Westinghouse
Electric Company

Box 355
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February 19, 2001
AW-01-1437

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Attention: J. S. Wermiel, Chief,
Reactor Systems Branch
Division of Systems Safety and Analysis

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: Addendum 1 to WCAP-12488-A / WCAP-14204-A, "Westinghouse Fuel Criteria Evaluation Process," (Proprietary / Non-proprietary)

Reference: Letter from H. A. Sepp to J. S. Wermiel, NSBU-NRC-01-5983, dated February 19, 2001

Dear Mr. Wermiel:

The application for withholding is submitted by Westinghouse Electric Company LLC, a Delaware limited liability company ("Westinghouse"), pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.790, Affidavit AW-01-1437 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-01-1437 and should be addressed to the undersigned.

Very truly yours,

Henry A. Sepp, Manager
Regulatory and Licensing Engineering

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

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COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Henry A. Sepp, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC, a Delaware limited liability company ("Westinghouse") and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

H. A. Sepp

Henry A. Sepp, Manager
Regulatory and Licensing Engineering

Sworn to and subscribed
before me this 20th day
of February, 2001.

Lorraine M. Piplica

Notary Public

LORRAINE M. PIPLICA COMMONWEALTH OF PA NOTARY PUBLIC

Notarial Seal
Lorraine M. Piplica, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Dec. 14, 2003
Member, Pennsylvania Association of Notaries

(1) I am Manager, Regulatory and Licensing Engineering, in the Nuclear Services Division, of the Westinghouse Electric Company LLC, a Delaware limited liability company ("Westinghouse") and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Electric Company.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Electric Company in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked "Addendum 1 to WCAP-12488-A / WCAP-14204-A, "Westinghouse Fuel Criteria Evaluation Process , (Proprietary / Non-proprietary)," February 19, 2001, for submittal to the Commission, being transmitted by Westinghouse Electric Company (W) letter (NSBU-NRC-01-5983) and Application for Withholding Proprietary Information from Public Disclosure, Henry A. Sepp, Westinghouse, Manager Regulatory and Licensing Engineering to the attention of J. S. Wermiel, Chief, Reactor Systems Branch, Division of Systems Safety and Analysis. The proprietary information as submitted by Westinghouse Electric Company is Addendum 1 to WCAP-12488-A / WCAP-14204-A which provides revisions to certain design criteria. This submittal is a follow-up to a presentation given to the NRC staff on October 17, 2000.

This information is part of that which will enable Westinghouse to:

(a) The proposed criteria replace indirect performance correlations with direct performance correlations that are more readily measured and provide direct feedback to design.

(b) The revised criteria conform to both NUREG-0800 and to current industry guidelines.

(c) These updated criteria will promote convergence between Westinghouse business units.

Further this information has substantial commercial value as follows:

(a) Westinghouse can continue to ensure the highest quality of fuel since the proposed criteria is more readily measurable and thus provides direct feedback to fuel designs.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing the enclosed improved core thermal performance methodology.

Further the deponent sayeth not.

Proprietary Information Notice

Transmitted herewith are proprietary and non-proprietary versions of documents furnished to the NRC. In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

Addendum 1 to WCAP-14204-A

Revisions to Design Criteria

Addendum 1 to WCAP-14204-A

Revisions to Design Criteria

Introduction

The purpose of this submittal it to update certain fuel licensing criteria that are applied to Westinghouse fuel. These criteria pre-date NUREG-0800[1] and are inconsistent with other Westinghouse business units and industry guidelines. The proposed criteria replace indirect performance correlations with direct performance correlations that are more readily measured and provide direct feedback to design. Both the current and proposed criteria are shown below. In this addendum, the term zircaloy is used in a generic sense and applies to both Zircaloy-4 and ZIRLO™ material.

Parameter:	Fuel Structural Hydrogen Content
Current Criteria:	The hydrogen content of zircaloy structural components shall be less than [ ] a,c.
Proposed Criteria:	The zircaloy structural component stresses will be consistent with ASME Code Section III requirements after accounting for thinning due to corrosion.

Parameter:	Fuel Cladding transient Strain
Current Criteria:	The transient strain will be less than 1% and fuel centerline melt will not occur.
Proposed Criteria:	Same as current criteria.

Parameter:	Fuel Cladding Stress
Current Criteria:	The transient stress will be less than [ ] a,c.
Proposed Criteria:	Cladding stresses will be consistent with ASME Code Section III requirements.

The following sections give the bases for justifying the changes to the design criteria.

