigue criterion proposed in Reference 1 is acceptable for licensing applications to CE 16x16 fuel up to a rod-average burnup of 60 MWd/kgM.

Evaluation - The fuel and cladding models used to determine fuel and cladding diametral strain for the fatigue analysis are those in the FATES3B code (Reference 16) which has been approved by the NRC (Reference 17). The power history used for the fatigue analysis includes conservative estimates of daily power cycling and AOOs and has been described previously in Reference 2. This analysis also accounts for a conservative number of hot and cold shutdowns during the fuel lifetime. This power history takes into account the extra duty required for rod-average burnups up to 60 MWd/kgM. Therefore, we conclude that the strain fatigue analysis models referenced are acceptable for application to the ANO-2 use of the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

(d) Fretting Wear

Bases/Criteria - Fretting wear is a concern for fuel and burnable poison rods and the guide tubes. Fretting wear may occur on the fuel and/or burnable rod cladding surfaces in contact with the spacer grids if there is a reduction in grid spacer spring loads in combination with small amplitude, flow-induced, vibratory forces. Guide tube wear may result when there is flow-induced vibration between the control rod ends and the inner wall of the guide tubes.

While Section 4.2 of the SRP does not provide numerical bounding value acceptance criteria for fretting wear, it does stipulate that the allowable fretting wear should be stated in the safety analysis report and that the stress/strain and fatigue limits should presume the existence of this wear.

The report has addressed fuel and burnable poison rod fretting wear by referring to Reference 2 and stating that no significant wear has been observed for CE fuel rods, and no additional fretting wear was expected due to the extension of rod-average burnup level to 60 MWd/kgM. Indicated in Reference 2 is that a specific fretting wear limit was not used for CE fuel assembly components, because it has not been a problem for current CE fuel designs. This same data was used to explain why fretting wear was not accounted for in the fuel and burnable poison rod analyses for cladding stress and fatigue. In order to support this claim, in the previous review, CE provided fuel examination information from 744 assemblies with average burnups up to approximately 32 MWd/kgM that showed no failures or significant wear on the surface of their fuel or burnable poison rods. It is noted that since this time, CE has performed a visual examination of 14x14 designed fuel rods irradiated to rod-average burnups up to 56 MWd/kgM and found no surface anomalies other than minor scratches (Reference 13).

Due to the lack of significant fretting wear in the examination of more than 744 CE fuel assemblies, with rod-average burnups to 56 MWd/kgM and existing fuel surveillance programs, we conclude that CE has demonstrated that fretting wear in their fuel and burnable poison rods will be acceptable up to rod-average burnups of 60 MWd/kgM.

Guide tube wear, however, was observed in several CE fuel assemblies in 1977. Since then a design change in the guide tubes has greatly reduced guide tube wear for both 14x14 and 16x16 fuel assembly designs. However, it was noted in the NRC review of Reference 2 that very limited low burnup data were available for this new guide tube design (Reference 3). For this submittal, ANO-2/CE was requested (Reference 8) to provide guide tube wear data for the new unsleeved guide tube design to be used in the subject reload and future CE 16x16 plant reloads and compare this data to their maximum predicted wear correlation. ANO-2/CE has provided (Reference 9) this comparison, which demonstrates that the measured wear data is a factor of 3 below the CE correlation for maximum wear. However, it should be noted that the maximum in-reactor operating times of the wear data are only one-third of those expected for rod-average burnups to 60 MWd/kgM. The ANO-2/CE response has argued that this lack of wear data at the maximum burnup level requested is satisfactory because 1) the CE maximum guide tube fretting wear correlation is very conservative, and 2) there is a large margin between maximum predicted fretting wear at the maximum burnup level requested and the minimum amount of allowable wear that a guide tube can sustain without violating any design criteria.

Due to the conservative nature of the CE guide tube fretting wear correlation and the large margin that exists before design criteria are violated, we conclude that guide tube wear in the CE 16x16 fuel design is acceptable up to a rod-average burnup level of 60 MWd/kgM.

Evaluation - The ANO-2/CE submittal has suggested that the lack of a large amount of measured fretting wear in CE fuel and burnable poison rods supports their conclusion that they do not need to include the effects of cladding thinning due to fretting wear in their stress, strain, and fatigue analyses for the fuel and burnable poison rods. However, this does not answer the question of what effect the calculated impact of a small reduction in cladding thickness has on safety and design analyses, e.g., LOCA and stress/strain. In the past, CE (Reference 2) has indicated that the most limiting LOCA analysis is early-in-life when stored energy is the highest and fretting wear is insignificant for this analysis. We agree with this assessment. ANO-2/CE has also responded to a question on cladding thinning due to oxidation by conservatively reducing cladding thickness of the 16x16 fuel rods by 3 mils in their stress analysis [see Section 3.0(e)]. This inclusion of cladding thinning due to corrosion is judged to bound thinning due to fretting wear because corrosion is the greater of the two thinning mechanisms and because these two mechanisms do not occur simultaneously at the same location on a fuel rod. For example, where fretting wear is present on the fuel or burnable poison rod, oxidation will not be present and vice versa. Therefore, it is concluded that cladding thinning of the fuel and burnable poison rods due to fretting wear are bounded by CE's analysis of cladding thinning due to oxidation.

As noted in the "Criteria" section, guide tube wear has been a problem in the past for CE assemblies. Design changes have been implemented by CE for both 14x14 and 16x16 assemblies to reduce guide tube wear. Both out-of-reactor and in-reactor confirmation tests have been performed to show that these design changes have resulted in a significant decrease in guide tube wear for in-reactor residence times that are one-third of those expected for an extended burnup level of 60 MWd/kgM. Extrapolating the guide tube wear to the in-reactor residence time expected for an extended rod average burnup level of 60 MWd/kgM has demonstrated that guide tube wear will remain at a relatively low level. We conclude that guide tube wear is not expected to be a problem up to a rod-average burnup of 60 MWd/kgM for the newly designed guide tubes in the CE 16x16 design (based on the low level of wear at lower burnups). The licensee should continue to examine guide tubes up to the extended burnup levels requested to confirm that wear is not a problem at these burnup levels.

(e) Oxidation and Crud Buildup

Bases/Criteria - Section 4.2 of the SRP identifies cladding oxidation and crud buildup as potential fuel system damage mechanisms. General mechanical properties of the cladding are not significantly impacted by thin oxides or crud buildup. The major means of controlling fuel damage due to cladding oxidation and crud is through water chemistry controls, materials used in the primary system, and fuel surveillance programs that are all reactor specific. Because these controls are already included in the specific reactor design, a design limit on cladding oxidation and crud is considered to be redundant, and thus, not necessary.

This does not, however, eliminate the need to include the effects of cladding oxidation and crud in safety analyses such as for LOCA and mechanical analyses. This will be discussed in further detail in the evaluation presented below.

Evaluation - As noted above, the amount of cladding oxidation expected for a particular reactor is dependent on fuel rod powers (surface heat flux), chemistry controls, and primary inlet coolant temperatures used by that reactor, but the amount of oxidation increases with in-reactor residence time and cannot be eliminated. Therefore, extending the rod-average burnup level to 60 MWd/kgM could result in 1) thicker oxide layers that provide an extra thermal barrier that increases cladding and fuel temperatures, and 2) cladding thinning that can affect the mechanical analyses. The degree of this effect on thermal and mechanical analyses is dependent on reactor coolant temperatures and the level of success of a reactor's chemistry controls.

The ANO-2/CE submittal (Reference 1) has provided oxide thickness measurements from fuel rod cladding irradiated in ANO-2 near the burnup level requested and placed a conservative upper bound limit on the measured values. The upper bound oxide thickness at a rod-average burnup of 60 MWd/kgM was used to estimate the increase in cladding temperatures and stress, and found to have little impact on either of these analyses. Therefore, we conclude that cladding oxidation is acceptable for the CE 16x16 fuel design in ANO-2 up to a rod-average burnup of 60 MWd/kgM.

There is an indication that cladding corrosion may limit the fuel rod performance lifetime for higher burnup irradiations for specific plants. Because cladding oxidation is dependent on reactor-specific conditions, such as reactor coolant temperatures and water chemistry, it is necessary to examine cladding oxidation on a reactor-specific basis. Also, future requests to extend the rod-average burnup limit beyond 60 MWd/kgM should be accompanied with reactor-specific corrosion data at the burnup levels requested.

(f) Rod Bowing

Bases/Criteria - Fuel and burnable poison rod bowing are phenomena that alter the design-pitch dimensions between adjacent rods. Bowing affects local nuclear power peaking and the local heat transfer to the coolant. Rather than placing design limits on the amount of bowing that is permitted, the effects of bowing are included in the safety analysis. This is consistent with the SRP and the NRC has approved this for current burnup levels (Reference 3). The methods used for predicting the degree of rod bowing at the extended burnups requested are evaluated below.

Evaluation - The CE analysis methods used to account for the effect of fuel and poison rod bowing in 14x14 and 16x16 fuel assemblies are presented in Reference 2 and CENPD-225 (Reference 20) with its supplements. These methods have been approved by the NRC (References 3 and 20) for fuel and Type 3 poison rods to current burnup levels.

Reference 2 has compared 14x14 rod bow data with burnups to 45 MWd/kgM to their licensing rod bow model and demonstrated that the model becomes more conservative at higher burnups. These data appeared to suggest that the rate of rod bow significantly decreases at burnups greater than 30 to 35 MWd/kgM while the CE analytical model for rod bow assumes little or no decrease in the rate of rod bowing with burnup. This results in very conservative predictions of rod bowing in CE 14x14 designed fuel at high burnup levels. Reference 2 has also demonstrated that the CE rod bowing model for 16x16 fuel rods was very conservative by comparison to data with burnups up to 33 MWd/kgM. ANO-2 has indicated that they routinely perform visual examination of their fuel assemblies to provide assurances of satisfactory performance of their fuel. The phenomenon of rod bowing is generic to all LWRs even though design differences such as the length between spacers and rod diameter are important to the amount of rod bowing. Therefore, other fuel vendor experience with rod bowing is valuable in evaluating the trend in rod bowing at extended burnups.

FRAMATOME has measured rod bow on their FRAGEMA fuel assemblies for fuel burnups up to 53 MWd/kgM and found that the rate of rod bowing versus burnup decreases at burnups greater than 30 to 35 MWd/kgM (Reference 21). Similar measurements of rod bowing have been made by Kraftwerk Union AG (KWU) on their fuel designs up to burnups of 50 MWd/kgM (Reference 22) and found that due to the scatter in their limited data, the decrease in the rate of rod bowing was not as evident as that demonstrated in References 2 and 21. However, KWU did find that rod bowing was limited to gap closures of less than 40% on their fuel designs which is consistent with the data in Reference 2.

We conclude that the CE analysis methods (Reference 20) applied to the CE 16x16 fuel design in ANO-2 will remain conservative up to the extended burnup level requested and, therefore, are acceptable up to a rod-average burnup level of 60 MWd/kgM.

(g) Axial Growth

Bases/Criteria - The core components requiring axial-dimensional evaluation are the CEAs, burnable poison rods, fuel rods, and fuel assemblies. The CEAs are not included in this extended burnup review. The growth of burnable poison and fuel rods is mainly governed by a) the irradiation and stress-induced growth of the Zircaloy-4 cladding, and b) the behavior of poison, fuel, and spacer pellets, and their interaction with the Zircaloy-4 cladding. The growth of the fuel assemblies is a function of both the comprehensive creep and the irradiation-induced growth of the Zircaloy-4 guide tubes. For the Zircaloy cladding and fuel assembly guide tubes, the critical tolerances that require controlling are a) the spacing between the fuel rods and the upper fuel assembly fitting (i.e., shoulder gap), and b) the spacing between the fuel assemblies and the core internals. Failure to adequately design for the former may result in fuel rod bowing, and for the latter, may result in collapse and failure of the assembly hold-down springs. With regard to inadequately designed shoulder gaps, problems have been reported (References 23, 24, 25, and 26) in foreign (Obrigheim and Beznau) and domestic (Ginna and ANO-2) plants that have necessitated predischarge modifications to fuel assemblies.

