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September 14, 2010

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Dr. Kaye D. Lathrop
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Re: License Renewal Proceeding, Indian Point Nuclear Generating Station, Unit 2 and Unit 3
Docket Nos. 50-247-LR/50-286-LR; ASLBP No. 07-858-03-LR-BD01

Dear Administrative Judges:

The State of New York and Riverkeeper, Inc. respectfully submit the enclosed Counter Statement of Material Fact, Combined Response to Entergy's Motion for Summary Disposition of Combined Contentions NYS 26/26A and RK TC-1/TC-1A, the declaration of Janice A. Dean, and two supporting expert declarations from Dr. Richard Lahey and Dr. Joram Hopenfeld.

The declarations and Counter Statement of Material Fact discuss deficiencies in the recent CUF_{en} Reanalysis prepared by Westinghouse and provided by Entergy. Out of an abundance of caution, the State and Riverkeeper have provisionally designated portions of the accompanying Counter Statement of Material Fact and declarations as containing proprietary information because certain Westinghouse documents have been designated as containing proprietary information. In accordance with this Board's September 4, 2009 Protective Order, non-redacted and non-public versions of the declarations are being served on the Board and its staff, the Secretary and her staff, counsel for Entergy, and counsel for NRC Staff – while redacted and public versions of the two declarations are being served on the remaining parties. The State and Riverkeeper reserve the right to later request that the proprietary designation be removed.

Respectfully submitted,

s/
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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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In re:	Docket Nos. 50-247LR and 50-286LR
License Renewal Application Submitted By	ASLB No. 07-858-03-LR-BD01
Entergy Indian Point 2, LLC, Entergy Indian Point 3, LLC, and Entergy Nuclear Operations, Inc.	DPR-26, DPR-64 September 14, 2010

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STATE OF NEW YORK AND RIVERKEEPER, INC. COMBINED RESPONSE TO ENTERGY MOTION FOR SUMMARY DISPOSITION OF COMBINED CONTENTIONS NYS 26/26A AND RK TC-1/TC1-A (METAL FATIGUE)

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INTRODUCTION

A central safety concern inherent in the proposal to allow a forty year old nuclear reactor to continue operating for an additional 20 years is whether the principal components of the reactor are able to withstand another 20 years of operational stress. Key to this inquiry is the issue of whether metal components, particularly those associated with the reactor pressure vessel, and other critical safety systems, have become so fatigued by transients during operation that they are no longer able to retain their structural integrity throughout an additional 20 years of operation and the inevitable additional transients and stresses associated with such operation.

The State of New York and Riverkeeper initially presented two contentions that directly addressed this concern (NYS 26 and RK TC-1) and later amended those contentions to address new information provided by Entergy in Amendment 2 to its License Renewal Application ("LRA") (NYS 26-A and RK TC1-A).[1] The ASLB admitted both contentions, as amended, with certain limitations, and directed the submission of a consolidated contention on metal fatigue. *Entergy Nuclear Operations, Inc.* (Indian Point Nuclear Generating Units 2 and 3), LBP-08-13 at 104-116, 152-62, & 228, 68 NRC 43 (July 31, 2008). The State and Riverkeeper complied and

[1] New York State Notice of Intention to Participate and Petition to Intervene at 227-33 and Declaration of Dr. Richard T. Lahey, Jr. (Nov. 30, 2007), ADAMS Accession Nos. ML073400187, ML073400193; Petitioner State of New York's Request for Admission of Supplemental Contention No. 26-A (Metal Fatigue) and Declaration of Dr. Richard T. Lahey, Jr., in Support of the State of New York's Supplemental Contention 26-A (April 7, 2008), ADAMS Accession No. ML081750691; Riverkeeper, Inc.'s Request for Hearing and Petition to Intervene in the License Renewal Proceeding for the Indian Point Nuclear Power Plant (Nov. 30, 2007), at 7-15 and Declaration of Dr. Joram Hopenfeld in Support of Riverkeeper's Contentions TC-1 and TC-2 (Nov. 28, 2007), ADAMS Accession No. ML073410093; Riverkeeper, Inc.'s Request for Admission of Amended Contention 6 (March 5, 2008) and Declaration of Dr. Joram Hopenfeld in Support of Riverkeeper's Amended Contention TC-1 (March 4, 2008), ADAMS Accession No. ML080840441.

timely submitted a consolidated contention.[2] *See* Consolidated Contention of Petitioners State of New York (No. 26/26-A) and Riverkeeper, Inc. (TC-1/TC1-A) – Metal Fatigue, ML082400524 (Aug. 21, 2008) ("Consolidated Contention"). The Consolidated Contention, which is the subject of Entergy's Summary Disposition Motion ("SD Motion"), is:

> Entergy's License Renewal Application Does Not
> Include an Adequate Plan to Monitor and Manage the
> Effects of Aging Due to Metal Fatigue on Key Reactor Components

Id. at 3 (NYS 26/26-A & RK TC-1/TC1-A). By its terms the contention covers the full gamut of the AMP for metal fatigue of key reactor components and is neither limited to TLAA calculations or CUF_{en} calculations. Rather the Consolidated Contention calls into question the adequacy of the metal fatigue AMP. As such it is not, as Entergy would have it (SD Motion at 23-24), merely a contention of omission.[3] Rather it is a contention that challenges, on the merits, the adequacy of what Entergy has proposed to do to meet its obligations under 10 C.F.R. § 54.21(c)(1)(iii).

LEGAL STANDARDS

The regulations at 10 C.F.R. § 2.1205 govern summary disposition motions, and require the Board to apply the summary disposition standard set forth in Subpart G. 10 C.F.R. § 2.1205(c). In general, the Commission applies the same standard that the federal courts apply when ruling on motions for summary judgment under Rule 56 of the Federal Rules of Civil Procedure. *See Entergy Nuclear Vt. Yankee L.L.C.*, 63 N.R.C. 116 (Jan. 31, 2006), citing *Advanced Medical Systems. Inc.* (One Factory Row, Geneva, Ohio 44041), CLI-93-22, 38

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[2] Entergy did not challenge or in any other way respond to the Consolidated Contention when submitted.

[3] While some of the bases of the consolidated contention may no longer be valid, the contention itself is still valid because the AMP remains inadequate.

N.R.C. 98, 102 (1993). Under the Subpart G standard, summary disposition is proper "if the filings in the proceeding, depositions, answers to interrogatories, and admissions on file, together with the statements of the parties and the affidavits, if any, show that there is no genuine issue as to any material fact and that the moving party is entitled to a decision as a matter of law." 10 C.F.R. § 2.710(d)(2). Summary disposition "is not a tool for trying to convince a Licensing Board to decide, on written submissions, genuine issues of material fact that warrant resolution at a hearing." *Entergy Nuclear Vt. Yankee L.L.C.*, 63 NRC at 121, *quoting Private Fuel Storage, L.L.C.* (Independent Spent Fuel Storage Installation), LBP-01-39, 54 N.R.C. 497, 509 (2001). The moving party bears the burden of demonstrating that there is no genuine issue as to any material fact. 10 C.F.R. § 2.325; *Entergy Nuclear Vt. Yankee L.L.C., quoting Private Fuel Storage, L.L.C.*, 63 NRC at 121. Any doubt as to the existence of a genuine issue of material fact is resolved against the moving party. *Id., citing Advanced Medical*, CLI-93-22, 38 N.R.C. at 102. "Because the burden is on the moving party, the Board must examine the record in the light most favorable to the non-moving party and give the non-moving party the benefit of all favorable inferences that can be drawn from the evidence." *Id.* When conflicting expert opinions are involved, summary disposition is rarely appropriate. *Entergy Nuclear Vt. Yankee L.L.C., quoting Private Fuel Storage, L.L.C.*, 63 N.R.C. at 122, citing *Phillips v. Cohen*, 400 F.3d 388, 399 (6th Cir. 2005) ("competing expert opinions present the 'classic battle of the experts' and it [is] up to [the finder of fact] to evaluate what weight and credibility each expert opinion deserves").

THE REQUIREMENTS OF 10 C.F.R. § 54.21(c)(1)

The Consolidated Contention filing provided a succinct and accurate statement of the relevant law, a statement with which Entergy appears to agree in its SD Motion:

> NRC regulations require an applicant to provide in the license renewal application an evaluation of TLAAs and show that those analyses "remain valid for the period of extended operation" and have been "projected to the end of the period of extended operation." 10 C.F.R. §54.21(c)(l)(i), (ii). If those TLAAs demonstrate that corrective action is necessary, the Applicant goes to the next step of demonstrating, also in the license renewal application, that the corrective action will occur through the adequate management of the effects of aging on the intended function for the period of extended operation. 10 C.F.R. § 54.21(c)(l)(iii).

Consolidated Contention NYS 26-A/RK TC1-A, at 4-5 (footnote omitted); *see* SD Motion at 4-5. However, Entergy then offers a distorted and inaccurate description of what obligations are imposed on it pursuant to § 54.21(c)(1).

First, Entergy argues that so long as it does something that it asserts complies with NUREG-1801, Rev. 1 ("GALL") and calls it a CUF_{en} analysis and if all the numbers produced by that analysis are less than 1 based on current projected transients and operating conditions for the next 20 years, there can be no dispute with the methodology it used to produce the CUF_{en} results. In short, Entergy believes that once it declares that what it has done is in compliance with the requirements of GALL and other NRC guidance documents, there cannot be any dispute about whether it was in fact in compliance with those requirements or whether in fact compliance with those guidelines is sufficient to demonstrate compliance with the requirements of 10 C.F.R. § 54.21(c)(1). Nothing in any Commission decisions supports such an *ipse dixit* legal theory. Rather, in the Commission's most recent expression of opinion on the meaning of 10 C.F.R. § 54.21(c)(1) it was clear that challenges to claims that an applicant had met the requirements of that section, particularly the requirements of § 54.21(c)(1)(iii), were appropriate for license renewal proceedings, particularly where, as here, the challenge was based on the failure of an applicant, that purports to comply with GALL, to actually be in compliance with the guidance in GALL. *Entergy Nuclear Vermont Yankee, L.L.C.* (Vermont Yankee Nuclear Power

Station), CLI-10-17 at 45 ("An applicant may commit to implement an AMP that is consistent with the GALL Report and that will adequately manage aging. But such a commitment does not absolve the applicant from demonstrating, prior to issuance of a renewed license, that its AMP is indeed consistent with the GALL Report. We do not simply take the applicant at its word") and 47 ("And of course, any AMP is subject to challenge before a board in a license renewal proceeding").

Second, Entergy ignores the fact that the CUF_{en} analysis it has now submitted (the "CUF_{en} Reanalysis") is the *second* such analysis it has completed. It also did a CUF_{en} analysis as part of its initial LRA and that analysis demonstrated that several key components will reach a CUF_{en} of greater than 1 during the period of extended operation. LRA at pp. 4.3-24 to 4.3-25 (Tables 4.3-13, 4.3-14). While there is nothing improper about refining an initial CUF_{en} analysis in order to attempt to demonstrate compliance with AMP requirements, once a CUF_{en} analysis has raised a red flag about any components exceeding the CUF_{en} threshold of 1, according to GALL, industry guidance and sound engineering practice, Entergy should expand the scope of its CUF_{en} analysis to include a greater number of components. Entergy failed to expand the scope of the CUF_{en} analysis.

Third, Entergy argues that, because in *Vermont Yankee* the Commission observed that it is not necessary to do a CUF_{en} analysis in order to demonstrate that a proper AMP exists, its CUF_{en} Reanalysis is actually surplusage and its SD Motion should be granted solely on the fact that it committed to do a CUF_{en} reanalysis that was in compliance with GALL. This interpretation of the relevant law is flawed in two important ways. First, as noted above, "[w]e do not simply take the applicant at its word." *Vermont Yankee,* CLI-10-17 at 45. Second, had Entergy not done a CUF_{en} Reanalysis, its LRA would have to be evaluated in light of the CUF_{en}

analysis it submitted with its LRA which demonstrated that a number of components would have CUF_{en} values >1. By choosing not to do a "refined" CUF_{en} analysis, the guidance in GALL would require Entergy to implement either of the two remaining "corrective actions to prevent the usage factor from exceeding the design code limit during the period of extended operation" - i.e. "repair of the component, [or] replacement of the component." GALL at X M-1 - M-2; *see also* SD Motion at 21-22 where Entergy concedes that if it did not do the CUF_{en} Reanalysis and show all the values <1 it would have had to implement "Option 2 (*i.e.*, 'repair or replace the affected locations [before exceeding a CUF of 1.0]')"). To avoid that consequence, Entergy chose instead to do the CUF_{en} Reanalysis.[4] It is that reanalysis, not a promise to do that reanalysis, which has to form the basis for Entergy's SD Motion.

ARGUMENT

I. PURSUANT TO 10 C.F.R. § 2.710(c) SUMMARY DISPOSITION SHOULD BE DENIED

The provisions of 10 C.F.R. § 2.710(c) provide in pertinent part:

> Should it appear from the affidavits of a party opposing the motion that he or she cannot, for reasons stated, present by affidavit facts essential to justify the party's opposition, the presiding officer may refuse the application for summary decision . . .

Id.; *see also Long Island Lighting Company* 23 N.R.C. 577 (1986) ("The rules further provide that if essential facts are not available for response to the motion, the Board may deny it or make such other order as is appropriate. 10 C.F.R. § 2.749(c) [predecessor of 10 C.F.R. § 2710(c)]"). The attached September 8, 2010 Declaration of Dr. Richard T. Lahey, Jr. ("Lahey 2010 Declaration") at ¶¶ 9 & 11 and September 13, 2010 Declaration of Dr. Joram Hopenfeld

[4] The SD Motion asserts that the CUF_{en} Reanalysis was done because this Board said no LRA could be issued unless the calculation was done first. SD Motion at 17.

("Hopenfeld Sept. 13, 2010 Declaration") at ¶¶ 11-15, 17,annexed hereto as Attachments 1 and 2, respectively, demonstrate that without certain critical data which almost certainly would have been part of any competent CUF_{en} calculation it is not possible to fully challenge the assertions contained in Entergy's SD Motion. Missing from the record upon which Entergy relies for its SD Motion are:

1. the complete WESTEMS computer code manual, which was used by Westinghouse to generate the CUF_{en} Reanalysis upon which Entergy relies;

2. a "propagation of error" analysis which should have been conducted as a matter of standard engineering practice;

3. the thermal-hydraulics methodology used;

4. the criteria used for selecting critical parameters for the environmental correction factor, including the dissolved oxygen, temperature, strain rate, sulfur content, number of transients predicted for the future and heat transfer coefficients; and

5. the references identified in the two Westinghouse proprietary reports (Attachments 15 and 16) to the SD Motion which are not publically available.

See Lahey 2010 Declaration at ¶¶ 9 and 11; Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-15, 17.

Pursuant to the requirements of 10 C.F.R. § 2.336(a)(2)(i) Entergy is obligated to produce:

> A copy, or a description by category and location, of all documents and data compilations in the possession, custody, or control of the party that are relevant to the contentions, provided that if only a description is provided of a document or data compilation, a party shall have the right to request copies of that document and/or data compilation.

10 C.F.R. § 2.336(a)(2)(i). When it produced the supplemental information related to its CUF_{en} calculations, Entergy did not provide critical documents relevant to those calculations. Dr. Lahey explains the problem:

> [I]n order to perform more mechanistic, and presumably less conservative, fatigue evaluations, Entergy contracted with Westinghouse (W) to redo the fatigue analyses for IP-2 and IP-3. These results were reported separately [WCAP-17199-P, "Environmental Fatigue Evaluation for Indian Point Unit 2" (June 2010) & WCAP-17200-P, "Environmental Fatigue Evaluation for Indian Point Unit 3" (June 2010)]. The calculations were done using WESTEMS, a proprietary computer code of W [5], but unfortunately the documentation for this code has not been provided to me for review.3 Without being able to review the WESTEMS code manuals, in which the detailed assumptions and models (particularly for the thermal-hydraulics) used by W are presumably given, it is not possible to fully understand and critique the validity of Entergy's new CUF_{en} results.
>
>> 3. Two brief proprietary excerpts of the WESTEMS computer code manual were provided to the State of New York on Friday evening, September 3, 2010. I reviewed these brief excerpts, but they did not shed light on the thermal-hydraulics models employed in the WESTEMS code.

Lahey 2010 Declaration at ¶ 9. In addition, as Dr. Lahey further states, Entergy has also not produced any error analysis, which is a standard and critical part of any properly conducted CUF_{en} calculation:

> Unfortunately an error analysis was not made available by either Entergy or Westinghouse, nor were any results provided showing that the computational results exhibited nodal convergence, or how they were bench-marked against representative experimental data and/or analytical solutions. Normally, one would expect to see a detailed "propagation-of-error" type of analysis [*e.g.*, Vardeman & Jobe, "Basic Engineering Data Collection and Analysis," Duxbury, pp. 310-311 (2001)] to determine the overall uncertainty in the CUF_{en} results given by W. Indeed, all engineering analyses are based on mathematical models of reality and assumptions which inherently involve some level of error. As a consequence, without a well documented error analysis, the accuracy of Entergy's and Westinghouse's new fatigue results are quite uncertain.

Id. at ¶ 11. Dr. Lahey also explained why these documents were particularly important to

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[5] Both the State of New York and Riverkeeper have signed the Confidentiality Agreement approved by the Board (Protective Order, September 4, 2009) in this case so the fact that the requested information may be "proprietary" provides no excuse for the failure to produce it. Either Entergy relies on an analysis, the documentation for which it produces, or Entergy cannot rely on the analysis. Neither NRC regulations nor fundamental concepts of due process allow it to use "black box" calculations and "secret" documentation to support its submissions.

evaluate the revised CUF_{en} analysis given how close to the limiting value of 1.0 the calculations were for several components. *Id.* at ¶ 11.[6] Dr. Hopenfeld provided similar details of the nature of the missing information and its importance to evaluating the adequacy and reliability of the CUF_{en} Reanalysis. Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-15.

Entergy asserts that its CUF_{en} Reanalysis is consistent with GALL. SD Motion at 17. However, GALL requires that the analysis be sufficiently reliable that the numbers produced by the CUF_{en} analysis will, if they are <1.0, assure that Entergy will be able to meet the GALL Report's goal of:

> maintaining the fatigue usage factor below the design code limit and considering the effect of the reactor water environment, as described under the program description, [such that it] will provide adequate margin against fatigue cracking of reactor coolant system components due to anticipated cyclic strains.

GALL at X M-1. Drs. Lahey and Hopenfeld state in their 2010 Declarations that it is not possible to gauge the reliability of the CUF_{en} Reanalysis without the relevant data, which Entergy has not produced. Lahey 2010 Declaration at ¶¶ 9 and 11; Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-15, 17. Entergy asserts that the calculation it has completed is the refined CUF_{en} calculation required by Commitment 33 and this Board, that the actual CUF_{en} values are <1 and that the CUF_{en} calculation method they have used will be able to assure that a CUF_{en} >1 will not be reached for any component in the future. SD Motion at 18. However, Drs. Lahey and Hopenfeld have indicated that they cannot test the correctness of those assertions about the accuracy of the CUF_{en} Reanalysis calculation without the missing documents and data. Lahey 2010 Declaration at ¶¶ 9 and 11; Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-15, 17. Entergy

[6] Out of an abundance of caution, the State provisionally designated portions of paragraph 11 of Dr. Lahey's declaration as containing proprietary information; for this reason the State does not repeat that information here.

asserts that the CUF_{en} Reanalysis calculations comply with the guidance contained in various NRC guidance documents. SD Motion at 19-20. The guidance documents do not dictate the precise methodology and criteria to be used in calculating CUF_{en} but largely describe the parameters that a proper CUF_{en} calculation must address. Entergy and Westinghouse decided what values would be used for those parameters but, as Drs. Lahey and Hopenfeld demonstrate, Entergy has not disclosed the methodology and criteria it used for determining the value for those parameters and, thus, it is not possible to determine whether what Entergy has done achieves the goals set forth in the NRC guidance documents which it claims to be following. Lahey 2010 Declaration at ¶¶ 9 and 11; Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-15, 17.

The State of New York and Riverkeeper promptly requested that Entergy provide the essential and relevant information Drs. Lahey and Hopenfeld identified but to date, only a few fragments of the computer code manual have been provided and nothing else. *See* Declaration of Janice A. Dean, annexed hereto as Attachment 3; Lahey 2010 Declaration, n.3. No other documents have been provided although, since the date of the Westinghouse reports dated June 2010, Entergy has filed two § 2.336 disclosures and has not included in either of them any of the missing documents. As Drs. Lahey and Hopenfeld 2010 Declarations make clear, the relevance of the non-disclosed documents to the Consolidated Contention is indisputable. The fact that Entergy may have believed the contention would be declared moot by this Board does not provide it with the right to refuse to produce all documents relevant to an admitted contention so long as the contention remains valid. Similarly, it is no defense for Entergy to assert that the relevant documents are in the possession of its expert, Westinghouse. It is well-established that the duty imposed on an applicant pursuant to 10 C.F.R. § 2.336, to produce all relevant documents extends to retained experts:

> The duty to disclose applies to the parties and the NRC Staff ("[e]ach party and the NRC staff shall make its initial disclosures ... based on the information and documentation then reasonably available to it." 10 C.F.R. § 2.336(c) (emphasis added)). But, as we see it, this obligation flows down to an individual who is retained to serve as expert witnesses [sic] on behalf of a party. Thus, if the expert witness has "a copy of the analysis or other authority" upon which his or her opinion is based, *see* 10 C.F.R. § 2.336(a)(1), and it is extant and reasonably available to that witness and/or the party, then the mandatory disclosure should include that "analysis or other authority."

In re Progress Energy Fla., Inc., 2009 NRC LEXIS 45 (NRC 2009) at *19, n. 10.

In sum, it is clear that the State and Riverkeeper are unable to fully respond to the SD Motion because Entergy has, without any legal justification, refused to produce the most critical and fundamental documentation relevant to its CUF_{en} Reanalysis. Under these circumstances, the Board should deny the SD Motion. Nonetheless, as the following discussion demonstrates, there are several deficiencies in the SD Motion that are so apparent that even with the limited available information, summary disposition should be denied.