Structural Hydrogen Criteria

The Westinghouse imposed hydrogen criteria for both cladding and structural components is defined[2] as:

> "The clad and structural component hydrogen pickup is limited to [ ] a,c at end of life to preclude loss of ductility due to hydrogen embrittlement by the formation of zirconium hydride platelets."

The criterion is based on historical data for unirradiated zircaloy which showed that hydrogen levels of [ ] a, c were acceptable. No differentiation was made between heated (cladding) and unheated (structural) surfaces.

Recent data for zircaloy material shows that ductility does not suddenly decrease and that some ductility remains at hydrogen concentrations well in excess of [ ] a, c. Unheated structural components are not susceptible to hydrogen redistribution due to temperature gradients within the components. Thus, high local hydrogen concentrations do not exist. Irradiation reduces the material ductility and increases the material yield and ultimate strengths. Thus, any analysis of irradiated components should account for changes in ductility and material strength due to both irradiation and hydrogen pickup.

Effects of Hydrogen Content on Zircaloy Structural Material Properties

Westinghouse has conducted programs to collect material property data on both unirradiated and irradiated zircaloy. Tensile test results for grid strap material and assembly thimble tubes are described below.

Tensile tests were performed on unirradiated ZIRLO™ strip material that is used to manufacture grid straps. Tests were conducted at room and elevated [ ] a, b, c temperatures. Hydrogen charging was used to give material hydrogen concentrations up to [ ] a, b, c. The ductility, defined as plastic strain or the total strain minus the elastic strain, is plotted versus hydrogen content in Figure 1. The plot shows a [ ] a, b, c. Significant ductility exists for hydrogen concentrations up to [ ] a, b, c.

Projections of the data indicate that ductility will still exist for hydrogen concentrations [ ] a, b, c.

Yield strength of the strip material is plotted versus hydrogen content in Figure 2. There is [ ] a, b, c. The ultimate strength is plotted versus the hydrogen content in Figure 3. There is [ ] a, b, c.

Tensile tests were also conducted on hydrogen charged unirradiated thimble tubes. The room temperature ductility is plotted versus the hydrogen content in Figure 4. There is [

] a,b,c. The ductility at elevated temperatures is plotted in Figure 5. These tests were conducted [

] a,c shown in Figure 5. These data illustrate that at elevated temperatures, [ ] a,b,c for the unirradiated ZIRLO™ thimble tubes for hydrogen concentrations [ ] a,b,c.

Yield and ultimate strength of the unirradiated ZIRLO™ thimble tubes are plotted versus the hydrogen content in Figures 6 and 7. There are [
] a,b,c with the hydrogen content. There is [
] a,b,c as the hydrogen content increases.

Material property data have also been obtained from irradiated Zircaloy-4 and ZIRLO™ thimble tubes. These tubes were irradiated to burnups of about [
] a,c. Sample hydrogen concentrations were [ ] a,b,c. The room and elevated temperature ductility are shown in Figures 8 and 9. The trends for [
] a,b,c. The minimum ductility at elevated temperatures [
] a,b,c.

The yield and ultimate strength at room and elevated temperatures are shown in Figures 10 and 11. There are [
] a,b,c. Comparisons of the data for unirradiated and irradiated ZIRLO™ thimble tubes shows that [
] a,b,c.

Comparisons of the ductility of irradiated and unirradiated Westinghouse thimble tubes at elevated temperature are shown in Figure 12. Irradiation reduces the ductility [
] a,b,c.

A survey of the literature indicates that other fuel vendors have published similar data. General Electric reports[3] that the total and uniform elongation of irradiated Zircaloy-2 at operating temperatures are independent of the hydrogen content in the range of 0 to 815 ppm. Siemens has published[4] data for the elongation after fracture of irradiated zircaloy with hydrogen contents up to 2000 ppm and concludes that the influence of irradiation on the ductility and strength of zircaloy is dominant at both room and operating temperatures. They further conclude that even high hydrogen contents do not add to the effects of irradiation and do not have an additional influence on reducing the ductility.

The third Nuclear Fuel Industry Research Program (NFIR) sponsored a program to gather data on the properties of irradiated cladding and guide tubes. A specific objective of the program was to evaluate the decrease in ductility of Zircaloy-4 materials due to reactor irradiation and increasing hydrogen content. Both cladding and guide tube materials were included in the studies. The results of the material property measurements are reported in References 5 and 6.

