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September 9, 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 proposed new and amended contention concerning metal fatigue along with a motion for leave and two supporting expert declarations from Dr. Richard Lahey and Dr. Joram Hopenfeld.

The declarations 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 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.

The State of New York is also serving a notice of change of email addresses for its representatives. A certificate of service is also enclosed.

Respectfully submitted,

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TEMPLATE=SECY041 DS03

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

STATE OF NEW YORK'S AND RIVERKEEPER'S MOTION FOR LEAVE TO FILE A NEW AND AMENDED CONTENTION CONCERNING THE AUGUST 9, 2010 ENTERGY REANALYSIS OF METAL FATIGUE

A. Introduction

Pursuant to 10 C.F.R. § 2.309(f)(2) the State of New York seeks leave to file the attached Consolidated Contention NYS-26B/RK-TC1B. The Contention is based on Entergy's filing, on August 10, 2010, of a new cumulative use environmental fatigue calculation for certain components of IP 2 and IP 3 ("CUF_{en} Reanalysis"), which was filed in an attempt to meet its obligations under 10 C.F.R. § 54.51(c)(1)(iii) with regard to metal fatigue. The CUF_{en} Reanalysis is not merely a minor alteration in the previous analysis, but represents an entirely new CUF_{en} analysis using different assumptions and input values and producing markedly different results. The new analysis does not merely modify a few parts of the prior analysis but is, rather, a replacement of that prior analysis. Review of the CUF_{en} Reanalysis and its supporting documentation reflects that many modifications were made and the result is an entirely new analysis.[1] These changes reflect Entergy's attempt to address the fact that in its

[1] Entergy concedes that what it is now submitting is intended to totally replace the CUF_{en} analysis that it prepared as part of its initial License Renewal Application ("LRA"). Attachment 1 to NL-10-082 (August 9, 2010); *see* LRA at § 4.3.3 describing the previous CUF_{en} analysis conducted by Entergy.

original CUF_{en} analysis a number of components were shown to have CUF_{en} values >1.0. Attachment 1 to NL-10-082 (August 9, 2010). While Entergy refers to these reanalyses as "refined fatigue analyses to determine valid CUFs" (NL-10-082, Attachment 1 at 1), in fact Entergy has removed conservatisms contained in the original CUF_{en} analysis in order to make it appear that the CUF_{en} values were all <1.

This proposed consolidated contention is based on the CUF_{en} Reanalysis. Pursuant to the Scheduling Order issued by the Board on July 1, 2010, this proposed consolidated contention is timely, having been filed within 30 days of the date on which Entergy provided the Board and the parties with its CUF_{en} Reanalysis.[2] *See* Scheduling Order dated July 1, 2010 at 6. Thus, the remainder of this pleading addresses the other factors in 10 C.F.R. § 2.309(f)(2) as well as the requirements of 10 C.F.R. § 2.309(f)(1) as required by the Board's July 1, 2010 Order. *Id.*

[2] The initial filing by Entergy on August 10, 2010, was devoid of much of the supporting documentation, including the two Westinghouse reports (Westinghouse, WCAP-17199-P, "Environmental Fatigue Evaluation for Indian Point Unit 2," (June 2010) and Westinghouse, WCAP-17200-P, "Environmental Fatigue Evaluation for Indian Point Unit 3," (June 2010)) which contain the analysis upon which Entergy relies for its assertion that it has now met its AMP commitment with regard to metal fatigue,. The Westinghouse reports were received by the State on August 12, 2010, but none of the non-publically available references in those documents were provided. Upon receipt, the reports were provided to Dr. Richard T. Lahey, Jr. and Dr. Joram Hopenfeld, who noted the absence of several documents that were essential to properly evaluate whether Entergy, by way of Westinghouse, had used a reliable methodology for the CUF_{en} Reanalysis. Among the missing information were the Westinghouse Code Manual for the WESTEMS computer code, a "propagation of error" analysis, and the criteria used for selecting various critical parameters, all of which would be expected to exist if the most fundamental methodologies were followed. *See* September 2010 declarations of Dr. Richard T. Lahey ("Lahey Declaration") at ¶ 11 and Dr. Joram Hopenfeld ("Hopenfeld Declaration") at ¶¶ 10-15. After a number of days of negotiation between a New York State attorney and an attorney for Entergy, excerpts from the Computer Code Manual were provided on Friday, September 3, 2010. However, since the excerpts did not provide a description of the detailed assumptions and criteria for their selection (particularly for the thermal-hydraulics) that were used it was not possible to fully evaluate the methodology used by Entergy. After reviewing the excerpts of the Computer Code Manual, on Monday, September 6, 2010, the State requested a description of the thermal-hydraulics models relied on by the code but has yet to receive the document. In addition, Entergy refused to even seek a copy, or acknowledge the existence, of a "propagation of error" analysis. For this reason the proposed consolidated contention assumes that, since Entergy has the burden of proof, and it has not produced a "propagation of error" analysis, no such analysis was conducted. In addition, the proposed consolidated contention specifically reserves the right to file additional amendments to the consolidated contention within 30 days of when the full Computer Code Manual, with all relevant material including a description of thermal-hydraulics models, is provided. Discussions with Entergy continue on the disclosure issue.

B. The Contention Meets All The Requirements of 10 C.F.R. § 2.309(f)(2)

The contention fully meets 10 C.F.R. § 2.309(f)(2) which requires for admissibility, in pertinent part, a showing that:

> (i) The information upon which the amended or new contention is based was not previously available;
>
> (ii) The information upon which the amended or new contention is based is materially different than information previously available; and
>
> (iii) The amended or new contention has been submitted in a timely fashion based on the availability of the subsequent information.

Id.

1. Information Not Previously Available

Since this contention is based upon a document first filed on August 10, 2010 and on the new information contained in that document regarding the CUF_{en} Reanalysis, the contention relies on information not previously available and thus meets the first prong of the test set forth in 10 C.F.R. § 2.309(f)(2)(i).