II. ENTERGY'S ASSERTED BASES FOR SUMMARY DISPOSITION ARE FLAWED

Entergy offers two legal theories, either of which it asserts warrant the grant of SD. Both are wrong as a matter of law.

A. Entergy's Assertion of Compliance With GALL, Even If Staff Agrees With Entergy, Does Not Resolve the CUF_{en} Issue

Entergy claims "[t]he bottom line is crystal clear: Entergy's commitment to implement a Fatigue Monitoring Program that the Staff has found consistent with the GALL Report establishes Entergy's compliance with § 54.2 1(c)(l)(iii)." SD Motion at 17. Entergy relies on *Vermont Yankee*, apparently believing the Commission concluded that so long as Entergy and NRC Staff agree that the AMP complies with GALL, the issue is closed and beyond challenge. But that is not what the Commission ruled. Instead, the Commission:

> reiterate[s] here that a commitment to implement an AMP that *the NRC finds* is consistent with the GALL Report constitutes one acceptable method for compliance with 10 C.F.R. § 54.21(c)(1)(iii).

Vermont Yankee, CLI-10-17 at 44 (emphasis added); *see also id.* at 47 (accepting as correct, but rejecting as applied to the case before it, the argument that an applicant's "commitment to comply with the GALL provision related to metal fatigue, [may] satisf[y] the Staff but [it] does not and cannot prevent the Board from reviewing the substance of the commitment and . . . explor[ing] any deficiencies alleged in that commitment to the extent they are raised by an intervenor"). NRC Staff is a *part* of the NRC, just as is this Board and the Commissioners, but in this proceeding NRC Staff is a party, not the decider, and the issue of compliance with the AMP requirement is one this Board is authorized to decide, if, as here, the issue is properly raised in an admitted contention.

The Commission also ruled in *Vermont Yankee* that it is not sufficient for an applicant to assert that it will comply with GALL. "[A] commitment does not absolve the applicant from demonstrating, prior to issuance of a renewed license, that its AMP is indeed consistent with the GALL Report." *Id.* CLI-10-17 at 45. In this case, according to the Commission's *Vermont Yankee* decision, Entergy could have demonstrated compliance with the requirements of § 54.21(c)(1)(iii) by describing the parameters of the CUF_{en} calculation it "will" use in any refined CUF_{en} calculation by proving that use of that calculation would meet the GALL goal:

> In order not to exceed the design limit on fatigue usage, the aging management program (AMP) monitors and tracks the number of critical thermal and pressure transients for the selected reactor coolant system components. The AMP addresses the effects of the coolant environment on component fatigue life by assessing the impact of the reactor coolant environment on a sample of critical components for the plant.

GALL at X M-1. However, a mere assertion of compliance, without providing the relevant parameters, as described by Drs. Lahey and Hopenfeld in the declarations annexed hereto, does not "demonstrate" compliance. Entergy must make the case that what it has done meets the requirements with which it claims to be in compliance. All Entergy has done is provide self-serving descriptions of the results of the calculations. Because it has not described the methodology or criteria used for selecting the values for the critical parameters in the calculations, Entergy has failed to "demonstrate" compliance with GALL or NRC Regulations.

Thus, Entergy's mere assertion that it will do a calculation that it asserts will comply with GALL and the Staff's acceptance of the assertion does not foreclose the issue in license renewal.

B. Genuine Disputes of Material Fact Remain Regarding Whether Entergy's CUF_{en} Reanalysis Complies With GALL or NRC Regulations

Entergy chose to do the actual calculation and not merely to promise to do it, and, as noted above, its SD Motion must be evaluated in light of what it has done, not what it might have done. Ironically, although Entergy did the calculation, it has failed to demonstrate that its CUF_{en} Reanalysis complies with either GALL or NRC Regulations. Entergy has failed to disclose all the parameters of the CUF_{en} Reanalysis calculation. Thus, the record on which Entergy bases its SD Motion is insufficient to meet its regulatory duty to "demonstrate" that what it has done and what it plans to do in the future would achieve the goal of monitoring and tracking the critical transients by addressing the effects of the coolant environment on component fatigue life. *See* Lahey 2010 Declaration at ¶¶ 9 and 11 and Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 20-23.

The Consolidated Contention directly challenges the methodology Entergy and Westinghouse used in their CUF_{en} calculation and the gaps in information about that methodology, deficiencies that persist in the CUF_{en} Reanalysis. For example:

1. "Entergy fails to address NRC guidance requiring that if CUFs for representative *components in the license renewal application are more than 1.0, the applicant must*

evaluate all components that are subject to the effects of aging. *See* Riverkeeper's Hearing Request at 14-15, citing NUREG-1801, Rev. 1, Generic Aging Lessons Learned Report, Vol. 2 at X M-1 - X-M2 (2005) ("Gall Report"); Electric Power Research Institute, Material Reliability Program: Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application Revision 1, at 3-4 (2005)." Consolidated Contention at 16.

2. "Entergy does not provide any details on the analytical method and analysis approach it proposes to use. These details are critical since, depending on the calculational method to be used, e.g., a multidimensional FEM code, and the assumptions made, an applicant can obtain almost any answer that it wishes. Lahey Decl. II, ¶ 7. Additionally, Entergy does not indicate how its new calculational method will be benchmarked to assure its validity. *Id.*, ¶ 8. In other words, since Entergy has not provided any data that will be used to benchmark, neither New York nor the NRC can be assured that it is representative data and that the calculational method will be properly assessed. *Id.* . . . [T]his vagueness in Entergy's proposed 'refined analysis' is unacceptable." Consolidated Contention at 15.

3. "The proposed methodology . . . simply does not demonstrate that the Applicant has met its legal obligations to satisfy the required elements of 10 C.F.R. § 54.21(c)(1)(iii)." *Id.* at 15-16.

4. "Entergy's continued proposal of a 'more refined' re-analysis of the most fatigued-limited components in IP2 and IP3 leaves too much opportunity for Entergy to reach a manipulated and predetermined result -- namely, CUFs of <1.0 for the limiting components. Indeed, it appears that Entergy expects that these new analyses will demonstrate that all of the most limiting CUFs are<1,0, and, only if this is not so, does Entergy propose to replace the most fatigue-limited components. Unfortunately, there are too many opportunities for gaming the reanalysis, and the safety-related stakes are too high, to simply accept Entergy's unspecified new analytical approach on faith." April 7, 2008 Declaration of Dr. Richard T. Lahey, Jr. ("Lahey Decl II") at ¶ 5.

In admitting the State's and Riverkeeper's contentions, the Board stated that:

> Entergy has not provided the details of the approach and assumptions used in the analyses, how the calculations will be verified, or a summary of the resulting CIRs for each locations. . . In LRA Amendment 2, Entergy commits to performing the work using a time-tested analytical method and, in accordance with ASME codes, applying parameters consistent with the GALL Report, deriving analysis factors from unspecified formulae in various NUREGS, and applying its Part 50, Appendix B Quality Assurance program to govern this activity. However, the range of possible calculations that might result from the application of this approach does not meet the demonstration requirements of Section 54.21(c)(1)(iii) for an AMP.

Memorandum and Order (Ruling on Petitions to Intervene and Requests for Hearing) LBP-08-13 at 161-162 ("Admissibility Order") at 113. The Board went on to find that:

> [M]any of the arguments proffered by Entergy and the NRC Staff and subsequently addressed by Riverkeeper in its Reply, present us with material disputes . . . including, but not limited to, questions relating to (1) the extent to which an applicant must expand the scope of its TLAAs to meet the recommendations of the GALL Report and NUREG/CR-6260...

Admissibility Order at 161-162. Entergy does not demonstrate these issues have been resolved, nor that there is no dispute with regard to them.

Entergy asserts that "NYS and Riverkeeper argue that Commitment 33 lacks sufficient detail regarding the approach to be used in calculating refined CUF_{en}, values for the relevant IPEC components. The EAF analyses prepared by Westinghouse, however, refute that allegation and render both NY S-26126A and TC-1/1A moot." SD Motion at 18. However, it continues to insist that it need only look at the 6 locations identified in NUREG-6260 and that there is no "requirement" that it look further. SD Motion at 20. This conclusion by Entergy is challenged by several authorities:

1. GALL at X M-2 ("Acceptable corrective actions include repair of the component, replacement of the component, and a more rigorous analysis of the component to demonstrate that the design code limit will not be exceeded during the extended period of operation. For programs that monitor a sample of high fatigue usage locations, corrective actions include a review of additional affected reactor coolant pressure boundary locations"), with which it claims to be in compliance;

2. EPRI Report, MRP-47, Materials Reliability Program: Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application (Rev. 1, Sept. 2005) at 3-4 ("plant-unique evaluations may show that some of the NUREG/CR-6260 locations do not remain within allowable limits for 60 years of plant operation when environmental effects are considered. In this situation, plant specific evaluations should expand the sampling of locations accordingly to include other locations where high usage factors might be a concern" (Fn. omitted)); and

3. Drs. Richard T. Lahey and Joram Hopenfeld in their declarations attached to this

pleading (Lahey 2010 Declaration at 6-7); Hopenfeld Sept. 13, 2010 Declaration ¶ 21).

Thus, this material issue, whether the scope of the components in the CUF_{en} calculation that Entergy has now done and that it intends to periodically update are sufficient, remains in controversy and summary disposition is not appropriate.

Entergy also asserts there is no longer any dispute about whether it has provided sufficient details of the CUF_{en} calculation to permit a full evaluation of its sufficiency to meet the requirements of GALL or NRC Regulations. SD Motion at 18-20. However, despite the many pages of reports and references included in its SD Motion and 10 C.F.R. § 2.336 disclosures regarding the CUF_{en} Reanalysis, there are huge gaps of relevant information that do, or should, exist but which have not been disclosed. Moreover, no disclosures have been made of underlying documents that supported the CUF_{en} Reanalysis in the § 2.336 filings by Entergy since June, when the Reanalysis was completed. This is particularly surprising given that Entergy recognizes the CUF_{en} Reanalysis calculations are "are highly complex, require specialized technical acumen, and involve the use of sophisticated, state-of-the-art computer based analytics, including finite element analysis." SD Motion at 17-18. Among the missing information are fundamental components of the analysis including the following:

1. A "propagation of error" analysis, which is a standard engineering analysis for assessing uncertainty in calculations of this complexity (Lahey 2010 Declaration at ¶ 11);

2. The Code Manual for the proprietary WESTEMS Code used by Westinghouse, in "which the detailed assumptions and models (particularly for the thermal-hydraulics) used by W are presumably given," and without which "it is not possible to fully understand and critique the validity of Entergy's new CUFen results" (Lahey 2010 Declaration at ¶ 9);

3. The criteria used for selecting the critical parameters needed to calculate the

> environmental correction factor used for each transient including the basis for the selection of expected transients in the future, dissolved oxygen, temperature, heat transfer coefficients, sulfur content and strain rate (Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-15).

Thus, a controversy continues regarding the level of detail provided by Entergy and whether what it has presented is sufficient to carry its burden of demonstrating that the CUF_{en} calculated values of <1 are sufficiently reliable to meet GALL and NRC Regulations.

CONCLUSION

For the reasons stated above, Entergy's Motion for Summary Disposition should be denied.

Respectfully submitted,

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UNITED STATES
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

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In re:

License Renewal Application Submitted by
Entergy Nuclear Indian Point 2, LLC,
Entergy Nuclear Indian Point 3, LLC, and
Entergy Nuclear Operations, Inc.

Docket Nos. 50-247-LR; 50-286-LR
ASLBP No. 07-858-03-LR-BD01

DPR-26, DPR-64

September 14, 2010

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The State of New York and Riverkeeper, Inc. Provisionally Designate Portions of the Counter-Statement of Material Facts as Containing Confidential Proprietary Information Subject to Non-Disclosure Agreement

Redacted, Public version

THE STATE OF NEW YORK AND RIVERKEEPER, INC.'S COUNTER-STATEMENT OF MATERIAL FACTS

The State of New York and Riverkeeper, Inc. respectfully submit the following counter-statement in response to Entergy's August 25, 2010 Statement of Material Facts.

GENERAL OBJECTIONS

A large portion of what Entergy has submitted as statements of material fact consist of either quotes or summaries of the contents of documents, statements of law, or legal argument. The referenced documents, laws and arguments are the best evidence of their content and speak for themselves. The State and Riverkeeper have below disputed only facts; they have largely reserved their counterarguments, including interpretations of documents, for their accompanying memorandum of law. The State and Riverkeeper dispute any statement of fact that they have not specifically addressed below.

SPECIFIC RESPONSES AND COUNTERSTATEMENTS

Statements 1 - 7: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statements 8-9: The State and Riverkeeper do not dispute these statements.

Statements 10-11: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statements 12-13: The State and Riverkeeper do not dispute these statements.

Statement 14: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statement 15: The State and Riverkeeper do not dispute these statements.

Statement 16: The State and Riverkeeper dispute this statement because the analysis done by Entergy has not been demonstrated to be conservative. *See* September 8, 2010 Declaration of Richard T. Lahey, Jr. ("Lahey 2010 Declaration") at ¶ 10; Declaration of Dr. Joram Hopenfeld ("Hopenfeld Sept. 13, 2010 Declaration) at ¶ 16.

Statement 17: The State and Riverkeeper do not dispute these statements.

Statement 18: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statement 19: The State and Riverkeeper reiterate their general objection with reference to the last sentence of the Statement. The referenced documents speak for themselves.

Statement 20: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statement 21: Disputed. The six locations listed in NUREG/CR-6260 are <u>not</u> the only ones for which Entergy is required to perform CUF_{en} analyses in light of Entergy's first run of calculations which resulted in numerous CUF_{en} values above 1.0. NUREG-1801, Rev. 1, Vol. 2, pg. X M-2 and EPRI, MRP-47; "*Guidelines for Addressing Fatigue Environmental Effects in a Licensing Renewal Application,*" pg. 3-4 (2005) both require an applicant, when plant-unique evaluations show that some of the NUREG/CR-6260 locations do not remain within allowable limits for 60 years of plant operation when environmental effects are considered, to expand the sampling of locations beyond those listed in NUREG/CR-6260 to include other locations where high usage factors might be a concern. Lahey 2010 Declaration at ¶ 8; Hopenfeld Sept. 13, 2010 Declaration") at ¶ 21.

Statements 22-27: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statement 28: The State and Riverkeeper do not dispute the description of what Entergy did, but do object to the extent the statement seeks to characterize the content of documents that speak for themselves

Statement 29: The State and Riverkeeper object to this statement to the extent it implies that what Entergy did in 2007 *adequately* "addressed EAF effects" or that the components analyzed were all the "critical" locations required. *See* Consolidated Contention of Petitioners State of New York (No. 26/26-A) and Riverkeeper, Inc. (TC-1/TC-1-A) – Metal Fatigue," ML082400524 (filed August 21, 2008) at 3; March 5, 2008, Riverkeeper Contention TC1-A and Declaration of Dr. Joram Hopenfeld; April 7, 2008 NYS Supplemental Contention 26-A and Declaration of Dr. Richard T. Lahey; Lahey 2010 Declaration at ¶ 8 and Hopenfeld Sept. 13, 2010 Declaration at ¶ 21.

Statement 30: The State and Riverkeeper object to this statement to the extent it claims that what Entergy did in its CUF_{en} Reanalysis is "[c]onsistent with the GALL Report" because Entergy has not provided information sufficient to determine whether the calculations done by it were consistent with GALL. Lahey 2010 Declaration at ¶ 11 and Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-17, 20-23.

Statements 31-35: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statement 36: The State and Riverkeeper do not dispute that this is what Entergy has said it will do.

Statement 37: The State and Riverkeeper disagree because Entergy will use the same flawed CUF_{en} analysis it has used in its reanalysis for future calculations and this will not ensure that they will not exceed the maximum permissible limits for metal fatigue. Lahey 2010 Declaration at ¶¶ 11-14; Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-17, 23.

Statement 38: The State and Riverkeeper disagree for the reasons identified in response to Statement 37.

Statement 39: The State and Riverkeeper disagree with the statement that what Entergy is doing is "[c]onsistent with GALL" for the reasons identified in response to Statement 37.

Statement 40: The State and Riverkeeper disagree with the premise of this statement that future calculations will provide an accurate projection of places for which repair and/or replacement of components is warranted. The reasons for this disagreement are those contained in the response to Statement 37.

Statement 41: The State and Riverkeeper reiterate their general objection; the referenced documents speak for themselves.

Statement 42: The State and Riverkeeper disagree with this statement because insufficient information has been provided to know what Westinghouse did or whether it was done properly. Lahey 2010 Declaration at ¶ 11; Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-17.

Statement 43: The State and Riverkeeper do not dispute this statement except to note that it is not material to the Summary Disposition Motion.

Statements 44-49: The State and Riverkeeper dispute these statements because insufficient information has been provided to know what Westinghouse did or whether it was done properly. Lahey 2010 Declaration at ¶ 11; Hopenfeld Sept. 13, 2010 Declaration at ¶¶ 11-17.

ADDITIONAL MATERIAL FACTS IN DISPUTE

1. Entergy's LRA included two tables (4.3-13 and 4.3-14) containing values of environmentally adjusted cumulative usage factors ("CUF_{en}") for representative plant

components. Four of these values exceeded unity, indicating susceptibility to the aging effects of metal fatigue during the period of extended operation. For several of the representative components listed in these tables, Entergy did not perform a fatigue analysis to discern the value of the CUF_{en}. Hopenfeld Sept. 13, 2010 Declaration at ¶ 9.

2. The methodology employed to calculate Entergy's new CUF_{en} calculations calls into question the validity of results. While Entergy describes the general methodology employed to derive the revised calculations, many critical underlying assumptions reveal the potential for a wide margin of error. [redacted] *See* NUREG/CR-6909; EnvFat 1.0 User's Manual, Version 1.0 (May 2009), IPECPROP000567831; Environmental Fatigue Evaluation for Indian Point Unit 2, WCAP-17199-P, Revision 0 (Westinghouse, June 2010); Environmental Fatigue Evaluation for Indian Point Unit 3, WCAP-17200-P, Revision 0 (Westinghouse, June 2010)). Hopenfeld Sept. 13, 2010 Declaration at ¶ 12.

3. The F_{en} equations articulated in NUREG/CR-6909 are derived from laboratory tests on the effect of strain and coolant environments on fatigue life. In such equations, the F_{en} is expressed in terms of dissolved oxygen, temperature, sulfur content, and strain rate for several materials of interest. However, identifying the relevant terms is only the beginning of the inquiry; because significant differences exist between the laboratory and the reactor environments, there are numerous uncertainties in applying such F_{en} equations to reactor components, including flow and strain rates, loading history, mean stress, oxygen, surface finish, and water impurities. *See* NUREG/CR-6909, pg. 72 (discussing 13 uncertainties in applying Fen equations to actual reactor components); Hopenfeld Sept. 13, 2010 Declaration at ¶ 12.

4. To appropriately apply such F_{en} equations to actual reactor components, the results must be adjusted to account for the varying parameters. Entergy has presented no evidence to suggest that the methodology employed to re-calculate CUFen appropriately considered all relevant factors. In consideration of relevant uncertainties, NUREG/CR-6909 specifies appropriate bounding F_{en} values of 12 and 17 for stainless steel and carbon and low alloy steels (LAS), respectively. Entergy, however, continues to use unrealistically low F_{en} values that are not justified in light of the wide range of parameters unaccounted for. Hopenfeld Sept. 13, 2010 Declaration at ¶ 12.

5. One of the largest uncertainties in determining appropriate F_{en} values is the concentration of dissolved oxygen (DO) in the water at the surface of each component during the transient. The F_{en} varies exponentially with the DO and is, therefore, sensitive to the uncertainties in the DO concentration. Because DO has a negative solubility coefficient in water, the amount of oxygen dissolved in the coolant increases significantly during shutdown transients. Data of the Electrical Power Research Institute (EPRI) on actual oxygen concentrations in a reactor during start up and shut downs shows that oxygen concentrations vary by more than an order of magnitude with the change in temperature. *See* R&D Status Report, EPRI Journal (Jan/Feb 1983). Hopenfeld Sept. 13, 2010 Declaration at ¶ 13

6. Since DO levels are not measured at the surface of reactor components during transients, the actual DO levels, and resulting F_{en}, are subject to uncertainties. For example, an uncertainty of five in DO levels at the surface of a given component could lead to under-predicting the F_{en} by a factor of five at a minimum. [redacted]

[redacted] *See* Hopenfeld Sept. 13, 2010 Declaration at ¶ 13.

7. NRC reports specify that "the values of temperature and DO may be conservatively taken as the maximum values for the transient." *See* NUREG/CR-6583 at pg. 78. [redacted] Entergy's new metal fatigue evaluation fails to specify DO values used in the calculations of F_{en} for each component during the transients; without an understanding of the DO levels used in each transient for the calculations of F_{en}, it is impossible to conclude that the claimed CUF_{en} values, which Westinghouse and Entergy's recent refined analysis purport to predict to a ten-thousandth of a decimal point, are accurate. Hopenfeld Sept. 13, 2010 Declaration at ¶ 13.

8. Entergy's evaluation also fails to specify the heat transfer coefficients used for each component during the transients. The CUF_{en} value will vary greatly depending on the heat transfer coefficient. The heat transferred to the surface reactor components during transients controls the cyclic thermal stresses and, therefore, directly affects the CUF_{en}. The local heat transfer rate primarily depends on component geometry, flow rate, and the local temperature difference between the coolant and the surface of the component. Hopenfeld Sept. 13, 2010 Declaration at ¶ 14.

9. Heat transfer rates are calculated by multiplying an experimental heat transfer coefficient, "h", by the local temperature difference Δ T. The heat transfer coefficient has been measured for many different geometries and flow conditions and is known for well-defined conditions. The flow at the surface of reactor components, however, is not well defined during

transients and, therefore, approximations and assumptions are required in selecting the proper h for a given set of conditions. Such approximations lead to uncertainties in the CUF_{en}. Hopenfeld Sept. 13, 2010 Declaration at ¶ 14.