Data in Reference 5 (page 4-18) illustrates that the total plastic elongation of the irradiated guide tubes decreases from about 8 % with no hydrogen present to about 0.3 % at a hydrogen concentration of about 1300 ppm. This sensitivity of ductility to the hydrogen content is somewhat greater than determined by Westinghouse, General Electric, and Siemens. Tensile strength was found to increase with the hydrogen content. Hydrogen charging was performed on unirradiated archive samples and the tensile properties were determined. The hydrogen contents of the archive samples was higher than the irradiated samples, and there was a large scatter in the data. However, it is still clear that irradiation had a much greater impact on reducing the ductility than did the hydrogen charging.

Tensile strains for both irradiated and unirradiated guide tube material at operating temperature is shown in Figure 3-15 of Reference 6. Irradiation has a much larger effect on reducing the ductility than does the hydrogen content. There is a weak dependence of ductility on the hydrogen content. Tensile strengths increase slightly with the hydrogen content.

In summary, the Westinghouse and other industry data show that:

- The ductility of unirradiated zircaloy does not abruptly decrease above hydrogen concentrations of [ ] a,c. There is a gradual decrease in ductility with increases in hydrogen concentrations up to [ ] a,c. At operating temperatures, significant ductility still exists for hydrogen concentrations up to [ ] a,c.

- The ductility of irradiated zircaloy is primarily affected by irradiation.
- While hydrides contribute to the embrittlement of irradiated zircaloy, the [ ] a,c.
- Hydrogen content has little effect on the tensile strength of irradiated zircaloy at either room or operating temperatures.
- The yield strength of irradiated recrystallized zircaloy at operating temperatures is [ ] a,b,c. The value is [ ] a,b,c at room temperature.

Impacts of Hydrogen Content on Grids

Irradiation, corrosion, and hydrogen uptake could potentially impact the strength of grids. The seismic capability of grids is performed by testing them under simulated conditions. NUREG-0800(1) specifies that grid crush tests should be performed on unirradiated production grids at, or corrected to, operating temperature. A number of phenomena associated with irradiation could impact the seismic/LOCA capability. Westinghouse has conducted tests to verify that unirradiated production grids would continue to demonstrate the minimum seismic/LOCA capability when accounting for corrosion, wall thinning due to corrosion, hydrogen uptake, and enlargement of the grid cell size.

A series of tests were conducted on unirradiated 5x5 grid sections with oxidation, wall thinning, hydrogen pickup, and enlargement of the grid cell size. The test sections were conditioned by oxidizing them in autoclaves in steam and steam/lithium mixtures. Hydrogen uptake was due to oxidation of the zircaloy material.

- One-sided oxide thickness ranged from [ ] a,b,c.
- Hydrogen content was up to [ ] a,b,c.
- Wall thinning varied from [ ] a,b,c.
- Grid spring-to-rod gaps varied from [ ] a,b,c.

The test results are illustrated in Figure 13 where the grid section crush strength is plotted versus the hydrogen content. The figure illustrates that the crush strength, P, is [ ] a, b, c. The data also show that [ ] a, b, c. Additional evaluations showed that the crush strength and seismic capability factor were [ ] a, b, c.

Tests were also conducted on full size grids which had been oxidized in air to give internal strap thinning values of [ ] a, b, c. The cell sizes were adjusted to give [ ] a, b, c. Grid crush strength and stiffness data were compared to production grids with no wall thinning and with both open and closed rod-to-grid gaps. The seismic capability factor is plotted versus the percent of internal strap thinning in Figure 14. There is [ ] a, b, c.

These data from the grid crush tests indicate that [ ] a, b, c.

Evaluation of Thimble Tube Stresses

Thimble tube stresses are evaluated using Westinghouse design procedures that follow the ASME Code Section III guidelines. An evaluation was performed that considered both unirradiated beginning-of-life conditions with no wall thinning and with wall thinning and irradiation strengthening of the thimble tube material. The evaluation was performed for a limiting design and considered shipping/handling loads and Condition I – IV events. It was concluded that [ ] a, b, c. Since [ ] a, c.

Revised Westinghouse Design Criteria for Hydrogen

A review of material property data for Westinghouse zircaloy structural material indicates that [ ] a, b, c. There is no decrease of yield or ultimate strength with the hydrogen content. Ductility is primarily affected by irradiation, and [

] a, c. The impact of irradiation on thimble tube stresses has also been evaluated. It was concluded that [

] a, b, c. Thus, the ductility of thimble tubes is not an issue with present designs. Crush tests on 5x5grid sections showed that the seismic capability factor [

] a, b, c. Crush tests on full size production grids showed that there was [

] a, b, c.