2. The New Information Is Materially Different Than Previously Available Information

It was not until Entergy had completed its CUF_{en} Reanalysis, that the State of New York and Riverkeeper were able to examine a "refined" analysis in which CUF_{en} values were alleged to be <1.0. The reanalysis includes numerous modifications to the basic assumptions which went into the original CUF_{en} analysis, relies on a proprietary computer code from Westinghouse and produces markedly different results from the initial CUF_{en} analysis, including looking at different components and using different assumptions. *See* Declaration of Nelson F. Azevedo in Support of Applicant's Motion for Summary Disposition of Contentions NYS-26/26A and Riverkeeper TC-1/1A at 9-12, 14-16.

C. The Contention Meets All the Requirements of 10 C.F.R. § 2.309(f)(1)

1. The Contention Is Within the Scope of License Renewal

The New York State and Riverkeeper have raised a contention that Entergy's LRA, as amended in the past and most recently by Entergy's "Notification of Entergy's Submittal Regarding Completion of Commitment 33 for Indian Point Units 2 and 3", does not contain an adequate aging management plan for key systems, structures, and components that will suffer the effects of metal fatigue, contrary to the requirements of 10 C.F.R. § 54.21(c)(1). The Board has already ruled that the issue of whether an applicant has an adequate AMP to deal appropriately with metal fatigue of plant systems is within the scope of license renewal. Memorandum and Order (Ruling on Petitions to Intervene and Requests for Hearing) LBP-08-13 at 112-117, 161-162. Thus the current contention, which continues the challenge to Entergy's now-modified attempt to provide an adequate AMP for metal fatigue, is within the scope of this license renewal proceeding.

2. The Issues Raised Are Material to the Findings that the NRC Must Make to Support the Action that is Involved in this Proceeding

The issue of metal fatigue is material to this relicensing proceeding because, if the petitioners are correct in their contention, the NRC must make certain findings to protect the public health and safety, and the environment, and either deny the license renewal, or impose significant modifications on the applicant's operations. The petitioners have demonstrated in the attached contention, particularly through the Declarations of Dr. Lahey and Dr. Hopenfeld, that metal fatigue is a significant safety and public health issue. Inadequate management of the effects of metal fatigue on key reactor components could lead to failures of the components to perform their intended safety functions and/or cracks in these components, which could result in breaking away of parts which would interfere with other components and systems performing their safety functions.

3. Adequate Bases Have Been Provided For the Contention

The bases for this contention are detailed and exceed the regulatory requirement for a "brief explanation." They describe a number of methodological errors in Entergy's submission regarding the CUF_{en} Reanalysis including deficiencies in the AMP as proposed by Entergy that make the calculations provided unreliable. The contention also reiterates deficiencies noted in the earlier admitted contention regarding the lack of sufficient detail in the portion of the AMP related to how Entergy will deal with components for which CUF_{en} values are predicted to be >1.0. The bases for this new contention are not that Entergy has omitted something but that what they have presented does not meet their burden to prove that the AMP for metal fatigue is adequate to meet the requirements of 10 C.F.R. § 54.51(c)(1)(iii).[3]

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[3] Since this is the second effort by Entergy to meet the requirements of 10 C.F.R. § 54.51(c)(1), its LRA should be judged by what it has already provided and it should not be permitted to submit further information or analyses intended to expand on its current submission. Given the requirements of 10 C.F.R. § 2.336, Entergy has produced all the documents in its possession or the possession of experts (in this case Westinghouse) that are relevant to the metal fatigue issue (*see* September 1, 2010 Entergy Nineteenth Update to Mandatory Disclosures; August 2, 2010 Entergy Eighteenth Update to Mandatory Disclosure; July 1, 2010 Entergy Seventeenth Update to Mandatory Disclosures; June 1, 2010 Entergy Sixteenth Update to Mandatory Disclosures). In light of those discovery regulations, Entergy certainly should not now be allowed to support its CUF_{en} analysis with any documentation that was in existence prior to August 10th, 2010. In addition, allowing further amendments to its LRA, without at least requiring that it meet requirements similar to those in 10 C.F.R. § 2.309(c) applicable to late filings by intervenors, would place New York State and Riverkeeper at a distinct disadvantage by requiring them to once again expend time and resources to address new information and new analyses. Such subsequent filings would also cause substantial delay in the resolution of this hearing since the information would be provided close to, if not after, the time the Board has set for prefiled direct testimony and the parties would have to be given additional time to analyze the new information and formulate yet another metal fatigue contention. This situation would be particularly egregious given that it would be the result of Entergy pursuing the metal fatigue issue in precisely the same piecemeal fashion as it did in the *Vermont Yankee* proceeding and causing precisely the same delay and prejudice to the intervenors. *See Entergy Nuclear Vermont Yankee, L.L.C.)*(Vermont Yankee Nuclear Power Station), CLI-10-17 at 23 (July 8, 2010) ("The procedural history of Contentions 2, 2A, 2B, and 2C is lengthy and muddled – due, in large part, to Entergy's multiple revisions to the relevant portions of its license renewal application as it responded to multiple Staff inquiries and, in a related vein, Entergy's apparent lack of precision as to the specific subsection of section 54.21(c)(1) with which it sought to comply for the components at issue."). Just as the Board has set time limits on when motions for summary disposition or new contentions can be filed, it should reject any further pre-August 10th documentation offered by Entergy that Entergy has not already produced and any testimony by experts based on such documentation.

4. A Concise Statement of Facts and Expert Opinion Support the Contention

Dr. Richard Lahey and Dr. Joram Hopenfeld have offered their expert opinions that Entergy's August 10, 2010 Environmental Fatigue Analyses is methodologically flawed and, along with the remainder of Entergy Commitment 33, do not provide an AMP that adequately addresses the requirements of 10 C.F.R. § 54.51(c)(1)(iii). These experts have based their opinions upon Entergy's own submissions, their review of NRC regulations, NRC and industry guidance, technical studies and their extensive professional experience.