For burnable poison and fuel rods, CE has a design basis that sufficient shoulder gap clearances must be maintained throughout the design lifetime of the fuel at a 95% confidence level. Similarly, for fuel assembly axial growth, CE has a design basis that sufficient clearance must be maintained between the fuel assembly and the upper guide structure throughout the design lifetime of the fuel assembly at a 95% confidence level. This basis allocates a fuel assembly gap spacing which will accommodate the maximum axial growth, when establishing the design minimum initial fuel assembly clearance with respect to the core internals. These design bases and limits dealing with axial growth prevent mechanical interference and thus have been approved by NRC for previous extended burnup levels (Reference 3). We conclude that these design bases and limits will ensure that contact is prevented, and thus, are found to be acceptable for the CE 16x16 fuel design to 60 MWd/kgM.

Evaluation - The CE methods and models used for predicting fuel rod and assembly growth in this submittal (Reference 1) have been changed somewhat from those previously approved to better predict the new higher exposure growth data. This evaluation will discuss the new revised models used to predict fuel rod and assembly growth. We will then discuss how CE uses these revised models to predict 1) the shoulder gap spacings between the fuel rod and the upper fuel assembly fitting, and 2) the gap spacing between the fuel assembly and core internals.

The new revised fuel and burnable poison rod growth model is based on CE 14x14 and 16x16 rod data with rod-average burnups above those requested. The model predicts a "best estimate" value of rod growth with uncertainties. The new revised assembly growth model is based on the SIGREEP computer code and growth data from assemblies with stress relief annealed (SRA) guide tubes with assembly average burnups below those requested in this submittal. The SIGREEP prediction of assembly growth takes into account the different axial stresses on the guide tubes for different CE plant fuel assemblies including the ANO-2 assemblies and uses input parameters with assigned statistical uncertainties along with Monte Carlo random selection techniques and combinations of these uncertainties to obtain a probability density function of assembly growth at a given fluence (burnup) level.

The CE evaluation of shoulder gap spacing uses the lower bound probability density function for assembly growth and the upper bound probability density function for rod growth with uncertainties in the SIGREEP computer code to predict the shoulder gap at an upper bound 95% probability with a 95% confidence level. This CE methodology for predicting an upper bound 95/95 shoulder gap spacing has been compared to measured shoulder gap data (Reference 1) that have assembly-average burnups below those requested in this submittal. These CE upper bound predictions do indeed bound the shoulder gap data and appear to become even more conservative at the higher burnup levels. It should be noted that in the shoulder gap calculation the amount of fuel rod growth is much greater than the amount of assembly growth, therefore, the prediction of fuel rod growth dominates the analysis of shoulder gap spacing. It should also be noted that the CE rod growth data have rod-average burnups greater than those requested in this submittal.

We conclude that the CE analysis methodology is acceptable for application to the CE 16x16 design up to a rod-average burnup of 60 MWd/kgM because 1) CE has fuel rod growth data above the burnup level requested, 2) fuel rod growth dominates the shoulder gap spacing analysis, and 3) the large amount of conservative margin CE has demonstrated in their prediction of shoulder gap spacing.

The CE analysis of the gap spacing between the upper fuel assembly and core internals uses the SIGREEP probability density function for assembly growth to predict a minimum 95/95 value for this gap spacing in order to prevent bottoming out of the assembly hold-down springs. Because CE does not have assembly growth data up to the burnup level requested, they were questioned (Reference 8) on the gap margin that exists at the burnup level requested in this submittal to prevent bottoming of the hold-down spring. ANO-2/CE's response (Reference 9) indicated that there was approximately one-third of the original as-fabricated gap spacing left prior to bottoming out of the hold-down spring at the burnup requested. Due to this significant margin and CE's conservative analysis methodology, we conclude that bottoming out and failure of the hold-down spring due to fuel assembly growth is not expected for the CE 16x16 design up to a rod-average burnup of 60 MWd/kgM. However, we encourage ANO-2 to visually examine the hold-down springs for those assemblies discharged with rod-average burnups near or at the 60 MWd/kgM level.

(h) Rod Internal Pressure

Bases/Criteria - Rod internal pressure is a driving force for, rather than a direct mechanism of, fuel system damage that could contribute to the loss of dimensional stability and cladding integrity. Section 4.2 of the SRP presents a rod pressure limit that is sufficient to preclude fuel damage in this regard, and it has been widely used by the industry; it states that rod internal gas pressure should remain below the nominal system pressure during normal operation, unless otherwise justified. CE has elected to justify a rod internal pressure limit above system pressure in Reference 27 and this proprietary rod pressure limit has been approved by the NRC.

The CE design criterion used to establish this proprietary rod pressure limit is: "The fuel rod internal hot gas pressure shall not exceed the critical maximum pressure determined to cause an outward cladding creep rate that is in excess of the fuel radial growth rate anywhere locally along the entire active length of the fuel rod." In addition, CE has evaluated the impact of this rod pressure limit on hydride reorientation and accident analyses. The NRC approved rod pressure limit defined in Reference 27 is also acceptable for application to the CE 16x16 fuel design to a rod-average burnup of 60 MWd/kgM.

Evaluation - CE has indicated that they will use the FATES3B (Reference 16) computer code to calculate maximum rod internal pressures and this code has been approved by NRC in Reference 17. The FATES3B code has been verified against fission gas release data from a variety of fuel designs with rod-average burnups up to 60 MWd/kgM. The use of the approved FATES3B code is recommended over the earlier approved FATES3A code (Reference 18) because the former has been verified against a much larger data base at higher burnup levels.

ANO-2/CE were questioned on the apparent small underprediction of fission gas release by the FATES3B code when fission gas release values were low (<3% release) at high burnup levels and the impact of this underprediction on licensing analyses. ANO-2/CE responded that licensing analyses are typically performed in a conservative manner on the peak operating rod, i.e., a rod with high temperatures, high fission gas release and high internal rod pressures, and therefore, the small underprediction in fission gas release at low temperatures were insignificant for licensing analyses. They also demonstrated that the amount of underprediction was small in terms of calculated internal rod pressures in these low temperature rods. We concur with this assessment and conclude that the FATES3B code is acceptable for the analysis of internal rod pressures for the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

In addition to the computer code, the input power history to the code is very important for the internal rod pressure calculation. Consequently, CE has been required by NRC in the past, to define a methodology for determining the power history for the rod pressure calculation. This methodology was first reviewed and approved for Reference 2 and CE has provided an example of how this methodology is applied in Reference 1. We conclude that the use of the approved FATES3B code along with the approved CE power history methodology described in References 1 and 2 is acceptable for licensing applications for the CE 16x16 fuel design to a rod-average burnup of 60 MWd/kgM.

(i) Assembly Liftoff

Bases/Criteria - The SRP calls for the fuel assembly hold-down capability (wet weight and spring forces) to exceed worst-case hydraulic loads for normal operation, which includes AOOs. The NRC-approved CE Extended Burnup Topical Report (Reference 2) has endorsed this design basis. This is also found to be acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

Evaluation - CE methodology for assembly liftoff analysis has been summarized in Reference 2 and approved by the NRC for current burnups in Reference 3. The fuel assembly liftoff force is a function of plant coolant flow, spring forces, and assembly dimensional changes. Extended burnup irradiation will result in additional hold-down spring relaxation and assembly length increases which will have opposing effects on the assembly hold-down force, i.e., the length increase will compress the spring, and therefore, increase the hold-down force. Industry experience has demonstrated that the assembly length increase due to irradiation more than compensates for spring relaxation so that the hold-down force increases with increased burnup. In fact, a major concern at extended burnups is that the assembly length change will compress the spring to the extent that it will bottom out and break. This issue has been addressed satisfactorily in Section 3.0(g), "Axial Growth." Consequently, we conclude that the issue of assembly liftoff has been satisfactorily addressed for the CE 16x16 fuel design to a rod-average burnup of 60 MWd/kgM.

(j) Control Material Leaching

Bases/Criteria - The SRP and GDC require that reactivity control be maintained. Rod reactivity can sometimes be lost by leaching of certain poison materials if the cladding of control-bearing material has been breached.

Evaluation - Reactivity loss from burnable poison rods at extended burnup levels is found to be insignificant because nearly all of the reactivity controlling boron-10 is burned out at these burnup levels. Consequently, reactivity loss due to leaching of burnable poison rods at the extended burnup level requested is considered to be insignificant.

Control rod lifetimes are not changed in this submittal from those previously approved by the NRC, and therefore, are not affected by this request to extend fuel rod-average burnups up to 60 MWd/kgM. We conclude that the issue of control material leaching has been satisfactorily addressed for the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

3.0 FUEL ROD FAILURE

In the following paragraphs, fuel rod failure thresholds and analysis methods for the failure mechanisms listed in the SRP are reviewed. When the failure thresholds are applied to normal operation including AOOs, they are used as limits (and hence SAFDLs) since fuel failure under those conditions should not occur according to the traditional conservative interpretation of GDC 10. When these thresholds are used for postulated accidents, fuel failures are permitted but they must be accounted for in the dose calculations required by 10 CFR Part 100. The basis or reason for establishing these failure thresholds is thus established by GDC 10 and Part 100, and only the threshold values and the analysis methods used to assure that they are met are reviewed below.

(a) Hydriding

Bases/Criteria - Internal hydriding as a cladding failure mechanism is precluded by controlling the level of hydrogen impurities during fabrication. The moisture level in the uranium dioxide fuel is limited by CE to a proprietary value less than 20 ppm, and this specification is compatible with the ASTM specification (Reference 28) which allows two micrograms of hydrogen per gram of uranium (i.e., 2 ppm). This is the same as the limit described in the SRP and has been found acceptable by NRC (Reference 3) and continues to be acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM

External hydriding due to waterside corrosion is a possible reason for the observed ductility decrease at local burnups >55 MWd/kgM discussed in Section 2.0(b). Garde (Reference 29) has recently proposed that the ductility decrease is due to a combination of hydride formation and irradiation damage at these high burnup levels. The issue of cladding ductility has already been discussed in Section 2.0(b) and found to be acceptable for the CE 16x16 design to a rod-average burnup of 60 MWd/kgM.

Evaluation - The issue of internal hydriding is not expected to be affected by an increase in rod-average burnup level because this failure mechanism is dependent on the amount of hydrogen impurities introduced during fuel fabrication. Fuel failures due to internal hydriding occur early in a fuel rods lifetime and are not dependent on the length of irradiation. Because CE limits the level of hydrogen impurities in their fuel fabrication process, this methodology is found acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

The major issue for external hydriding at extended burnup levels is an increase in hydriding that results in a decrease in cladding ductility reducing the threshold for cladding failure. The issue of decreased cladding ductility at the extended burnup level requested has already been discussed in Section 2.0(b) of this report and found to be acceptable for the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

(b) Cladding Collapse

Bases/Criteria - If axial gaps in the fuel pellet column were to occur due to densification, the cladding would have the potential of collapsing into this axial gap (i.e., flattening). Because of the large local strains that would result from collapse, the cladding is assumed to fail. It is a CE design basis that cladding collapse is precluded during the fuel rod and burnable poison rod design lifetime. This design basis is the same as that in the SRP and has been approved by the NRC (Reference 3). We conclude that this design basis is also acceptable for the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

Evaluation - The longer in-reactor residence times associated with the burnup extension requested for ANO-2 fuel will increase the amount of creep of an unsupported fuel cladding. Extensive post-irradiation evaluations (Reference 2) by CE have not shown any evidence of cladding collapse or large local ovalities in their fuel designs. This is primarily the result of their use of prepressurized rods and stable (non-densifying) fuel in current generation designs.

In addition, CE has performed several post-irradiation examinations that have looked for axial gap formation in their modern fuel designs and concluded that the largest measured gaps are much smaller than those required to achieve cladding collapse for current CE fuel designs at a rod-average burnup of 60 MWd/kgM (Reference 1). These CE measured cold axial gaps have been corrected to hot axial gaps in the fuel rod during in-reactor operation for the cladding collapse analysis. The resulting hot gap used in the cladding collapse analysis is in excess of that expected at a 95% probability and a 95% confidence level based on a CE statistical analysis of the hot gaps (Reference 9). This cladding collapse analysis has demonstrated that the CE 16x16 cladding will not collapse at a rod-average burnup greater than 60 MWd/kgM. Therefore, ANO-2 has proposed that they no longer be required to address cladding collapse for new cores or reload batches of the CE 16x16 design unless design or manufacturing changes are introduced which would significantly reduce cladding collapse times for this fuel design. We conclude that this proposed approach is acceptable for future CE cores or reload batches of the 16x16 design with the requirement that the issue of cladding collapse be reevaluated should rod-average burnups exceed 60 MWd/kgM.

(c) Overheating of Cladding

Bases/Criteria - The design limit for the prevention of fuel failures due to overheating is that there will be at least a 95% probability at a 95% confidence level that the departure from nucleate boiling ratio (DNBR) will not occur on a fuel rod having the minimum DNBR during normal operation and AOOs. This design limit is consistent with the thermal margin criterion in Section 4.2 of the SRP, and thus, has been found acceptable for application to CE fuel designs (Reference 2). This design limit is not impacted by the proposed extension in burnup. Therefore, we conclude that this design limit remains acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

Evaluation - As stated in Section 4.2 of the SRP, adequate cooling is assumed to exist when the thermal margin criterion to limit the DNBR or boiling transition in the core is satisfied. The analysis methods employed to meet the DNBR design basis are provided in References 30 through 34. These analysis methods have been approved by NRC for current burnup levels and are also found to be acceptable for application to the CE 16x16 design up to a rod-average burnup of 60 MWd/kgM.

The impact of rod bowing on DNB for the CE 16x16 design in ANO-2 has been addressed in Reference 35. We conclude that ANO-2 has adequately addressed the issue of cladding overheating for the CE 16x16 design up to a rod-average burnup of 60 MWd/kgM.

(d) Overheating of Fuel Pellets

Bases/Criteria - As a second method of avoiding cladding failure due to overheating, CE precludes centerline fuel pellet melting during normal operation and AOOs. This design limit is the same as given in the SRP and has been approved for use at current levels. We conclude that this design limit is also acceptable for the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

Evaluation - The design evaluation of the fuel centerline melt limit is performed with the approved CE fuel performance code, FATES3B (Reference 16). This code is also used to calculate initial conditions for transients and accidents. As noted earlier, the FATES3B code is acceptable for fuel performance calculations up to a rod-average burnup of 62 MWd/kgM (Reference 17).

In the CE centerline melting analysis, the melting temperature of the UO_2 is assumed to be 5080°F unirradiated and is decreased by 58°F per 10 MWd/kgM. This relation has been almost universally adopted by the industry and has been previously accepted by the NRC (Reference 3). Recent UO_2 fuel melting data with burnups to 30 MWd/kgM by Komatsu have shown no discernible decrease in melting temperature with burnup, and a drop of approximately 20°F per 10 MWd/kgM for UO_2-20% PuO with burnups up to 110 MWd/kgM (Reference 36). This demonstrates the conservatism employed by CE in their fuel melting temperature analysis at extended burnup levels. Therefore, we conclude that the ANO-2/CE analysis methods for fuel melting are acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

(e) Excessive Fuel Enthalpy

Bases/Criteria - The SRP guidelines for a severe reactivity initiated accident (RIA) in a PWR, Section 4.2.II.A.2(f), state that for "all RIAs in a PWR, the thermal margin criteria (DNBR) are used in a fuel failure criteria to meet the guidelines of Regulatory Guide 1.77 (Reference 37) as it relates to fuel failure." ANO-2/CE has adopted this criterion for fuel failure in addition to other more stringent criteria for RIAs (Reference 38). These criteria are still applicable to the burnup extension requested and therefore, are acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

Evaluation - The NRC approved analysis methods for evaluating RIAs in CE plants is provided in Reference 39 and the specific analyses for ANO-2 are provided in Reference 38. The approved analysis methods described in Reference 39 are still applicable to the burnup extension requested and therefore, are acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

The steady-state fuel operational data that are input to the CEA ejection analysis from the FATES3B code are dependent on fuel burnups. As noted earlier, the FATES3B code is acceptable for steady-state fuel performance applications for CE 16x16 fuel up to the 60 MWd/kgM rod-average burnup level requested in this submittal.

(f) Pellet/Cladding Interaction (PCI)

Bases/Criteria - As indicated in Section 4.2 of the SRP, there are no generally applicable criteria for PCI failure. However, two acceptance criteria of limited application are presented in the SRP for PCI: 1) less than 1% transient-induced cladding strain, and 2) no centerline fuel melting. Both of these limits are used in CE fuel designs [see Sections 2.0(b) and 3.0(d)] and have been found to be acceptable in this application.

Evaluation - As noted earlier, CE uses the FATES3B code (Reference 16) to demonstrate that their fuel meets both the cladding strain and fuel melt criteria. This code has been found to be acceptable for these applications [see Sections ..0(b) and 3.0(d)] and therefore, is acceptable for evaluating PCI failures for CE 16x16 fuel designs up to a rod-average burnup of 60 MWd/kgM.

CE has also presented PCI power ramping tests on fuel rods that are similar to their fuel designs up to rod-average burnups of approximately 48 MWd/kgM that demonstrate that the ramp terminal power level for fuel failure does not decrease with increased burnup. In addition, the maximum power capability of extended burnup fuel is reduced because of fissile material burnout, therefore, limiting the driving force for PCI failures. Consequently, we believe that CE 16x16 fuel designs have adequate PCI resistance up to a rod-average burnup of 60 MWd/kgM.

(g) Cladding Rupture

Bases/Criteria - Zircaloy cladding will burst (rupture) under certain combinations of temperature, heating rate, and differential pressure; conditions that occur during a LOCA. While there are no specific design criteria in the SRP associated with cladding rupture, the requirements of Appendix K to 10 CFR Part 50 must be met as those requirements relate to the incidence of rupture during a LOCA; therefore, a rupture temerature correlation must be used in the LOCA emergency core cooling system (ECCS) analysis. These Appendix K requirements for cladding rupture are not impacted by ANO-2's request to extend rod-average burnup to 60 MWd/kgM and therefore, we conclude that these requirements remain applicable to CE 16x16 fuel designs up to the burnup level requested.

Evaluation - An empirical cladding creep model is used by CE to predict the occurrence of cladding rupture in their LOCA-ECCS analysis. The rupture model is directly coupled to the cladding ballooning and flow blockage models used in the NRC approved ECCS evaluation model described in Reference 40.

The CE cladding rupture model is not affected by ANO-2's request to extend their burnup limit. Therefore, we conclude that the CE model for cladding rupture for LOCA-ECCS analyses is acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

Another concern raised during previous high-burnup reviews (Reference 27), is that these higher burnups can result in fuel rod pressures that exceed system pressure and these higher fuel rod pressures can affect cladding rupture during a LOCA. For those CE fuel reloads that have calculated peak rod pressures above system pressure, CE has previously agreed (Reference 27) to reevaluate their LOCA-ECCS analyses to determine the most limiting LOCA conditions for these reloads. Therefore, we conclude that CE has addressed the issue of fuel rod pressures exceeding system pressure on cladding rupture in the LOCA-ECCS analysis.

Those important parameters that are input to the rupture analysis that can be burnup dependent, such as rod pressures, fission gas release, fuel stored energy, and gap conductance are calculated with the NRC approved code FATES3B. As noted earlier, the FATES3B code has been verified with data up to rod-average burnups of 60 MWd/kgM. Therefore, we conclude that the use of the FATES3B code is acceptable for input to LOCA-ECCS analyses of the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM, as requested in this submittal.

(h) Mechanical Fracturing

Bases/Criteria - Mechanical fracturing of a fuel rod could potentially arise from an externally applied force such as a hydraulic load or a load derived from core-plate motion. To preclude such failure, the applicant has stated (Reference 2) that fuel rod fracture stress limits shall be in accordance with the criteria given in Table 9-1 of CENPD-178 Revision 1 (Reference 41).

The review of CENPD-178, Revision 1, and the criteria given in Table 9-1 (Reference 41), has been completed and found acceptable by NRC for current burnup levels (Reference 3). The CE fracture stress limits in Reference 41 are conservatively based on unirradiated Zircaloy properties and are judged to remain conservative up to a rod-average burnup of 60 MWd/kgM for the mechanical fracturing analysis. Consequently, these criteria are also found to be acceptable for application to the CE 16x16 design up to a rod-average burnup of 60 MWd/kgM. However, future requests to extend the burnup beyond 60 MWd/kgM should be accompanied with measured cladding yield and fracture strength data to demonstrate that the rod fracture stress limits described in Reference 41 remain conservative up to the burnup level requested.

Evaluation - The mechanical fracturing analysis is done as a part of the seismic-LOCA loading analysis. A discussion of the seismic-LOCA loading analysis is given in Section 4.0(d) of this report.

4.0 FUEL COOLABILITY

For accidents in which severe fuel damage might occur, core coolability must be maintained as required by several GDCs (e.g., GDC 27 and 35). In the following paragraphs, limits and methods to assure that coolability is maintained for the severe damage mechanisms listed in the SRP, are reviewed.

(a) Fragmentation of Embrittled Cladding

Bases/Criteria - The most severe occurrence of cladding oxidation and possible fragmentation during an accident is a result of a significant degree of cladding oxidation during a LOCA. In order to reduce the effects of cladding oxidation for a LOCA, CE uses an acceptance criteria of 2200°F on peak cladding temperature and a 17% limit on maximum cladding oxidation as prescribed by 10 CFR 50.46. These criteria provided by CE for the LOCA analysis are acceptable for application to the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

Evaluation - The NRC approved cladding oxidation models in Reference 42 are used by CE to determine that the above criteria are met, as a result of the LOCA analysis. These models are not affected by the proposed extended burnup operation; however, the steady-state operational input provided to the LOCA analysis is burnup dependent. As noted earlier, those burnup dependent parameters important to the LOCA analysis, such as stored energy, gap conductance, fission gas release, and rod pressures from steady-state operation, are provided by the FATES3B code (Reference 16). Also, as noted earlier, FATES3B is acceptable for providing input to the evaluation of LOCA up to the requested rod-average burnup of 60 MWd/kgM.

The use of Reference 41 is also acceptable for evaluating cladding oxidation and fragmentation during a LOCA for the CE 16x16 fuel up to the rod-average burnup level requested in this submittal.

(b) Violent Expulsion of Fuel Material

Bases/Criteria - In a CEA ejection accident, large and rapid deposition of energy in the fuel could result in melting, fragmentation, and dispersal of fuel. The mechanical action associated with fuel dispersal might be sufficient to destroy fuel cladding and the rod-bundle geometry and to provide significant pressure pulses in the primary system. To limit the effects of CEA ejection, Regulatory Guide 1.77 recommends that the radially-averaged energy deposition at the hottest axial location be restricted to less than 280 cal/g. This limit has been explicitly evaluated for ANO-2 in Reference 38 and the 280 cal/g limit remains acceptable up to a rod-average burnup of 60 MWd/kgM.

Evaluation - The CEA ejection analysis methods used by ANO-2/CE are described in the NRC approved report in Reference 39. The CEA ejection analysis for ANO-2 that utilizes the methods in Reference 39 are provided in Reference 38. In general, the most limiting assemblies in a CEA ejection accident are low burnup assemblies because these assemblies have the greatest power and, therefore, enthalpy capability in the core. The maximum enthalpies for fuel at a rod-average burnup of 60 MWd/kgM will be significantly bounded by the low burnup assemblies because power capability of this high burnup fuel is low. Consequently, fuel at extended burnup levels is expected to remain well below the 280 cal/g limit. We conclude that the analysis methods used by ANO-2/CE for evaluating the CEA ejection accident are acceptable for application to the CE 16x16 fuel up to the rod-average burnup requested in this submittal.

(c) Cladding Ballooning and Flow Blockage

Bases/Criteria - In the LOCA-ECCS analyses of CESSAR plants, empirical models are used to predict the degree of cladding circumferential strain and assembly flow blockage at the time of hot-rod and hot-assembly burst. These models are each expressed as functions of differential pressure across the cladding wall. There are no specific design limits associated with ballooning and blockage, and the ballooning and blockage models are integral portions of the ECCS evaluation model. We conclude that ANO-2 has addressed this issue in their LOCA-ECCS evaluation (Reference 40).

Evaluation - The cladding ballooning and flow blockage models used in the CE LOCA-ECCS analysis described in Reference 40 are directly coupled to the models for cladding rupture temperature and burst strain [discussed in Section 3.0(c)]. The CE cladding deformation, rupture, and flow blockage models used in Reference 40 are the same as those proposed by NRC in NUREG-0630 (Reference 43). These models are not affected by the burnup extension requested in this submittal and therefore, Reference 40 remains acceptable for application to the CE 16x16 fuel design up to the rod-average burnup requested in this submittal.

The steady-state operational input that is provided to the LOCA analysis from the FATES3B fuel performance code (Reference 16) is burnup dependent. As noted earlier [see Section 3.0(g)], the FATES3B code has been verified against data to rod-average burnups of 62 MWd/kgM and previously approved for extended burnup application to the LOCA analysis (Reference 17). Therefore, this code is also acceptable for use in providing input to LOCA analyses of the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

(d) Structural Damage from External Forces

Bases/Criteria - To withstand the mechanical loads of a LOCA or an earthquake, the fuel assembly is designed to satisfy the stress criteria listed in Table 9-1 of Reference 41, and guide-tube deformation is limited such as to not prevent CEA insertion during the safe shutdown earthquake (SSE). These criteria have been found acceptable (Reference 3) for current burnup fuel and are also found acceptable for CE 16x16 fuel designs up to a rod-average burnup of 60 MWd/kgM.

Evaluation - The CE methods used to evaluate the mechanical loads due to a combined seismic-LOCA event are described in Reference 41. It is noted that the seismic-LOCA analyses are not affected by an increase in rod-average burnup up to 60 MWd/kgM and, therefore, previous bounding seismic-LOCA analyses remain applicable at this burnup level. This report has been approved by the NRC for current burnup levels and remains applicable for the CE 16x16 fuel design up to a rod-average burnup of 60 MWd/kgM.

5.0 DESIGN BASIS ACCIDENT ANALYSIS RELATIVE TO EXTEND FUEL BURNUP

The licensee has requested authorization to allow fuel burnup up to 60 MWd/kgM. The staff and licensee evaluated the potential impact of this change on the radiological assessment of design basis accidents (DBA) which were previously analyzed in the licensing of ANO-2.

The licensee, in discussions with the staff, concluded that the design basis accidents previously analyzed in their FSAR bound any potential radiological consequences of DBA that could result with the extended fuel burnup.

The staff reviewed a publication which was prepared for the NRC entitled, "Assessment of the Use of Extended Burnup Fuel in Light Water Reactors," NUREG/CR 5009, February 1988. The NRC contractor, the Pacific Northwest Laboratory (PNL) of Battelle Memorial Institute, examined the changes that could result in the NRC DBA assumptions, described in the various appropriate SRP sections and/or Regulatory Guides, that could result from the use of extended burnup fuel (up to 60 MWd/kgM). The staff agrees that the only DBA that could be affected by the use of extended burnup fuel, even in a minor way, would be the potential thyroid doses that could result from a fuel handling accident. PNL estimated that I-131 fuel gap activity in the peak fuel rod with 60 MWd/kgM burnup could be as high as 12%. This value is approximately 20% higher than the value normally used by the staff in evaluating fuel handling accidents (Regulatory Guide 1.25, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facilities for Boiling and Pressurized Water Reactors").

PNL concluded in their report that for fuel damage accidents, "The percentage of fission-product inventory released from the fuel would not likely change as a result of the extended burnup; however, the fission-product inventory in the fuel would change for the long half-life fission products and actinides.... " PNL also concluded that the actinides would only minimally contribute to doses compared to the fission products and that the main concern for the actinides would be from the long-term effects of inhalation (lung dose) and ingestion of food products (vegetables, milk, and meat) raised in, or fed on food grown in contaminated soil. PNL concluded that the inventory of fission products, cesium-137 and strontium-90 would increase by a factor of almost 2 in the extended burnup fuel. However, the staff has concluded that their contribution to dose would be minimal.

For the fuel handling accident, PNL concluded that the use of Regulatory Guide 1.25 procedures for the calculation of accident doses for extended burnup fuel may be utilized. These procedures give conservative estimates for noble gas release fractions that are above calculated values for peak rod burnups of 60 MWd/kgM. Iodine-131 inventory, however, may be up to 20% higher than that predicted by Regulatory Guide 1.25 procedures.

The staff, therefore, reevaluated the fuel handling accidents for the ANO-2 facility with an increase in iodine gap activity in the fuel damaged in a fuel handling accident. Table 1 presents the fuel handling accident thyroid doses presented in the operating licensing Safety Evaluation Report, dated November 1977, and in the Supplemental SERs dated March and September 1978, and the increased thyroid doses (by 20%) resulting from extended burnup fuel.

Table 1

Thyroid Doses as a Consequence of DBA Fuel Handling Accidents

	Exclusion Two Hour Boundary		Low Population Zone	
	Thyroid Dose (Rem)		Thyroid Dose (Rem)	
Fuel Handling Accident	A*	B**	A*	B**
Spent Fuel Area	35	42	3	3.6
Containment Building ***	<35	<42	<3	<3.6

*A SER/SSER #2 dose

**B Extended fuel burnup dose

***SER Supplement 1 dated March 1978 indicated that consequences of this accident are bound by the consequences of a fuel handling accident in the spent fuel area.

The staff concludes that the only potential increased doses that could result from DBA with extended fuel burnup to 60 MWd/kgM is the thyroid dose resulting from fuel handling accidents and these doses remain well within the 300 Rem thyroid exposure guideline values set forth in 10 CFR Part 100 and that this small calculated increase is not significant.

C. EMERGENCY CIRCUMSTANCES

[As stated in the licensee's application for amendment,] the requested changes constitutes an emergency situation pursuant to 10CFR50.91(a)(5) because: (1) absent NRC action by November 28, 1990, ANO-2 must be shutdown; (2) this emergency situation could not have been avoided by Entergy Operations; and (3) the proposed change does not involve a significant hazards consideration.

1. Current Condition

ANO-2 currently is operating at 100 percent power in Cycle 8 and has accumulated approximately 332 effective full power days (EFPDs) as of November 21, 1990. Entergy Operations has calculated that at approximately 340 EFPDs, currently estimated to occur on November 29, 1990, continued operation of ANO-2 will be precluded because the facility will reach the rod average fuel burnup limit of 52 MWD/Kg. The current condition of the facility cannot be rectified absent the proposed change to the license or plant shutdown and refueling (not presently scheduled until February 1991).

2. Time Constraints

The NRC first requested that a license amendment be submitted by Entergy Operations on November 15, 1990. Because the change proposed in this submittal must be reviewed and approved by the NRC prior to November 29, 1990, the 30 day notice and comment provisions of 10CFR50.91(a)(2) cannot be met. Accordingly, Entergy Operations has developed this request for issuance of a license amendment pursuant to the emergency provisions of 10CFR50.91(a)(5). This request has been submitted in a timely manner considering the need to develop a significant hazards evaluation and the need to support the emergency request.

Moreover, Entergy Operations initially had requested NRC review and approval of the methodology to evaluate an increase to the ANO-2 fuel pin burnup limit on July 20, 1989. Since that submittal, Entergy Operations maintained active communication with the NRC to monitor the staff review of the request (see Entergy Operations letters to the staff in May and September, 1990 to address specific NRC technical questions). Not until the NRC staff requested a license amendment on November 15, 1990, was there an indication of the need for such an amendment. Therefore, Entergy Operations has acted in a timely fashion with this submittal which provides the NRC staff with adequate time to process an emergency change in accordance with 10CFR50.91(a)(5).

3. Hardship Absent Relief

Without NRC approval of this emergency request, ANO-2 must shutdown and either await completion of the standard license amendment process, or change the fuel in the facility to permit continued operation. These options present hardship to Entergy Operations which are outweighed by the approval of the emergency request, especially considering the absence of a significant hazards associated with the proposed change. ...

4. ...

5. Plan for Compliance

ANO-2 is currently in compliance with the applicable requirements of the operating license and Technical Specifications and will continue to maintain compliance with these and any other requirements. With the approval of the proposed change, continued operation of ANO-2 beyond 340 EFPDs will be possible and specifically permitted; hence, at no time does Entergy Operations anticipate non-compliance.

...

Based on the above, the staff has determined, pursuant to 10 CFR 50.91(a)(5), that failure to act in a timely manner will result in plant shutdown. Further, the licensee maintained communication with the NRC staff and promptly submitted its amendment request when it was determined such action was warranted. Accordingly, the Commission has determined that emergency circumstances exist which warrant prompt action by the Commission.

D. FINAL NO SIGNIFICANT HAZARDS CONSIDERATION DETERMINATION

The Commission's regulations in 10 CFR 50.92 state that the Commission may make a final determination that a license amendment involves no significant hazards considerations, if operation of the facility, in accordance with the amendment would not:

(1) Involve a significant increase in the probability or consequences of any accident previously evaluated; or

(2) Create the possibility of new or different kind of accident from any accident previously evaluated; or

(3) Involve a significant reduction in a margin of safety.

This amendment has been evaluated against the standards in 10 CFR 50.92 and does not involve any significant hazards considerations. The following excerpt from the licensee's submittal lists these criteria and the licensee's description:

> Criterion 1 - Does not Include a Significant Increase in the Probability or Consequence of an Accident Previously Evaluated.
>
> The effects of extended burnup up to 60 MWd/kg have been evaluated in the the [sic] Combustion Engineering ... [CE] Report CEN-386-P with respect to the previously identified 21 fuel performance topics that were judged to be burnup dependent and/or important in determining the behavior of extended burnup fuel. Using the results of this [CE] Report, it was concluded that the fuel performance characteristics do not significantly change with extended burnup up to 60 MWd/kg and with the exception of the fuel handling accident, no change in consequences of a design basis accident is expected.
>
> With respect to the fuel handling accident, extended burnup will result in fewer fuel movements over the life of the plant in comparison to lower burnup fuel management schemes and thus a decrease in the probability of an accident occurrence. The consequences of a fuel handling accident are also not significantly affected. The effect of extended burnup with respect to offsite dose consequences as a result of a fuel handling accident has been previously evaluated by the NRC in NUREG/CR-5009, "Assessment of the Use of Extended Burnup Fuel in Light Water Power Reactors." This report concludes that there would be a slight increase (by 20%) in

thyroid doses resulting from increased Iodine 131 gap activity from burnups to 60 MWd/kg. The resulting doses are small fractions of the applicable regulatory requirements of 10CFR Part 100 as concluded in Calvert Cliffs Safety Evaluation Report of January 10, 1990.

Criterion 2 - Does not Create the Possibility of a New or Different Kind of Accident from any Previously Evaluated

Since the early 1980's, significant data have been accumulated on the effects of high burnup on fuel. This data and analytical techniques have been utilized to project the effects of high burnup in support of this amendment. The measured and projected effects show the fuel will continue to exhibit stable predictable performance. Therefore, no new or different kind of accident will be created.

Criterion 3 - Does not Involve a Significant Reduction in the Margin of Safety

The [CE] Report in support of this amendment has evaluated the 21 fuel performance topics that were judged to be burnup dependent and/or important in determining the behavior of extended burnup fuel. This evaluation for each cycle concluded adequate margins of safety continue to be provided with fuel burnup to 60 MWd/kg.

Accordingly, the Commission has determined that this amendment involves no significant hazards considerations.

E. STATE CONSULATION

In accordance with the Commission's regulations, efforts were made to contact the Arkansas State representative. The state representative was contacted and had no comments.

F. ENVIRONMENTAL CONSIDERATION

Pursuant to 10 CFR 51.21, 51.32, and 51.35, an Environmental Assessment and Finding of No Significant Impact has been prepared and published in the Federal Register on November 14, 1990 (55 FR 47593). Accordingly, based upon the environmental assessment, the Commission has determined that the approval of the extended fuel burnup limit for ANO-2 will not have a significant effect on the quality of the human environment.

G. CONCLUSIONS

We have reviewed the ANO-2 request, as submitted in Reference 1, to extend the burnup level of the CE 16x16 fuel design to a rod-average burnup of 60 MWd/kgM in accordance with the SRP, Section 4.2. We conclude that this request by ANO-2, is acceptable. However, it should be stressed that future requests to extend the rod-average burnup limit beyond 60 MWd/kgM should be accompanied with corrosion, cladding strain, and yield and fracture strength data at the extended burnup levels requested. These data are necessary to support the irradiation of higher burnup fuel beyond 60 MWd/kgM.

The staff has concluded, based on the considerations discussed above, that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, and (2) such activities will be conducted in compliance with the Commission's regulations, and the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

Dated: November 27, 1990

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