All of these results support the conclusion that the current Westinghouse imposed hydrogen criteria for structural components is inappropriate. The desirable characteristics of a design criterion are:

- Related to a physical criteria,
- There is a basis for quantifying the criteria, and
- The criterion can be readily verified by measurements.

The data and discussions provided previously show that the first two characteristics are not met by the current Westinghouse structural hydrogen content limit. Verification of the hydrogen content is difficult in that it requires sending a structural section to a hot cell for analysis, and there can be large uncertainties associated with the measurement methods. The difficulties in performing such measurements severely limit the amount of data available for verification. It is thus concluded that the current structural hydrogen criterion possesses none of the desired characteristics of a design criterion.

A more appropriate criterion that has all of the desired characteristics is a wall thinning criteria. It is proposed that Westinghouse eliminate the current hydrogen content criteria and replace it with the following criteria:

> "The zircaloy structural component stresses will be consistent with ASME Code Section III requirements after accounting for thinning due to corrosion."

Updated Fuel Rod Cladding Stress Criteria

A review was performed of the fuel rod design criteria presented in References 2, 8 and 9. Those criteria were correlated with the design criteria presented in NUREG-0800(1) and in the robust fuel program technical requirements document(10). Based on this review it was determined that the following changes were needed in the criteria.

- Remove cladding transient stress criterion.
- Add cladding stress criterion based on ASME pressure vessel criteria.

A detailed description and justification for the proposed removal of the transient stress criterion and substitution of static stress criterion are given below.

Transient Stress: The design limit for the fuel rod cladding stress under normal operation and AOOs is that the volume averaged effective stress, considering interference due to uniform cylindrical pellet-to-cladding contact is less than the [

] a, c.

This limit was designed to protect the cladding during pellet-cladding interaction (PCI). This is one of four criteria which were imposed to protect the cladding from PCI during Condition I and II operation. These four criteria are:

- Transient Stress [ ] a, c,
- Transient Strain < 1%,
- No Centerline Fuel Melt, and
- Cladding Total Strain < 1%

The remaining three criteria which protect the cladding from PCI are detailed below.

Transient Strain: The design limit for the fuel rod cladding transient strain during AOOs is that the total tensile strain due to uniform cylindrical pellet thermal expansion during the transient is less than 1% of the pre-transient value.

The transient strain is the change in total strain from the start to the peak of the transient.

$$\varepsilon_{trans} = \varepsilon_{tot\_at\_trans\_peak} - \varepsilon_{tot\_at\_start}$$

Total Strain: The design limit for the fuel rod cladding total strain during normal steady state operation is that the total strain of the cladding shall not exceed [ ] a, c. The total strain consists of both plastic and elastic components and is determined in PAD[7] at any time step by:

[ ] a, c

No Centerline Fuel Melt: The design limit for fuel temperature analysis during Condition I and II is that there is at least a 95% probability that the peak kW/ft fuel rods will not exceed the UO_2 melting temperature.

These three criteria are sufficient to protect the cladding from PCI. The transient stress criterion is redundant and does not represent industry practice. The criterion to be substituted is based on industry practice and is described next.

Fuel Rod Cladding Stress: Maximum cladding stress intensities excluding PCI induced stress will be evaluated using ASME pressure vessel guidelines[11]. Cladding corrosion is accounted for as a loss of load carrying material. Stresses are combined to calculate a maximum stress intensity which is then compared to criteria based on the ASME code.

Criteria: Sm = the minimum of:

- 1/3 σ_{ult} minimum specified at room temperature
- 1/3 σ_{ult} value at temperature
- 2/3 σ_y minimum specified at room temperature
- 2/3 σ_y value at temperature

Su = the minimum of:

- σ_{ult} minimum specified at room temperature
- σ_{ult} value at temperature

where: σ_y is the 0.2% offset yield strength

σ_{ult} is the ultimate tensile strength

Stress Intensity Limits		
Loading Conditions	**Description**	**Limit**
Pm	Primary Membrane	Sm
Pm + Pb	Primary Membrane + Bending	1.5Sm
Pm + Pb + Pl	Primary Membrane + Bending + Local	1.5Sm
Pm + Pb + Pl + Q	Primary Membrane + Bending + Local + Secondary	3.0Sm
Pm	Faulted Conditions - Primary Membrane	Minimum of 0.7Su or 1.6 Sm
Pm + Pb Pm + Pb + Pl	Faulted Conditions - Primary Membrane + Bending	Minimum of 1.05Su or 2.4 Sm