5. A Genuine Dispute Exists with the Applicant on a Material Issue of Law or Fact

State of New York and Riverkeeper have provided sufficient information that a genuine dispute exists with Entergy regarding several material issues of the fact including whether the CUF_{en} calculations submitted by Entergy are reliable, whether they meet guidance provided in GALL, whether they comply with the requirements of 10 C.F.R. § 54.51(c)(1)(iii), and whether the remainder of the AMP provides sufficient detail to meet the requirements of GALL that "[t]he program provides for corrective actions to prevent the usage factor from exceeding the design code limit during the period of extended operation. 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." NUREG-1801, Rev. 1 XM-1-2, September 2005.

Entergy believes (1) that its calculations are complete and adequate even though they do not include the appropriate scope of components, (2) that it need not conduct, or provide as supporting evidence, the widely recognized essential for such calculations – a "propagation of error" analysis – or other descriptions of the methodology used to select the numerous assumptions and inputs required for the calculations, all of which are required to facilitate proper assessment of the calculations and to test the reliability of CUF_{en} results, and (3) that it need not specify what it plans to do to adequately manage the key reactor components that will suffer the effects of metal fatigue during extended operations other than to say it will do what it is required to do.

The areas of disagreement on both legal and factual issues could not be clearer and the need to resolve these issues at a hearing is apparent. Entergy's assertion, in its pending Motion for Disposition, that its CUF_{en} Reanalysis forecloses any further dispute over the adequacy of the AMP for metal fatigue, will be addressed in detail when New York State and Riverkeeper file their opposition to that Motion. However, it is already apparent from the Declarations of Dr. Lahey and Dr. Hopenfeld, that merely labeling its filing a CUF_{en} Reanalysis and merely asserting that it is in compliance with GALL, 10 C.F.R. § 54.51(c)(1)(iii) and has fulfilled Commitment 33, is a far cry from even meeting its *prima* facie obligation to demonstrate, that its labels and assertions are correct.

F. Conclusion

For the reasons stated, the State of New York and Riverkeeper respectfully request that the Atomic Safety and Licensing Board grant leave to file the accompanying contention.

Respectfully submitted,

s/

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s/

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dated: September 9, 2010

10 C.F.R. § 2.323 Certification

Pursuant to 10 C.F.R. § 2.323(b) and the Board's July 1, 2010 scheduling order, I certify that I have made a sincere effort to contact the other parties in this proceeding, to explain to them the factual and legal issues raised in this motion, and to resolve those issues, and I certify that my efforts have been unsuccessful.

/s/
John J. Sipos
Assistant Attorney General
State of New York

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 September 9, 2010

PETITIONERS STATE OF NEW YORK AND RIVERKEEPER, INC. NEW AND AMENDED CONTENTION CONCERNING METAL FATIGUE

New York State 26-B/Riverkeeper TC-1B (Metal Fatigue)

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 IN VIOLATION OF 10 C.F.R. § 54.21(c)(1)(iii).

BASES

1. This contention is an amendment to, and thus an addition to, the already-admitted consolidated contention filed by the State and Riverkeeper on August 21, 2008. The admitted bases for that contention are incorporated here by reference.

2. NRC and the nuclear industry have recognized that metal fatigue of reactor components poses a significant challenge for extending the operating life of power reactors from

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<u>BASES</u>

1. This contention is an amendment to, and thus an addition to, the already-admitted consolidated contention filed by the State and Riverkeeper on August 21, 2008. The admitted bases for that contention are incorporated here by reference.

2. NRC and the nuclear industry have recognized that metal fatigue of reactor components poses a significant challenge for extending the operating life of power reactors from

40 years to 60 years. A critical measure of metal fatigue of reactor components is the environmentally adjusted cumulative usage factor, which is also known by its acronym "CUF_{en}."

3. Aging effects on intended functions of nuclear power plant equipment include fatigue or "cyclic stress" of metal parts due to repeated stresses during plant operation. Material composition, strain rate, temperature, and local water chemistry are some of the factors that contribute to fatigue of metal parts. Equipment failures from fatigue may result in small leaks, which, if not detected in time, could result in a pipe rupture. Fatigue can also create small cracks that propagate and cause a given component to malfunction and/or break up and form loose parts, which would interfere with the safe operation of a plant. Such failures may occur during steady state or during anticipated or unanticipated transients and may have serious consequences to public health and safety.

4. For example, if one of the feed water distribution nozzles (J-tubes) were to fail from fatigue, pieces from the broken nozzle could be lodged between steam generator tubes, causing the tubes to rupture and leading to a potential core melt. Components that are susceptible to fatigue, therefore, must, as required by NRC regulations, have a planned management program to ensure that the plant functions efficiently and safely.

5. A common figure of merit used to appraise the possibility of fatigue failure is the cumulative usage factor (CUF), which is the ratio of the number of cycles experienced by a structure or component divided by the number of allowable cycles for that structure or component. At a nuclear power plant, the maximum number of cycles that should be experienced by any structure or component should always result in a CUF of less than 1.0. In

other words, the number of actual cycles experienced should always be less than the number of allowable cycles. The cumulative usage factor (CUF) was developed from laboratory tests in "plain" air, and did not take account of the operating environment inside power reactors. The environmentally adjusted cumulative usage factor (CUF_{en}) seeks to address the effects of the operating environment on reactor components.