10. Typical variations in h could increase stress by a factor of 2. To assess the uncertainty of h, it is imperative to know the component geometry, the piping geometry upstream of the component, the flow velocities, and the corresponding expressions for h, none of which are specified in Entergy's new evaluation. Without an understanding of the values of h and the assumptions used to arrive at such values, it is impossible to conclude that Entergy's new CUF_{en} calculations are accurate to the degree Entergy now claims. Hopenfeld Sept. 13, 2010 Declaration at ¶ 14.

11. The number of transients that were used in the calculations directly affects the CUF_{en}. Because the actual number transients during the extended period of operation is not known, Entergy made certain unknown assumptions in obtaining this number. Entergy's documentation related to the newly calculated CUF_{en} values fails to describe how the number of transients was obtained or the underlying assumptions employed. Hopenfeld Sept. 13, 2010 Declaration at ¶ 15.

12. Given the large uncertainties in the input parameters and other assumptions used to generate the revised metal fatigue calculations, the methodology employed by Entergy suggests the likelihood of a wide margin of error. Accordingly, the CUF_{en} values now cited by Entergy may underestimate the detrimental effects of the environment on fatigue strength of the subject components. Notably, many of the revised calculations remain very close to unity and with a margin of error to account for varying input data and other assumptions, such numbers could be considerably higher than the 1.0 regulatory threshold. Hopenfeld Sept. 13 Declaration at

¶ 14.

13. Based on Counter Statements 1-12, Entergy's revised CUFen calculations can not be used as the basis for concluding that the aging effects of metal fatigue will be adequately managed at Indian Point during the period of extended operation. In response to CUF_{en} values in excess of regulatory limits, Entergy opted to conduct additional analyses, and update its calculations. There is little evidence to suggest that the recalculated CUFen values are accurate to the degree Entergy now claims. This fails to comply with the AMP articulated in the GALL Report, which specifies that acceptable corrective action includes "a more rigorous analysis of the component to demonstrate that the design code limit will not be exceeded during the extended period of operation." NUREG-1801 § X.Ml, Metal Fatigue of Reactor Coolant Pressure Boundary, ¶¶ 5,7. Hopenfeld Sept. 13, 2010 Declaration at ¶ 20.

14. Given Entergy's previous findings in its initial April 2007 LRA that CUF_{en} values for various components exceeded the regulatory threshold, and the questionable nature of the recently revised calculations to demonstrate that the CUF_{en} values of such components would remain under 1.0, a necessary part of an effective plan to monitor for metal fatigue is to expand the scope of the fatigue analysis beyond simply representative components, to identify other components whose CUF may be greater than 1.0. However, Entergy continues to refuse to do so. Entergy must identify additional reactor locations for potential high susceptibility to metal fatigue as noted in industry guidance document, MRP-47, Revision 1, Electric Power Research Institute, Materials Reliability Program: *Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application* at 3-4 (2005), in order to ensure that appropriate aging management measures are taken in a timely fashion. Entergy's failure to expand its fatigue analysis is inconsistent with the GALL Report AMP, which specifies that

"[f]or programs that monitor a sample of high fatigue usage locations, corrective actions include a review of *additional* affected reactor coolant pressure boundary locations," and that sample locations identified in NUREG/CR-6260 are simply the "minimum" set of components to analyze. NUREG-1801 § X.M1, Metal Fatigue of Reactor Coolant Pressure Boundary, ¶¶ 5, 7 (emphasis added). Hopenfeld Sept. 13 Declaration at ¶ 21.

15. The lack of a reliable, transparent, complete assessment of CUF_{en} values for susceptible plant components at Indian Point fails to comply with the "Scope of Program" articulated in the GALL Report, which specifies that a program for managing metal fatigue must include adequate "preventative measures to mitigate fatigue cracking of metal components of the reactor coolant pressure boundary caused by anticipated cyclic strains in the material." NUREG-1801 § X.M1, ¶ 1 (emphasis added). Hopenfeld Sept. 13, 2010 Declaration at ¶ 22.

16. Entergy's plans for correcting metal fatigue related degradation depend initially upon calculating the vulnerability of plant components. Entergy intends to rely upon future CUF_{en} calculations throughout the period of extended operation to manage metal fatigue. Entergy's calculations are meant to signify when components require inspection, monitoring, repair, or replacement, and, according to Entergy, will trigger when such actions are taken. Accordingly, the validity of Entergy's monitoring program depends upon the accuracy of the calculations of the CUF_{en}. Thus, Entergy's flawed methodology for calculating CUF_{en}, which Entergy states it intends to employ throughout the period of extended operation, as well as Entergy's refusal to expand the scope of components to be assessed, renders Entergy's vague commitments to inspect, repair, and replace affected locations insufficient to ensure proper management of metal fatigue during the license renewal term. Hopenfeld Sept. 13, 2010 Declaration at ¶ 23.

17. In light of the absence of comprehensive, accurate metal fatigue calculations to properly guide Entergy's aging management efforts, Entergy has failed to define specific criteria to assure that susceptible components are inspected, monitored, repaired, or replaced in a timely manner. Once components with high CUFs have been properly identified, Entergy must describe a fatigue management plan for each such component that should, at a minimum, rank components with respect to their consequences of failure, establish criteria for repair versus defect monitoring, and establish criteria for the frequency of the inspection (considering for example defect size changes and uncertainties in the stress analysis and instrumentation), and allow for independent and impartial reviews of scope and frequency of inspection. Hopenfeld Sept. 13, 2010 Declaration at ¶ 24.

18. In the original relicensing submittal for IP Units 2 & 3, Entergy analyzed typical limiting PWR structures and fittings using some of those given in NUREG/CR-6260 [pg. 5-62], and this analysis showed that some important structures and components will significantly exceed the environmentally-adjusted $CUF_{en} = 1.0$ criterion during the proposed extended operations period. In particular, the pressurizer surge line and nozzle (on the primary side), the reactor coolant system charging system nozzle, the steam generator main feed water nozzles and tube/tube-sheet welds (on the secondary side), and the upper joint canopy of the IP-2 control rod drive mechanisms, all had unacceptably high CUF_{en} (e.g., $CUF_{en} > 9.0$ for the IP-2 and IP-3 pressurizer surge lines and $CUF_{en} > 15$ for the IP-2 RCS charging system nozzle [LRA-Section 4]). Once CUF_{en} violations were found, Entergy was expected [NUREG-1801, Rev. 1, Vol. 2, pg. X M-2; EPRI, MRP-47; "Guidelines for Addressing Fatigue Environmental Effects in a Licensing Renewal Application," pg. 3-4 (2005)] to also do fatigue analyses for other important reactor structures and fittings. However, this was not done. Lahey 2010 Declaration at ¶ 8.

19. In order to perform more mechanistic, and presumably less conservative, fatigue evaluations, Entergy contracted with Westinghouse to redo the fatigue analyses for IP-2 and IP-3. These results were reported separately [WCAP-17199-P, "Environmental Fatigue Evaluation for Indian Point Unit 2" (June 2010) & WCAP-17200-P, "Environmental Fatigue Evaluation for Indian Point Unit 3" (June 2010)]. The calculations were done using WESTEMS, a proprietary computer code of Westinghouse; however the full documentation for this code was not provided for review. Without being able to review the WESTEMS code manuals, in which the detailed assumptions and models (particularly for the thermal-hydraulics) used by Westinghouse are presumably given, it is not possible to fully understand and critique the validity of Entergy's new CUF_{en} results. Lahey 2010 Declaration at ¶ 9.

20. The new CUF_{en} results filed with the ASLB by Entergy ["Applicant's Motion for Summary Disposition of NYS Contentions 26/26A & Riverkeeper Technical Contentions 1/1A (Metal Fatigue of Reactor Components)" (August 25, 2010)] show that the previously most limiting CUF_{en} were reduced by more than an order of magnitude (i.e., the results for the pressurizer surge line piping and RCS piping charging system nozzle), which is a significant change that must be very carefully reviewed and verified since it significantly erodes safety margins. Additionally, for the first time, limiting fatigue analysis results were given for the residual heat removal (RHR) system piping and nozzles, and the results for these components were very close to the unity limit. That is, for the IP-2 RHR line, $CUF_{en} = 0.9434$ and for the IP-3 RHR line, $CUF_{en} = 0.9961$. Thus, almost any reasonable error in these results could lead to a violation of the NRC's $CUF_{en} = 1.0$ limit. Lahey 2010 Declaration at ¶ 10.

21. An error analysis was not made available by either Entergy or Westinghouse, nor were any results provided showing that the computational results exhibited nodal convergence,

or how they were bench-marked against representative experimental data and/or analytical solutions. Normally, one would expect to see a detailed "propagation-of-error" type of analysis [e.g., Vardeman & Jobe, "Basic Engineering Data Collection and Analysis," Duxbury, pp. 310-311 (2001)] to determine the overall uncertainty in the CUF_{en} results given by Westinghouse. Indeed, all engineering analyses are based on mathematical models of reality and assumptions which inherently involve some level of error. As a consequence, without a well documented error analysis, the accuracy of Entergy's and Westinghouse's new fatigue results are quite uncertain.

22. There are many possible sources of error in these results. Specifically:

(i) [redacted]

(ii) [redacted]

[redacted]

(iii) [redacted]

(iv) [redacted]

(v) [redacted]

The accuracy of Westinghouse's new fatigue evaluations, certainly those that are close to CUF_{en} = 1.0, are quite uncertain and this uncertainty must be quantified with a detailed error analysis. Lahey 2010 Declaration at ¶ 11.

23. In-core fatigue failures of irradiated baffle-to-former bolts have been observed in operating PWRs [e.g., WCAP-14577, Rev. 1, "License Renewal Evaluation: Aging Renewal Evaluation: Aging Management of Reactor Internals," pg. 2-29 (Oct. 2000); USNRC Staff Report, "Final Safety Evaluation of by the Office of Nuclear Reactor Regulation Concerning

Westinghouse Owners Group Report, WCAP-14575, Revision 1, License Renewal Evaluation: Aging Management for Class 1 Piping and Associated Pressure Boundary Components, Project No. 686," (Nov. 8, 2000)] and B&W designed PWRs have had fatigue-induced failures of various in-core components even when CUF < 1.0 (presumably due to undetected manufacturing flaws) [Entergy Email: Esquillo to Stuard et al., Subject: " Section XI – Cracking" (8/30/06)]. The possible effect of fatigue on the failure of in-core components was apparently known to Entergy [Entergy Email: Batch to Finnin, Subject: "Need to Evaluate High Cycle Fatigue to IPEC Baffle Bolts?" (12/28/06)]. Lahey 2010 Declaration at ¶ 12.

24. Unlike postulated nuclear reactor accidents, the fatigue failures of in-core bolts are actuarial events that have happened and will likely happen again for sufficiently stressed materials. Moreover, it is not possible to inspect (e.g., using UT) all the bolts within a RPV, and the nuclear industry has recommended [EPRI Report, MRP-228; "Materials Reliability Program: Inspection Standard for PWR Internals," (July 2009)] that an analysis be done to support continued operations if bolt failures are found during in-core non-destructive evaluations (NDE). However, it appears that these analyses will not take into account the various accident-induced pressure/thermal shock loads within the RPV, such as those due to a DBA LOCA. In this regard it is important to note that, unlike for the primary piping system, in-core DBA LOCA loads were not affected by the leak-before-break (LLB) rulings of the USNRC [NUREG/CR-4572; NUREG/CR-1061, Vol. 3; 10 C.R.F. Part 50, Appendix-A]. Doing an adequate safety analysis is important since further shock-load-induced bolting failures may lead to a blocked or distorted core geometry which, in turn, may not allow the ability to cool the core and can lead to core melting. Lahey 2010 Declaration at ¶ 12.

25. Like all mechanical systems, as nuclear power plants exceed their original design

life (i.e., 40 years) they begin to wear out and thus, to assure safe operation during plant life extension, it is important not to erode the original design-basis safety factors in the interest of keeping the plants running. In particular, in addition to bolting fatigue failure concerns, many other highly irradiated in-core structures and fittings (e.g., core baffles, formers, etc.) will be subjected to some of the same (and even more) fatigue-inducing transients as those which effect the components that are external to the RPV (e.g., those that were analyzed by Westinghouse). Lahey 2101 Declaration at ¶ 13.

26. No fatigue analysis of the in-core components identified in the preceding Paragraph was done or provided and there was apparently no recognition of the importance of DBA LOCA, secondary side LOCA and ATWS loads on the integrity of these structures. As for in-core bolting, not doing a proper fatigue and safety analysis of these in-core structures and fittings is completely unacceptable since the shock-load-induced failure of in-core components may lead to a distorted core geometry, which may, in turn, not allow the ability to cool the core and result in core melting. Lahey 2010 Declaration at ¶ 13.

27. The revised fatigue analyses done by Westinghouse for Entergy are not sufficient to allow the closure of Commitment-33 for IP-2 & IP-3. That is, while a re-analysis of fatigue was performed for Entergy by Westinghouse, it was not possible to thoroughly review the details of the models and assumptions used in these fatigue evaluations and there was no accompanying error analysis. Thus, the accuracy and uncertainty of these calculations (several of which were very close to $CUF_{en} = 1.0$) is unclear. Moreover, there were no fatigue evaluations done for various important irradiated and embrittled structures and fittings within the RPV, nor were there any analyses presented showing the effect of various thermal/pressure shock loads on the limiting fatigued structures both within and outside the RPV. Thus, without a more complete

fatigue and safety analysis (including a detailed error analysis) there is no valid technical basis on which to claim that the aging phenomena associated with metal fatigue has been adequately addressed by Entergy. Lahey 2010 Declaration at ¶ 14.

Respectfully submitted,

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Dated: September 14, 2010

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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In re:	Docket Nos. 50-247LR and 50-286LR
License Renewal Application Submitted By	ASLB No. 07-858-03-LR-BD01
Entergy Indian Point 2, LLC, Entergy Indian Point 3, LLC, and Entergy Nuclear Operations, Inc.	DPR-26, DPR-64
--x	

DECLARATION OF JANICE A. DEAN

I, Janice A. Dean, declare under penalty of perjury that the following is true and correct:

1. On or about August 18, I contacted Paul Bessette, counsel for Entergy, to request the WESTEMS computer code manual. Mr. Bessette indicated that he would inquire with his client about it.

2. On or about August 23, Riverkeeper counsel Deborah Brancato and I called Mr. Bessette to request Westinghouse's error analysis. Mr. Bessette said his request for the WESTEMS computer code manual was pending but that he did not have an "ETA" or expected time of arrival for it, but he expressed his opinion that production of the error analysis would constitute unauthorized discovery.

3. On August 25, Mr. Bessette, Riverkeeper counsel Phillip Musegaas, and I spoke in the context of Mr. Bessette's consultation for Entergy's summary disposition motion; during that call Mr. Bessette reiterated that Westinghouse was considering the State's request for the computer code manual but that Mr. Bessette did not intend to ask his client for the error analysis the State and Riverkeeper requested because in his view to provide the analysis would constitute unauthorized discovery.

4. On September 1, 2010, Mr. Bessette and I spoke again and Mr. Bessette indicated that he intended to provide the State with an excerpt of the computer code manual by Friday, September 3, which would include the portions of the manual which Westinghouse deemed relevant. Mr. Bessette indicated that Entergy had not changed its position on the error analysis.

5. On Friday, September 3, Entergy provided the State and Riverkeeper with an excerpt from the WESTEMS computer manual (which, as discussed in their declarations, the State's expert Dr. Richard Lahey and Riverkeeper's expert Dr. Joram Hopenfeld view as inadequate because the excerpt does not discuss the thermal-hydraulics models employed in the WESTEMS code and because of other missing information. *See* Declaration of Dr. Richard Lahey (Sept. 8, 2010), n.3, and Declaration of Joram Hopenfeld (Sept. 13, 2010) at ¶¶ 12-16).

6. To date Entergy has not provided the State with an error analysis.

Pursuant to 28 U.S.C. § 1746, I declare under penalty of perjury that the foregoing is true and correct.

Executed on

September 13, 2010
New York, New York

Janice A. Dean
Janice A. Dean

UNITED STATES
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In re:	Docket Nos. 50-247-LR; 50-286-LR
License Renewal Application Submitted by	ASLBP No. 07-858-03-LR-BD01
Entergy Nuclear Indian Point 2, LLC, Entergy Nuclear Indian Point 3, LLC, and Entergy Nuclear Operations, Inc.	DPR-26, DPR-64
	September 9, 2010

The State of New York provisionally designates

the attached Declaration of Dr. Richard T. Lahey

dated September 8, 2010 as containing

Confidential Proprietary Information

Subject to Nondisclosure Agreement

REDACTED, PUBLIC VERSION

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In re:	Docket Nos. 50-247LR and 50-286LR
License Renewal Application Submitted By	ASLB No. 07-858-03-LR-BD01
Entergy Indian Point 2, LLC, Entergy Indian Point 3, LLC, and Entergy Nuclear Operations, Inc.	DPR-26, DPR-64

DECLARATION OF DR. RICHARD T. LAHEY, JR.

I, Richard T. Lahey, Jr., declare under penalty of perjury that the following is true and correct:

1. I am the *Edward E. Hood Professor Emeritus of Engineering* at Rensselaer Polytechnic Institute (RPI) in Troy, New York, a member of the National Academy of Engineering (NAE), a Fellow of the American Nuclear Society (ANS) and the American Society of Mechanical Engineers (ASME), and an expert in matters relating to the operations, safety, and the aging of nuclear power plants. I have previously submitted a declaration in support of the Notice of Intention to Participate and Petition to Intervene filed by the State of New York in this proceeding on November 30, 2007, which sets forth my qualifications in detail and is incorporated by reference.[1] By way of summary, I have held various positions in

[1] I also submitted a declaration in support of the State of New York's Supplemental Contention 26-A dated April 7, 2008, which is also incorporated by reference.

the nuclear industry and academia, and served on numerous panels and committees for the U.S. Nuclear Regulatory Commission (USNRC), Idaho National Engineering Laboratory (INEL), Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI), and the National Academy of Science (NAS). I have also held various positions in the nuclear industry and academia, including Dean of Engineering and Chair of the Department of Nuclear Engineering & Science at RPI, and was lead engineer and manager of various departments responsible for heat transfer mechanisms and core and safety development for the General Electric Company (GE). Over the last 40 years, I have also published numerous books, monographs, chapters, articles, studies, reports, and journal papers on nuclear engineering and nuclear reactor safety technology, and most of these publications have been peer reviewed. My *curricula vitae,* which more fully describes my educational and professional background and qualifications, is attached to this declaration and is available at: http://www.rpi.edu/~laheyr/laheyvita.html.

2. The factual statements and the expression of opinion in this declaration are based on, among other things, my best professional knowledge, my extensive professional experience in nuclear reactor technology, and my review of Entergy's Submittal Regarding the Completion of Commitment-33 for Indian Point Units 2 and 3 (Aug. 10, 2010)("Environmental Fatigue Evaluations") that conveyed Entergy's NL-10-082 communication to NRC Staff, two Westinghouse Electric Company LLC environmental fatigue evaluations of Indian Point Unit 2 and Indian Point Unit 3 (received by the State on August 12, 2010), the Applicant's Motion for

Summary Disposition of New York State Contentions 26/26A and Riverkeeper Technical Contentions 1/1A (Metal Fatigue of Reactor Components)(Aug. 25, 2010), and other documents referenced in this declaration. This new declaration is based on, and expands upon, many of the concerns that I raised in my prior ASLB testimony concerning metal fatigue associated with the relicensing of Indian Point reactors Units 2 & 3 (or IP-2 & 3).

3. As I stated in my initial declaration on this issue in support of the State of New York's Contention 26, in my professional judgment, the applicant failed to demonstrate that it had adequately accounted for the aging phenomena of metal fatigue in Indian Point Unit 2 and Unit 3. My professional judgment has not fundamentally changed based upon Entergy's August 10, 2010 submission of their new Environmental Fatigue Evaluations.

4. Entergy's Indian Point Units 2 & 3 are currently under consideration for 20-year life extensions beyond their original 40-year design life. If approved, these plants will be licensed for operational levels of about 48 effective full power years (EFPY). These Westinghouse (W) designed plants are 4 loop PWRs currently[2] rated at 3,216.4 MW_t. They are sited on the Hudson River in Buchanan, NY, which is about 24 miles north of the New York City (NYC) border. Because of their close proximity to a very highly populated area (*i.e.*, NYC metropolitan area), which is also the world's leading financial center, it is vital that IP Units 2 & 3 fully and

[2] The USNRC approved a stretch power increase of 3.26% for IP-2 in 2004 and a 4.85% increase for IP-3 in 2005; IP-2 and IP-3 also received 1.4% power uprates in 2003 and 2002, respectively.

unambiguously meet all reasonable and applicable criteria for safe operation. This is particularly true when considering life extension, since fatigue failures are much more likely as the plants age.

5. The standard review plan of the USNRC for the license renewal applications of nuclear power plants is given in NUREG-1800, Rev. 1 (Standard Review Plan). This plan is a highly prescriptive process which allows little opportunity for the discovery of any new age-related safety concerns. However, I believe that all important safety concerns must be addressed to assure the health and safety of the American public during extended plant operations. The NRC Staff have also prepared a guidance document entitled the "Generic Aging Lessons Learned (GALL) Report," NUREG-1801, Rev. 1, in which Staff seeks to describe Aging Management Programs (AMP) for the extended operations of nuclear power plants. In the case of fatigue, Entergy has now submitted further environmental fatigue evaluations for both Indian Point Unit 2 and Unit 3, which were prepared by Westinghouse, and has thus elected to try and close out metal fatigue issues during the ASLB relicensing hearings. Unfortunately, as will be discussed subsequently, their new fatigue analyses are incomplete, inadequate and unacceptable.

6. While the USNRC's review process is fairly comprehensive, it fails to consider some very important age-related safety issues associated with the extended operation of a pressurized water nuclear reactor (PWR) power plant. For example, the fatigue of various highly irradiated (and embrittled) structures and

fittings within the reactor pressure vessels (RPV) due to operational and abnormal transients (*e.g.*, SCRAMs). In addition, the impact of thermal and pressure shock loads on the fatigue-weakened structures and fittings both outside and inside the RPV. Typical shock loads include those associated with the plant's design basis accident (DBA) loss of coolant accident (LOCA), various secondary side LOCAs and anticipated transients without SCRAM (ATWS) events. In my opinion this is an extremely serious deficiency in the USNRC's standard review plan for plant life extension as well as Entergy's aging management plan (AMP).

7. Fatigue is a very important age-related safety concern, particularly when plant life extension is being considered. In fact, it is one of the primary things that must be considered when doing a time-limited aging analysis (TLAA) or developing an aging management program for the extended operation of a power reactor. A common figure of merit used in the American Society of Mechanical Engineers (ASME) code [Section-III] to appraise the possibility of fatigue failure is the cumulative usage factor (CUF), which is the ratio of the number of cycles experienced divided by the number of allowable cycles. The maximum number of cycles which can be experienced by a structure or component before cracking is expected occurs when CUF = 1.0, and one should have CUF < 1.0 during the period of plant operation. In addition, since the high pressure/temperature primary coolant is known [*e.g.*, NUREG/CR-6909] to degrade the fatigue life of immersed metal structures and components, the USNRC also requires that environmental corrections be applied to the calculated CUF, and it specifies formulas/curves to be

used for these corrections [*e.g.*, NUREG/CR-5704; NUREG/CR-6583]. Moreover, the environmentally-adjusted fatigue analyses must satisfy $CUF_{en} < 1.0$ during extended plant operations.

8. In the original relicensing submittal for IP Units 2 & 3, Entergy analyzed typical limiting PWR structures and fittings using some of those given in NUREG/CR-6260 [pg. 5-62], and this analysis showed that some important structures and components will significantly exceed the environmentally-adjusted $CUF_{en} = 1.0$ criterion during the proposed extended operations period. In particular, the pressurizer surge line and nozzle (on the primary side), the reactor coolant system charging system nozzle, the steam generator main feed water nozzles and tube/tube-sheet welds (on the secondary side), and the upper joint canopy of the IP-2 control rod drive mechanisms, all had unacceptably high CUF_{en} (*e.g.*, $CUF_{en} > 9.0$ for the IP-2 and IP-3 pressurizer surge lines and $CUF_{en} > 15$ for the IP-2 RCS charging system nozzle [LRA-Section 4]). In my opinion, if these results can not be conclusively shown to be invalid by doing more detailed fatigue analyses, the deficient components should be replaced/repaired <u>prior</u> to extended operations; indeed, it would be the only responsible thing to do since the last thing one wants is to induce a primary or secondary side LOCA due to a fatigue failure. In any event, once CUF_{en} violations are found Entergy was expected [NUREG-1801, Rev. 1, Vol. 2, pg. X M-2; EPRI, MRP-47; "Guidelines for Addressing Fatigue Environmental Effects in a Licensing Renewal Application," pg. 3-4 (2005)] to also

do fatigue analyses for other important reactor structures and fittings. However, this was not done.

9. Anyway, in order to perform more mechanistic, and presumably less conservative, fatigue evaluations, Entergy contracted with Westinghouse (W) to redo the fatigue analyses for IP-2 and IP-3. These results were reported separately [WCAP-17199-P, "Environmental Fatigue Evaluation for Indian Point Unit 2" (June 2010) & WCAP-17200-P, "Environmental Fatigue Evaluation for Indian Point Unit 3" (June 2010)]. The calculations were done using WESTEMS, a proprietary computer code of W; however the full documentation for this code was not provided to me for review.[3] Without being able to review the WESTEMS code manuals, in which the detailed assumptions and models (particularly for the thermal-hydraulics) used by W are presumably given, it is not possible to fully understand and critique the validity of Entergy's new CUF_{en} results.

10. The new CUF_{en} results filed with the ASLB by Entergy ["Applicant's Motion for Summary Disposition of NYS Contentions 26/26A & Riverkeeper Technical Contentions 1/1A (Metal Fatigue of Reactor Components)" (August 25, 2010)] show that the previously most limiting CUF_{en} were reduced by more than an order of magnitude (*i.e.*, the results for the pressurizer surge line piping and RCS piping charging system nozzle), which is an astonishing change, and one that must

[3] Two brief proprietary excerpts of the WESTEMS computer code manual were provided to the State of New York on Friday evening, September 3, 2010. I reviewed these brief excerpts, but they did not shed light on the thermal-hydraulics models employed in the WESTEMS code.

be very carefully reviewed and verified since it significantly erodes safety margin. Additionally, for the first time, limiting fatigue analysis results were given for the residual heat removal (RHR) system piping and nozzles, and the results for these components were <u>very close</u> to the unity limit. That is, for the IP-2 RHR line, CUF_{en} = **0.9434** and for the IP-3 RHR line, CUF_{en} = **0.9961**. Thus, almost any reasonable error in these results could lead to a violation of the USNRC's CUF_{en} = 1.0 limit.

11. Unfortunately an error analysis was not made available by either Entergy or Westinghouse, nor were any results provided showing that the computational results exhibited nodal convergence, or how they were bench-marked against representative experimental data and/or analytical solutions. Normally, one would expect to see a detailed "propagation-of-error" type of analysis [*e.g.*, Vardeman & Jobe, "Basic Engineering Data Collection and Analysis," Duxbury, pp. 310-311 (2001)] to determine the overall uncertainty in the CUF_{en} results given by W. Indeed, all engineering analyses are based on mathematical models of reality and assumptions which inherently involve some level of error. As a consequence, without a well documented error analysis, the accuracy of Entergy's and Westinghouse's new fatigue results are quite uncertain. What is clear, however, is that there are many possible sources of error in these results. *For example*:

(i) [redacted]

[redacted]

(ii) [redacted]

(iii) [redacted]

(iv) [redacted]

(v) [redacted]

In any event, in my opinion, the accuracy of W's new fatigue evaluations, certainly those that are close to CUFen = 1.0, are quite uncertain and this uncertainty must be quantified with a detailed error analysis.

12. It is also significant to note that in-core fatigue failures of irradiated baffle-to-former bolts have been observed in operating PWRs [*e.g.*, WCAP-14577, Rev. 1, "License Renewal Evaluation: Aging Renewal Evaluation: Aging Management of Reactor Internals," pg. 2-29 (Oct. 2000); USNRC Staff Report, "Final Safety Evaluation of by the Office of Nuclear Reactor Regulation Concerning Westinghouse Owners Group Report, WCAP-14575, Revision 1, License Renewal Evaluation: Aging Management for Class 1 Piping and Associated Pressure Boundary Components, Project No. 686," (Nov. 8, 2000)] and B&W designed PWRs have had fatigue-induced failures of various in-core components even when CUF <

1.0 (presumably due to undetected manufacturing flaws) [Entergy Email: Esquillo to Stuard et al., Subject: " Section XI – Cracking" (8/30/06)]. Moreover, the possible effect of fatigue on the failure of in-core components was apparently known to Entergy [Entergy Email: Batch to Finnin, Subject: "Need to Evaluate High Cycle Fatigue to IPEC Baffle Bolts?" (12/28/06)]. Unlike postulated nuclear reactor accidents, the fatigue failures of in-core bolts are actuarial events that have happened and will likely happen again for sufficiently stressed materials. Moreover, it is not possible to inspect (*e.g.*, using UT) all the bolts within a RPV, and the nuclear industry has recommended [EPRI Report, MRP-228; "Materials Reliability Program: Inspection Standard for PWR Internals," (July 2009)] that an analysis be done to support continued operations if bolt failures are found during in-core non-destructive evaluations (NDE). However, it appears that these analyses will not take into account the various accident-induced pressure/thermal shock loads within the RPV, such as those due to a DBA LOCA. In this regard it is important to note that, unlike for the primary piping system, in-core DBA LOCA loads were not affected by the leak-before-break (LLB) rulings of the USNRC [NUREG/CR-4572; NUREG/CR-1061, Vol. 3; 10 C.R.F. Part 50, Appendix-A]. In any event, I believe that not doing an adequate safety analysis is totally unacceptable since further shock-load-induced bolting failures may lead to a blocked or distorted core geometry which, in turn, may not allow the ability to cool the core and can lead to core melting.

13. Like all mechanical systems, as nuclear power plants exceed their original design life (*i.e.*, 40 years) they begin to wear out and thus, to assure safe operation during plant life extension, it is important not to erode the original design-basis safety factors in the interest of keeping the plants running. In particular, in addition to the previously discussed bolting fatigue failure concerns, many other highly irradiated in-core structures and fittings (*e.g.*, core baffles, formers, etc.) will be subjected to some of the same (and even more) fatigue-inducing transients as those which effect the components that are external to the RPV (*e.g.*, those that were analyzed by W). However, no fatigue analysis of these important in-core components was done or provided and there was apparently no recognition of the importance of DBA LOCA, secondary side LOCA and ATWS loads on the integrity of these structures. As for in-core bolting, I believe that not doing a proper fatigue and safety analysis of these in-core structures and fittings is completely unacceptable since the shock-load-induced failure of in-core components may lead to a distorted core geometry, which may, in turn, not allow the ability to cool the core and result in core melting.

14. In summary, there are important age-related safety issues associated with the operation of IP Units 2 & 3 during a proposed 20-year life extension. In particular, there is a need to properly analyze and/or replace/repair components and structures which may reach or exceed their fatigue life prior to the end of extended plant operations. In my opinion, the revised fatigue analyses done by W for Entergy are not sufficient to allow the closure of Commitent-33 for IP-2 & IP-3. That is,

while a re-analysis of fatigue was performed for Entergy by W, it was not possible to thoroughly review the details of the models and assumptions used in these fatigue evaluations and there was no accompanying error analysis. Thus, the accuracy and uncertainty of these calculations (several of which were very close to $CUF_{en} = 1.0$) is unclear. Moreover, there were no fatigue evaluations done for various important irradiated and embrittled structures and fittings within the RPV, nor were was there any analyses presented showing the effect of various thermal/pressure shock loads on the limiting fatigued structures both within and outside the RPV. Thus, without a more complete fatigue and safety analysis (including a detailed error analysis) there is no valid technical basis on which to claim that the aging phenomena associated with metal fatigue has been adequately addressed by Entergy.

Pursuant to 28 U.S.C. § 1746, I declare under penalty of perjury that the foregoing is true and correct.

September 8, 2010
Troy, New York

R. T. Lahey

Dr. Richard T. Lahey, Jr.

Referenced Documents

American Society of Mechanical Engineers (ASME) code, Section-III

Cengel & Turner, "Fundamentals of Thermal-Fluid Sciences," McGraw-Hill, (2001)

Electric Power Research Institute (EPRI), MRP-47; "Guidelines for Addressing Fatigue Environmental Effects in a Licensing Renewal Application," (2005)

Electric Power Research Institute (EPRI) Report, MRP-228; "Materials Reliability Program: Inspection Standard for PWR Internals," (July 2009)

Entergy, License Renewal Application, Section 4

Entergy, License Renewal Application, Amendment 2

Entergy's Submittal Regarding the Completion of Commitment-33 for Indian Point Units 2 and 3 (Aug. 10, 2010),

> *conveying* Entergy's NL-10-082 communication to NRC Staff (Aug. 9, 2010)

Entergy's Motion for Summary Disposition of New York State Contentions 26/26A and Riverkeeper Technical Contentions 1/1A (Metal Fatigue of Reactor Components)(Aug. 25, 2010)

Entergy Email: Esquillo to Stuard et al., Subject: "Section XI – Cracking" (8/30/06) and email string:

> Friday; June 16, 2006; 10:25 AM; From: Mark A. Rinckel; To: Ron Finnin; Cc: acox@entergy.com, Michael D. Stroud, Virglio M. Esquillo, and Stan Batch; Subject: Section XI—Cracking

> Wednesday; August 30, 2006; 9:33 AM; From: Virgilio M. Esquilla; To: William L. Stuard, Mark L. Warren, Carole L. Naugle, and Kenneth R. Allison; Subject: FW: Section XI—Cracking

> Friday; December 8, 2006; 9:16 AM; From: Kenneth R. Allison; To: William L. Stuard; Subject: FW: Section XI--Cracking; Attach: Section XI-Standards.pdf

Entergy Email: Batch to Finnin, Subject: "Need to Evaluate High Cycle Fatigue to IPEC Baffle Bolts?" (12/28/06) and email string :

Friday; December 28, 2006; 1:58 PM; From: Stan Batch; To: Ron Finnin; Cc: Don Fronabarger, Ted S. Ivy; Subject: need to evaluate high cycle fatigue for IPEC baffle bolts?

Friday; January 12, 2007; 10:14 AM; From: Stan Batch; To: Walter Wittich and Nelson F. Azevedo; Cc: Ron Finnin and Don Fronabarger; Subject: need to evaluate high cycle fatigue for IPEC baffle bolts?

Kreith, "Principles of Heat Transfer," *Int. Text Book Co.*, (1961)

Lahey, R. T., Declaration in Support of Notice of Intention to Participate and Petition to Intervene filed by the State of New York in Indian Point license renewal proceeding on November 30, 2007

Lahey, R. T., Declaration in support of the State of New York's Supplemental Contention 26-A in Indian Point license renewal proceeding, dated April 7, 2008

NRC Staff, Standard Review Plan, NUREG-1800, Rev. 1 (2005)

NRC Staff, Generic Aging Lessons Learned (GALL) Report, NUREG-1801, Rev. 1 (2005)

NRC Staff Report, "Final Safety Evaluation of by the Office of Nuclear Reactor Regulation Concerning Westinghouse Owners Group Report, WCAP-14575, Revision 1, License Renewal Evaluation: Aging Management for Class 1 Piping and Associated Pressure Boundary Components, Project No. 686," (Nov. 8, 2000)

NUREG/CR-6909

NUREG/CR-5704

NUREG/CR-6583

NUREG/CR-6260

NUREG/CR-4572

NUREG/CR-1061, Vol. 3

Westinghouse, WCAP-17149-P, Rev. 1, “Evaluation of Pressurizer Insurge/Outsurge Transients for Indian Point Unit 2,” IPECPROP00056663 (July 2010)

Westinghouse, WCAP-17162-P, Rev. 1, “Evaluation of Pressurizer Insurge/Outsurge Transients for Indian Point Unit 3,” IPECPROP00056717 (July 2010)

Westinghouse, WCAP-17199-P, “Environmental Fatigue Evaluation for Indian Point Unit 2,” (June 2010)

Westinghouse, WCAP-17200-P, “Environmental Fatigue Evaluation for Indian Point Unit 3,” (June 2010)

Westinghouse, WCAP-14577, Rev. 1, "License Renewal Evaluation: Aging Renewal Evaluation: Aging Management of Reactor Internals," (Oct. 2000)

Westinghouse, WESTEMS computer code manual (brief excerpts)

Vardeman & Jobe, “Basic Engineering Data Collection and Analysis,” Duxbury, (2001)

Attachment

curricula vitae

Richard T. Lahey, Jr., Ph.D.

VITA

Dr. Richard T. Lahey, Jr.

The Edward E. Hood Professor Emeritus of Engineering

Rensselaer Polytechnic Institute

Troy, New York

Education

B.S. Marine Engineering-1961, U.S. Merchant Marine Academy
M.S. Mechanical Engineering-1964, Rensselaer (RPI)
M.E. Engineering Mechanics-1966, Columbia University
Ph.D. Mechanical Engineering-1971, Stanford University

Professional Experience

7/61 - 9/61 Cities Service Company, New York, New York

Third Assistant Engineer - Operating Engineer on "jumbo" tanker, S/S Fort Hoskins also had responsibility for maintenance of all electrical equipment.

9/61 - 8/64 Knolls Atomic Power Laboratory, Schenectady, NY

Engineer - Various assignments on advanced naval nuclear submarine (S5G) design.
Thermal Development Group - Experimental work on DNB and hydrodynamic instability.
Fluid Systems Group - Systems design and documentation.
Safety Analysis Group - Analytical investigation of hypothetical accident conditions development of analog and digital computer models.

9/64 - 6/66 Columbia University, New York, New York

Research Assistant - University research in the area of biomechanics (blood flow, pulmonary mechanics, etc.)

8/61 - 8/67 U.S. Navy

Naval Officer - USNR

7/66 - 6/71 General Electric, San Jose, California

Principal Development Engineer - Responsible for experimental and analytical investigations in two-phase flow and boiling heat transfer phenomena, including: hydrodynamic stability, subchannel analysis, CHF and Pressure drop.

6/71 - 6/72 General Electric Company, San Jose, California

Manager, Heat Transfer Mechanisms - Responsible for applied research in the are of subchannel analysis, transient analysis and detailed Boiling Water Nuclear Reactor (BWR) heat transfer mechanisms.

6/72 - 11/73 General Electric Company, San Jose, California

Manager, Core Development - Responsible for all non-safety related thermal-hydraulic development work in support of the boiling water nuclear reactor.

11/73 - 10/75 General Electric Company, San Jose, California

Manager, Core and Safety Development - Responsible for all heat transfer and fluid flow and reactor physics development work in support of the boiling water nuclear reactor. Responsible for all foreign and domestic safety R&D programs.

10/75 - 6/87 Rensselaer Polytechnic Institute, Troy, New York

Chairman, Department of Nuclear Engineering & Science - Teaching, research and management of academic department concerned with nuclear technology.

5/87 - 4/89 Rensselaer Polytechnic Institute, Troy, New York

Professor, Department of Nuclear Engineering and Engineering Physics, and, Professor, Department of Chemical Engineering - University teaching and research.

4/89 - Present, Rensselaer Polytechnic Institute, Troy, New York

The Edward E. Hood, Jr. Professor of Engineering (4/89-9/08 ;**Emeritus** 9/08-Present), Department of Mechanical, Aerospace & Nuclear Engineering and, Chemical Engineering - University teaching and research.

5/91 - 6/94 Rensselaer Polytechnic Institute, Troy, New York

Director, Center for Multiphase Research - University teaching, research and administration.

7/94 - 3/98 Rensselaer Polytechnic Institute, Troy, New York

Dean of Engineering - Academic administration and research.

Consulting

Argonne National Laboratory

Long Island Lighting Company

Battelle Northwest Laboratories
Brookhaven National Laboratory
Babcock & Wilcox Company
Combustion Engineering (ABB)
Corning, Inc
Creare, Inc.
EG&G Idaho, Inc. (INEL)
Electric Power Research Institute
Exxon Nuclear Company, Inc.
General Electric
General Public Utilities
International Atomic Energy Agency
Air Products

NYS-DEC ; NYS- OAG

Norhtrop Grumman

Nuclear Associates International
Oak Ridge National Laboratory
PJM Interconnection(***Board Member***)
Sandia Laboratories
Savannah River Laboratory
Singer Link-Miles
Stauffer Chemical Company
Stone & Webster
U.S. Department of Energy
U.S. Nuclear Regulatory Commission
Westinghouse (NED)
Yankee Atomic Electric Company

Jason Associates

NYC (Couch White , LLP)

Professional Memberships and Technical Review Groups

American Nuclear Society (ANS)

President, Northeastern New York Section (78-79)

Member, Board of Directors (79-82)

Member, ANS Executive Committee (80-82)

Member, Executive Committee - Power Division (79-82)

Chairman, Technical Group for Thermal-Hydraulics (79-80)

Member, Executive Committee - Thermal-Hydraulics (80-81)

Member, E.E.&A. Accreditation Committee (84-87)

Member, NHTC Coordinating Committee (86-89)

Member, ANS Nominating Committee (86)

American Society of Mechanical Engineers (ASME)

Nucleonics Heat Transfer Committee (ASME K-13)

Chairman (78-81)

American Society of Engineering Education (ASEE)

Chairman, Program Committee (86-87)

Chairman, Nuclear Engineering Division (87-88)

American Institute of Chemical Engineers (AIChE)

Chairman, Energy Transport Field Research Committee (87-91)

Association of Engineering Colleges in New York State (AECNYS)

Secretary/Treasurer (96)

ECPD Council

ASME Representative, (76-79)

Engineering Manpower Commission (EMC)

Commissioner (81-84)

Council on Competitiveness

Member (94-98)

Nuclear Engineering Department Heads Organization (NEDHO)

Chairman (82-83)

Liaison with USNRC and USDOE (82-87)

International Center for Multiphase Flow - Japan

Corresponding Member (USA)

The New York Academy of Sciences (NYAS)

Member (90-09)

Society of the Sigma Xi

Member (70-Present)

Editorial Boards

Journal of Nuclear Engineering & Design (Formerly Editor -NE&D , 83-94)

International Journal of Heat & Mass Transfer

International Communications in Heat & Mass Transfer

Journal of Multiphase Science & Technology

Nuclear Safety Review Board (RPI)

Chairman (76-87)

EG&G Scientific Advisory Committee

Member (76-83)

Review Group Membership

USNRC Advanced Code Review Group (76-84)

USNRC Two-Phase Instrumentation Review Group (76-84)

USNRC Containment Code Review Group (77-84)

USNRC Two-Phase Flow Calibration Review Group (78-84)

USNRC LOFT Review Group (77-83)

USNRC EBTF Research Review Group (79-82)

USNRC 2D/3D Review Group (79-84)

USNRC BWR BDHT Review Group (79-84)

EPRI Design Review Committee Member for MAAP Code (88-93)

EPRI Design Review Committee Member for BWRSAR Code (88-90)

LILCO Peer Review Committee Member (88-92)

USDOE Savannah River Laboratory (SRL) Review Group Member (88-92)

USDOE Advanced Neutron Source (ANS) Review Panel (88-92)

ORNL Engineering Technology Division Advisory Committee - Chairman (89-92)

ORNL Advanced Neutron Source (ANS) Reactor Advisory Committee - Chairman (92-93)

ORNL CASL Science Council - Member (2010 - Present)

National Association of Corporate Directors (NACD) - Member (97-Present)

National Academy Activities

Member, National Research Council (NRC) -Space Science Boards Committee on Microgravity Research (1997-2008)

Member, National Research Council (NRC) Study on: "Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies" (1998-2000).

Member, National Research Council (NRC)I Study on: "The Safety and Security of Commercial Spent Fuel Storage" (2004 - 2006).

Member, National Research Council (NRC) Decadal Study on: "Biological and Physical Sciences in Space" (2009 - 2010).

Honors

- Elected Fellow of ANS (1980)
- Elected Life Fellow of ASME (1980)
- Elected ***National Academy of Engineering*** (1994)
- Elected ***Russian National Academy of Sciences-Baskortostan*** (1995)
- Graduated (with Honors) - USMMA (1961)
- Nominated: G.E.s Steinmetz Award (1975)
- Whos Who in Engineering
- Whos Who in the East
- International Whos Who in Energy & Nuclear Sciences
- Whos Who in Technology Today
- American Men & Women of Science (17^{th} Edition)
- The International Whos Who of Intellectuals (Vol. VI)
- *Fulbright-Hays* Fellowship (1983-1984)
- Elected Senior Fellow-Magdalen College of Oxford University (1983-1984)
- Keynote Lecture, 5^{th} Indian Heat & Mass Transfer Conference, Hyderabad, India (1980)
- Editor, ***Journal of Nuclear Engineering and Design***, (1983-1994)
- Appointed IAEA Expert to Assist Argentina in Nuclear Power Research (1985-Present)
- Keynote Lecturer, International Workshop on Two-Phase Flow Fundamentals, NBS, Gaithersburg, MD (1985)
- People-to-People Delegation Leader to the PRC on Nuclear Reactor Safety (11/4-25/85)
- Keynote Lecture, 4^{th} International Symposium on Multi-Phase Transport & Particulate Phenomena - Miami, Florida (1986)
- Keynote Lecturer, International Centre for Heat and Mass Transfer, Dubrovnik, Yugoslavia (1987)
- Chairman, DOE/EPRI Second International Workshop on Two-Phase Flow Fundamentals (3/87)
- Visiting Professor, University of Pisa, Pisa, Italy (1987)
- Visiting Professor , Universite Claude Bernarde, Lyon, France (1987)
- Appointed External Dissertation Reviewer - Univeriti Malaya (1987)
- Visiting Professor of Engineering , Centro Atomico, Bariloche, Argentina (1988)
- Keynote Lecture, Japan Society of Multiphase Flow - Tokyo, Japan (1988)

- Appointed Honorary Senior Fellow - Magdalen College of Oxford University (1989-Present)
- Elected Chairman of RPI Faculty Council (1989-1991)
- Japan Society for the Promotion of Science (JSPS) Fellowship (1990)
- Keynote Lecture, American Society of Mechanical Engineers, Dallas, TX (1990)
- Alpha Nu Sigma Honor Society (1992)
- Plenary Lecturer, International Symposium on Instabilities in Multiphase Flows - Rouen, France (5/92)
- Member, Editorial Advisory Board - ***International Journal of Heat and Mass Transfer***
- Member, Editorial Advisory Board - ***International Communications in Heat and Mass Transfer***
- U.S. Representative, International Information Center for Multiphase Flow (ICeM)
- Mark S. Mills Award of the ANS [Advisee: Susana Kalkach-Navarro] (1993)
- Elected Member of RPI Engineering Research Council (1993-1994)
- General Chairman, International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-7), Sept. 10-15, 1995
- Member, Advisory Editorial Board - ***Heat Transfer Research***
- Keynote Lecture, MFTP-2000, Antalya, Turkey (2000)
- Member, Presidium, ICMS-2000, UfA, Russia (2000)
- Listed as an Expert Knowledge Provider , Intota web site, *www.intota.com* (2001)
- Keynote Lecture , HEAT-2002 , Kielce,Poland (2002)
- Member - Engineering Advisory Board , U.S. Merchant Marine Academy (2003-2005)
- Elected to Palmer C. Ricketts Society of Patroons - RPI (2004-present)
- Co-Chair , Japan/US Seminar on Two-Phase Flow Dynamics , Nagahama, Japan (2004)
- Plenary Lecture , PISA' 04 , Pisa , Italy (2004)
- Keynote Lecture , Yadigaroglu Retirement Seminar , ETH-Zurich , Zurich, Switzerland (2004)
- Keynote Lecture, ISMF' 05, Xi'an , China (2005)
- Keynote Lecture, NURETH-11 , Avignon, France (2005)
- ***Alexander von Humbolt*** Senior Scientist Fellowship-FZK (2005-2006)
- Keynote Lecture , NURETH-12 , Pittsburgh , PA. (2007)

Awards

- Meritorious Service Award of the ANS (1983)
- **Glenn Murphy Award** of the ASEE (1985)
- Technical Achievement Award of the ANS (1985)
- United States Merchant Marine Academy Alumni Association, Outstanding Professional Achievement Award (1986)
- ***E.O. Lawrence Memorial Award*** of the USDOE (1988)
- **Arthur Holly Compton Award** of the ANS (1989)
- ***Donald Q. Kern*** Award of the AIChE (1989)
- ***Glenn T. Seaborg*** Medal of the ANS (1992)
- ASME/ANS NHTC Best Paper Award (1993)
- **William H. Wiley Distinguished Faculty Award**-RPI (2004)

Books and Monographs

"Out-of-Pile Subchannel Measurements in a Nine-Rod Bundle for Water at 1000

PSIA," Progress in Heat and Mass Transfer, Vol. 6, 1972 (with B. Shiralkar)

"Non-Equilibrium Two-Phase Flows" (Associate Editor), ASME Symposium Volume, 1975.

The Thermal-Hydraulics of a Boiling Water Nuclear Reactor , ANS Monograph, 1977 (with F. Moody).

"Light Water Reactors: Thermal-Hydraulic Aspects of Nuclear Reactor Safety" (Associate Editor), ASME Symposium Volume, 1977.

"Topics in Two-Phase Heat Transfer & Flow" (Associate Editor), ASME Symposium Volume, 1977.

"Power Reactor Concepts and Systems Overview," Chapter 2, Nuclear Reactor Safety Heat Transfer, Hemisphere Press, 1980.

"Light Water Nuclear Reactors," Chapter 4, Nuclear Reactor Safety Heat Transfer, Hemisphere Press, 1980.

"Fundamental Concepts of System Safety Modeling," Chapter 8, Nuclear Reactor Safety Heat Transfer, Hemisphere Press, 1980.

"Basic Mechanisms in Two-Phase Flow and Heat Transfer," (Associate Editor), ASME Symposium Volume, 1980.

"Section 507: Vaporization/Boiling Heat Transfer," Heat Transfer and Fluid Flow Data Book, General Electric Company, 1981.

"Transient Analysis of Two-Phase Systems," Two-Phase Flow Dynamics , Hemisphere Press, 1981.

"Current Boiling Water Nuclear Reactor LOCA Issues," Two-Phase Flow Dynamics , Hemisphere Press, 1981.

"Advances in Two-Phase Flow Instrumentation," Advances in Nuclear Science and Technology, Vol. 13, 1981 (with S. Banerjee).

"On the Junction Problem in Two-Phase Flow," Selected Topics in Two-Phase Flow, Tapir, 1984.

"An Analysis of Density-Wave Oscillations in Ventilated BWR Fuel Rod Bundles ," Multi-Phase Flow and Heat Transfer III, Part A: Fundamentals, eds. Veziroglu & Bergles, Elsevier, 1984 (with R. Taleyarkhan and M. Podowski).

"Three Dimensional Conical Probe Measurements in Turbulent Air/Water Two-Phase Pipe Flow," TSI Quarterly (Flow Lines), 1987 (with S.K. Wang, S.J. Lee and O.C. Jones, Jr.)

"Phase Distribution in a Triangular Duct," Multiphase Science and Technology , Vol. 3, Hemisphere Press, 1987.

"Dividing Flow in a Tee Junction," Multiphase Science and Technology , Vol. 3, Hemisphere Press, 1987.

"On the Analysis of Instabilities in Two-Phase Flows," Multiphase Science and Technology, Vol. 4, pp. 183-370, Hemisphere Press, 1989 (with M. Podowski).

"The Three Dimensional Time and Volume-Averaged Conservation Equations of Two-Phase Flows," Advances in Nuclear Science & Technology, Vol. 20, pp. 1-69, 1989 (with D.A. Drew).

"The Prediction of Phase Separation in a Branching Conduit Using a Three-Dimensional Two-Fluid Model," Editor, T.N. Veziroglu, Multiphase Transport and Particulate Phenomena, Vol. 1, Hemisphere Corp., 1990 (with S. Kalkach-Navarro, S.J. Lee and D.A. Drew).

"Relation of Microstructure to Constituitive Relations," Editors, Daniel D. Joseph and David G. Schaeffer, Two Phase Flows and Waves, Vol. 26, Springer-Verlag, 1990 (with D.A. Drew and G.S. Arnold).

"The Dispersion and Attenuation of Small Amplitude Standing Waves and the Propagation of Acoustic Pressure Pulses in Bubbly Air/Water Two-Phase Flows," Multiphase Science & Technology, Vol. 6, Hemisphere Press, 1992 (with A.E. Ruggles).

"Boiling Heat Transfer - Modern Developments and Advances," Elsevier, 1992 (Editor).

"Analytical Modeling of Multiphase Flows," Editor, M.D. Roco, Particulate Two-Phase Flow, 1993 (with D.A. Drew).

The Thermal-Hydraulics of a Boiling Water Nuclear Reactor , Second Edition, ANS Monograph, 1993 (with F.J. Moody).

"Two-Phase Flow," The Engineering Handbook, CRC Press, 1994.

Multiphase Science and Technology , Volume 8, "Two-Phase Flow Fundamentals," Begell House, Inc., New York, 1996 (Co-Editor with G.F. Hewitt, et al).

"A CFD Analysis of Multidimensional Two-Phase Flow and Heat Transfer Phenomena," Process, Enhanced and Multiphase Heat Transfer (A.E. Bergles - Festschriff), Begell House, Inc., New York, 1996.

"Two-Phase Instabilities," International Encyclopedia of Heat & Mass Transfer, CRC Press, 1997.

"The Air Carryunder Induced by Plunging Liquid Jets," International Encyclopedia of Heat & Mass Transfer, CRC Press, 1997 (with F. Bonetto).

"Three-Phase Flow Measurements using A Hot-Film Anemometer," Applied Optical Measurements, Editor, M. Lehner et al, Springer, 1999.

" Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies" , National Reserach Council - Space Studies Board Topical Report , 2000

"Sonoluminescence and the Search for Sonofusion", Advances in Heat Transfer, Academic Press, Vol. 35, pp: 1-168, 2005.

"Recent Advances and Results in Acoustic Inertial Confinement Bubble Nuclear Fusion", Low Energy Nuclear Reactions and New Energy Technologies Source Book V.2, Oxford University Press, Chapter-8, pp: 139-157, 2009 (with R.P. Taleyarkhan, C.D. West,R.I. Nigmatulin, R.C. Block, J.S. Cho, Y. Yu).

"Acoustic Inertial Confinement (Bubble) Nuclear Fusion", Energy Encylopedia, John Wiley & Sons, 2010 (with R.P. Taleyarkhan, R. I. Nigmatulin).

Refereed Publications (Journals)

"Mass Flux and Enthalpy Distribution in a Rod Bundle for Single- and Two-Phase Conditions," ***Journal of Heat Transfer***, May 1971 (with B. Shiralkar).

"An Exact Solution for Flow Transients in Two-Phase Systems by the Method of Characteristics," ***Journal of Heat Transfer***, November 1973 (with J.M. Gonzalez-Santalo).

"The Variation of the Vapor Volumetric Fraction During Flow and Power Transients," ***Nuclear Engineering and Design***, 25, 1973 (with B. Shiralkar).

"The Effect of Obstacles on a Liquid Film," ***Journal of Heat Transfer*** , November 1973 (with B. Shiralkar).

"On the Various Forms of the Conservation Equations in Two-Phase Flow," ***International Journal of Multiphase Flow***, No. 2, 1976 (with G. Yadigaroglu).

-An Exact Analytical Solution of Pool Swell Dynamics During Depressurization by the Method Characteristics," ***Nuclear Engineering and Design***, 45, 101-116, 1978 (with H.W. Vea).

"A Turbine-Meter Evaluation Model for Two-Phase Transients," ***Journal of Heat Transfer***, 102, 2/9-13, 1980 (with P.S. Kamath).

"The Analysis of Virtual Mass Effects in Two-Phase Flow," ***Int. J. of Multiphase Flow***, 5, 233-242, 1979 (with D.A. Drew and L. Cheng).

"Application of General Constitutive Principles to the Derivation of Multidimensional Two-Phase Flow Equations," ***Int. J. Multiphase Flow***, Vol. 4, 243-264, 1979 (with D.A. Drew).

"An Experimental Technique for Determination of Steam Fraction in Flowing Steam/Air Mixtures," ***Nuclear Technology***, 48, 1980 (with N. Saba and J.C. Corelli).

"The Analysis of Boiling Water Reactor Long-Term Cooling," ***Nuclear Technology***, 49, 1980 (with P.S. Kamath).

"The Analysis of CCFL using Drift-Flux Models," ***Journal of Nuclear Engineering and Design***, 61, 245-255, 1980 (with K. Ohkawa).

"The Effect of Gravity and Friction on the Stability of Boiling Flow in a Channel," AIChE Symposium Series, #199, Vol. 76, 1980- ***Chem. Eng. Commun***., Vol. 11, 59-79, 1981 (with J-L. Achard and D.A. Drew).

"Transient Analysis of DDT Rakes, " ***Nuclear Engineering and Design***, 65, 342-367, 1981 (with P.S. Kamath).

"Development of a Radio-Frequency Excited Local Impedance Probe," ***Nucl. Eng. and Design***, 67, 125-136, 1981 (with M. Vince and G. Krycuk).

"The Effect of Virtual Mass on the Numerical Stability of Accelerating Two-Phase Flows," ***Int. J. Multiphase Flow***, 6, 1981, (with L. Cheng, D.A. Drew and J.E. Flaherty).

"The Measurement of Phase Separation in Wyes and Tees," ***Nucl. Eng. and Design***, 64, No. 1, 1981 (with T.J. Honan).

"Phase Distribution Mechanisms in Turbulent Two-Phase Flow in Channels of Arbitrary Cross Section," ASME ***J. of Fluids Eng.***, 103, 583-589, 1981 (with D.A. Drew).

"On the Development of an Objective Flow Regime Indicator," ***Int. J. Multiphase Flow***, 8, No. 2, 93-124, 1982 (with M.A. Vince).

"Phase Distribution Mechanisms in Turbulent Low Quality Two-Phase Flow in a Circular Pipe," ***J. of Fluid Mechanics***, 117, 91-106, 1982 (with D.A. Drew).

"Optical Probe for High Temperature Local Void Fraction Determination," ***J. of Applied Optics***, 21, 886, 1982 (with M.A. Vince, H.E. Breed and G. Krycuk).

"Measurement of Flow in Large Pipes by the Pulsed Neutron Activation Method," ***Nucl. Sci. Eng.***, 82, 19-33, 1982 (with M.L. Perez-Griffo and R.C. Block).

"An Experimental Investigation of BWR Parallel Channel Effects," ***Nucl. Eng. and Design***, 73, 425-440, 1983 (with W.M. Conlon).

"The Prediction of Pressure Drop and CCFL Breakdown in Countercurrent Two-Phase Flow," ***J. of Heat Transfer***, 105, 1983 (with A. Ostrogorsky and R.R. Gay).

"An Investigation of BWR/4 Parallel Channel Effects During a Hypothetical LOCA for Both Intact and Broken Jet Pumps," ***Nuclear Technology***, Vol. 65, No. 2, 1984 (with M. Fakory).

"The Analysis of Phase Separation Phenomena in Branching Conduits," ***Int. J. of Multiphase Flow***, Vol. 10, 1984 (with N. Saba)

"Measurement of Virtual Mass and Drag Coefficients of a Disk Oscillating Sinusoidally in a Two-Phase Mixture," ***Int. J. of Multiphase Flow***, 10, No. 3, 1984 (with P.S. Kamath and D.R. Harris).

"NUFREQ-NP: A Computer Code for the Stability Analysis of Boiling Water Reactors," ***Nuc. Sci & Eng.***, 88, 1984 (with S.J. Peng, M.Z. Podowski and M. Becker).

"The Development of a Gamma-Ray Scattering Densitometer for the Non-Intrusive Measurement of Local Void Fraction," ***Nuclear Technology***, 67, 1984 (with K. Ohkawa).

"An Instability Analysis of Ventilated Channels," ***J. Heat Transfer***, 107, 175-181, 1985 (with R. Taleyarkhan and M. Podowski).

"The Analysis of Nonlinear Density-Wave Oscillations in Boiling Channels ," ***J. of Fluid Mechanics***, 155, 213-232, 1985 (with J.L. Achard and D.A. Drew).

"An Analytical Model for the Analysis of BWR/4 Long-Term Cooling with Either Intact or Broken Jet Pump Seals," ***J. of Nuclear Engineering and Design***, 85, 1985 (with M.R. Fakory).

"An Analysis of Wave Propagation in Bubbly Two-Component Two-Phase Flows ," ***J. of Heat Transfer***, 107, 1985, (with L.Y. Cheng and D.A. Drew).

"Measurement of Flow in a Horizontal Pipe using the Pulsed Photon Activation Technique," ***Nuc. Sci. Eng.***, 91, No. 3, 1985 (with T.F. Lin, R.C. Bloc, O.C. Jones, Jr. and M. Murase).

"Film Thickness Measurements and Modeling in Horizontal Annular Flows," ***Physicochemical Hydrodynamics***, Vol. 6, No.1/ 2, pp. 197-206, 1985 (with T.F. Lin, O.C. Jones, Jr., R.C. Block and M. Murase).

"The Development of a Closed Form Analytical Model for the Stability Analysis of Density-Wave Oscillations in Boiling Water Nuclear Reactors," ***Nucl. Eng. and Design***, 92, No. 2, 1986 (with G.C. Park, M. Becker, M. Podowski and S.J. Peng).

"A Stability Analysis of Ventilated Boiling Channels," ***J. Nucl. Eng. and Design***, 93, No. 1, 1986 (with M. Podowski and R.P. Taleyarkhan).

"BWR Linear Stability Analysis," ***J. Nucl. Eng. and Design***, 93, No. 1, 1986 (with S.J. Peng and M. Podowski).

"Advances in the Analytical Modeling of Linear and Nonlinear Density-Wave

Instability Modes," ***Journal of Nuclear Engineering and Design***, 95, pp. 5-34, 1986.

"Current Understanding of Phase Separation Mechanisms in Branching Conduits," ***Journal of Nuclear Engineering and Design***, 95, 1986.

"Horizontal Annular Flow Measurements Using Pulsed Photon Activation and Thickness Distribution Modeling," ***Journal of Nuclear Engineering and Design*** , 95, 1986 (with T.F. Lin, R.C. Block, O.C. Jones, Jr. and M. Murase).

"The Measurement of Phase Distribution in a Triangular Conduit," ***Int. J. of Multiphase Flow***, 12, No. 3, 405-425, 1986 (with S. Sim).

"The Virtual Mass and Lift Force on a Sphere in Rotating and Straining Flow," ***J. of Multiphase Flow***, Vol. 13, No. 1, pp. 113-121, 1987 (with D.A. Drew).

"3-D Turbulence Structure and Phase Distribution Measurements in Bubbly Two-Phase Flows," ***International Journal of Multiphase Flow***, Vol. 13, No. 3, pp. 327-343, 1987 (with S.K. Wang, S.J. Lee and O.C. Jones, Jr.).

"An Experimental Investigation of BWR/4 Long-Term Cooling with either Intact or Broken Jet Pumps," ***Journal of Nuclear Engineering and Design***, Vol. 99, pp. 391-402, 1987 (with M. Fakory).

"An Experimental Study of Two-Dimensional Phase Separation Phenomena," ***International Journal of Multiphase Flow***, Vol. 13, No. 3, pp. 327-344, 1987 (with K.M. Bukhari).

"The Effect of Fuel Rod Dynamics on BWR Stability Margin," ***Journal of Nuclear Engineering and Design***, Vol. 99, pp. 5-14, 1987 (with R. Taleyarkhan and M.Z. Podowski).

"A Linear Model to Study Fluid Dynamic Instabilities in Boiling Channels due to Density Oscillations," ***International Journal of Heat & Technology*** , Vol. 5, No. 3.4, 1987 (with F,. DAuria, N. DeSanctis, P. DiMarco and M. Podowski).

"An Investigation of the Propagation of Pressure Perturbations in Bubbly Air/Water Flows," ***Journal of Heat Transfer***, Vol. 110, 494-499, 1988 (with A. Ruggles, D.A. Drew and H. A. Scarton).

"A Study on Single and Two-Phase Pressure Drop in Branching Conduits, " ***Int. J. of Experimental Thermal and Fluid Science***, Vol. 1, No. 2, 1988 (with S.T. Hwang).

"Phase Separation in Dividing Two-Phase Flows," ***Int. J. of Multiphase Flow***, Vol. 14, No. 4, 1988 (with S.T. Hwang and H. Soliman).

"The Prediction of Two-Phase Turbulence and Phase Distribution Phenomena Using a k-Epsilon Model, ***Japanese Journal of Multiphase Flow*** , Vol. 3, No. 4, 335-368, 1989 (with S.J. Lee and O.C. Jones, Jr.).

"An Experimental Investigation of Phase Distribution in an Eccentric Annulus ," ***Int. J. of Multiphase Flow***, Vol. 15, No. 3, 4470457, 1989 (with K. Ohkawa).

"Phase Separation in Impacting Wyes and Tees," ***Int. J. of Multiphase Flow***, Vol. 15, No. 6, 965-976, 1989 (with S.T. Hwang and H. Soliman).

"An Analysis of Stability and Oscillation Modes in Boiling Multichannel Loops Using Parameter Perturbation Methods," ***International Journal of Heat and Mass Transfer***, Vol. 32, No. 11, pp. 2055-2064, 1989 (with A. Clausse and M. Podowski).

"The Relationship Between Standing Waves, Pressure Pulse Propagation and Critical Flow Rate in Two-Phase Mixtures," ***Journal of Heat Transfer***, Vol. 111, 467-473, 1989 (with A.E. Ruggles and D.A. Drew).

"Derivation of Constitutive Equations for Interfacial Force and Reynolds Stress for a Suspension of Spheres Using Ensemble Averaging," ***Journal of Chemical Engineering Communications***, Vol. 86, pp. 43-54, December 1989 (with G. Arnold and D.A. Drew).

"A Lumped Parameter Model for Linear and Nonlinear Analysis of Excursive and Density-Wave Instabilities in Boiling Channels," ***Energia Nucleare***, Vol. 6, No. 3, pp. 53-59, September-December, 1989 (with P. DiMarco, A. Clausse and D.A. Drew).

"A Nodal Analysis of Instabilities in Boiling Channels," ***Heat & Technology***, Vol. 8, No. 1-2, 1990 (with P. DiMarco, A. Clausse and D.A. Drew).

"Statistical Analysis of Turbulent Two-Phase Pipe Flow," ***Journal of Fluids Engineering***, Vol. 113, pp. 89-95, 1990 (with S.K. Wang, S.J. Lee and O.C. Jones, Jr.)

"The Prediction of Two-Phase Turbulence and Phase Distribution Phenomena Using a Reynolds Stress Model," ***Journal of Fluids Engineering***, Vol. 112, pp. 107-113, 1990 (with M. Lopez de Bertodano, S.J. Lee and D.A. Drew).

"Void Wave Dispersion in Bubbly Flows," ***Nuclear Engineering and Design***, Vol. 121, No. 1, pp. 1-10, 1990 (with J-W. Park and D.A. Drew and A. Clausse)

"An Assessment of Multiphase Flow Models using the Second Law of Thermo-Dynamics," ***Int.J. of Multiphase Flow***, Vol. 16, No. 3, pp. 481-494, 1990 (with G. Arnold and D.A. Drew).

"The Influence of Flow Development on Subcooled Boiling," ***Int. Communications in Heat & Mass Transfer***, Vol. 17, No. 5, pp. 545-554, 1990 (with A. Clausse).

"The Analysis of Phase Separation and Phase Distribution Phenomena using Two-Fluid Models," ***Nuclear Engineering & Design***, Vol. 122, pp. 17-40, 1990.

"Some Supplemental Analysis Concerning the Virtual Mass and Lift Force on a Sphere in a Rotating and Straining Flow," ***International Journal of Multiphase Flow***, Vol. 16, No. 6, pp. 1127-1130, 1990 (with D.A. Drew).

"An Application of Fractal and Chaos Theory in the Field of Two-Phase Flow and Heat Transfer," ***W&Scaronrme- und Stoff&Yumlbertragung***, vol. 26, pp. 351-363, 1991.

"Void Wave Propagation Phenomena in Two-Phase Flow," ***AIChE Journal***, Vol. 37, No. 1, pp. 123-135, Jan. 1991.

"The Use of Fractal Techniques in Flow Regime Identification," ***Int. J. Multiphase Flow***, Vol. 17, No. 4, pp. 545-552, 1991 (with F. Franca, M. Acikgoz and A. Clausse).

"A Contribution to Mathematical Modeling of Bubbly/Slug Flow Regime Transition," ***Chemical Engineering Communications***, Vol. 102, pp. 69-85, April 1991 (with S. Valenti, A. Clausse and D.A. Drew).

"The Analysis of Periodic and Strange Attractors During Density-Wave Oscillations in Boiling Flows," ***J. of Chaos, Solitons and Fractals***, Vol. 1, No. 2, pp. 167-178, 1991 (with A. Clausse).

"An Analysis of Non-Linear Instabilities in Boiling Systems," ***Journal of Dynamics and Stability of Systems***, Vol. 6, No. 3, pp. 191-216, 1991 (with P. DiMarco and A. Clausse).

"An Analysis of the Eigenvalues of Bubbly Two-Phase Flows," ***Chemical Engineering Communications***, Vol. 106, pp. 93-117, August 1991, (with T.C. Haley and D.A. Drew).

"Analysis of Phase Distribution in Fully Developed Laminar Bubbly Two-Phase Flow," ***International Journal of Multiphase Flow***, Vol. 17, No. 5, pp. 635-652, 1991 (with S.P. Antal and J.E. Flaherty).

"A Contribution to the Prediction of Phase Separation in Branching Conduits," ***Chemical Engineering Communications***, Vol. 111, pp. 79-105, 1992 (with R.H. Kimpland, B.J. Azzopardi and H.M. Soliman).

"Global Volumetric Phase Fractions in Horizontal Three Phase Flows," ***AIChE Journal***, Vol. 38, No. 7, pp. 1049-1059, 1992 (with M. Acikgoz and F. Franca).

"An Experimental Study of Three-Phase Flow Regimes," ***Int. J. Multiphase Flow***, Vol. 18, No. 3, pp. 327-336, 1992 (with F. Franca and M. Acikgoz).

"On the Development of Multidimensional Two-Fluid Models for Vapor/Liquid Two-Phase Flows," ***Chemical Engineering Communications***, Vol. 118, pp. 125-140, Nov/Dec. 1992.

"On the Use of Drift-Flux Techniques for the Analysis of Horizontal Two-Phase Flows," ***Int. J. Multiphase Flow***, Vol. 18, No. 6, pp. 787-801, 1992.

"A Characteristic Analysis of Void Waves Using Two-Fluid Models," ***Nuclear Engineering & Design***, Vol. 139, No. 1, pp. 45-58, 1993 (with T.C. Haley and D.A. Drew).

"An Experimental Study on Air Carryunder Due to a Plunging Liquid Jet," ***Int. J. Multiphase Flow***, Vol. 19, No. 2, pp. 281-294, 1993 (with F. Bonetto).

"Phase Distribution in Complex Geometry Conduits," ***Nuc. Eng. & Design***, Vol. 141, Nos. 1&2, pp. 177-201, 1993 (with M. Lopez de Bertodano and O.C. Jones, Jr.)

"Buoyantly-Driven Two-Phase Countercurrent Flow in Liquid Discharge From a Vessel With an Unvented Gas Space," ***Nuc. Eng. & Design***, Vol. 141, Nos. 1&2, pp. 237-248, 1993 (with Christopher E. Henry, Robert E. Henry and S. George Bankoff).

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"Phase Distribution in Bubbly Two-Phase Flow in Vertical Ducts," ***Int. J. Multiphase Flow***, Vol. 20, pp. 805-818, 1994 (with M. Lopez de Bertodano and O.C. Jones).

"Phase Distribution and Turbulence Structure for Solid/Fluid Upflow in a Pipe," ***Int. J. Multiphase Flow***, Vol. 20, No. 3, pp. 453-479, 1994 (with A. Alajbegovic, A. Assad and F. Bonetto).

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"Advancements in the Multidimensional Analysis of Multiphase Flows " , Proceedings of HEFAT-2003 , Victoria Falls , Zambia ,June 23-26 , 2003 (with D. Drew , K. Jansen , A. Galimov and S. Nagrath).

"The Modeling of Lift and Dispersion Forces in Two-Fluid Model Simulations, Part-

I : Jet Flows" , Proceedings of the ASME/JSME Meeting , Honolulu , Hawaii ,July 6-10 , 2003 (with M. Lopez de Bertodano , F. Moraga and D. A. Drew).

"The Modeling of Lift and Dispersion Forces in Two-Fluid Model Simulations, Part-II : Boundary Layer Flows" , Proceedings of the ASME/JSME Meeting , Honolulu , Hawaii ,July 6-10 , 2003 (with F. Moraga , M. Lopez de Bertodano , and D. A. Drew).

"An Analytical Study on Interfacial Wave Structure Between a Liquid Film and Gas Core in a Vertical Circular Channel" , Proceedings of NURETH-10 , Seoul ,Korea , October 5-9 , 2003 (with F. Inada and D. A. Drew).

"A Non-Linear Model for Bubble-Induced Turbulent Viscosity in Bubbly Two-Phase Flow" , Proceedings of NURETH-10 , Seoul,Korea , October 5-9 ,2003 (with I. Bolotnov , F. Moraga and D. A. Drew).

"An Analytical Study on Interfacial Wave Structure Between Liquid Film and Gas Core in a Vertical Channel" , Proceedings of NURETH-10 , Seoul, Korea , October 5-9 , 2003 (with F. Inada and D.A. Drew).

"Modeling and Simulation of Full Scale Bubbly Flows around Surface Ships," Proc. of 3rd Int. Symposium of Two-Phase Flow Modeling and Experiments, Pisa, Italy, Sept. 22-24, 2004 (with F. Moraga, D. A. Drew).

"Simulating Churn -Turbulent Flows in a Bubble Column using a Three Field, Two-Fluid Model," Proc. of 5th Int. Conf. Multiphase Flow (ICMF'04), Yokohama, Japan, May 30-June 4, 2004 (with S. Antal, M. Al-Dahhan).

"The Analysis of Void Wave Propagation and Instability using Two-Fluid Models," Proc. of 5th Int. Conf. Multiphase Flow (ICMF'04), Yokohama, Japan, May 30-June 4, 2004 (with J. Yin).

"An Analysis of Interacting Instability Modes," Proc. of Japan/US Seminar on Two-Phase Flow Dynamics, Nagahama, Japan, Dec. 6-11, 2004 (with J. Yin, M. Jensen).

"Analysis of Void Wave Propagation and Sonic Velocity using a Two-Fluid Model," Proc. of Japan/US Seminar on Two-Phase Flow Dynamics, Nagahama, Japan, Dec. 6-11, 2004.

"The Analysis of Linear and Nonlinear Bubble Cluster Dynamics," Proc. of Japan/US Seminar on Two-Phase Flow Dynamics, Nagahama, Japan, Dec. 6-11, 2004 (with I. Akhatov, R. Nigmatulin).

"Modeling Wall-Induced Forces on Bubbles for Inclined Walls," Proc. of Japan/US Seminar on Two-Phase Flow Dynamics, Nagahama, Japan, Dec. 6-11, 2004 (with F. Moraga, S. Cancelos).

"The Design of Acoustic Chambers for Bubble Dynamics Research," Proc. of Japan/US Seminar on Two-Phase Flow Dynamics, Nagahama, Japan, Dec. 6-11, 2004 (with S. Cancelos, F. Moraga, P. Bouchilooux).

"Bubble Nuclear Fusion Technology - Status and Challenges," Proc. of Japan/US Seminar on Two-Phase Flow Dynamics, Nagahama, Japan, Dec. 6-11, 2004 (with R. Taleyarkhan, R. Nigmatulin).

"The Analysis of Interfacial Waves," Proc. 3rd Int. Symposium of Two-Phase Flow Modeling and Experiments, Pisa, Italy, Sept. 22-24, 2004 (with A. Galimov, D. A. Drew).

"The Analysis of Sonofusion" , Proc. ISMF ' 05 , Xi'an , China, July 3-6 , 2005 (with R.I. Nigmatulin ,R.P. Taleyarkhan).

"The Effect of an Accumulator on Pressure-Drop and Density-Wave Oscillations using a Linear Frequency Domain Model", Proc. ISMF ' 05 , Xi'an , China , July 3-6 , 2005 (with J. Yin , M.K. Jensen , M.Z. Podowski).

" Sonofusion - Fact or Fiction" , Proc. NURETH-11 , Avignon , France , October 2-6, 2005 (with R.P. Taleyarkhan , R.I. Nigmatulin).

"Multidimensional Modeling of Developing Two-Phase Flows in a Large Adiabatic Riser " , Proc. NURETH-11 , Avignon , France , October 2-6 , 2005 (with S. Antal , M. Z. Podowski , D. Barber ,C. Delfino).

"Nanoscale Bubble Thermonuclear Fusion in Acoustically Cavitated Deuterated Liquid" , Proc. NURETH-11, Avignon , France , October 2-6 ,2005 (with R. Nigmatulin , R. Taleyarkhan).

"Stabilitaetsanalyse eins Stroemungskanals mit ueberkritischen Dampfzustaenden" , Proc. Compact fur Kerntechnische Gesell Shaft (KTG) , Aachen , Germany , May 16-18 , 2006 (with T. Ortega-Gomez , A. Class ,T. Schulenberg).

"Stability Analysis of a Uniformly Heated Channel with Supercritical Water" , Proc. ICONE-14 , Miami , Florida , July 17-20 , 2006 (with T. Ortega-Gomez , A. Class , T. Schulenberg).

"Computation of the Unsteady Two-phase Flow Around a Manuvering Surface Ship", Proc. 26th Symposium on Naval Hydrodynamics , Rome, Italy , Sept. 17-22, 2006 (with M. Hyman , F. Moraga , D.A. Drew).

"The Effect of Gravity Level on the Stability of a Rankine Cycle Power System" , Proc. ICAPP 2007, Nice , France, May 13-18, 2007 (with W. Schlichting , M. Podowski).

"The Modeling of Two-Phase Turbulence" , Proc. ICMF-2007 , Leipzig, Germany , July 9-13 ,2007 (with I. Bolotnov , D. Drew , K. Jansen).

"Convergence Studies of Turbulent Channel Flows using a Stabilized Finite Element Method" , Proc. 9th US National Congress on Computational Mechanics , San Francisco , CA , July 23-26 , 2007 (with A. Trofimova , A. Tejada-Martinez , K. Jansen).

"Stability Analysis of a Boiling Loop in Space" , Proc. COMSOL Conference-2007, Boston, MA, October 4-6 , 2007 (with W. Schlichting, M. Podowski, T. Ortega-Gomez).

"On the Direct Numerical Simulation of Two-Phase Flows", Proc. NURETH-12, Pittsburgh, PA, Sept. 30 - Oct. 4 , 2007.

"Density-Wave Oscillations in Coupled Parallel Channels under Supercritical Pressure Conditions", Proc. ANS/ENS International Winter Meeting , Washington DC , November 11-15 , 2007 (with T. Ortega-Gomez , A. Class, T. Schulenberg).

"Multidimensional Analysis of Developing Two-Phase Flows in an ESBWR with and without Riser Channels" , Proc. ICAPP ' 08 , Anaheim, CA , June 8-12, 2008 (with H. Murakawa and S. Antal).

"Multidimensional Analysis of Developing Two-Phase Flows using Multifield Simulation in Natural Circulation BWR Chimney", Proc. IFHT2008 , Tokyo, Japan, Sept. 17-19 , 2008 (with H. Murakawa and S. Antal).

" A Subgrid Model for Predicting Air Entrainment Rates in Bubbly Flows" , Proc. 61st Meeting of the APS- Division of Fluid Dynamics, San Antonio , TX , Nov. 23-25 , 2008 (with Jingsen Ma , A. Oberai, D. Drew and F. Moraga).

"On the Operating Characteristics of Acoustic Chambers for Sonofusion", Proc. NURETH-13 , Kanazawa City, Japan , Sept. 27 - Oct.2 , 2009 (with Markus Stokmaier, Bernard Maoulin, Andreas Class and Thomas Schulenberg).

"A Comprehensive Subgrid Air Entrainment Model for Reynolds-averaged Simulations of Free-Surface Bubbly Flows", Proc. 62nd Meeting of the APS-Division of Fluid Dynamics, Minneapolis, MN , Nov. 22-24, 2009 (with Jingsen Ma , A. Oberai, D. Drew and M. Hyman).

"The Numerical Simulation of Two-Phase Annular Flow", Proc. ICMF 2010, Tampa, Florida, May 30-June 4 , 2010 (with Joseph Rodriguez and Ken Jansen).

"Direct Numerical Simulation of Turbulent Two-Phase Bubbly Channel Flow" , Proc. ICMF 2010, Tampa, Florida, May 30-June 4 , 2010 (with Igor Bolotnov, Ken Jansen , Donald Drew , Assad Oberai and Michael Podowski).

"DES and RaNS Modeling of a 3-D Hydraulic Jump with Air Entrainment using a Two-Fluid Model", Proc. ICMF 2010, Tampa, Florida, May 30-June 4 , 2010 (with Jingsen Ma, Assad Oberai and Donald Drew).

"A Generalized Sub-Grid Air Entrainment Model for RaNS Modeling of Bubbly Flows", Proc. ICMF 2010, Tampa, Florida, May 30-June 4 , 2010 (with Jingsen Ma , Assad Oberai and Donald Drew).

"Sub-grid Air Entrainment Model for RANS and LES Simulations of Free Surface Turbulence Bubbly Flows", Proc. 28th ONR Symposium on Naval Hydrodynamics, Cal Tech , Pasadena , CA , Sept. 12-17, 2010 (with Assad Oberai, Jingsen Ma, and Donald Drew).

" A Detached Direct Numerical Simulation of Two-Phase Turbulent Bubbly Channel Flow" , Proc. 7th Int. Conference on Multiphase Flow (ICMF 2010), Tampa, FL. May30 - June 4, 2010 (with I. A. Bolotnov, K.E. Jansen, D.A. Drew, A.A. Oberai, M.Z. Podowski).

" The Simulation of Air Entrainment in a Hydraulic Jump using Two-Fluid DES and RaNS Models", Proc. 7th Int. Conference on Multiphase Flow (ICMF 2010), Tampa, FL. May30 - June 4, 2010 (with J. Ma, A.A. Oberai, D.A. Drew).

"A Generalized Subgrid Air Entrainment Model for RaNS Modeling of Bubbly Flows around Ship Hulls", Proc. 7th Int. Conference on Multiphase Flow (ICMF 2010), Tampa, FL. May30 - June 4, 2010 (with J. Ma, A.A. Oberai, M.C. Hyman, D.A. Drew).

" ATwo-Way Coupled Polydispersed Simulation of Bubbly Flow Beneath a Plunging Liquid Jet", Proc. ASME Fluids Engineering Division (FED) Summer Meeting , Montreal, Quebec-Canada, August 1-5, 2010 (with J. Ma, A.A. Oberai, D.A. Drew).

"Acoustic Chambers for Sonofusion Experiments : FE - Analysis Highlighting Performance Limiting Factors" , Proc.17th International Congress on Sound and Vibration (ICSV 17), Cario, Egypt , July 18-22, 2010 (with Markus J. Stokmaier, Andreas G. Class, Thomas Schulenberg).

" Influence of Bubbles on Liquid Turbulence Based on the Direct Numerical Simulation of Channel Flows", Proc. 63rd Annual APS Meeting - Division of Fluid Dynamics , Long Beach, CA, Nov. 21-23, 2010 (with Igor Bolotnov, Donald D. Drew and Michael Z. Podowski).

Unrefereed Publications

"Control Rod Oscillator Tests: Garigliano Nuclear Reactor," GEAP-5534, August 1967.

"BWR Stability Considerations Resulting from Garigliano Research and Development Program," International Symposium on Dynamics of Two-Phase Flow, presented at University of Eindohoven, The Netherlands, 1967 (with J. Hodde).

"Representation of Space-Time Velocity and Pressure Fluctuation Correlations by a Tentative Phenomenological Model," Stanford University Report MD-22, August

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"Subchannel and Pressure Drop Measurements in a Nine-Rod Bundle for Diabatic and Adiabatic Conditions," GEAP-13049, March 1970 (with B. Shiralkar, et al)

"A Stochastic Wave Model Interpretation of Correlation Functions for Turbulent Shear Flows," Stanford University Report MD-26, May 1971.

"The Analysis of Transient Critical Heat Flux," GEAP-13249, 1972 (with J. Gonzalez).

"General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application,"NEDO-10958, November 1973.

"A Turbine-Meter Evaluation Model for Two-Phase Transients (TEMPI)," EG&G Idaho, Inc. Topical Report, 1977 (with P. Kamath).

"Transient Analysis of a Drag-Disk in Two-Phase Flow," EG&G Topical, NES-483, 1978 (with P. Kamath and D.R. Harris).

"The Measurement of Phase Separation in Wyes and Tees," USNRC Topical Report, NUREG/CR-0557, 1978 (with T.J. Honan).

"The Development of a Side-Scatter Gamma Ray System for the Measurement of Local Void Fraction," USNRC Topical Report, NUREG/CR-0677, 1978 (with S. Schell).

"A Review of Selected Void Fraction and Phase Velocity Measurement Techniques," Proceedings of the FDI Two-Phase Instrumentation Course, Dartmouth College, 1978.

"The Analysis of Proposed BWR Inlet Flow Blockage Experiments at PBF," EG&G Idaho, Inc., Topical Report, 1978 (with K. Ohkawa).

"Virtual Mass Effects in Two-Phase Flows," USNRC Topical Report, NUREG/CR-0020, 1979 (with L. Cheng and D.A. Drew).

"Flow Patterns & Phase Distribution Phenomena," Invited paper given at Two-Phase Flow Summer Course, Munich, Germany, 1979.

"Two-Phase Flow Instability," Invited paper given at Two-Phase Flow Summer Course, Munich, Germany, 1979.

"The Measurement of Void Fraction and Phase Velocity using Electrical Impedance Probes," Invited paper given at Two-Phase Instrumentation course, Grenoble, France, 1979.

"Radioactive Tagging Techniques in Two-Phase Flow," Invited paper given at Two-Phase Instrumentation Course, Grenoble, France, 1979.

"Photon Attenuation and Scattering Techniques in Two-Phase Flow," Invited paper given at Two-Phase Flow Instrumentation Course, Grenoble, France, 1979.

"Two-Phase Flow Phenomena in Nuclear Regulatory Technology," USNRC Topical Report, NUREG/CR-0677, 1979 (with S. Schell and R.R. Gay).

"Force & Torque Flow Measurement Methods," Proceedings of Stanford Summer Course on Two-Phase Flow Instrumentation, 1980.

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"The Analysis of Linear and Nonlinear Instability Phenomena in Heated Channels," USNRC Topical Report, NUREG/CR-1718, 1980 (with J.L. Achard and D.A. Drew).

"Flow Regime Identification and Void Fraction Measurement Techniques in Two-Phase Flow," USNRC Topical Report, NUREG/CR-1692, 1980 (with M.A. Vince).

"An Assessment of the Literature Related to LWR Instability Models," NUREG/CR-1414, 1980 (with D.A. Drew).

"Transient Analysis of DTT Rakes," USNRC Topical Report, NUREG/CR-2151, 1981 (with P.S. Kamath).

"The Analysis of Countercurrent Two-Phase Flow Pressure Drop and CCFL Breakdown in Diabatic and Adiabatic Conduits," NUREG/CR-2386, 1981 (with A. Ostrogorsky and R.R. Gay).

"Parallel Channel Effects During the Emergency Core Cooling of a BWR," Proceedings of the 9th Water Reactor Safety Information Meeting, Washington, DC 1981.

"Transient and Sustained Instabilities in Multiphase Flows," Proceedings of the 2nd Multiphase Flow and Heat Transfer Symposium Workshop, 1981 (with J.L. Achard).

"The Measurement of Two-Dimensional Phase Separation Phenomena," USNRC Topical Report, NUREG/CR-1936, 1981 (with M. Barasch).

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"The Analysis of Proposed BWR Inlet Flow Blockage Experiments Using

MAYU4b," USNRC Topical Report, NUREG/CR-2260 and EG&G Topical Report, EGG-2181, 1982 (with M.E. Nissley and R.R. Gay).

"The Analysis of Pulsed Neutron Activation Technique," USNRC topical Report, NUREG/CR-2471, 1981 (with M.L. Griffo and R.C. Block).

"An Experimental Investigation of Boiling Water Nuclear Reactor Parallel Channel Effects During a Postulated Loss-of-Coolant Accident," USNRC Topical Report, NUREG/CR-2971, 1982 (with W.M. Conlon).

"An Analysis of Density-Wave Oscillations in Ventilated Channels," USNRC Topical Report, NUREG/CR-2972, 1982 (with R. Taleyarkhan and M. Podowski).

"Phase Separation Phenomena in Branching Conduits," USNRC Topical Report, NUREG/CR-2590, 1982 (with N. Saba).

"The Development of NUFREQ-N, An Analytical Model for the Stability Analysis of Nuclear Coupled Density-Wave Oscillations in Boiling Water Nuclear Reactors," USNRC Topical Report, NUREG/CR-3375, 1983 (with G.C. Park, M. Podowski and M. Becker).

"An Analysis of Wave Dispersion, Sonic Velocity and Critical Flow in Two-Phase Mixtures," USNRC Topical Report, NUREG/CR-3372, 1983 (with L. Cheng and D.A. Drew).

"Air/Water Subchannel Measurements of the Equilibrium Quality and Mass Flux Distribution in a Rod Bundle," USNRC Topical Report, NUREG/CR-3373, 1983 (with R. Sterner).

"Parallel Channel Effects and Long-Term Cooling During Emergency Core Cooling in a BWR/4," USNRC Topical Report, NUREG/CR-3376, 1983 (with M. Fakory).

"The Development of Gamma Ray Scattering Densitometer and Its Application to the Measurement of Two-Phase Density Distribution in an Annular Test Section," USNRC Topical Report, NUREG/CR-3374, 1983 (with K. Ohkawa).

"An Analysis of Boiling Water Nuclear Reactor Stability Margin," USNRC Topical Report, NUREG/CR-3291, 1983 (J. Balaram, C.N. Shen and M. Becker).

"The Measurement of Phase Distribution Phenomena in a Triangular Conduit," USNRC Topical Report, NUREG/CR-3576, 1983 (with S. Sim).

"Mechanistic Core-Wide Meltdown and Relocation Modeling for BWR Applications," NUREG/CR-3525, 1983 (with M.Z. Podowski and R. Taleyarkhan).

"Mathematical Modeling of U-Tube Steam Generator Dynamics for Slow Transients and Small Break Loss-of-Coolant Accidents," EPRI report RP11, 63-5, 1983.

"The Measurement of Countercurrent Phase Separation and Distribution in a Two-Dimensional Test Section," USNRC Topical Report, NUREG/CR-3577, 1984 (with K.M. Bukhari).

"Current Understanding of Phase Separation Mechanics in Branching Conduits," Proceedings of the U.S.-Japan Seminar on Two-Phase Flow Dynamics, Lake Placid, NY 1984.

"Advances in Analytical Modeling of Linear and Nonlinear Density-Wave Instability Modes," Proceedings of the U.S.-Japan Seminar on Two-Phase Flow Dynamics, Lake Placid, NY 1984.

"Modeling Two-Phase Flow Division at T Junctions," Proceedings of the H.T.F.S. Symposium, Coventry, England, 1984 (with B. Azzopardi and M. Cox).

"NUFREQ-NP: A Digital Computer Code for the Linear Stability Analysis of Boiling Water Nuclear Reactors," NUREG/CR-4116 USNRC Topical Report, 1984 (with S.J. Peng and M.Z. Podowski).

"Analytical Methods for Multicomponent Systems," Proceedings of Workshop on Industrial Applications of Multiphase Flow, UCSB, 1985.

"Light Water Nuclear Reactor LOCA Technology," Proceedings of Workshop on Industrial Applications of Multiphase Flow, UCSB, 1985.

"Condensation Heat Transfer," Proceedings of the RPI Summer Course on Two-Phase Heat and Mass Transfer in Single and Multicomponent Systems, 1985.

"Multicomponent Condensation," Proceedings of the RPI Summer Course on Two-Phase Heat and Mass Transfer in Single and Multicomponent Systems, 1985.

"Multicomponent Boiling," Proceedings of the RPI Summer Course on Two-Phase Heat and Mass Transfer in Single and Multicomponent Systems, 1985.

"The Modeling of BWR Core Meltdown Accidents - For Application in the MELRPI.MOD2 Computer Code," NUREG/CR-3889, 1985 (B.R. Koh, S.H. Kim, R. Taleyarkhan and M.Z. Podowski).

"Basic Conservation Equations," Proceedings of the RPI Summer Course on Computer Simulation of Multiphase Flows, 1986.

"Interfacial Transfer Laws," Proceedings of the RPI Summer Course on Computer Simulation of Multiphase Flows, 1986.

"Closure Conditions for Two-Fluid Models of Two-Phase Flow," Proceedings of the Sixth Symposium on Energy Engineering Sciences, ANL, 1988 (with G. Arnold and D.A. Drew).

"The Relationship Between Microstructure and the Averaged Equations of Two-

Phase Flow," EUROMECH 234, Toulouse, France, May, 1988 (with G. Arnold and D.A. Drew).

"The Analysis of Phase Separation Phenomena in Branching Conduits," Proceedings of the JAPAN/US Seminar on Two-Phase Flow Dynamics, Kyoto, Japan, July 1988.

"An Analysis of Wave Propagation Phenomena in Two-Phase Flow," Proceedings of the JAPAN/US Seminar on Two-Fluid Flow Dynamics, Kyoto, Japan, July, 1988

"Phase Distribution and Phase Separation Phenomena in Two-Phase Flows," Proceedings of the Japan Society of Multiphase Flow, 1988.

"An Analysis of Wave Propagation Phenomena in Two-Phase Flow," Proceedings of RPI Summer Course of Modern Developments in Boiling Heat Transfer and Two-Phase Flow, 1988.

"An Analysis of Phase Distribution Phenomena in Two-Phase Flow," Proceedings of RPI Summer Course of Modern Developments in Boiling Heat Transfer and Two-Phase Flow, 1988.

"An Analysis of Phase Separation in Branching Conduits," Proceedings of RPI Summer Course of Modern Developments in Boiling Heat Transfer and Two-Phase Flow, 1988.

"The Development of APRIL.MOD2 - A Computer Code for Core Meltdown Accident Analysis of Boiling Water Nuclear Reactors," NUREG/CR-5157, July, 1988 (with S. Kim, et al).

"An Analysis of Wave Propagation Phenomena in Two-Phase Flow," Proceedings of RPI Summer Course of Modern Developments in Boiling Heat Transfer and Two-Phase Flow, 1989.

"An Analysis of Phase Distribution Phenomena in Two-Phase Flow," Proceedings of RPI Summer Course of Modern Developments in Boiling Heat Transfer and Two-Phase Flow, 1989.

"An Analysis of Phase Separation in Branching Conduits," Proceedings of RPI Summer Course of Modern Developments in Boiling Heat Transfer and Two-Phase Flow, 1989.

"Degraded BWR Core Modeling - Physical Simulations of Selected Components," ESEERCO EP84-4 Final Report, September 1989 (with M.Z. Podowski).

"The Analysis of Void Wave Phenomena," Proceedings of the Eighth Symposium on Energy Engineering Sciences, pp. 27-34, ANL Report CONF-9005183, 1990 (woth J-W. Park and D.A. Drew).

"Degraded BWR Core Modeling - APRIL.MOD3 Severe Accident Code," ESEERCO EP84-4 Final Report, July 1990 (with M.Z. Podowski).

"Multiphase Thermal Science," Proceedings of the NSF Workshop on Thermal Sciences, Chicago, April 19-21, 1991.

"A Four Field Model for Two-Phase Flow," 12th Symposium on Energy Engineering Sciences, 4/27-29/94, Argonne National Laboratory (with D.A. Drew).

"Synchronic Nonlinear Forcing of a Sonoluminescent Microbubble using Fast Ultrasonic Pulses," Proceedings of the APS, March 1996 (with F.J. Bonetto and G.A. Delgadino).

"A CFD Analysis of Multidimensional Two-Phase Flow and Heat Transfer Using a Four Field Two-Fluid Model," Proceedings of the Thirteenth U.S. National Congress on Applied Mechanics, U of Florida, June 21-26, 1998.

"A CFD Analysis of Multidimensional Two-Phase Flow & Heat Transfer with a Four Field Two-Fluid Model," Proceedings of IMUST Meeting, Santa Barbara, CA, March 18-20, 1999.

"A Center-Averaged Two-Fluid Model for Wall-Bounded Flows," ONR Free Surface and Bubbly Flows Workshop, La Jolla, CA, Feb. 24-26, 1999 (with A.E. Larreteguy and D.A. Drew).

"Multidimensional Two-Fluid Modeling of Two-Phase Flow and Heat Transfer In a Boiling Channel with Applications to CHF Modeling in Forced-Convection Sucooled Boiling," National Science Agency of Tiawan Report, August 1999 (with C. Pan and D. A. Drew)

"An Analysis of Two-Phase Flow and Heat Transfer using a Multidimensional, Multi-Field, Two-Fluid Computational Fluid Dynamics (CFD) Model", Proceedings of the Japan/US Seminar on Two-Phase Flow Dynanmics, Santa Barbara, California, June 5-8, 2000 (with D.A. Drew).

"An Analysis of Rectified Diffusion in a Sonoluminescing Gas Bubble", Proceedings of the Japan/US Seminar on Two-Phase Flow Dynamics, Santa Barbara, California, June 5-8, 2000 (with S. Bae and R. Nigmatulin).

"On the Multidimensional Analysis of Two-Phase Flows" , Proceedings of the USDOE Workshop on Scientific Issues in Multiphase Flow , U. Illinois-CU ,May 7-9 , 2002 (with D. Drew).

"Sonoluminescence and the Search for Sonoluminescence" , ANS Panel on Advances in Fusion Technology , ANS Annual Meeting , Hollywood , Florida , June 9-13 , 2002

"Response - Tabletop Fusion Revisited (by: A. Galonsky)" , *Science* on-line , 2002 (with R. Taleyarkhan , R. Block and C. West).

"Response - Questions Regarding Nuclear Emissions in Cavitation Experiments (by: M. Saltmarsh and D. Shapira)" , *Science* on-line , 2002 (with R. Taleyarkhan , R. Block and C. West).

"Energetics of Nano-to-Macro Scale Triggered Tensioned Metastable Fluids", ORNL/TM-2022/233 , 2002 (with R. Taleyarkhan , C. West , J. Cho and I. Akhatov).

"The Modeling of Bubbly Flows Around Ship Hulls" , Maui High Performance Computing Center, Application Brief , 2002 (with F. Moraga and D. A. Drew).

"Full-Scale Simulations of the Research Ship Roger Revelle", Maui High Performance Computing Center, Application Brief , 2003 (with F. Moraga and D. A. Drew).

"The Development of Interfacial Drag and Non-Drag Laws for Stratified Flow using PHASTA-2I" , Proceedings of the American Physical Society, East Rutherford , NJ ,Nov.23-25 , 2003

"Computational Multiphase Fluid Dynamics (CMFD) Analysis of a Single ESBWR Riser Channel," ISL Final Topical Report, 2004 (with S. Antal, M. Popowski).

"Research in Support of the Use of Rankine Cycle Energy Conversion Systems for Space Power and Propulsion," NASA/CR-2004-213142, 2004 (with V. Dhir)

"Safety and Security of Commercial Spent Nuclear Fuel Storage," Classified National Research Council (NRC) Topical Report, 2004.

"Nuclear Engineering External Review Committee Report," Purdue University Report, 2004.

"The CMFD Analysis of Three-Field Chemical Reactors," CREL Topical Report, 2004 (with S. Antal).

"The Sonofusion Research Project at KIT and RPI" , Proceedings of the 62nd Meeting of the American Physical Society - Division of Fluid Dynamics, Minneapolis, Minnesota, November 22-24, 2009 (with Markus Stokmaier, Bernard Malouin, Andreas Class , Thomas Schulenberg).

Special Courses Taught

- RPI Summer Program on Nuclear Reactor Design & Basic Nuclear Technology (RPI sponsored), Troy, NY 1997-1983
- Short course in Introduction to Nuclear Power, Continuing Education Center, (CEC sponsored) Sheraton Motor Inn, East Brunswick, NJ, 1978
- Two-Phase Flow and Heat Transfer (B&W sponsored), Alliance, OH, 1978
- Two-Phase Flow and Heat Transfer (EG&G sponsored), Idaho Falls, ID, 1979-1983
- Two-Phase Flow Instrumentation course (FDI sponsored), Dartmouth University, 1978

- Multiphase Flow Instrumentation course (CEA sponsored), Grenoble, France, 1979
- Workshop on Transient Analysis of Reactors (FRG sponsored), Munich, Germany, 1979
- Reactor Thermal-Hydraulics, AIChE short course, 1976 -1983
- Stanford summer course on Two-Phase Flow Instrumentation, 1980
- Course on Two-Phase Flow and Boiling, Yankee Atomic Electric Company, 1980
- Summer school on Reactor Thermal-Hydraulics (ICHMT sponsored), Dubrovnik, Yugoslavia, 1980
- Stanford summer course on Two-Phase Flow & Heat Transfer (Stanford sponsored), Stanford University, 1982
- Simposio Internacional Sobre Flujos Bifasicos en Tuberias (Mexican sponsored), Cuernavaca, Mexico, 1983
- Lecture Series No. 8, Construction Aspects of Two-Phase Flow Equipment (Norwegian sponsored), Trondheim, Norway, 1984
- Workshop on Industrial Applications of Multiphase Flow (UCS sponsored), Santa Barbara, CA 1985
- Workshop on Two-Phase Heat and Mass Transfer in Single and Multicomponent Systems (RPI sponsored), Troy, NY 1986
- Modern Developments in Boiling Heat Transfer and Two-Phase Flow (CMR sponsored), Troy, NY 1988-present
- An Introduction to Applied Nonlinear Dynamics - Bifurcations, Fractals and Chaos in Heat Transfer and Fluid Flow (ETH sponsored), Zurich, Switzerland, 1994-1996
- Short Course on Multiphase Flow and Heat Transfer (ETH sponsored), Zurich, Switzerland, 1994-1996
- 2001 Frederic Joliot/Otto Hahn Summer School , Karlsruhe , Germany , August 20-29 , 2001
- Short Course on "Transient Multiphase Flow and Heat Transfer at Microgravity" , NASA , Glenn Resrarch Center , Cleveland , Oh. Sept. 17-19 , 2002 (with M.Z. Podowski)

Research Funding

USNRC

Two-Phase Flow Phenomena in Nuclear Reactor Technology

$1,006,240 6/1/76-5/31/80.

Technical Assistance Program for the Thermal-Hydraulic Stability Analysis Relating to Light Water Nuclear Reactors
$676,425 3/15/76-94/83.

Multidimensional Effects in LWR Thermal-Hydraulics
$176,000 6/1/80-1/31/81.

The Development of Thermal-Hydraulic Stability Methods for BWR's
$100,000 9/5/81-9/4/83.

ONR

An Experimental Study of Plunging Liquid Jet Induced Air Carryunder and Dispersion
$122,883 11/1/90-10/30/91.

A Study of Spreading Two-Phase Jets
$120,000 1/1/94-12/31/95.

A Study of Spreading Two-Phase Jets
$138,892 3/1/95-12/31/95.

Bubbly Flow Dynamics and Numerical Implementation in Complex Flows
$707,701 2/1/96-6/30/2000.

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$170,748 9/1/83-8/31/85.

Perform Bubble Fusion Analysis and Experiments at RPI and ORNL
$95,000 4/3/98-9/30/99.

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$164,784 , 7/28/99-7/27/2003.

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$15,000 9/1/86-6/30/87.

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$304,667 2/1/84-1/31/86.

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$396,544 7/26/04 - 9/30/07

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In Progress

- None

Doctoral

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In Progress

- Markus Stokmaier (FZK)

UNITED STATES
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In re:	Docket Nos. 50-247-LR; 50-286-LR
License Renewal Application Submitted by	ASLBP No. 07-858-03-LR-BD01
Entergy Nuclear Indian Point 2, LLC, Entergy Nuclear Indian Point 3, LLC, and Entergy Nuclear Operations, Inc.	DPR-26, DPR-64 September 13, 2010

Riverkeeper, Inc. provisionally designates the attached Declaration of Dr. Joram Hopenfeld dated September 13, 2010 as containing Confidential Proprietary Information Subject to Nondisclosure Agreement

REDACTED, PUBLIC VERSION

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In re:	Docket Nos. 50-247-LR; 50-286-LR
License Renewal Application Submitted by	ASLBP No. 07-858-03-LR-BD01
Entergy Nuclear Indian Point 2, LLC, Entergy Nuclear Indian Point 3, LLC, and Entergy Nuclear Operations, Inc.	DPR-26, DPR-64 September 13, 2010

DECLARATION OF DR. JORAM HOPENFELD IN OPPOSITION TO ENTERGY'S MOTION FOR SUMMARY DISPOSITION OF NEW YORK STATE CONTENTIONS 26/26A & RIVERKEEPER TECHNICAL CONTENTIONS 1/1A (METAL FATIGUE OF REACTOR COMPONENTS)

Joram Hopenfeld, hereby declares under penalty of perjury that the following is true and correct:

1. I have been retained by Riverkeeper, Inc. ("Riverkeeper") as an expert witness in proceedings concerning the application by Entergy Nuclear Operations, Inc. ("Entergy") for the renewal of two separate operating licenses for the nuclear power generating facilities located at Indian Point on the east bank of the Hudson River in the Village of Buchanan, Westchester County, New York, for twenty years beyond their current expiration dates.

2. I submit this declaration in opposition to Entergy's August 25, 2010 Motion for Summary Disposition of New York State Contentions 26/26A & Riverkeeper Technical Contentions 1/1A (Metal Fatigue of Reactor Components) (hereinafter "Entergy's Motion for Summary Disposition").

3. My professional and educational qualifications are described in the *curriculum vitae* appended hereto as Attachment 1. Briefly summarized, I am an expert in the field relating to nuclear power plant aging management. I am a mechanical engineer and hold a doctorate in mechanical engineering. I have 45 years of professional experience in the fields of thermal-hydraulics, material/environment interaction instrumentation, design, project management, and nuclear safety regulation, including 18 years in the employ of the U.S. Nuclear Regulatory Commission ("NRC").

4. My extensive professional experience has afforded me with knowledge and expertise regarding the material degradation phenomenon known as "metal fatigue," that is, the fatigue or "cyclic stress" of metal parts due to repeated stresses during plant operation. Most

recently, I was a technical consultant and expert witness for the New England Coalition in the Vermont Yankee license renewal proceeding, where I testified at an adjudicatory hearing concerning metal fatigue.

5. I reviewed the April 30, 2007 License Renewal Application ("LRA") submitted by Entergy to renew the operating licenses for Indian Point Units 2 and 3, and assisted Riverkeeper with the preparation of Contention TC-1, which challenged Entergy's aging management plan for addressing metal fatigue at Indian Point during the proposed period of extended operation.

6. I reviewed Entergy's January 22, 2008 amendment to its original LRA, in which Entergy purported to provide additional information regarding its aging management program for addressing metal fatigue, and assisted Riverkeeper with the preparation of an amended contention (Riverkeeper Contention TC1-A) to articulate the ongoing deficiencies with Entergy's plan to deal with metal fatigue.

7. I have reviewed Entergy's Motion for Summary Disposition together with its attendant declarations and attachments, including Entergy's submission to the Atomic Safety and Licensing Board ("ASLB") dated August 10, 2010 entitled "Notification of Entergy's Submittal Regarding Completion of Commitment 33 for Indian Point Units 2 and 3" (NL-10-082), and two Westinghouse proprietary documents entitled "Environmental Fatigue Evaluation for Indian Point Unit 2" and "Environmental Fatigue Evaluation for Indian Point Unit 3." I have also reviewed excerpts of two proprietary Westinghouse computer program manuals, provided to Riverkeeper on September 3, 2010. After a review of these documents, for the reasons explained more fully below, it remains my professional opinion that Entergy has, to date, failed to demonstrate that the affects of metal fatigue will be adequately managed at Indian Point during the proposed period of extended operation.

8. A discussion of various assertions in Entergy's filing, sufficient to establish that Entergy's arguments are by no means dispositive and that technically credible and substantial disputes of fact remain, follows below.

Entergy's "Refined" Fatigue Evaluations

9. Entergy's LRA included two tables (4.3-13 and 4.3-14) containing values of environmentally adjusted cumulative usage factors ("CUF_{en}") for representative plant components. Four of these values exceeded unity, indicating susceptibility to the aging effects of metal fatigue during the period of extended operation. For several of the representative components listed in these tables, Entergy did not perform a fatigue analysis to discern the value of the CUF_{en}.

10. Entergy's August 2010 "refined" fatigue analysis undertook to recalculate the CUF_{en} values for the representative components of LRA tables 4.3-13 and 4.3-14. Entergy's new assessment now purports to determine valid CUF_{en} values that are less than 1.0 (i.e., unity) for the previously problematic components, and for those components for which CUF_{en} values were previously undetermined.

11. I disagree with Entergy's conclusory and, as yet, unsupported statement that "valid assumptions, transients, cycles, external loadings, analysis methods, and F_{en} factors were used in the EAF [environmentally-assisted fatigue] analyses for IP2 and IP3." *See* Entergy Motion for Summary Disposition at 19-20; *id.* at Attach. 2, ¶ 44. Although Entergy claims that "[t]he specific methodology and assumptions used by Westinghouse to determine refined CUF_{en} values for the relevant IPEC components are fully documented," *see* Entergy Motion for Summary Disposition, Attach. 2, ¶ 44; *see also* Entergy Motion for Summary Disposition at 2 ("By completing these evaluations and fully disclosing the associated methodologies, assumptions, and results, Entergy has both satisfied Commitment 33 and addressed the issues admitted by the Board in NYS-26/26A and TC-1/1A"), Entergy has, in fact, failed to explain various assumptions and methodologies employed to recalculate CUF_{en} values, calling into question the validity of the outcome.

12. While Entergy describes the general methodology employed to derive the revised calculations, many critical underlying assumptions reveal the potential for a wide margin of error. [redacted] *See* NUREG/CR-6909; EnvFat 1.0 User's Manual, Version 1.0 (May 2009), IPECPROP00056783; Environmental Fatigue Evaluation for Indian Point Unit 2, WCAP-17199-P, Revision 0 (Westinghouse, June 2010); Environmental Fatigue Evaluation for Indian Point Unit 3, WCAP-17200-P, Revision 0 (Westinghouse, June 2010)). The F_{en} equations articulated in NUREG/CR-6909 are derived from laboratory tests on the effect of strain and coolant environments on fatigue life. In such equations, the F_{en} is expressed in terms of dissolved oxygen, temperature, sulfur content, and strain rate for several materials of interest. However, identifying the relevant terms is only the beginning of the inquiry; because significant differences exist between the laboratory and the reactor environments, there are numerous uncertainties in applying such F_{en} equations to reactor components, including flow and strain rates, loading history, mean stress, oxygen, surface finish, and water impurities. *See* NUREG/CR-6909, pg. 72 (discussing 13 uncertainties in applying F_{en} equations to actual reactor components). To appropriately apply such F_{en} equations to actual reactor components, the results must be adjusted to account for the varying parameters. Entergy has presented no evidence to suggest that the methodology employed to re-calculate CUF_{en} appropriately considered all relevant factors. In consideration of relevant uncertainties, NUREG/CR-6909 specifies appropriate bounding F_{en} values of 12 and 17 for stainless steel and carbon and low alloy steels (LAS), respectively. To the contrary, Entergy continues to use unrealistically low F_{en} values (for example, 1.74-2.45 for LAS), that are, as yet, not justified in light of the wide range of parameters unaccounted for.

13. One of the largest uncertainties in determining appropriate F_{en} values is the concentration of dissolved oxygen (DO) in the water at the surface of each component during the transient. The F_{en} varies exponentially with the DO and is, therefore, sensitive to the uncertainties in the DO concentration. Because DO has a negative solubility coefficient in water, the amount of oxygen dissolved in the coolant increases significantly during shutdown transients. Data of the Electrical Power Research Institute (EPRI) on actual oxygen concentrations in a

reactor during start up and shut downs shows that oxygen concentrations vary by more than an order of magnitude with the change in temperature. *See R&D Status Report*, EPRI Journal (Jan/Feb 1983). Since DO levels are not measured at the surface of reactor components during transients, the actual DO levels, and resulting F_{en}, are subject to uncertainties. For example, an uncertainty of five in DO levels at the surface of a given component could lead to under-predicting the F_{en} by a factor of five at a minimum. [redacted] NRC reports specify that "the values of temperature and DO may be conservatively taken as the maximum values for the transient." *See* NUREG/CR-6583 at pg. 78. [redacted] In any event, Entergy's new metal fatigue evaluation fails to specify DO values used in the calculations of F_{en} for each component during the transients; without an understanding of the DO levels used in each transient for the calculations of F_{en}, it is impossible to conclude that the claimed CUF_{en} values, which Westinghouse and Entergy's recent refined analysis purport to predict to a ten-thousandth of a decimal point, are accurate.

14. Furthermore, Entergy's evaluation does not specify the heat transfer coefficients used for each component during the transients. The CUF_{en} value will vary greatly depending on the heat transfer coefficient. The heat transferred to the surface reactor components during transients controls the cyclic thermal stresses and, therefore, directly affects the CUF_{en}. The local heat transfer rate primarily depends on component geometry, flow rate, and the local temperature difference between the coolant and the surface of the component. Heat transfer rates are calculated by multiplying an experimental heat transfer coefficient, "h", by the local temperature difference, Δ T. The heat transfer coefficient has been measured for many different geometries and flow conditions and is known for well-defined conditions. The flow at the surface of reactor components, however, is not well defined during transients and, therefore, approximations and assumptions are required in selecting the proper h for a given set of conditions. Such approximations lead to uncertainties in the CUF_{en}. Typical variations in h could increase stress by a factor of 2. To assess the uncertainty of h, it is imperative to know the component geometry, the piping geometry upstream of the component, the flow velocities, and the corresponding expressions for h, none of which are specified in Entergy's new evaluation. Without an understanding of the values of h and the assumptions used to arrive at such values, the methodology employed by Entergy to re-calculate CUF_{en} remains highly questionable and it is impossible to conclude that Entergy's new CUF_{en} calculations are accurate to the degree Entergy now claims.

15. Moreover, the number of transients that were used in the calculations directly affects the CUF_{en}. Because the actual number transients during the extended period of operation is not known, Entergy made certain unknown assumptions in obtaining this number. Entergy's documentation related to the newly calculated CUF_{en} values fails to describe how the number of

transients was obtained or the underlying assumptions employed. This serves to cast further doubt upon methodology employed by Entergy and the accuracy of Entergy's new calculations.

16. Based on the foregoing, I disagree with Entergy's apparent position that its "CUF values result[ed] from conservative fatigue calculations" or that Entergy's revised calculations have necessarily taken "advantage of excess conservatisms inherent in the original fatigue analyses." *See* Entergy Motion for Summary Disposition, Attach. 1, ¶ 16. In light of the various uncertainties discussed above, it is far from clear that Entergy's new analysis is conservative. Any conservatisms Entergy claims to have take into account are overshadowed by the numerous uncertainties which Entergy has failed to even describe, as discussed above.

17. Given the large uncertainties in the input parameters and other assumptions used to generate the revised metal fatigue calculations, the methodology employed by Entergy suggests the likelihood of a wide margin of error. Accordingly, the CUF_{en} values now cited by Entergy may underestimate the detrimental effects of the environment on fatigue strength of the subject components. Notably, many of the revised calculations remain very close to unity and with a margin of error to account for varying input data and other assumptions, such numbers could be considerably higher than the 1.0 regulatory threshold. At a minimum, in light of Entergy's failure to provide information critical for a proper assessment of the validity of the refined CUF_{en} analysis, as discussed above, I am not yet in a position to fully refute Entergy's various assertions contained in its Motion for Summary Disposition.

18. Accordingly, Entergy's revised CUF_{en} calculations can not be used as the basis for concluding that the aging effects of metal fatigue will be adequately managed at Indian Point during the period of extended operation.

Inadequacy of Entergy's Aging Management Plan ("AMP") for Metal Fatigue

19. Entergy has failed to demonstrate that it has a program to monitor, manage, and correct metal fatigue related degradation sufficient to comply with 10 C.F.R. § 54.21(c), or the regulatory guidance of NUREG-1801, *Generic Aging Lessons Learned (GALL) Report*.

20. In response to CUF_{en} values in excess of regulatory limits, Entergy opted to conduct additional analyses, and update its calculations. As explained above, despite Entergy's assertions that the recalculated usage factors are within proper limits, there is paltry evidence to suggest that the recalculated CUF_{en} values are accurate to the degree Entergy now claims. This fails to comply with the AMP articulated in the *GALL Report*, which specifies that acceptable corrective action includes "a more rigorous analysis of the component to demonstrate that the design code limit will not be exceeded during the extended period of operation." NUREG-1801 § X.M1, Metal Fatigue of Reactor Coolant Pressure Boundary, ¶ 7. Based on the discussion above, Entergy's August 2010 metal fatigue calculations fail to make such a demonstration.

21. I continue to disagree with Entergy's position that "there is no requirement or need for Entergy to 'broaden' its EAF analyses beyond the components identified in LRA Tables 4.3-13 and 4.3-14." *See* Entergy Motion for Summary Disposition, Attach. 2, ¶ 51. Given Entergy's

previous findings in its initial April 2007 LRA that CUF_{en} values for various components exceeded the regulatory threshold, and the questionable nature of the recently revised calculations to demonstrate that the CUF_{en} values of such components would remain under 1.0, a necessary part of an effective plan to monitor for metal fatigue is to expand the scope of the fatigue analysis beyond simply representative components, to identify other components whose CUF may be greater than 1.0. Entergy must identify additional reactor locations for potential high susceptibility to metal fatigue as prescribed by industry guidance document, MRP-47, Revision 1, Electric Power Research Institute, *Materials Reliability Program: Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application* at 3-4 (2005), in order to ensure that appropriate aging management measures are taken in a timely fashion. Entergy's failure to expand its fatigue analysis is inconsistent with the *GALL Report* AMP, which specifies that "[f]or programs that monitor a sample of high fatigue usage locations, corrective actions include a review of *additional* affected reactor coolant pressure boundary locations," and that sample locations identified in NUREG/CR-6260 are simply the "minimum" set of components to analyze. NUREG-1801 § X.M1, Metal Fatigue of Reactor Coolant Pressure Boundary, ¶¶ 5, 7 (emphasis added).

22. The lack of a reliable, transparent, complete assessment of CUF_{en} values for susceptible plant components at Indian Point fails to comply with the "Scope of Program" articulated in the *GALL Report*, which specifies that a program for managing metal fatigue must include adequate "*preventative measures* to mitigate fatigue cracking of metal components of the reactor coolant pressure boundary caused by anticipated cyclic strains in the material." NUREG-1801 § X.M1, ¶ 1 (emphasis added).

23. Entergy's plans for correcting metal fatigue related degradation depend initially upon calculating the vulnerability of plant components. Indeed, Entergy intends to rely upon future CUF_{en} calculations throughout the period of extended operation to manage metal fatigue. Entergy's calculations are meant to signify when components require inspection, monitoring, repair, or replacement, and, according to Entergy, will trigger when such actions are taken. Accordingly, the validity of Entergy's monitoring program depends upon the accuracy of the CUF_{en} calculations. Thus, Entergy's flawed methodology for calculating CUF_{en}, as discussed above, which Entergy ostensibly intends to employ throughout the period of extended operation, as well as Entergy's refusal to expand the scope of components to be assessed, renders Entergy's vague commitments to inspect, repair, and replace affected locations insufficient to ensure proper management of metal fatigue during the license renewal term.

24. In light of the absence of comprehensive, accurate metal fatigue calculations to properly guide Entergy's aging management efforts, Entergy has failed to define specific criteria to assure that susceptible components are inspected, monitored, repaired, or replaced in a timely manner. Once components with high CUFs have been properly identified, Entergy must describe a fatigue management plan for each such component that should, at a minimum, rank components with respect to their consequences of failure, establish criteria for repair versus defect monitoring, and establish criteria for the frequency of the inspection (considering for example defect size changes and uncertainties in the stress analysis and instrumentation), and allow for independent and impartial reviews of scope and frequency of inspection.

Conclusion

25. For the foregoing reasons, Entergy has failed to demonstrate that the aging effects of metal fatigue will be adequately managed for the period of extended operation, as required by 10 C.F.R. § 54.21.

In accordance with 28 U.S.C. §1746, I declare under penalty of perjury that the foregoing is true and correct.

Executed on Sept 13, 2010.

Joram Hopenfeld

Joram Hopenfeld

List of References

Entergy NL-08-021, License Renewal Application Amendment 2, Indian Point Nuclear Generating Unit Nos. 2 and 3, Docket Nos. 50-247 and 50-286 (Jan. 22, 2008), ADAMS Accession No. ML080290659

Entergy NL-10-082, License Renewal Application – Completion of Commitment #33 Regarding the Fatigue Monitoring Program, Indian Point Nuclear Generating Unit Nos. 2 and 3, Docket Nos. 50-247 and 50-286, License Nos. DPR-26 and DPR-64 (Aug. 9, 2010), ADAMS Accession No. ML102300504

EnvFat 1.0 User's Manual, Version 1.0 (May 2009), IPECPROP00056783

Environmental Fatigue Evaluation for Indian Point Unit 2, WCAP-17199-P, Revision 0 (Westinghouse, June 2010)

Environmental Fatigue Evaluation for Indian Point Unit 3, WCAP-17200-P, Revision 0 (Westinghouse, June 2010)

Indian Point Energy Center License Renewal Application (April 30, 2007)

MRP-47, Revision 1, Electric Power Research Institute, *Materials Reliability Program: Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application*

NUREG-1801, *Generic Aging Lessons Learned (GALL) Report* (Sept. 2005), Section XI.M1

NUREG-1800, *Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants* (Sept. 2005), Section 4.3

NUREG/CR-6260, Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components (March 1995)

NUREG/CR-6583, *Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels*

NUREG/CR-6909, *Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials*

R&D Status Report, EPRI Journal (Jan/Feb 1983)

Safety Evaluation Report Related to the License Renewal of Indian Point Nuclear Generating Unit Nos. 2 and 3, Docket Nos. 50-247 and 50-286, Entergy Nuclear Operations, Inc. (Nov. 2009), NUREG-1930, ADAMS Accession No. ML093170671

ATTACHMENT 1

to

Declaration of Dr. Joram Hopenfeld in Opposition
to Entergy's Motion for Summary Disposition of
NYS 26/26A & RK TC1/1A (Metal Fatigue)
(September 13, 2010)

Curriculum Vitae for Dr. Joram (Joe) Hopenfeld

1724 Yale Pl., Rockville, MD 20850

Tel: 301 340 1625

A. Professional Expertise:

a. **Nuclear Safety and Licensing** (design basis/severe accidents)

b. **Thermal/Hydraulics** (Transient Boiling, Jet Mixing, Reentry Heat transfer, molten metal/coolant interactions, pool fires, computer code developments)

c. **Materials/Environment Interaction** (corrosion, erosion, stress corrosion, fatigue,. cavitation, fouling)

d. **Radioactivity Transport (10 CFR Part 100)**

e. **Industrial Instrumentation and Environmental Monitoring.**

B. Current Position - CEO, Noverflo, Inc

C. Education - Engineering- University of California at Los Angeles: BS 1960, MS 1962, Ph.D 1967.

D. Summary of Work Experience

1. Nuclear Plant Related Experience

I have 45 years of experience in industry and government primarily in the areas of thermal hydraulics, materials, corrosion, radioactivity transport, instrumentation, PWR steam generator transient testing and accident analysis. I have managed major international programs on steam generator performance during steam generator tube ruptures, steam line and feed line breaks. Following a decade of studies and several Advisory Committee on Reactor Safety hearings, the Nuclear Regulatory Commission, ("NRC") adopted my position regarding the safety consequences of operating with degraded steam generator tubes. In 2001 the NRC initiated a major program on the effects of steam generator tube degradation on plant safety (see NRC website). I have consulted to law firms and citizen groups regarding Steam Generators, Thermal Hydraulics, Corrosion , and Material Fatigue in connection with license renewals and a power upgrades.

2. Non Nuclear Related Experience

I am the owner and the CEO of a small Maryland company, Noverflo, Noverflo is developing advanced fiber optic sensors for the oil & gas and the environmental monitoring industries. In 2004 Noverflo has completed a three year program which was sponsored by the U.S. Department of Energy. The program produced a new system for automatic tank gauging, which will be presented at the 2006 National Petrochemicals and Refiners Association Maintenance Conference.

In 1994-1996 Noverflo has developed and commercialized a shutoff valve for fuel tanks to comply with new EPA regulations.

E. Brief Employment History

A. Recent Consulting

1. Winston & Strawn , 1400 L St. Washington D.C

2001

Provided assistance in connection with the February 2000 steam generator event at Indian Point.

2. C-10 Research and Education Foundation, Inc. 44Merrimac St. Newburyport, MA

2002-2003

Provided assistance in the preparation of a 2.206 petition to the NRC and other matters in connection with steam generator problems at the Seabrook Station

3. California Earth Corps (Sabrina D. Venskus, Attorney at Law, Santa Monica, CA)
2005

Provided testimony to the Public Utility Commission of the State of California on behalf of California Earth Corps in connection with the San Onofre steam generator replacement project.

4. **New England Coalition** (Raymond Shadis, Edgecomb, Maine 04556)

5-200

Te ... ess in connection with Vermont Yankee power uprate and life extension hearings before the **Atomics Safety and Licensing Board.** Prepare contentions and testify before the Board.

ployment

...ion testing of materials for the design and operation of liquid metal cooled nuclear reactors. Modeling Transient Boiling in water and sodium. Modeling Sodium Fires. Modeling ... of SNAP fuel rods on reentry into the earth atmosphere. Atomics International, Canoga Par...

1971- 1973- Participated in the resolution of design issues as related to material behavior in the Breeder reactor environment. Atomic Energy Commission

1973 – 1978 Project Manager for the safety evaluation and testing of steam generators for liquid metal reactors. Managed the development of thermal –hydraulic computer codes such as COBRA. ERDA/Department of Energy. Responsible for testing material compatibility and cavitation damage in sodium. Development of acoustic leak detection systems for sodium/water reactions.

1978 – 1982 Project Manager for the development of materials and instrumentation for high temperature steam generators for fossil plants. Responsible for the resolution of issues relating to corrosion/erosion and NOx /SOx emissions, Department of Energy.

1982 – 2001 Program manager for the resolution of various, thermal hydraulics, material corrosion and safety issues primarily in relation to PWR steam generators. Nuclear Regulatory Commission.

Publications

In addition to numerous reports, I have published 15 papers in peer-reviewed technical journals in the areas of thermal-hydraulics, corrosion/ erosion, steam generator dose releases during accidents, steam explosions, sensors and ECM machining.

Peer Reviewed

1 "New Fiber Optic Based Technology for Automatic Tank Gauging", **Sensors** ,December 2006

2. "Distributed Fiber Optic Sensors for Leak Detection In Landfills", Proceeding of SPIE Vol 3541 (1998)

3. "Continuous Automatic Detection of Pipe Wall Thinning", ASME Proceedings of the 9th, International Conference on Offshore Mechanics and Arctic Engineering. Feb. 1990

4 "Iodine Speciation and Partitioning in PWR Steam Generators", Nuclear Technology, March 1990

5. Comments on "Assessment of Steam Explosion Induced Containment Failures" Letter to the Editor, Nuclear Science and Engineering, Vol. 103, Sept. 1989

6. "Experience and Modeling of Radioactivity Transport Following Steam Generator Tube Rupture", Nuclear Safety, 26,286, 1985

7. "Simplified Correlations for the Predictions of Nox Emissions from Power Plants". AIAA Journal of Energy, Nov.-Dec., 1979

8. "Grain Boundary Grooving of Type 304 Stainless Steel in Armco Iron Due to Liquid Sodium Corrosion", Corrosion, 27, No.11, 428, 1971

9. "Corrosion of Type 316 Stainless Steel with Surface Heat Flux in 1200 Flowing Sodium", Nuclear Engineering and Design, 12; 167-169, 1970

10. "Prediction of the One Dimensional Cutting Gap in Electrochemical Machining", ASME Transaction, J. of Engineering for Industry, p100 (1969)

11. "Electrochemical Machining- Prediction and Correlation of Process Variables", ASME Transactions, J. of Engineering for Industry, 88:455-461, (1966)

12. "Laminar Two-Phase Boundary Layers in Subcooled Liquids", J. of Applied Mathematics and Physics (ZAMP), 15, 388-399 (1964)

13. "Onset of Stable Film Boiling and the Foam Limit", International j. of Heat Transfer and Mass Transfer, 6; 987-989 (1963)) (co-author)

14 "Operating Conditions of Bubble Chamber Liquids", The Review of Scientific Instruments, 34, 308-309. (1963); co-author

15. "Similar Solutions of the Turbulent Free Convention Boundary Layer for an Electrically Conducting Fluid in the Presence of a Magnetic Field," AIAA J. 1:718-719 (1965)

Not Peer Reviewed (Recent Publications Only)

1. **New Fiber Optic Based Technology for Automatic Tank Gauging** (ATG), NPRA – 2006 Reliability and Maintenance Conference, May 23-26, San Antonio, TX

2. **Automatic Tank Gauging: A New Level of Accuracy; A New Device Promises Greater Accuracy for Custody Transfer by Combining Fiber- Optic Sensing with a Pressure.** Sensors Magazine, 12/01/06

3. **PlasticOptical Fibers Sensors for Industrial Process Controls and Environmental Monitoring, POF World West 2007, June 25-27. 2007**

List of Patents

1. Automatic Shut-Off Valve for Liquid Storage Tanks, 5,522,415
2. Method and Apparatus for Detecting the Presence of Fluids, 5,200,615
3. Sensors For Detecting Leaks, 5,187,366
4. Method for Monitoring Thinning of Walls and Piping Components 4,922,74
5. Method for Monitoring Thinning of Pipe Walls, 4,779,453
6. Looped Fiber Optic Sensor for the Detection of Substances (5,828,798)
7. Coated Fiber Optic Sensor for The Detection of Substances (5,982,959)
8. Method and Apparatus for Analyzing Information of Sensors Provided Over Multiple Waveguides (6,870,607)

Honors

1. Engineer of Distinction – Published by Engineers Joint Council
2. American men and Women in Science
3. The Blackwall Award for Machine Tools
4. Member Sigma-Xi

Professional Activities

1. Reviewed papers for the ASME Journal and the Journal of Sensors and Actuators
2. Taught a class on Diesel Engines at Montgomery College, Rockville, MD.
3. Served as a member of a Railroad Committee that development a standard for locomotive Fueling
4. Funded and sponsored research and development work at the Engineering Department of the University of Virginia. The research produced a novel method of measuring pipe wall thinning from erosion/corrosion