The stresses to be considered due to and the stress category are listed:

Stress Due to	Stress Category
Differential Pressure	Primary Membrane
Ovality	Primary Bending
Flow induced vibration	Primary Bending
Fuel Assembly Bow	Primary Bending
Fuel Rod Bow	Primary Bending
Spacer grid contact force	Primary Local
Thermal differential across the cladding	Secondary

Conclusions

The current criteria applied to Westinghouse fuel pre-date NUREG-0800[1] and do not conform completely to NUREG-0800[1], to industry guidelines[10], and to those criteria in use at other Westinghouse business units. The proposed updated criteria conform to both NUREG-0800[1] and to industry guidelines[10]. These updated criteria are sufficient to preclude fuel damage and will also promote convergence between Westinghouse business units.

References

1. U. S. NRC, "USNRC Standard Review Plan, Section 4.2, Fuel System Design," NUREG-0800, July 1981.

2. Davidson, S. L. (Ed.), et al., "VANTAGE + Fuel Assembly Reference Core Report," WCAP-12610-P-A, April 1995, pg. 12.

3. S. Wisner and R. B. Adamson, "G E Nuclear Energy," 1996 , Vol. 3, pg. 1.

4. W. Jahreib, R. Manzel and E. Ortlieb, "Annual Meeting on Nuclear Technology," Cologne, 1993 pg. 303.

5. A. Hermann, et. al., "Fuel Cladding Integrity at High Burnups (Part I)," NFIR-III/EPRI, DRAFT TR-108753-P1, July 1999, pg. 4-18.

6. R. C. Kuo, et al., "Fuel Cladding Integrity at High Burnups (Part II)," NFIR-III/EPRI, TR-108753 P2, August 1999, pg. 3-47.

7. Foster, J. P. and Sidener, S., "Westinghouse Improved Performance Analysis and Design Model (PAD 4.0)," WCAP-15063-P-A, Revision 1 with Errata, July, 2000.

8. Davidson, S. L. (Ed.), et al., "Westinghouse Fuel Criteria Evaluation Process," WCAP-12488-A (Proprietary), WCAP-14204-A (Non-proprietary), October 1994.

9. Davidson, S. L. (Ed.), et al., "Extended Burnup Evaluation of Westinghouse Fuel," WCAP-10125-P-A, December 1985.

10. EPRI, "Robust Fuel Program Technical Requirements for Nuclear Fuel Performance," TR-110689, November 1999.

11. ASME Pressure Vessel Code, Section III, Article NG-3000, 1998.

Figure 1. Ductility vs Hydrogen Content for Unirradiated ZIRLO™ Strip Material

a, b, c

[ ]

Figure 2. Yield Strength vs Hydrogen Content for Unirradiated ZIRLO™ Strip Material

a, b, c

[ ]

Figure 3. Ultimate Strength vs Hydrogen Content for Unirradiated ZIRLO™ Strip Material

a, b, c

[ ]

Figure 4. Room Temperature Ductility vs Hydrogen Content for Unirradiated ZIRLO™ Thimble Tubes

a, b, c

[ ]

Figure 5. Elevated Temperature Ductility vs Hydrogen Content for Unirradiated ZIRLO™ Thimble Tubes

a, b, c

Figure 6. Room Temperature Strength vs Hydrogen Content for ZIRLO™ Thimble Tubes

a, b, c

Figure 7. Elevated Temperature Strength vs Hydrogen Content for Unirradiated ZIRLO™ Thimble Tubes

a, b, c

[ ]

Figure 8. Room Temperature Ductility of Irradiated Thimble Tubes

a, b, c

[ ]

Figure 9. Elevated Temperature Ductility of Irradiated Thimble Tubes

a, b, c

[ ]

Figure 10. Room Temperature Strength of Irradiated Thimble Tubes

a, b, c

[ ]

Figure 11. Elevated Temperature Strength of Irradiated Thimble Tubes

a, b, c

Figure 12. Elevated Temperature Ductility of Unirradiated and Irradiated Westinghouse Thimble Tubes

a, b, c

Figure 13. Crush Strength vs Hydrogen Content for Unirradiated 5x5 Grid Sections

a, b, c

[ ]

Figure 14. Seismic Capability Factor vs Grid Strap Thinning for Production Grids

a, b, c

[ ]