6. The NRC provides guidance in NUREG-1800, Rev. 1, *Standard Review Plan for Renewal Applications for Nuclear Power Plants* (SRP). According to Section 4.3.1.1 of the SRP, metal components may be designed or analyzed based on requirements in the American Society of Metal Engineers (ASME) Boiler and Pressure Vessel Code or the American National Standards Institute (ANSI) guidance. "A[n] [ASME] Section III Class I fatigue analysis requires the calculation of the CUF, based on the fatigue properties of the materials and the expected fatigue service of the component." SRP § 4.3.1.1. In order to be acceptable, a CUF value must be less than or equal to 1.0. *Id.* The factors considered in the fatigue analysis must include "the effects of coolant environment on component fatigue life." *Id.*, § 4.3.1.2. Those components with a CUF greater than 1.0 are deemed likely to develop cracks and must therefore be subjected to further analysis and management under 10 C.F.R. § 54.21(c)(1)(iii). The ASME Section III design curves, developed in the late 1960s and early 1970s, are based on tests conducted in laboratory air environments at ambient temperatures. More recent fatigue test data from the United States, Japan, and elsewhere show that the LWR environment can have a significant impact on the fatigue life of carbon and low-alloy steels, as well as austenitic stainless steel. Research efforts addressing the environmental degradation of fatigue crack nucleation concluded

that exposure to LWR environments has a detrimental effect on the fatigue life of metal components, which affects the major categories of structural materials (*i.e.*, carbon steel, low-alloy steel, and austenitic stainless steel). In general, the study results show that degradation is exacerbated by increasing temperature, decreasing loading rate, increasing sulfur content of the materials, and oxygen content of the coolant (for carbon and low-alloy steels), and decreasing oxygen content of the coolant (for austenitic stainless steels). Numerous examples of fatigue cracking of nuclear power plant components have been reported.

7. NUREG-1801, Rev. 1, *Generic Aging Lessons Learned (GALL) Report* (2005) ("NUREG-1801") also provides guidance. NUREG-1801 advises that a license renewal applicant may comply with the regulations by addressing "the effects of the coolant environment on component fatigue life by assessing the impacts of the reactor coolant environment on a sample of critical components for the plant." *Id.*, Vol. 2 at X M-1. Examples of critical components are identified in NUREG/CR-6260, *Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components* (1995). The sample of critical components "can be evaluated by applying environmental life correction factors to the existing ASME Code fatigue analyses." NUREG-1801, Vol. 2 at X M-1.

8. If these components are found not to comply with the acceptance criteria (*i.e.*, CUF less than 1.0), "corrective actions" must be taken, which "include a review of additional affected reactor coolant pressure boundary locations." *Id.* at X M-2. As explained further in Electric Power Research Institute industry guidance document MRP-47:

> The locations evaluated in NUREG/CR-6260 [2] for the appropriate vendor/vintage plant should be evaluated on a plant-unique basis. For cases

> where acceptable fatigue results are demonstrated for these locations for 60 years of plant operation including environmental effects, additional evaluation or locations need not be considered. However, plant-unique evaluations may show that some of the NUREG/CR-6260 [2] 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.

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) ("MRP-47").

9. When a license applicant is unable to demonstrate that CUFs are less than 1.0, the applicant must develop and submit a methodology to manage fatigue so that public health and safety during the life extension period will be maintained at least at the current level. NUREG-1801 states that the requirements of 10 C.F.R. Part 50 Appendix B set forth "acceptable" corrective actions for components that are subject to aging management. The Part 50 corrective actions are as follows:

> Measures shall be established to assure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and nonconformance are promptly identified and corrected. In the case of significant conditions adverse to quality, the measures shall assure that the cause of the condition is determined and corrective action taken to preclude repetition. The identification of the significant condition adverse to quality, the cause of the condition, and the corrective action shall be documented and reported to appropriate levels of management.

10 C.F.R. Part 50, Appendix B, Section XVI.

10. Based on the NRC regulations and guidance an aging management program should (a) provide a reliable method for detecting cracks in pressure systems; (b) provide for a

thorough assessment of the component's condition (which may include stress analysis); and (c) contain criteria for deciding whether the component should be repaired or replaced or merely monitored. If monitoring is selected, the frequency of monitoring must be clearly specified, as required by ASME Section XI, Appendix L (1998).

11. Entergy has failed to satisfy the NRC's regulatory two-step process outlined in 10 C.F.R. § 54.21(c)(1) because (1) its TLAA analysis, submitted with its April 2007 License Renewal Application, demonstrated a number of components would have CUF_{en} values >1.0 and (2) its attempt to then demonstrate that it complied with the aging management program requirements of § 54.21 (c)(1)(iii) by having an adequate aging management plan for those key reactor components fails because the CUF_{en} Reanalysis fails to comply with the scientific and technical standards for such an analysis, because it fails to comply with the guidance in GALL including expanding the scope of the components to be evaluated to include others within the reactor coolant pressure boundary, because the rest of the AMP relies upon the flawed methodology of the CUF_{en} Reanalysis for future calculations and because the rest of the AMP lacks the detail contemplated by GALL and required to determine whether it is in fact an adequate aging management plan.

12. Instead of providing concrete and verifiable details on its corrective action option of repair or replacement, Entergy merely includes a vague description of its proposed "corrective actions":

> The program requires corrective actions including repair or replacement of affected components before fatigue usage calculations determine the CUF exceeds 1.0. Specific corrective actions are implemented in accordance with the IPEC corrective action program. Repair or replacement of the affected component(s), if

> necessary, will be in accordance with established plant procedures governing repair and replacement activities. These established procedures are governed by Entergy's 10 CFR 50 Appendix B QA program and meet the applicable repair or replacement requirements of the ASME Code Section XI.

Entergy Indian Point LRA Amendment 2, Attachment 1 at 2.

13. As part of its April 2007 application for permission to renew the operating licenses for Indian Point Unit 2 and Unit 3, Entergy completed and submitted a CUF_{en} analysis that disclosed that several of the reactors' components will exceed CUF_{en} values of 1.0 during the period of proposed extended operation for the two reactors.

14. Since Entergy has completed a CUF_{en} analysis for several components of IP Unit 2 and Unit 3 that discloses that several of those components will exceed CUF_{en} values of 1 during the proposed period of extended operation, Entergy must, as a part of its license renewal application, refine the CUF_{en} analysis to determine whether CUF values for any components remain at or above 1.0 during the period of proposed extended operation *and* provide the State and the public with a tangible, detailed, reliable, and prescriptive aging management plan (or AMP) to address the issue of repair or replacement of the component including the schedule for repair or replacement and the scope of the repair or replacement for each component whose CUF_{en} was, or in the future may be, calculated to exceed 1.0 during extended operation.

15. On August 10, 2010, Entergy provided the parties in this proceeding with a CUF_{en} Reanalysis that Entergy asserts demonstrates that certain reactor components will not have a CUF_{en} value exceeding 1.0 during the period of extended operation; however, Entergy's recent

CUF_{en} Reanalysis is flawed in fundamental ways that make it unreliable as well as inadequate and unable to meet the NRC requirements for an aging management plan.[1]

16. The scope of the components for which the CUF_{en} Reanalysis has been done is incorrect and improperly narrow. Once Entergy's CUF_{en} analysis demonstrated that several components had values >1, the CUF_{en} Reanalysis and the related aging management plan should have include "other locations where high usage factors might be a concern." This was not done.

17. As a general matter, a CUF_{en} analysis is the function of several variables, each of which has a margin of error. These variables include dissolved oxygen (DO) content, flow and strain rates, loading history, mean stress, oxygen, surface finish, water impurities, and thermal-hydraulics and heat transfer analysis. Thus, Entergy's recently submitted CUF_{en} Reanalysis is subject to a number of errors in the assumption and analyses such that the true value of the CUF for at least some of the components could exceed 1 during the period of extended operation. In order to determine the margins of error created by each of these assumptions, a "propagation of error" analysis is required.

18. However, Entergy's recent CUF_{en} Reanalysis was submitted, and all relevant documents related to that analysis were provided, and no "propagation of error" analysis was provided. Such an analysis is an essential part of any properly done calculation of the type

[1] The State of New York and Riverkeeper reserve the right to file additional amendments to the consolidated contention within 30 days of when Entergy or Westinghouse provide error analyses for the CUF_{en} Reanalysis, the full Computer Code Manual for the WESTEMS code, with all relevant material including a description of thermal-hydraulics models used in the code or employed in the CUF_{en} Reanalysis, non-publically available references in the Westinghouse evaluations and analyses that relate to the CUF_{en} Reanalysis, and the criteria used for selecting various critical parameters for the CUF_{en} Reanalysis.

carried out by Entergy, and, if it existed, it should have already been produced pursuant to 10 C.F.R. § 2.336. Entergy has ignored the impact of these potential errors on its CUF_{en} conclusions and has incorrectly asserted that its CUF_{en} Reanalysis demonstrates that there will not be any CUF value in excess of 1.0 during extended operation based on current projections. Entergy has failed to demonstrate that its CUF_{en} Reanalysis does in fact support the conclusion that no values are >1.0.

19. In its license renewal application for Indian Point Unit 2 and Unit 3, Entergy has elected to proceed under 10 C.F.R. § 54.21(c)(1)(iii), and not under 10 C.F.R. §§ 54.21(c)(1)(i) or (ii).

20. Entergy has failed, and continues to fail, to satisfy the requirements of section 54.21(c)(1)(iii) in several ways:

- Entergy has inappropriately limited the number of reactor components that must undergo a fatigue analysis, by both failing to broaden its fatigue analysis beyond the representative components identified in Tables 4.3-13 and 4.3-14 of its original LRA as required by ERPI's MRP-47 (pg.3-4) and the NRC's NUREG-1801 Rev.1, Vol.2 (pg. X M-2).

- Entergy has failed to provide details on Westinghouse's thermal-hydraulics methodology for analyzing CUF_{en} and a detailed error analysis, so the accuracy of the new fatigue results is in question. Unfortunately, the consequences of inaccuracies may be significant (*e.g.*, several of the new CUF_{en} calculations were very close to unity, and thus the CUF_{en} may exceed unity if virtually any errors are present). Without an error analysis neither the Petitioners, Staff, nor this Board can confirm that the inherent uncertainties in Westinghouse's fatigue analyses have been adequately taken into account, and whether or not $CUF_{en} > 1.0$ would be expected during extended plant operations. Notably, Entergy also failed to provide for a review of its analytical methods and the assumptions that were used in the calculations it submitted previously an issue which Petitioners raised in their Joint Consolidated Contention of Petitioners State of New York (No. 26/26-A) and Riverkeeper, Inc. (TC-1/TC1-A) - Metal Fatigue which was admitted by the Board.

- Entergy did not present a fatigue evaluation of important structures and fittings within the RPV (including, but not limited to, bolting). This is important because in-core failures of irradiated baffle-to-former bolts have been observed in operating PWRs, and B&W designed PWRs have had fatigue-induced failures of various in-core components even when CUF < 1.0. That is, in-core bolting fatigue failures are actual events, and should be expected to occur again during extended plant operations. In addition, there are many other in-core structures and fittings which will be both highly irradiated (and embrittled) and fatigued-weakened. It is vital that the level of fatigue-induced degradation of the strength and ductility of these components be determined so that their ability to withstand various operational and abnormal loads can be determined.

- Entergy did not evaluate the potential failure of highly fatigued structures and fittings (both internal and external to the RPV) due to DBA LOCA , secondary side LOCA and ATWS loads. As a consequence it is not possible to appraise when, during the period of extended operations, that early failure of fatigue-weakened components might occur due to any of these large thermal/pressure shock-type loads. Significantly, if in-core structures fail this may lead to core blockages and/or a distorted core geometry which may not allow the ability to cool the core subsequent to an accident and can lead to core melting and a challenge to the integrity of the containment. On the other hand, if any fatigue-weakened external structures, which form part of the primary system's pressure boundary, fail a LOCA may occur. If so, this will present a significant challenge to the emergency core cooling systems (ECCS) of the disabled nuclear plant.

- Entergy's new CUF_{en} results show that the previously most limiting CUF_{en} were reduced by more than an order of magnitude, which significantly erodes safety margin. Additionally, for the first time, limiting fatigue analysis results were given for components whose CUF_{en} results were not discussed in the initial license renewal application filing. Entergy's new submission examined the residual heat removal (RHR) system piping and nozzles and reported that the CUF_{en} results for these results components were <u>very close</u> to NRC's $CUF_{en} = 1.0$ limit. That is, for the IP-2 RHR line, $CUF_{en} = 0.9434$ and for the IP-3 RHR line, $CUF_{en} = 0.9961$. Entergy CUF_{en} Reanalysis, NL-10-082, Attachment 1, at p 2-3. Since Entergy has refused to provide an error analysis, or even acknowledge if one was performed, it is not possible to determine when the Indian Point reactors might exceed their fatigue limit during extended operations. Also, because the new results for certain components are so close to $CUF_{en} = 1.0$ limit, almost any reasonable error in these results could lead to a violation of the NRC's $CUF_{en} =$ 1.0 limit.

- Entergy has not committed to repair or replace components when the CUF_{en} approaches unity (1.0) despite acknowledging that several critical components have CUF_{en} value greater than 1.0 (in the initial License Renewal Application) or are very close to 1.0 (in the August 9, 2010 NL-10-082 submission). NRC staff and the ASLB have recognized that a licensee should initiate corrective action when the CUF_{en} for a key component approaches 1.0 *See* LBP-08-13 at 115, 116, 68 NRC at 139, 140. Moreover, Entergy's flawed methodology for determining the vulnerability of plant components during the period of extended operation, as discussed herein, renders any plans or commitments to repair and replace affected locations utterly flawed and insufficient to ensure proper management of metal fatigue, in violation of 10 C.F.R. § 54.21(c)(1)(iii).

21. Additionally, based on F_{ens} that have been reported in the literature regarding component fatigue, it would be reasonable to apply a representative correction factor of up to seventeen to the CUFs in Tables 4.3-3 through 4.3-12. *See* NUREG/CR-6909 and Makoto Higuchi, *Revised Proposal of Fatigue Life Correction Factor Fen for Carbon and Low Alloy Steels in LWR Water Environments*, Transactions of the ASME, Vol. 1126 at 436-38 (November 2004). Moreover, in its most recent CUFen Reanalysis, Entergy continued to apply unrealistically low F_{en} values that do not adequately account for various uncertainties of the reactor environment (such as flow and strain rates, loading history, mean stress, oxygen, surface finish, and water impurities). To account for such uncertainties, Entergy should have applied the bounding F_{en} values of 12 and 17 for stainless steel and carbon, respectively, specified in NUREG/CR-6909.

22. Entergy's CUFen Reanalysis relies on general equations from NRC guidance documents without specifying the input parameters used for each transient. Notably, Entergy did not specify dissolved oxygen concentrations during the transients for the calculations of F_{en}. As F_{en} varies exponentially and is very sensitive to DO levels, Entergy's CUF_{en} calculations are

subject to a significant degree of error, calling into question the accuracy of the refined CUF_{en} values, which Westinghouse and Entergy purport to predict to a ten-thousandth of a decimal point. Accounting for appropriate DO levels would likely cause at least some of Entergy's refined CUF_{en} values to exceed unity.

23. Entergy fails to specify what heat transfer coefficients were used to derive the refined metal fatigue calculations, or the underlying assumptions to arrive at such values, which is necessary to determine the accuracy of Entergy's refined CUF_{en} values.

24. Entergy fails to specify how the number of transients was obtained or the underlying assumptions employed to obtain this number.

25. The methodology and process used by Entergy and Westinghouse in conducting the CUF_{en} Reanalysis is flawed in a number of ways as discussed above including the following reasons:

> (a) The methodology used by Entergy is deficient because the scope of the components that were subjected to CUF_{en} analysis was too narrow in light of previous CUF_{en} analyses showing values in excess of 1.0 for a number of components.
>
> (b) The methodology used by Entergy is deficient because there is no error analysis and thus the accuracy of the values provided, particularly for those where the number is very close to 1.0, is not established.
>
> (c) The methodology used by Entergy is deficient because there are in-core components that are subject to fatigue as a result of transients that are particularly vulnerable to failure from such transients because of other phenomena, like embrittlement, which has already weakened them, but which components are not included in the AMP CUF_{en} analysis.
>
> (d) The methodology used by Entergy is deficient because there is no documentation to support the reliability of the thermal-hydraulic analysis which is a central part of the CUF_{en} analysis.

(e) The methodology used by Entergy is deficient because in the future, additional CUF_{en} calculations will be made to determine whether corrective actions are required and those CUF_{en} calculations will rely on the same deficient calculation methodology now being used by Entergy.

In light of the above, the methodology and process disclosed by Entergy and Westinghouse in connection with recent CUF_{en} re-analysis of reactor component metal fatigue does not constitute a meaningful aging management program or comply with the parameters of the guidance and goals contained in NRC Staff guidance (GALL, NUREG-1801), in that the scope of the program is too narrow and does not encompass or adequately monitor and manage sufficient components, the CUF_{en} evaluations do not appear to adequately incorporate industry operating experience regarding fatigue cracking, the CUF_{en} evaluations do not include an error analysis, the details of the thermal-hydraulics modeling used in the CUF_{en} evaluations as well as details regarding the methodologies used for selecting numerous parameters and assumptions that were critical to the CUF_{en} evaluations, are not provided and therefore Entergy cannot demonstrate that it has reliably ensured that corrective or preventative actions or rigorous analysis will occur and thereby cannot ensure that the CUF_{en} =1.0 limit will not be exceeded during the period of extended operation for critical reactor components.

SUPPORTING EVIDENCE

NRC Regulations

26. 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" or have been "projected to the end of the period of extended operation." 10 C.F.R. § 54.21(c)(1)(i) and (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)(1)(iii).[3]

Previous Filings Concerning Metal Fatigue Analysis and Related Aging Management Program in the Indian Point License Renewal Proceeding

27. On April 23, 2007, Entergy filed its License Renewal Application (LRA) for the two operating reactors at Indian Point (IP2 and IP3). In the license renewal application, Entergy committed to address environmentally assisted fatigue in its Commitment 33 (which was later amended by letter NL-08-021 dated January 22, 2008).

28. On November 30, 2007, the State of New York and Riverkeeper filed Petitions to Intervene in which both Petitioners included the issue of metal fatigue as an aging management

[3] The full text of section 54.21(c)(1) reads as follows:

> **54.21 Contents of application--technical information.**
> Each application must contain the following information:
> * * *
> (c) An evaluation of time-limited aging analyses.
>
> (1) A list of time-limited aging analyses, as defined in § 54.3, must be provided. The applicant shall demonstrate that--
> * * *
>
> (iii) The effects of aging on the intended function(s) will be adequately managed for the period of extended operation.
>
> * * *

contention, challenging Entergy's aging management plan for addressing metal fatigue (Contentions 26 and TC-1, respectively). Specifically, the State and Riverkeeper argued that the cumulative usage factor or "CUF," which is a common figure of merit used to appraise the possibility of fatigue failure and which at a nuclear power plant should always be less than 1.0, exceeded 1.0 as to multiple components in Entergy's LRA.

29. Data stated in Tables 4.3-13 (IP2) and 4.3-14 (IP3) of the LRA indicate that some key reactor components will have a greater potential for cracking due to metal fatigue before the years 2033 and 2035, during the period of extended plant operation for each reactor. Entergy's data is summarized as follows:

Component	**Plant**	**Environmentally Adjusted CUF (Entergy's data)**	**Amount of exceedence of 1.0 CUF criterion**
Pressurizer surge line piping	IP2	9.21	nearly 10 times
Pressurizer surge line piping	IP3	9.21	nearly 10 times
Reactor coolant system (RCS) piping charging system nozzle	IP2	15.20	over 15 times
Pressurizer surge line nozzles	IP3	2.35	more than double

30. On January 22, 2008, Entergy submitted an amendment to its original LRA. This LRA amendment was denominated as "LRA Amendment 2." Riverkeeper and the State of New York subsequently filed supplemental or amended contentions in response to LRA Amendment 2 – these contentions were labeled TC-1A and NYS Contention 26-A, respectively.

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10 C.F.R. § 54.21(c)(1)(iii).

31. On July 31, 2008, the ASLB admitted New York State Contention 26/26-A and Riverkeeper, Inc. Contention TC-1/TC-1A and directed the two Petitioners "to confer and submit a draft of the Consolidated Contention for the Board's consideration within 21 days of [the] Order." Entergy Nuclear Operation, Inc. (Indian Point Nuclear Generating Units 2 and 3), LBP-08-13, ASLB Mem. & Order at 226-27, 228, 68 NRC 43, 217-19 (2008). As directed by the ASLB panel, the State and Riverkeeper submitted a joint consolidated contention on August 21, 2008, and also advised the Board that the State of New York will be the lead as to this joint consolidated contention. Although the Board's July 31, 2008 Order (LBP-08-13) offered Entergy and NRC Staff the opportunity to respond to the joint contention, neither submitted any pleadings related to the joint consolidated contention.

32. As admitted and consolidated by the Board, Consolidated Contention 26/26-A/TC-1/TC-1A alleged that "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." The contention critiqued the scope of the components Entergy analyzed, the methodology used, and, in the words of the Board, "the scope of commitment to monitor, manage, and correct age-related degradation" and "the degree of detail and specificity with which the repair/replacement decision criteria must be defined." LBP-08-13, Memorandum and Order (July 31, 2008) at 162.

33. On August 10, 2010, Entergy served on the ASLB and the parties to this proceeding a document entitled "Notification of Entergy's Submittal Regarding Completion of Commitment 33 for Indian Point Units 2 and 3" that enclosed an August 9, 2010 communication,

NL-10-082, from Entergy to NRC Staff entitled "License Renewal Application – Completion of Commitment #33 Regarding the Fatigue Monitoring Program." In NL-10-082, Entergy submitted the results of additional calculations performed by Westinghouse which purport to show that none of the CUF_{en} calculations for certain components exceeded 1.0. As such, Entergy believes that this calculation resolves commitment number 33 in the NRC Safety Evaluation Report on license renewal for Indian Point Nuclear Generating Unit 2 and Unit 3 and meets its obligations under 10 C.F.R. § 54.21. Numerous values in Entergy's recent CUF_{en} Reanalysis are very close to 1.0:

Component	**Plant**	**Environmentally Adjusted CUF (as reported in NL-10-082)**
Pressurizer surge line piping	IP2	0.822
RCS piping safety injection nozzle	IP2	0.8553
RHR Class 1 piping	IP2	0.9434
Pressurizer surge line piping	IP3	0.594
RCS piping charging system nozzle	IP3	0.722
RCS piping safety injection nozzle	IP3	0.8565
RHR Class 1 piping	IP3	0.9961

34. The State and Riverkeeper challenge the adequacy of Entergy's aging management program in this new and amended contention.

35. Because Entergy has already done a CUF_{en} analysis which shows values in excess of 1.0, in order to perform an adequate re-analysis, Entergy must now expand the scope of the components it examines for metal fatigue.

36. Entergy's "Notification of Entergy's Submittal Regarding Completion of Commitment 33 for Indian Point Units 2 and 3" does not expand the scope of the components it should have examined for metal fatigue. While Entergy's recent CUF_{en} Reanalysis did examine some components not examined in the April 2007 LRA, it did not expand the set of components in its recent CUF_{en} Reanalysis to include the components required under GALL, p. X M-2 ("for program that monitor a sample of high fatigue usage locations, corrective actions include a review of additional affected reactor coolant pressure boundary locations") and EPRI MRP-47.

Petitioners' Expert Declarations

37. This contention is also supported by the declarations of the State and Riverkeeper's experts, Dr. Richard T. Lahey, Jr. and Dr. Joram Hopenfeld filed in this proceeding. These declarations include the three Declarations of Richard T. Lahey, Jr., submitted with New York's Petition on November 30, 2007 ("Lahey Decl. I"), with New York's Supplemental Contention 26A on April 7, 2008 ("Lahey Decl. II"), and dated September 8, 2010 ("Lahey Decl. III"); and the three Declarations of Dr. Joram Hopenfeld, dated November 28, 2007 ("Hopenfeld Decl. I") (submitted with Riverkeeper's Petition on November 30, 2007), dated March 4, 2008 ("Hopenfeld Decl. II") (submitted with Riverkeeper's Amended Contention TC-1 on March 5, 2008), and dated September 9, 2010 ("Hopenfeld Decl. III"). These experts have reviewed Entergy's initial LRA, LRA Amendment 2, and Entergy's August 10, 2010 Notification of Entergy's Submittal Regarding Completion of Commitment 33 for Indian Point Units 2 and 3 as well as applicable NRC regulations and relevant NRC and industry guidance.

38. Dr. Lahey's and Dr. Hopenfeld's declarations and their citations to NRC regulations, NRC and industry guidance and reports, and any other supporting materials referenced in New York's 26/26A and Riverkeeper's TC1/T1-A contentions and the instant contention, are incorporated here as support for this new and amended joint contention.

Additional Documents

39. This contention is also supported by the following documents:

American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel 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)

Electric Power Research Institute (EPRI), *R&D Status Report*, EPRI Journal (Jan/Feb 1983)

Entergy, Indian Point License Renewal Application, Section 4

Entergy, Indian Point 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)

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)

NRC Staff, Draft Regulatory Guide DG-1144 (July 2006)

NRC Staff, Regulatory Guide 1.207 (March 2007).

NUREG/CR-6909, *Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials* (Feb. 2007)

NUREG/CR-5704, *Effects of LWR Coolant Environments on Fatigue Design Curves of Austenitic Stainless Steels* (April 1999)

NUREG/CR-6583, *Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels* (Feb. 1998)

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

NUREG/CR-4572, *NRC Leak-Before-Break Analysis Method for Circumferentially Through-Wall Cracked Pipes Under Axial Plus Bending Loads*, (March 1986).

NUREG/CR-1061, Vol. 3, *Report of the U S. Nuclear Regulatory Commission Piping Review Committee, Evaluation of Potential for Pipe Breaks*, (Nov. 1984)

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).

Albany, New York
September 9, 2010

Respectfully submitted,

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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 <u>W</u>. 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 <u>postulated</u> nuclear reactor accidents, the fatigue failures of in-core bolts are <u>actuarial</u> 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 Inta and Broken Jet Pumps," ***Nuclear Technology***, Vol. 65, No. 2, 1984 (with M Fakory).

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

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

"NUFREQ-N: 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).

"The Analysis of Void Waves in Two-Phase Flow," ***Nuc. Eng. & Design*** , Vol. 141, Nos. 1&2, pp. 203-224, 1993 (with J-W. Park and D.A. Drew).

"Interfacial Area Density, Mean Radius and Number Density Measurements in Bubbly Two-Phase Flow," ***Nuclear Engineering and Design***, Vol. 142, pp. 341-351, 1993 (with S. Kalkach-Navarro, D.A. Drew and R. Meyder).

"Development of a k-Epsilon Model for Bubbly Two-Phase Flow, Trans. ASME, ***J. of Fluids Engineering***, Vol. 116, No. 1, pp. 128-134, 1994 (with M. Lopez de Bertodano and O.C. Jones).

"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).

"Turbulent Bubbly Two-Phase Flow Data in a Triangular Duct," ***Nuclear Engineering and Design***, Vol. 146, pp. 43-52, 1994 (with M. Lopez de Bertodano and O.C. Jones).

"The Analysis of a Plunging Liquid Jet The Air Entrainment Process," ***Chemical Engineering Communications***, Vol. 130, pp. 11-29, 1994, (with F. Bonetto and D.A. Drew).

"The Measurement of Void Waves in Bubbly Two-Phase Flows," ***Nuclear Engineering and Design***, Vol. 149, pp. 37-52, 1994 (with J-W. Park and D.A. Drew).

"Analysis of the Bubbly/Slug Flow Regime Transition," Mark Mills Award Paper, ***Nuclear Engineering and Design***, Vol. 151, pp. 15-39, 1994 (with S. Kalkach-Navarro and D.A. Drew).

"Benchmarking and Qualification of the NUFREQ-NPW Code for Best Estimate Prediction of Multichannel Core Stability Margins," ***Nuclear Engineering and Design***, Vol. 151, pp. 157-171, 1994 (with R. Taleyarkhan, F.A. McFarlane and M.Z. Podowski).

"The Thermal-Hydraulics of Aseptic Food Processing," ***Int. J. Heat & Mass Transfer***, Vol. 37, Suppl.-1, pp. 233-239, 1994 (with M. Millies and D.A. Drew).

"On the Different Forms of Momentum Equations and on the Intra- and Interphase Interaction in the Hydromechanics of a Monodispersed Mixture," ***Chemical Engineering Communications***, Vol. 141-142, pp. 287-302, 1996, (with R.I. Nigmatulin and D.A. Drew).

"A First Order Relaxation Model for the Prediction of the Local Interfacial Area Density in Two-Phase Flows," ***Int. J. Multiphase Flow***, Vol. 22, No. 6, pp. 1073-1104, 1996 (with M. Millies and D.A. Drew).

"A Method for Superhigh Compression-Induced Temperatures in a Gas Bubble Using Non-Periodic Resonance Liquid Pressure Forcing," ***Chemical Eng. Communications***, Vols. 152-153, pp. 17-39, 1996, (with R.I. Nigmatulin, V. S.H. Shagapov and N.K. Vakhitova).

"The Analysis of Chaotic Instabilities in Boiling Systems," ***Nuclear Engineering and Design***, Vol. 167, No. 3, pp. 307-334, 1997 (with C.J. Chang).

"The Modeling of Core Melting and In-Vessel Corium Relocation in the APRIL Code," ***Nuclear Engineering and Design***, Vol. 177, Nos. 1-3, pp. 265-283, 1997 (with S.W. Kim, M.Z. Podowski and N. Kurul).

"The Resonant Supercompression and Sonoluminescence of a Gas Bubble in a Liquid Filled Flask," ***Chemical Eng. Communications***, Vol. 168, 145-171, 1998 (with R.I. Nigmatulin, I.S. Akhatov and N.K. Vakhitova).

"The Interaction of Background Ocean Air Bubbles with a Surface Ship," ***Int. J. Num. Meth. