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Project Number 694

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Attention: Chief, Information Management Branch,
Division of Inspection and Support Programs

Subject: Westinghouse Owners Group
Transmittal of WCAP-15604-NP, Rev. 1, (Non-Proprietary), "Limited Scope High Burnup Lead Test Assemblies" (MUHP-1046)

Reference: 1) Westinghouse Owners Group Letter, OG-00-116, "Transmittal of WCAP-15604-NP, Rev. 0, (Non-Proprietary), "Limited Scope High Burnup Lead Test Assemblies," November 15, 2000.

2) NRC Letter, "Acceptance Review of Westinghouse Topical Report, WCAP-15604-NP, Rev 0. 'Limited Scope High Burnup Lead Test Assemblies' (TAC No. MB0591)," January 25, 2001.

3) Westinghouse Owners Group Letter, OG-01-042, "Response to NRC Request for Additional Information on WCAP-15604-NP, "Limited Scope High Burnup Lead Test Assemblies," July 9, 2000.

In November 2000 the Westinghouse Owners Group (WOG) submitted WCAP-15604-NP, Rev. 0, "Limited Scope High Burnup Lead Test Assemblies," for approval (Ref. 1). In January 2000, the NRC issued a Request for Additional Information (RAI) and in July2001 the WOG provided a response to the RAI (Ref. 2 & 3). On September 26, 2001, a meeting with NRC and WOG representatives was held to review and discuss the RAI responses. At the conclusion of the meeting, the NRC asked the WOG to incorporate the RAI responses into WCAP-15604. Please find enclosed WCAP-15604-NP, Rev. 1, "Limited Scope High Burnup Lead Test Assemblies," that incorporates the RAI responses.

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If you require further information, feel free to contact Mr. Ken Vavrek in the Westinghouse Owners Group Project Office at 412-374-4302.

Very truly yours,

Robert H. Bryan, Chairman
Westinghouse Owners Group

enclosures

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Limited Scope High Burnup Lead Test Assemblies MUHP-1045

October 2000
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List of Acronyms

The following is a list of acronyms used in this report.

AOA(s)	Axial Offset Anomaly(ies)
BWR	Boiling Water Reactor
ECCS	Emergency Core Cooling System
ID	Inside Diameter
IRI	Incomplete Rod Insertion
ITF	Issue Task Force
LOCA	Loss of Coolant Accident
LTA(s)	Lead Test Assembly(ies)
PIE	Post Irradiation Examination
PWR	Pressurized Water Reactor
RCCA	Rod Control Cluster Assembly
RIA	Reactivity Insertion Accident
SER	Safety Evaluation Report

Executive Summary

This document provides the basis for the operation of a limited number of fuel assemblies to rod burnups greater than the current licensed lead rod average burnup limit and up to 75 GWD/MTU. The basis for the operation of these Limited Scope Lead Test Assemblies (LTAs) is:

- The fuel will be evaluated against and must meet all current design criteria except the burnup limits. Current or modified fuel performance methods and codes will be used even though they may not be licensed to these burnups. This is based on the need to 1) obtain higher burnup data to substantiate the fundamental fuel performance characteristics, and 2) to develop modified fuel performance models (developmental models) to more accurately model the behavior of high burnup fuel.

- The fuel will undergo examinations following operation and the results of those post irradiation examinations (PIEs) will be incorporated into a database and/or developmental models. In addition, the PIE data will be reported to the NRC for informational purposes. This data will likely be marked as proprietary by the vendors. When each vendor applies for their increased burnup limits, this data will be submitted, along with other available data to justify design criteria and limits. Thus, the data and developmental model performance will be shared with the NRC.

- The fuel will be typical production fuel with pre-characterization before operation above the current licensed lead rod average burnup limit. The fuel may also be an LTA, which was characterized during fabrication and was designed to test other aspects of the fuel assembly but was not initially identified as a high burnup LTA.

- The number of fuel assemblies with fuel rods exceeding the current licensed lead rod average burnup limits will be limited to up to a total of nine in PWRs and thirty-two in BWRs. Under this program, no fuel rod will exceed peak rod burnups greater than 75 GWD/MTU.

The rationale behind this program is to provide a means to generate data on an incremental basis to populate the range between the current lead rod average burnup limit and proposed future limit from fuel which has been operated under both nominal and limiting conditions (e.g., fuel that has experienced normal or possibly limiting fuel duty). These data along with the results from other industry programs will be used to set criteria and provide a design basis for future operation at burnups above the current licensed limit without the need for cycle specific NRC review or approval.

The review and approval of this report will then provide the means for both PWR and BWR utilities to justify the operation of Limited Scope LTAs on a 10 CFR 50.59 basis.

1.0 Introduction

1.1 Background

Traditionally, a Lead Test Assembly (LTA) is an assembly that is characterized at the fabrication stage and is designed with features that have limited or no in-reactor performance experience. This type of LTA is designed to test the in-reactor performance behavior of various features such as advanced cladding materials, different burnable absorbers, different skeletal components and new mid-grid designs. Many of these design features are typically tested extensively in out-of-reactor environments or in test reactors under atypical operating conditions, but lack the in-reactor commercial reactor experience under normal and limiting conditions.

Another type of LTA is designed to gather data on fuel performance above the current licensed burnup limit. These LTAs are typically based on current production designs and are irradiated to higher than current licensed burnup limits to obtain fuel performance data. The types of data that may be sought include: oxidation behavior, growth behavior, hydriding behavior, fission gas behavior, etc. In the past, as fuel performance data was obtained, it indicated that slight design modifications would be necessary to accommodate the higher burnups that were being sought (e.g., minor changes in the processing and/or chemical make-up of the cladding to better resist corrosion, increased plenum volumes to accommodate increased fission gas release, etc.). As a result, minor design changes have been implemented into the current production designs to accommodate higher burnup and retain high fuel reliability. Data from these LTAs will also provide the basis for improved fuel designs.

In the mid 1990's, new data from international test reactors suggested that the current design criteria that were being used to justify acceptability of fuel designs may not be adequate at the higher burnup levels that were being sought by the industry (see Section 4.1 for further details). As a result, the US-NRC and other international regulators, national and international test laboratories and the industry began a program to investigate whether revised design limits would be necessary for validation of high burnup fuel (e.g., above the current licensed levels). This effort is currently ongoing and the results of this effort will be a set of new design limits that must be satisfied in order to demonstrate acceptability of a particular fuel design to achieve a specified high burnup level. As part of the overall effort, the specified high burnup level will be defined. However, it has been pointed out by the NRC, at recent symposiums[1][2], that fuel performance data are needed at all burnup levels above the current licensed limits to justify acceptability of a fuel design and not just data at the maximum limit (e.g., sufficient data is needed to populate a range of burnups to justify the behavior of various parameters).

As a result of the various aspects of the high burnup industry program and the stated need for additional burnup data to demonstrate fuel performance behavior at all burnup levels above the current licensed limit, a proposal to the NRC was made in May 2000. This proposal described a Limited Scope LTA. The Limited Scope LTA, which is defined in the next section, will encourage more LTA programs to be pursued and will result in more data being obtained in the intermediate range of high burnup levels. Thus, when the revised design limits are established and the peak burnup limit is defined, sufficient data will be available to substantiate fuel performance behavior and fuel performance model predictive capability.

1.2 Description of Limited Scope Lead Test Assembly (LTA) Programs

A Limited Scope Lead Test Assembly shall be a fuel assembly based on a currently available design that is capable of reaching burnups beyond that currently licensed. The assembly may receive some limited pre-characterization prior to under-going exposure in the "test" cycle that would permit the assembly to exceed current licensed burnup limits. The fuel assembly shall be analyzed using either currently licensed fuel performance design models and methods or modified developmental versions of these models and shall demonstrate that currently licensed design limits are met for the extended burnup analyzed. However, the models and methods used for evaluation of the limited scope LTAs will not be required to be licensed to the projected burnups, but appropriate conservatism should be included. Limited pre-characterization measurements, if necessary, shall be assessed with the fuel performance design models and methods to ensure that the assembly will not exceed design limits after its final cycle of exposure. An LTA Report, documenting the above analyses to demonstrate acceptability of the LTA, shall be prepared and maintained by the utility/vendor in accordance with 10 CFR 50.59 criteria prior to the "test" cycle. Upon completion of the cycle of exposure, the LTA shall under-go a Post Irradiation Examination (PIE). Post Irradiation Examination of the LTA shall be documented in a PIE report and results of the PIE assessment shall be factored into future analysis to ensure that appropriate conservatisms are being maintained. In addition, tracking of the data results will provide the basis for developmental model creation to more accurately model fuel performance and to capture fuel performance fundamentals. Periodic status updates of the data gathered by the vendor/utility from these programs shall be presented to the NRC. Developmental model performance shall also be tracked against data and presented to the NRC.

1.3 Maximum Number of LTAs per Reload

The maximum number of assemblies that would be considered for a Limited Scope LTA program will vary from utility to utility, based on fuel management studies. However, for the overall Limited Scope LTA Program, the maximum number of LTAs per cycle per core shall be limited to nine assemblies for PWRs and thirty-two assemblies for BWRs. The rationale for setting the maximum number of assemblies is based on obtaining a sufficient amount of data while maintaining a high degree of confidence that no safety concerns exist.

Setting the number of Limited Scope High Burnup LTAs at the above levels is beneficial and justifiable for the following reasons:

- Makes the core design economical enough to offset increased analysis and surveillance costs,
- Allows for a variety of loading patterns and power histories in order to observe effects that might not be observable with even fewer LTAs,
- Allows for symmetric locations in the core to be driven to higher burnups and allows for a center assembly to be accommodated,
- Restricts the total number of assemblies exceeding the lead rod average licensed burnup limit to a value < 10% of the core, which is consistent with many core damage frequency scenarios (e.g., for PWR cores with 121, 157, 177, 193, 204, 217, 241 fuel assemblies, 9 assemblies would be 7.4%, 5.7%, 5.1%, 4.7%, 4.4%; 4.1% and 3.7% respectively; for BWR cores with 368, 560, 724, 764 fuel assemblies, 32 assemblies would be 8.7%, 5.7%, 4.4 % and 4.2% respectively).

Although 10% is within many core damage frequency scenarios, this topical was prepared for operation of fuel assemblies utilizing approved designs and materials. The only characteristic of these assemblies which is not part of typical operation is the extension of the rod average burnup to values greater than are currently licensed. However, some data already exists for these designs and materials at exposures above the current licensed limits. Based on this performance data, no anticipated shift in performance is expected relative to fuel that is maintained below the current licensed burnup limits. Therefore, there is no significant risk in terms of either fuel integrity or potential core damage in operating this number of assemblies to a slightly higher burnup.

With a maximum of 9 assemblies allowed for PWRs, initially eight assemblies would be able to reach burnups of between 62 – 68 GWD/MTU and one assembly may be able to reach 75 GWD/MTU lead rod average burnup as a central assembly that would be surrounded by feed assemblies. As plants' fuel management schemes move toward the high burnup regime, then four of the eight assemblies may be able to reach the 68 – 72 GWD/MTU region. Currently, it would not be economical for most plants to pursue getting all 9 assemblies to the upper end of the high burnup regime simply due to their fuel management schemes. Simply based on fuel management schemes alone, no more than 1– 5 assemblies would likely reach burnups of 68 – 75 GWD/MTU after the fuel management scheme reach a high burnup equilibrium.

Based on current fuel management schemes, the majority of these Limited Scope LTAs are expected to only reach peak rod burnups ranging from the current licensed limit to 68 GWD/MTU with a few obtaining the higher burnups in the range of 68 to 75 GWD/MTU. Since very few assemblies would be achieving the higher burnup levels, it is not anticipated that an unforeseen failure would occur based on experience to date. The most plausible potential failure would be a limited number of fuel rods that may fail due to a specific and limited condition, e.g., excessive oxidation. Since it is not anticipated that any fuel rods would fail in these assemblies due to the fact that they must meet current design criteria even at the higher burnup levels, any single failure that may occur would yield valuable data. If any failures occurred, their effects would be well within the Technical Specification limits for doses and in all cases, core coolable geometry would be maintained. To avoid even this limited failure condition, the NRC staff's recommendation that oxidation should be maintained less than 100 microns on a best estimate basis and that spallation and blistering should be avoided is adopted for the Limited Scope High Burnup LTAs as the criterion to meet pending the eventual revised design criteria that are being established by the EPRI Robust Fuel Program Working Group.

1.4 LTA Burnup, Duty and Locations

In the past, LTAs were restricted from being placed in limiting core locations. This treatment of LTAs does not yield a representative behavior of the fuel under normal operations. To determine if the LTA meets the need for which it was designed, it must experience the same limiting conditions as other fuel in the reactor and should not be restricted in power or core location except as needed to meet design criteria. The unique aspect of these LTAs is that they are a normal production fuel assembly which will fall into two general categories. These are:

- Fuel assemblies which are reinserted for additional exposure after achieving a burnup where normally they would be discharged so that the burnup limit is not exceeded.

- Fuel assemblies which have normal incore residence times, but are positioned in-core so that the power level results in the burnup limit being exceeded.

The maximum lead rod average burnup that these Limited Scope LTAs would experience is 75 GWD/MTU.

1.5 Licensing Basis

As specified in 10 CFR 50.59 (c)(1)(i) and (ii), "A licensee may make changes in the facility as described in the final safety analysis report (as updated), make changes in the procedures as described in the final safety analysis report (as updated), and conduct tests or experiments not described in the final safety analysis report (as updated) without obtaining a license amendment pursuant to 10 CFR 50.90 only if: (i) a change to the technical specifications incorporated in the license is not required, and (ii) the change, test, or experiment does not meet any of the criteria in paragraph (c)(2) of 10 CFR 50.59." The use of Limited Scope Lead Test Assemblies (LTAs) does not require Technical Specification changes and should meet all the criteria in paragraph (c)(2) of 10 CFR 50.59. The conclusion that a Limited Scope Lead Test Assembly should meet all the criteria in paragraph (c)(2) of 10 CFR 50.59 will be demonstrated by evaluations showing that the LTAs meets all current licensed design criteria at the anticipated assembly and fuel rod burnup.

The conclusion that the LTAs can be irradiated without prior NRC review and approval (per 10 CFR 50.59) rests on two steps. The acceptance of these steps by the NRC through approval of this report will be necessary to support the analytical justification of the Limited Scope high burnup LTAs. The first step involves an assumption about the use of current fuel design acceptance criteria. The second step is an assessment of the analytical models to be used and modification as necessary.

The first step is the assumption that the current fuel design acceptance criteria can be used to evaluate the performance of the LTAs beyond the current licensed limit. It is anticipated that future work will confirm the validity of most of the current criteria for burnups beyond the current licensed limit. One exception is the deposited enthalpy criteria for design basis reactivity insertion accidents. Currently available data indicates that this criteria may need to be revised. The small number of assemblies involved in these LTA programs, the conservative methods used in the industry to evaluate deposited enthalpy for hypothetical reactivity insertion accidents, and the low deposited enthalpy for high burnup assemblies is sufficient justification to use the current deposited enthalpy criteria for the LTAs.

The second step is the assessment of the models reviewed and approved by the NRC for the purpose of evaluating the performance of the LTAs beyond the current licensed limit. The analytical models used to evaluate the performance of the LTAs beyond the current licensed limit may need to be modified versions of the models reviewed and approved by the NRC. The modification of various models may be necessary to add conservatism to assure the safe operation of the LTAs. Alternatively, the modifications of various models may be necessary to remove excessive conservatism in order to demonstrate compliance with the acceptance criteria. The modifications would be based upon currently available data, data from the pre-characterization activity, or data collected as part of the PIEs for previous Limited Scope high burnup LTAs. If the available data indicates that the approved models are appropriate then no modifications to the approved models would be necessary. The developmental models would only be used for Limited

Scope high burnup LTAs. The justification of the model revisions would be documented and available for NRC review in accordance with 10 CFR 50.59 criteria and developmental model performance would be shared with the NRC along with the PIE data results.

Additional rationale for the use of developmental models is based on the following. If the developmental model is predicting previous data accurately and then uncertainties are added to the results, the model will be bounding for the reload analysis. These bounding results would be compared to current design limits since revised limits have not yet been defined. This method is an incremental approach that is based on real data and is less of an extrapolation then using the current licensed models with their uncertainties. The developmental models typically yield more bounding results than the current licensed models.

However, the situation may exist where a current licensed model is known to be conservative to reality and it is desired that the model be revised to remove some of the excess conservatism. Beginning with the current licensed model and demonstrating that on a best estimate basis, it is conservative to measured data, then creating a developmental model that more accurately reflects measured data is appropriate. The developmental model would still have uncertainties added to it for a formal verification analysis approach. As additional data is obtained, it would be validated against the best estimate calculations using the developmental model. The other aspect of comparing the developmental model with measured data is to determine if the current uncertainties are appropriate or whether the uncertainties would need to be revised. Again, this would be an incremental controlled process. In this fashion, the NRC would be aware of how the model is performing relative to the data, such that when sufficient data is obtained and a formal model revision is submitted to the staff for review and approval, the staff will be familiar with the model and the associated data. This approach will save the staff significant resource effort in the long run and will promote increased confidence that the models meet the specified design criteria.

2.0 Pre-characterization / Post Irradiation Examination of Data

2.1 Pre-characterization Inspection and Measurement

Pre-characterization is defined here as the measurement of particular fuel performance parameters just before the start of the cycle in which the burnup limits will be exceeded. The need for pre-characterization will be determined based on fuel performance trends and the projected margin. Typically the parameters which would be subject to pre-characterization are fuel rod cladding oxide thickness, fuel assembly and/or fuel rod growth, and guide thimble and/or assembly/channel bow measurements.

The purpose of the pre-characterization is to: 1) obtain data that is useful in understanding the fuel performance based on the known fuel duty, and 2) to ensure that fuel design criteria will not be exceeded in the projected cycle. Pre-characterization of LTAs is intended only as a "go/no go" check against design predictions. Therefore, the data obtained would be significantly less than the data obtained when the Limited Scope LTAs are discharged. As an example, only the most limiting fuel rods may be measured for oxide prior to the final cycle to ensure that sufficient margin exists for the planned cycle of operation.

With regards to obtaining data that is useful in understanding the fuel performance, based on known fuel duty, pre-characterization will provide pre-test cycle values for the parameters measured. The Post Irradiation Examinations (PIEs) provide the post-test cycle values. Comparison of pre and post cycle values will yield the incremental effects that the final cycle of exposure has on the Limited Scope High Burnup LTAs. This provides a measure of whether an unknown phenomenon exists and is occurring in the high burnup LTAs. It also provides a very accurate measure of how well the predictive fuel performance models are behaving for this last cycle of exposure. However, the incremental effects are only part of the equation. Integral results (e.g., as-fabricated conditions to end-of-life) are also necessary. The integral results from a traditional LTA provides an overall measure of the fuel performance model accuracy (e.g., it establishes the error bands for the performance model). Integral results from a Limited Scope High Burnup LTA also provides an overall measure of the fuel performance model behavior; however, the accuracy is sacrificed since nominal as-fabricated measurements would be used. This sacrifice in accuracy is outweighed by the amount of data obtained from Limited Scope LTAs. By having a statistically significant database of fuel performance measurements and then using traditional LTA results with incremental pre and post test cycle measurements on Limited Scope High Burnup LTAs, the overall fuel performance model capability is demonstrated and substantiated. It should be noted that in comparing fuel performance model results to the measured results, the models are run in a best estimate mode. For cycle design calculations and licensing purposes, the fuel performance models results would be a bounding value that would be compared to design limits (e.g., uncertainty analysis results would be included with the best estimate results such that the bounding results would be on a 95/95 basis). The design limits that would be used for the Limited Scope LTAs are the current design limits for licensed fuel. As part of other industry programs, the current design limits are being reviewed for high burnup application and will not be discussed herein.

The other purpose of the pre-characterization is to ensure that current design criteria are not violated. Since the fuel performance models are being extrapolated to burnups that have not been licensed, the pre-characterization provides a measure of how much margin exists for a given design criteria to its limit, based on model predictions compared to the pre-characterization measurement. Thus, pre-characterization is necessary and provides valuable information. However, as noted above, extensive amounts of pre-characterization are not necessary since the Limited Scope High Burnup LTAs were conceived to obtain statistical significant amounts of data to demonstrate fuel performance models. Limited pre-characterization measurements and traditional LTAs provide model accuracy.

Since this report was written to address all the fuel vendors, it was accounting for the needs of all the vendors. Several vendors have advanced cladding materials that show significantly less growth characteristics than Zircaloy-2 or Zircaloy–4 alloys. Therefore, based on model predictions, most of the assemblies that would be considered for a Limited Scope LTA program would have more than sufficient growth margin to accommodate an additional cycle of irradiation. Since there would be less growth, there would also be less assembly distortion. Thus, a need to force a pre-characterization of fuel rod/fuel assembly growth, guide thimble and/or assembly/channel bow measurements, would not necessarily be warranted, especially if the structural assembly is also fabricated with advanced materials designed to have substantially less growth than Zircaloy alloys. The one pre-characterization that would be universal to all the vendors would be cladding oxidation.

From a fuel rod design standpoint, the design criteria that are limiting at end-of-life and could be potentially challenged for these Limited Scope High Burnup fuel assemblies are: cladding oxidation, rod internal pressures, fatigue and growth. As noted above, growth may be the least limiting of these criteria, especially if advanced alloys are being used. Fatigue analyses typically show 30 – 50% margin to the cumulative fatigue usage factor of 1.0. Thus, fatigue is not the limiting criterion at these high burnup levels. Rod internal pressures for current generation PWR fuel are typically licensed to exceed system pressure and thus a potential of pellet to clad lift-off exists, albeit small, depending upon the rod internal pressure and the corresponding pressure limit characteristics of the cladding material. Again, this criteria can vary from vendor to vendor, as far as being limiting, depending upon the constituent makeup of the internal gases and cladding material characteristics and the corresponding pressure limit characteristics. The one factor that can lead to significantly increased fuel rod internal pressures is the oxidation on the cladding outer surface. Above certain oxidation levels, the impacts on rod internal pressure and the significant impacts on the cladding pressure limit characteristics would result in the rod internal pressure criterion being exceeded. Thus, by ensuring that the oxidation is kept to a minimum, then the fuel rod internal pressure criterion is less limiting than simply the oxidation criterion by itself. In addition to oxidation causing increases to rod internal pressures, crud deposition has a similar effect due to its poor thermal conductivity. Thus ensuring that crud deposition is kept to a minimum, also reduces the impacts on rod internal pressures.

Since each of the vendors have slightly different needs, the one criterion that would be universal to all the vendors would be the cladding oxidation. Based on further discussions with the staff, it is understood that at a minimum, clad oxidation, rod/assembly growth and visual examinations would be considered appropriate as a minimum set of pre-characterization exams. With the consideration that the Limited Scope High Burnup LTAs were conceived to attract plants into pursuing LTA programs and thus generating a substantial database of fuel characteristics behaviors; additional pre-characterization testing without a warranted need would simply add to the plant's outage schedule. This potential impact on a plant's outage schedule, whether real or only perceived, would deter the plants from pursing Limited Scope LTAs and thus would defeat the objective of gathering valuable fuel characteristics data. Therefore, it is agreeable to establish the minimum set of pre-characterization exams for the Limited Scope LTAs that will be done prior to the test cycle as: clad oxidation, rod/assembly growth and visual examinations for PWRs and clad oxidation, rod/assembly growth, channel bow, and visual examination for BWRs.

All pre-characterization checks would be decided upon in advance of the cycle in which the LTA(s) was/were to be inserted and shall be documented in an LTA report. This planning phase for the LTA program would have vendor and utility involvement, including planning of spot checks of an assembly that may be re-inserted. This is also when contingency plans would be made to substitute another assembly in place of the LTA if the spot checks yielded a "no-go" result. The contingency planning is essential to avoiding loading pattern problems just prior to startup.

2.2 Post Irradiation Examinations

The post irradiation examinations (PIEs) are the key inspections/examinations that will provide data for substantiating fuel performance behavior. These inspections/examinations are typically performed off critical path of an outage and therefore extensive measurements can be taken. The vast majority of these inspections are pool side inspections with an occasional hot cell examination done when deemed appropriate by the vendor/utility.

To provide clarification to the statements above, any LTA that is introducing a new design feature would most likely require a complete set of PIEs that are applicable to the specific feature. For example, a new cladding material would need corrosion measurements, profilometry, growth measurements, and rod-to-rod spacing measurements. A new guide thimble material would need OD/ID corrosion measurements, guide thimble distortion measurements, and assembly bow measurements. A new grid design would need corrosion measurements, grid cell sizing measurements, and grid width measurements. As far as hot cell examinations, a change in the fuel pellet may require a hot cell examination. Other instances that may trigger a possible hot cell examination would be anomalous profilometry measurements; anomalous fuel rod growth measurements, etc. As noted above, hot cell examinations are done when deemed appropriate by the vendor/utility. Unless there is a specific need for a hot cell examination, such as in the case of obtaining fuel pellet information, hot cell examinations are not normally planned in advance. Most hot cell examinations are planned after the pool side PIEs are completed and a determination is made that an anomalous condition exists that warrants further investigation.

2.2.1 Pool Side Examinations

As noted above, the vast majority of examinations are done pool side. These examinations will provide the majority of data points for the particular fuel characteristics which must be demonstrated to ultimately obtain higher burnup licensing limits. The following sections discuss the various examinations that typically may be performed in a pool side environment. Not all of these examinations would necessarily be required for each LTA program in each plant, but will be based on fuel parameter characteristic needs, fuel duty and operation environmental factors. Based on discussions with the staff, it is understood that at a minimum, clad oxidation, rod/assembly growth and visual examinations for PWRs and clad oxidation, rod/assembly growth, channel bow, and visual examination for BWRs would be considered appropriate as a minimum set of PIEs. Since PIEs need to be carefully planned and scheduled with the respective plants, and since the plant supplies personnel in an auxiliary role, it is desirable to obtain all the necessary data in one PIE rather then several separate PIEs. Therefore, even though a minimum set of PIEs is defined and agreed, numerous other inspections and measurements will most likely be done during the PIE since repeated PIEs are costly, inefficient and an ALARA concern. The intent of the PIEs is to obtain sufficient data to substantiate the particular fuel performance criteria of each vendor. The most common poolside examinations are listed below.

Oxide Thickness Measurements

The thickness of the ZrO_2 corrosion film on irradiated cladding surfaces and/or structural members is measured. Obtaining the oxide measurements is a check of the corrosion model used in the fuel performance codes and provides a check of the metal-wastage or wall thinning effects.

Cladding Diameter

Profilometry measurements provide an accurate profile of the fuel rod and are used as a means to determine cladding creep behavior and pellet-clad mechanical interaction effects.

Assembly Growth

The axial dimensional stability of fuel assemblies is an important parameter in assessing burnup limits. The fuel assembly predicted growth will be compared to the irradiated measured data to determine how well the irradiation growth model is behaving.

Fuel Rod Growth

The axial gaps between the fuel rod and the assembly top and bottom nozzles are measured during the PIE. The measured irradiated fuel rod growth will be compared to the irradiation growth model.

Guide Thimble Distortion Data

Guide thimble distortion data is obtained and compared to established guidelines which provide indications of possible assembly bow or guide thimble distortion within the fuel assembly.

Assembly Bow

Fuel assembly bow measurements provide a measure of how much assembly distortion has occurred.

Rod-to-Rod Spacing

Rod-to-rod spacing measurements provide a measure of how much individual rod distortion has occurred due to differential rod growth within the fuel assembly.

Guide Thimble ID Oxide Thickness

Guide thimble ID oxide thickness measurements are used to check the structural corrosion model and provides a check of the metal-wastage or wall thinning effects.

Grid Cell Size

Grid cell size measurements are used to check the structural growth model and to assess relaxation rates of grid designs.

Grid Width Measurements

Grid width measurements are obtained to determine in-reactor growth rates of grid material.

Channel Bow Measurements

Channel bow measurements provide a measure of how much assembly distortion has occurred.

3.0 LTA Assessment and Reporting

For each Limited Scope LTA program, the LTA(s) will be assessed to determine if they will meet their specified acceptable fuel design limits and other design criteria and to ensure that they will not result in a deviation of the accident analyses as documented in a plant's FSAR. A summary of the results from this assessment shall be documented in an LTA report which will be the basis, from the technical perspective, to address the 10 CFR 50.59 evaluation.

The following sections discuss fuel assembly, fuel rod, neutronic, thermal-hydraulic and accident analyses aspects of addressing a high burnup Limited Scope LTA. Since each vendor has specific design criteria that have been accepted by the NRC the following discussion demonstrates how one vendor would address the various design and operational aspects of a high burnup Limited Scope LTA. This illustrates the general approach to be taken by all vendors but is not intended to constrain or explicitly specify how other vendors would perform their analyses. Other vendors would necessarily use their own design criteria in place of those provided in this example.

The analytical models used to evaluate the performance of the LTAs beyond the current licensed limit may need to be modified versions of the models reviewed and approved by the NRC. The modification of various models may be necessary to add conservatism to assure the safe operation of the LTAs. Alternatively, the modifications of various models may be necessary to remove excessive conservatism in order to demonstrate compliance with the acceptance criteria. The modifications would be based upon currently available data, data from the pre-characterization activity, or data collected as part of the PIEs from previous Limited Scope high burnup LTAs. If the data indicates that the approved models are appropriate then no modifications to the approved models would be necessary. The modified models would only be used for Limited Scope high burnup LTAs. The justification of the model revisions would be documented and available for NRC review in accordance with 10 CFR 50.59 criteria and developmental model performance would be shared with the NRC along with the PIE data results.

Additional rationale for the use of developmental models is based on the following. If the developmental model is predicting previous data accurately and then uncertainties are added to the results, the model will be bounding for the reload analysis. These bounding results would be compared to current design limits since revised limits have not yet been defined. This method is an incremental approach that is based on real data and is less of an extrapolation then using the current licensed models with their uncertainties. The developmental models typically yield more bounding results than the current licensed models.

However, the situation may exist where a current licensed model is know to be conservative to reality and it is desired that the model be revised to remove some of the excess conservatism. Beginning with the current licensed model and demonstrating that on a best estimate basis, it is conservative to measured data, then creating a developmental model that more accurately reflects measured data is appropriate. The developmental model would still have uncertainties added to it for a formal verification analysis approach. As additional data is obtained, it would be validated against the best estimate calculations using the developmental model. The other aspect of comparing the developmental model with measured data is to determine if the current uncertainties are appropriate or whether the uncertainties would need revised. Again, this would be an incremental controlled process. In this fashion, the NRC would be aware of how the model is performing relative to the data, such that when sufficient data is obtained and a formal model revision is submitted to the staff for review and approval, the staff will be familiar with the model and the associated data. This approach will save the staff significant resource effort in the long run and will promote increased confidence that the models meet the specified design criteria.

3.1 Mechanical Review

From the mechanical perspective, there are very few specified acceptable fuel design limits or other design criteria that are impacted by high burnup effects. Two key assembly design criteria are discussed as follows: Fuel Assembly and Fuel Rod Growth Allowances, and Fuel Pellet Plenum Spring Solid Height. The fuel assembly and fuel rod growth allowances assure that sufficient space exists within the fuel assembly and core support structures to accommodate the maximum expected fuel rod and fuel assembly growth without axial interference. The fuel pellet plenum spring solid height requirement ensures that the plenum spring will not go solid during fuel rod operation and prevent free expansion of the fuel pellets. These evaluations would be checked and documented in the LTA report.

3.2 Neutronic Review

The evaluation of Limited Scope LTAs from the neutronic standpoint is not much different than that for currently licensed fuel products up to the current licensed lead rod average burnup limit. The effects of burnup on neutronics analyses up to the current licensed lead rod average burnup limit are discussed in vendor or utility specific proprietary topical reports. These reports typically show that the neutronic models are acceptable up to the current licensed lead rod average burnup limit based on comparison to surveillance data which is typically an SER requirement for acceptance of these models. Based on experience with other high burnup LTAs, these models are expected to yield acceptable results for burnups up to 75 GWD/MTU. Again, surveillance data of the core performance will be compared to predictions to demonstrate acceptability.

3.3 Thermal-Hydraulic Review

High burnup effects do not impact any of the thermal-hydraulic design criteria for a specific fuel product. Therefore, the Limited Scope LTAs will be evaluated along with the other fuel assemblies for acceptability from a reload standpoint.

3.4 Fuel Rod Design Review

Fuel rod design criteria are specified in the Standard Review Plan, Section 4.2 and assure that fuel system dimensions remain within operational tolerances and that functional capabilities are not reduced below those assumed in the safety analysis. Each vendor has specific fuel rod design criteria reviewed and approved by the NRC. <u>The criteria noted below may not apply to all vendors, but are provided as a sample of what would need to be justified for a Limited Scope LTA program by one vendor.</u> The currently licensed specific limits are specified in the proprietary topical reports submitted by the vendor and are not specified herein.

- Fuel Rod Internal Pressure
- Clad Stress and Strain
- Clad Oxidation and Hydriding
- Plenum Collapse
- Clad Flattening
- Fuel Rod Growth
- Fuel Temperature
- Clad Fatigue
- Clad Freestanding

For a Limited Scope LTA, only a few of these criteria would be limiting at the higher burnups. The evaluations of these criteria would be documented in the LTA report.

3.5 Safety Assessments

3.5.1 Non-LOCA Accidents

Since the Limited Scope LTA(s) would be analyzed as part of the reload design and must meet the current design limits, the Limited Scope LTA(s) would be covered by the Chapter 14/15 analysis of record. With regards to non-LOCA accident analyses, the one Chapter 14/15 analysis that is typically limiting and is considered the most severe of the reactivity initiated events is the rod ejection (PWR)/rod drop (BWR) accident. This event has received considerable interest as noted in Section 4.1. However, it was concluded that even if these events were to occur, the radiological consequences would be well within the NRC requirements for the event, even if it was conservatively assumed that high burnup fuel in the core would fail at extremely low levels of energy deposition.

3.5.2 LOCA Accidents

The Loss Of Coolant Accident (LOCA) is governed by 10 CFR 50.46 Acceptance Criteria. These criteria state that:

- The calculated maximum fuel element cladding temperature shall not exceed 2200 °F.
- The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation.
- The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.
- Calculated changes in core geometry shall be such that the core remains amenable to cooling.
- After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

These acceptance criteria are shown to be valid for the normal reload fuel in the core. Therefore, only those aspects of inserting Limited Scope LTAs need to be addressed. The two acceptance criteria that could be impacted by Limited Scope LTAs are: 1) the 2200 °F peak cladding temperature acceptance criterion, and 2) the total localized oxidation acceptance criterion of 17%. These evaluations would be checked and documented in the LTA report.

3.5.3 Radiological

There are two areas that will be discussed from a radiological standpoint as they will relate to the Limited Scope LTA(s): 1) the effect of high burnups on source terms and associated dose calculations and 2) the radiological consequences of an RIA for the rod ejection/drop accident.

The effects of high burnups on source terms and the associated doses have been discussed[4] in the past. One vendor's evaluations[4] discussed the impacts of extended fuel burnup level on source terms, gap fractions, normal operating plant releases, and accident doses. These evaluations addressed fuel burnup levels up to 75 GWD/MTU. Based on these previous evaluations, the use of Limited Scope LTAs would not result in an increased risk of radiological consequences on a reload basis.

With regards to the radiological consequences of an RIA for the rod ejection event, this evaluation has been addressed in Reference 3 and will not be repeated herein.

3.6 Reporting Requirements

For the Limited Scope High Burnup LTAs, a formal written notification will be made to the staff (for information purposes). This notification should include the following information:

- Utility Name,
- Plant Name,
- Cycle in which the Limited Scope High Burnup LTAs will be inserted,
- Anticipated number of LTAs intended to be inserted,
- Anticipated pre and post cycle burnups of each LTA,
- What planned PIEs are anticipated which would specify the purpose of the Limited Scope High Burnup LTAs, and
- An estimate of when the PIE will occur along with an estimate of when the PIE data will be available to share with the staff.

This letter would be for information only since it would be done early in the process (e.g., 9-12 months prior to the cycle) before all analyses were necessarily completed.

As for the PIEs, they are normally done after the test cycle has been completed and the subsequent cycle has started up and is off critical path with regards to the outage. This is scheduled between the vendor and the utility. Thus it would be difficult to specify a definitive schedule at this time. An anticipated date for the PIE would be provided in the initial notification letter to the staff. As for the PIE report itself, each vendor would have their own forms and the content of the report would vary based on the PIEs that are anticipated. However, as a minimum, the field report should specify:

- Utility Name,
- Plant Name,
- Fuel Assembly Identification Number,
- Specific Measurements (e.g., the actual data along with the maximum predicted values from the pre-test cycle analyses/evaluations),
- Environmental Conditions,
- Test Equipment used including accuracy,
- Calibration dates of test equipment used, and
- A comment section.

The PIE report shall be provided to the NRC by the utility. Again, this report is for information only. A formal PIE report would normally be compiled from the field report by the vendor with essentially the same information along with an engineering assessment of the data. This formal report is not required to be submitted since the pertinent engineering assessments from these reports would be shared with the staff at the typical fuel performance update meetings. The eventual culmination of all the data and engineering assessments by each of the vendors will be shared with the NRC as part of their high burnup licensing submittals. Thus, no formal submittal of individual PIEs would be required from the vendors.

4.0 Addressing Industry Issues

In considering the acceptability of high burnup Limited Scope LTAs, there are several current industry issues associated with fuel that the NRC has requested be addressed. These issues are Reactivity Insertion Accidents (RIAs), higher oxidation than predicted, excessive rod internal gas pressure at end-of-life, incomplete RCCA insertion (IRI), breakaway/accelerated growth of fuel rods and assemblies, fuel failures due to high fuel duty, high crud build-up, Axial Offset Anomalies (AOA), and adverse effects of water chemistry. Several of these issues are inter-related and will be briefly discussed based on their inter-relationship. The following discussions are an example of how one vendor has addressed these issues.

4.1 RIAs

In November 1994, the NRC requested that the fuel vendors review their previously approved topical reports to assess if these topical reports remain appropriate in light of the unexpectedly low failure threshold seen in the CABRI Reactivity Insertion Accidents (RIA) test results. Each vendor provided a response to the NRC request.

In Reference 3, the Industry Issues Task Force (ITF) provided to the NRC information detailing the safety significance assessment with respect to the potential reduction in failure threshold for high burnup fuel during postulated RIA. Reference 3 concluded that the probability of an RIA occurring was extremely small (10^{-4} to 10^{-6} per year). It was further concluded that even if these events were to occur, the radiological consequences would be well within the NRC requirements for the event, even if it was conservatively assumed that high burnup fuel in the core would fail at extremely low levels of energy deposition.

4.2 Excessive Rod Internal Gas Pressure and Increased Oxidation

In 1996, surveillance data on cladding oxidation indicated that the current corrosion model used by a vendor may under predict the observed corrosion seen in the field. In December 1996, the vendor introduced a new corrosion model that was demonstrated to be conservative and to bound the most recent surveillance data. When the new corrosion model was incorporated into the fuel performance model, the feedback effects of the increased corrosion resulted in "predicted" gap re-opening situations in some reload designs. Although the "predicted" gap re-opening issue was generally conservative, and subsequent model changes licensed through the NRC have mitigated this issue, the effect of the increased corrosion on rod internal pressure is real.

Based on design changes made to the fuel to regain rod internal pressure margins and a newly licensed fuel performance model, it is not expected that the Limited Scope LTAs would be susceptible to these issues. As part of the evaluations that would be performed for the Limited Scope LTAs, a corrosion and a rod internal pressure analysis would be required. If a Limited Scope LTA was projected to fall into a gap re-opening or excessive corrosion situation, it would not be permitted to be used.

4.3 Incomplete RCCA Insertion and Breakaway/Accelerated Growth

Incomplete RCCA Insertion (IRI) has occurred in the recent past. Root cause investigations have been initiated to determine the fundamental cause of this issue. There have been several root causes associated with this issue, one of which is breakaway/accelerated axial growth occurring within the fuel assembly skeleton. However, not all fuel assembly designs have shown susceptibility to IRI, and for those fuel assembly designs that have experienced IRI, numerous corrective actions have been implemented to resolve this issue. Due to the nature of this issue, each fuel vendor would need to determine the susceptibility of their fuel assembly designs to IRI. This assessment would be used to evaluate the susceptibility of assemblies to be used for the Limited Scope LTA program. The evaluation would be documented in the LTA report for each Limited Scope LTA program.

4.4 High Crud Build-up, AOA, Adverse Water Chemistry and High Fuel Duty Fuel Failures

High crud build-up, adverse water chemistry, high fuel duty and AOA have been determined to be inter-related. Some plants operating under these more demanding conditions have experienced increased crud deposition and AOA. A root cause investigation of AOA has determined that as the crud builds-up on high-power rods, boron from the primary coolant chemistry deposits within the crud matrix. The boron deposited in the crud can result in the axial offset anomaly (AOA). As the fuel reaches higher burnup levels, it no longer operates at the high power levels at which susceptibility to AOA has been observed. Since at high burnup, the Limited Scope LTAs will not operate at high power levels, they would not be susceptible to AOA. Assemblies that have unusual or high levels of corrosion as a result of having experienced AOA earlier in life will not be included in a Limited Scope LTA program if it is estimated that the additional exposure may lead to exceeding the corrosion design criterion.

In some cases excessive crud deposition on high-duty fuel has led to accelerated corrosion and failures. The Limited Scope LTAs will be at burnups where their fuel temperatures will be reduced and crud accelerated corrosion will not be a concern. Assemblies that have experienced crud-induced accelerated corrosion will not be included in a Limited Scope LTA program if it is estimated that the additional exposure may lead to exceeding the corrosion design criterion.

5.0 Feedback Mechanism for Future Design / Model Changes

The data obtained from the PIEs, conducted on the Limited Scope LTAs, will be used to evaluate the criteria, models and methods used in fuel rod design as well as to confirm the performance margins for individual fuel designs. Based on data trends observed, fuel design changes may be required to accommodate high burnup limits. The data trends may also identify changes to operational conditions that may be required to support the higher burnup limits. In addition, new models, criteria or methods may be required depending upon how the data trends with current models and methods. Typically, the data obtained from an individual PIE campaign is compared against the existing database to ensure that operation of additional Limited Scope LTAs will not result in design criteria being exceeded. It is also important to correlate the detailed operations data of fuel duty, temperature, chemistry, etc. with the observed fuel performance measurements that are obtained from these programs.

6.0 References

1. Chatterton, Margaret S. (NRC), "Regulatory Perspectives on High Burnup Fuel Issues and Burnup Extension," ICONE 8 Conference, Baltimore, MD, April 2-6, 2000.

2. Chatterton, Margaret S. (NRC), "Regulatory Perspectives on High Burnup Fuel Issues and Burnup Extension," ANS International Topical Meeting on Light Water Reactor Fuel Performance, Park City, UT, April 10-13, 2000.

3. Letter from Marion, A. (NEI) to R. Jones (NRC), "NEI Response to NRC Staff's Request for Information on Reactivity Insertion Accidents," December 28, 1994.

4. Davidson, S. L. (Ed.), et al., "VANTAGE + Fuel Assembly Reference Core Report," WCAP-14342-A (Non-Proprietary), April 1995.

Appendix A

NRC Request for Additional Information

And Associated Responses

OG-01-042
July 9, 2001

WCAP-15604-NP, Rev. 0
Project Number 694

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Chief, Information Management Branch,
Division of Inspection and Support Programs

Subject: Westinghouse Owners Group
Response to NRC Request for Additional Information on WCAP-15604-NP, "Limited Scope High Burnup Lead Test Assemblies," (MUHP-1046)

Reference: 1) WOG Letter, OG-00-116, R.H. Bryan to Document Control Desk, "Transmittal of WCAP-15604-NP, Rev. 0, (Non Proprietary), 'Limited Scope High Burnup Lead Test Assemblies'," November 15, 2000.

2) NRC Letter, L.R. Wharton to R.H. Bryan, "Acceptance Review of Westinghouse Topical Report, WCAP-15604-NP, Rev 0. 'Limited Scope High Burnup Lead Test Assemblies' (TAC No. MB0591)," January 25, 2001.

In November 2000 the Westinghouse Owners Group (WOG) submitted Westinghouse topical report WCAP-15604-NP, Rev. 0, "Limited Scope High Burnup Lead Test Assemblies"for NRC review (Reference 1). The NRC Staff has initiated review of the topical report and issued a Request for Additional Information (RAI) (Reference 2). Attachment 1 provides the WOG response to the RAIs. Pending final resolution of these RAIs, the WOG will revise WCAP-15604-NP as necessary.

If you require further information, feel free to contact Mr. Ken Vavrek in the Westinghouse Owners Group Project Office at 412-374-4302.

Very truly yours,

Signed Copy on File in WOG Project Office

Robert H. Bryan, Chairman
Westinghouse Owners Group

attachment

OG-01-042
July 9, 2001

cc:
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WOG Analysis Subcommittee Representatives (1L, 1A)
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Westinghouse Owners Group
Responses to NRC Request For Additional Information on WCAP-15604-NP, "Limited Scope High Burnup Lead Test Assemblies"

General Comments:

1. Maximum number of lead test assemblies (LTAs) allowed: The numbers proposed are too large and justification for the numbers proposed is not provided. For PWRs, eight might be a reasonable number provided adequate justification is provided. For BWRs, similar justification and maximum number needs to be provided. The subject of additional LTAs (traditional LTAs or LTAs for another purpose) in the core should also be addressed.

Response:

For the Limited Scope LTAs, it is desirable to have assemblies with a spread of burnups ranging from the current licensed limits up to the proposed maximum limit. Typical fuel management schemes would have eight assemblies designed to reach a burnup of between 62 – 68 GWD/MTU lead rod average burnups. An additional four assemblies would be designed to reach between 68 – 72 GWD/MTU with only one remaining assembly designed to reach 75 GWD/MTU. (The word "designed" in this case refers to the fuel management considerations and the loading pattern development, not a difference in the mechanical design of the fuel assemblies.) This provides the desired spread in burnup data that will be needed to justify high burnup fuel behavior when the new high burnup limits are established and each vendor will then have to substantiate their fuel performance behavior.

Since most plants do not currently have fuel management schemes that would be conducive to reaching the mid- to upper end of the high burnup spectrum, and with a reduced number of Limited Scope LTAs permitted to exceed the current licensed limit, it would take substantially longer (on the order of four to six additional years considering eighteen month cycles) to establish a statistically significant database over the entire burnup regime of fuel performance data to justify high burnup limits. However, since the staff considers the currently proposed number of Limited Scope LTAs to be too high, then an alternate proposal would be to allow a maximum of 9 assemblies to be classified as Limited Scope High Burnup assemblies in PWRs and 32 assemblies to be classified as Limited Scope High Burnup assemblies in BWRs.

Setting the Limited Scope High Burnup LTAs at the reduced levels above is still beneficial and justifiable for the following reasons:

- Makes the core design economical enough to offset increased analysis and surveillance costs,
- Allows for a variety of loading patterns and power histories in order to observe effects that might not be observable with even fewer LTAs,
- Allows for symmetric locations in the core to be driven to higher burnups and allows for a center assembly to be accommodated,
- Restricts the total number of assemblies exceeding the lead rod average licensed burnup limit to a value < 10% of the core, which is consistent with many core damage frequency scenarios (e.g., for PWR cores with 121, 157, 177, 193, 204, 217, 241 fuel assemblies, 9 assemblies would be 7.4%, 5.7%, 5.1%, 4.7%, 4.4%; 4.1% and 3.7% respectively; for BWR cores with 560, 724, 764 fuel assemblies, 32 assemblies would be 5.7%, 4.4 % and 4.2% respectively).

Although 10% is within many core damage frequency scenarios, this topical was prepared for operation of fuel assemblies utilizing approved designs and materials. The only characteristic of these assemblies which is not part of typical operation is the extension of the rod average burnup to values greater than are currently licensed. However, some data already exists for these designs and materials at exposures above the current licensed limits. Based on this performance data, no anticipated shift in performance is expected relative to fuel that is maintained below the current licensed burnup limits. Therefore, there is no significant risk in terms of either fuel integrity or potential core damage in operating this number of assemblies to a slightly higher burnup.

With a maximum of 9 assemblies allowed for PWRs, initially eight assemblies would be able to reach burnups of between 62 – 68 GWD/MTU and one assembly may be able to reach 75 GWD/MTU lead rod average burnup as a central assembly that would be surrounded by feed assemblies. As plants' fuel management schemes move toward the high burnup regime, then four of the eight assemblies may be able to reach the 68 – 72 GWD/MTU region. Currently, it would not be economical for most plants to pursue getting all 9 assemblies to the upper end of the high burnup regime simply due to their fuel management schemes. Simply based on fuel management schemes alone, no more than 1– 5 assemblies would likely reach burnups of 68 – 75 GWD/MTU after the fuel management scheme reach a high burnup equilibrium.

The other part of the general comment was related to the subject of traditional LTAs or LTAs for other purposes in the core with Limited Scope High Burnup LTAs. The Limited Scope High Burnup LTAs are still Lead Test Assemblies with a specialized purpose, high burnup data acquisition. Traditional LTAs are often specialized designs with specialized reviews (i.e., exemptions for alternate advanced cladding material) that are carefully factored into the loading pattern, such that they do not lead the core and are not normally in rodded locations. The traditional LTAs or LTAs for other purposes are also designed to gather data from 0 GWD/MTU up to current licensed lead rod average burnup limits. If the staff wants to limit the total number of LTAs in a core at one time, then it needs to be specified by the staff that this is their position. However, it should be noted that these types of limitations will sacrifice data collection from one program for another program. Thus if it is deemed that an LTA for other purposes is needed in place of the Limited Scope High Burnup LTAs then it will take additional years to obtain a statistically significant database. What is considered reasonable is that in cases where traditional LTAs are present the total number of lead assemblies (traditional or limited scope) that will be exposed to burnups above currently licensed levels will not exceed 9 for PWRs and 32 for BWRs.

2. Pre-characterization of the LTAs: If fuel is to be operated above the current licensed limit, it must be characterized before irradiation above that limit. The amount and type of pre-characterization should be described as well as why the proposed amount is adequate.

Response:

Pre-characterization of Limited Scope LTAs will be conducted for all assemblies taken to burnup limits above that which is currently licensed. The typical fuel parameters that would be subject to pre-characterization were discussed in WCAP-15604-NP, Section 2.1. These typical pre-characterization parameters are: fuel rod cladding oxide thickness, fuel assembly and/or fuel rod growth, and guide thimble and/or assembly/channel bow measurements. The purpose of the pre-characterization is to: 1) obtain data that is useful in understanding the fuel performance based on the known fuel duty, and 2) to ensure that fuel design criteria will not be exceeded in the test cycle.

With regards to obtaining data that is useful in understanding the fuel performance, based on known fuel duty, pre-characterization will provide pre-test cycle values for the parameters measured. The Post Irradiation Examinations (PIEs) provide the post-test cycle values. Comparison of pre and post cycle values will yield the incremental effects that the final cycle of exposure has on the Limited Scope High Burnup LTAs. This provides a measure of whether an unknown phenomenon exists and is occurring in the high burnup LTAs. It also provides a very accurate measure of how well the predictive fuel performance models are behaving for this last cycle of exposure. However, the incremental effects are only part of the equation. Integral results (e.g., as-fabricated conditions to end-of-life) are also necessary. The integral results from a traditional LTA provides an overall measure of the fuel performance model accuracy (e.g., it establishes the error bands for the performance model). Integral results from a Limited Scope High Burnup LTA also provides an overall measure of the fuel performance model behavior; however, the accuracy is sacrificed since nominal as-fabricated measurements would be used. This sacrifice in accuracy is outweighed by the amount of data obtained from Limited Scope LTAs. By having a statistically significant database of fuel performance measurements and then using traditional LTA results with incremental pre and post test cycle measurements on Limited Scope High Burnup LTAs, the overall fuel performance model capability is demonstrated and substantiated. It should be noted that in comparing fuel performance model results to the measured results, the models are run in a best estimate mode. For cycle design calculations and licensing purposes, the fuel performance models results would be a bounding value that would be compared to design limits (e.g., uncertainty analysis results would be included with the best estimate results such that the bounding results would be on a 95/95 basis). The design limits that would be used for the Limited Scope LTAs are the current design limits for licensed fuel. As part of other industry programs, the current design limits are being reviewed for high burnup application and will not be discussed herein.

The other purpose of the pre-characterization is to ensure that current design criteria are not violated. Since the fuel performance models are being extrapolated to burnups that have not been licensed, the pre-characterization provides a measure of how much margin exists for a given design criteria to its limit, based on model predictions compared to the pre-characterization measurement. Thus, pre-characterization is necessary and provides valuable information. However, as noted above, extensive amounts of pre-characterization are not necessary since the Limited Scope High Burnup LTAs were conceived to obtain statistical significant amounts of data to demonstrate fuel performance models. Limited pre-characterization measurements and traditional LTAs provide model accuracy.

Since this report was written to address all the fuel vendors, it was accounting for the needs of all the vendors. Several vendors have advanced cladding materials that show significantly less growth characteristics than Zircaloy-2 or Zircaloy-4 alloys. Therefore, based on model predictions, most of the assemblies that would be considered for a Limited Scope LTA program would have more than sufficient growth margin to accommodate an additional cycle of irradiation. Since there would be less growth, there would also be less assembly distortion. Thus, a need to force a pre-characterization of fuel rod/fuel assembly growth, guide thimble and/or assembly/channel bow measurements, would not necessarily be warranted, especially if the structural assembly is also fabricated with advanced materials designed to have substantially less growth than Zircaloy alloys. The one pre-characterization that would be universal to all the vendors would be cladding oxidation.

From a fuel rod design standpoint, the design criteria that are limiting at end-of-life and could be potentially challenged for these Limited Scope High Burnup fuel assemblies are: cladding oxidation, rod internal pressures, fatigue and growth. As noted above, growth may be the least limiting of these criteria, especially if advanced alloys are being used. Fatigue analyses typically show 30 – 50% margin to the cumulative fatigue usage factor of 1.0. Thus, fatigue is not the limiting criterion at these high burnup levels. Rod internal pressures for current generation PWR fuel are typically licensed to exceed system pressure and thus a potential of pellet to clad lift-off exists, albeit small, depending upon the rod internal pressure and the corresponding pressure limit characteristics of the cladding material. Again, this criteria can vary from vendor to vendor, as far as being limiting, depending upon the constituent makeup of the internal gases and cladding material characteristics and the corresponding pressure limit characteristics. The one factor that can lead to significantly increased fuel rod internal pressures is the oxidation on the cladding outer surface. Above certain oxidation levels, the impacts on rod internal pressure and the significant impacts on the cladding pressure limit characteristics would results in the rod internal pressure criterion being exceeded. Thus, by ensuring that the oxidation is kept to a minimum, then the fuel rod internal pressure criterion is less limiting than simply the oxidation criterion by itself. Also, with higher levels of oxidation, spalling of the oxide layer can occur that could lead to hot spots forming on the bare cladding surface. These hot spots would lead to additional oxidation of the bare cladding and a potential through-wall hole could be created due to the metal-wastage effects of the oxidation on the cladding material. In addition to oxidation causing increases to rod internal pressures, crud deposition has a similar effect due to its poor thermal conductivity. Thus ensuring that crud deposition is kept to a minimum, also reduces the impacts on rod internal pressures.

Since each of the vendors have slightly different needs, the one criterion that would be universal to all the vendors would be the cladding oxidation. Based on further telephone discussions with the staff, it is understood that at a minimum, clad oxidation, rod/assembly growth and visual examinations would be considered appropriate as a minimum set of pre-characterization exams. With the consideration that the Limited Scope High Burnup LTAs were conceived to attract plants into pursuing LTA programs and thus generating a substantial database of fuel characteristics behaviors; additional pre-characterization testing without a warranted need would simply add to the plant's outage schedule. This potential impact on a plant's outage schedule, whether real or only perceived, would deter the plants from pursing Limited Scope LTAs and thus would defeat the objective of gathering valuable fuel characteristics data. Therefore, it is agreeable to establish the minimum set of pre-characterization exams for the Limited Scope LTAs that will be done prior to the test cycle as: clad oxidation, rod/assembly growth and visual examinations.

3. Post irradiation examinations of the LTAs: The description of the post-irradiation program should include a minimum set of examinations that will be performed and justification for why this set is adequate, as well as details for deciding which types of LTAs require additional testing. In addition, the type of LTAs and/or examination results that trigger hot-cell examinations should be stated.

Response:

The types of Post Irradiation Examinations (PIEs) that would be performed were described in WCAP-15604-NP, Section 2.2.1. It was noted that "as a minimum, each Limited Scope LTA program will measure at least one of the following parameters: cladding oxidation, fuel assembly/fuel rod growth, or channel bow measurements". Since this report was written to address all the fuel vendors, it was accounting for the needs of all the vendors. As noted in Section 2.2.1, "the particular measured parameters [for PIEs] will vary based on the data needs of the particular vendors and the amount of data accumulated from previous LTA programs". The rationale for this statement and why it was inappropriate to specify more PIEs in the minimum set is based on the following.

Each one of the PWR vendors need to carefully measure and monitor corrosion effects in the high burnup regime; however, for BWRs, channel bow would tend to be more limiting than corrosion. To specify more than just a single parameter is now getting into the specific needs of each of the vendors with regards to the amount of data that would be needed to substantiate individual fuel performance criteria. One vendor may need a substantial amount of growth data to demonstrate both fuel performance behavior and to demonstrate that their current growth model is excessively conservative. Another vendor may need a substantial amount of data with regards to assembly grid growth relative to the fuel rod as it would be associated with fuel rod vibration. Another vendor may be developing a new advanced cladding alloy and will need substantial amounts of data in all areas to demonstrate the performance capability of the alloy. However, it was perceived that to specify more than what was stated in the topical report in Section 2.2.1 would be unduly placing additional burden on the various vendors who already have a substantial amount of data in certain areas. Thus it came down to the fuel assembly/fuel rod designs of each vendor and the amount of data that they already had to substantiate various fuel performance models versus what they needed. In addition, it was noted that certain vendors may need unique data that the others would not.

However, based on further telephone discussions with the staff, it is understood that at a minimum, clad oxidation, rod/assembly growth and visual examinations would be considered appropriate as a minimum set of PIEs. Since PIEs need to be carefully planned and scheduled with the respective plants, and since the plant supplies personnel in an auxiliary role, it is desirable to obtain all the necessary data in one PIE rather then several separate PIEs. Therefore, even though a minimum set of PIEs is defined and agreed to above, numerous other inspections and measurements will most likely be done during the PIE since repeated PIEs are costly, inefficient and an ALARA concern.

The second part of the question asks which LTAs require additional testing and what inspections results would trigger possible hot cell examinations. As noted above, any LTA that is introducing a new design feature would most likely require a complete set of PIEs that are applicable to the specific feature. For example, a new cladding material would need corrosion measurements, profilometry, growth measurements, and rod-to-rod spacing measurements. A new guide thimble material would need OD/ID corrosion measurements, guide thimble distortion measurements, and assembly bow measurements. A new grid design would need corrosion measurements, grid cell sizing measurements, and grid width measurements. As far as hot cell examinations, a change in the fuel pellet (e.g., density, diameter, or burnable absorber) would normally require a hot cell examination. Other instances that would normally trigger a possible hot cell examination would be anomalous profilometry measurements than what were expected; anomalous fuel rod growth measurements, etc. As noted in Section 2.2 of the topical report, the hot cell examinations are done when deemed appropriate by the vendor/utility. Unless there is a specific need for a hot cell examination, such as in the case of obtaining fuel pellet information, hot cell examinations are not normally planned in advance. Most hot cell examinations are planned after the pool side PIEs are completed and a determination is made that an anomalous condition exists that warrants further investigation.

4. Reporting: The intent to irradiate LTAs and the results of post irradiation examinations (PIEs) need to be reported to the NRC. A reporting template would serve as a model for each of these reports. The schedule for these reports should be specified. The specific purpose for the LTAs should be part of the initial report.

Response:

The intent to irradiate an LTA to higher burnups or for other purposes is currently reported to the NRC staff by the fuel vendors. This has been done during fuel performance update meetings with the staff by fuel vendors and by teleconferences with the staff by fuel vendors. It is also highly suggested, by the vendors, that the utility notify their respective resident inspector and PM of any LTA programs. In this fashion, the NRC is informed of LTA programs from both directions.

For the Limited Scope High Burnup LTAs, if it is desired that a formal written notification be made to the staff (for information purposes), then the following information is suggested to be included in such notification:

- Utility Name,
- Plant Name,
- Cycle in which the Limited Scope High Burnup LTAs will be inserted,
- Anticipated number of LTAs intended to be inserted,
- Anticipated pre and post cycle burnups of each LTA,
- What planned PIEs are anticipated which would specify the purpose of the Limited Scope High Burnup LTAs, and
- An estimate of when the PIE will occur along with an estimate of when the PIE data will be available to share with the staff.

This letter would be for information only since it would be done early in the process (e.g., 9-12 months prior to the cycle) before all analyses were necessarily completed.

As for the PIEs, they are normally done after the test cycle has been completed and the subsequent cycle has started up and is off critical path with regards to the outage. This is scheduled between the vendor and the utility. Thus it would be difficult to specify a definitive schedule at this time. An anticipated date for the PIE would be provided in the initial notification letter to the staff. As for the PIE report itself, each vendor would have their own forms and the content of the report would vary based on the PIEs that are anticipated. However, as a minimum, the field report should specify:

- Utility Name,
- Plant Name,
- Fuel Assembly Identification Number,
- Specific Measurements,
- Environmental Conditions,
- Test Equipment used including accuracy,
- Calibration dates of test equipment used, and
- A comment section.

A formal PIE report would be compiled from the field report with essentially the same information along with an engineering assessment of the data.

5. Safety Assessment: Analytical models used to evaluate the LTAs will likely need to be used beyond the currently approved limits for the models. Justification for use of these models beyond approved limits needs to be provided.

Response:

As part of the process in assessing Limited Scope High Burnup LTAs, detailed evaluations will be conducted to determine their acceptability. The results of these evaluations are normally documented in an LTA report that serves as the technical basis for a 10 CFR 50.59 evaluation. As noted previously, from a fuel rod design standpoint, the design criteria that are limiting at end-of-life and could be potentially challenged for these Limited Scope High Burnup fuel assemblies are: cladding oxidation, rod internal pressures, fatigue and growth. As noted previously, growth may be the least limiting of these criteria, especially if advanced alloys are being used. Fatigue analyses typically show 30 – 50% margin to the cumulative fatigue usage factor of 1.0. Thus, fatigue is not the limiting criterion at these high burnup levels. Rod internal pressures for current generation PWR fuel are typically licensed to exceed system pressure and thus a potential of pellet to clad lift-off exists, albeit small, depending upon the rod internal pressure and the corresponding pressure limit characteristics of the cladding material. Again, this criteria can vary from vendor to vendor, as far as being limiting, depending upon the constituent makeup of the internal gases and cladding material characteristics and the corresponding pressure limit characteristics. The one factor that can lead to significantly increased fuel rod internal pressures is the oxidation on the cladding outer surface. Above certain oxidation levels, the impacts on rod internal pressure and the significant impacts on the cladding pressure limit characteristics would results in the rod internal pressure criterion being exceeded. Thus, by ensuring that the oxidation is kept to a minimum, then the fuel rod internal pressure criterion is less limiting than simply the oxidation criterion by itself. Also, with higher levels of oxidation, spalling of the oxide layer can occur that could lead to hot spots forming on the bare cladding surface. These hot spots would lead to additional oxidation of the bare cladding and a potential through-wall hole could be created due to the metal-wastage effects of the oxidation on the cladding material. Therefore, the one fuel rod design criterion that stands out as potentially the most limiting is corrosion.

As noted before, the use of developmental models that accurately model the specific fuel performance parameter based on data obtained to date is done so in a best estimate fashion. If the developmental model is predicting previous data accurately and then uncertainties are added to the results, the model will be bounding for the reload analysis. These bounding results would be compared to current design limits since revised limits have not yet been defined. This method is an incremental approach that is based on real data and is less of an extrapolation then using the current licensed models with their uncertainties. The developmental models typically yield more bounding results than the current licensed models.

As for the other functional areas, nuclear, thermal-hydraulic, transient analyses and LOCA analyses are typically beginning-of-life limiting. The one exception to this would be the LOCA total localized oxidation limit of 17% which is end-of-life limiting. As noted above, the fuel rod criterion that tends to be the most limiting is corrosion or oxidation. By using a developmental model that was originally based on a licensed model, but has been modified to accurately model high burnup data, then the bounding results from that added into the LOCA analysis will yield a bounding evaluation of the 17% limit.

By taking currently licensed models and creating developmental models and factoring in the data of PIEs as it become available, ensures that the models are accurately modeling the fuel performance behavior. Adding uncertainties to these best estimate results and using this as a comparison tool in making final decisions on whether the LTAs are acceptable is less of an extrapolation then simply using the licensed models, especially when the developmental models may be more conservative.

Specific Comments:

1. 2nd bullet of Executive Summary: "data from post irradiation examinations (PIEs)…" This statement needs to state that data will be reported to the NRC.

   Response:
   This statement will be revised to state that the data will be reported to the NRC for informational purposes. It should be noted that this data will be marked as proprietary by the vendors. It will also be supplied as informational in nature. When each vendor applies for their increased burnup limits, this will be the data that will be submitted to justify design criteria and limits.

2. 3rd bullet of Executive Summary: First sentence needs to be modified to state that fuel will be characterized before operation above the current licensed rod average burnup.

   Response:
   The third bullet will be modified to read as follows:

   "The fuel will be typical production fuel with pre-characterization before operation above the current licensed lead rod average burnup limit. The fuel may also be an LTA, which was characterized during fabrication and was designed to test other aspects of the fuel assembly but was not initially identified as a high burnup LTA."

3. 4th bullet of Executive Summary: The maximum number of allowed LTAs stated is too large.

   Response:
   Will be revised to reflect the maximum number as specified in response to General Comment #1.

4. Page 3, 2nd paragraph: Pre-characterization oxide thickness should be limited. No pre-irradiation spallation or blistering should be allowed.

Response:
As stated in this paragraph, "... it is not anticipated that any fuel rods would fail in these assemblies due to the fact that they must meet current design criteria even at the higher burnup level, . . .". Each vendor has their own design criteria so it would be difficult to specify a single value here. In the past, the staff has recommended that oxidation should be maintained less than 100 microns on a best estimate basis and that spallation and blistering should be avoided. This recommendation can be adopted for the Limited Scope High Burnup LTAs as the criterion to meet pending the eventual revised design criteria that are being established by the Robust Fuel Program Working Group.

5. Page 4, 4th paragraph: More explanation is required for removal of any conservatism, as well as why additional uncertainty is not needed if additional uncertainty is not incorporated.

Response:
As noted in response to General Comment #5, the use of developmental models that accurately model the specific fuel performance parameter based on data obtained to date is done so in a best estimate fashion. If the developmental model is predicting previous data accurately and then uncertainties are added to the results, the model will be bounding for the reload analysis. These bounding results would be compared to current design limits since revised limits have not yet been defined. This method is an incremental approach that is based on real data and is less of an extrapolation then using the current licensed models with their uncertainties. The developmental models typically yield more bounding results than the current licensed models.

However, the situation may exist where a current licensed model is know to be conservative to reality and it is desired that the model be revised to remove some of the excess conservatism. Beginning with the current licensed model and demonstrating that on a best estimate basis, it is conservative to measured data, then creating a developmental model that more accurately reflects measured data is appropriate. The developmental model would still have uncertainties added to it for a formal verification analysis approach. As additional data is obtained, it would be validated against the best estimate calculations using the developmental model. The other aspect of comparing the developmental model with measured data is to determine if the current uncertainties are appropriate or whether the uncertainties would need revised. Again, this would be an incremental controlled process. In this fashion, the NRC would be aware of how the model is performing relative to the data, such that when sufficient data is obtained and a formal model revision is submitted to the staff for review and approval, the staff will be familiar with the model and the associated data. This approach will save the staff significant resource effort in the long run and will promote increased confidence that the models meet the specified design criteria.

6. Page 5: See general comments on pre-characterization.

Response:
Refer to response to General Comment #2.

7. Page 6: See general comments on PIE.

Response:
Refer to response to General Comment #3.

8. Page 8, 3rd paragraph: See comment above on removing conservatism.

Response:
Refer to response to Specific Comment #5.

9. Page 9: Some parameter limits, like oxide thickness, will apply to all fuel. These should be stated, as well as why others do not apply to all fuel.

Response:

Section 3.0 of WCAP-15604-NP was provided to illustrate what would need to be done on a reload basis to demonstrate how the LTAs would be assessed and documented in an LTA report. LTA reports are prepared by the vendors and provided to the utility as the technical basis for a 10 CFR 50.59 evaluation. Section 3.0 was not provided to be all encompassing since each vendor has different reload methods and different design criteria. It would not be feasible to get into that level of detail in this document since much of the vendors' methodology and specifics of their design criteria are proprietary.

Section 3.0 was provided as a sample. It also included an acknowledgment that each vendor would do their appropriate assessments and document it in an LTA report of some type to be provided to the utility in support of 10 CFR 50.59 evaluations.

10. Pages 11 and 12, Sections 3.5.3 and 4.1: These sections need to be expanded and updated to include recent work and discussions on burnup extension.

Response:

Again, Section 3.5.3 and 4.1 were provided to illustrate what would be needed from a general sense. These sections do not necessarily document the most recent data or positions since much of that would be considered proprietary by each vendor. Again, each vendor would document their specific assessments for these areas and document such assessments in an LTA report.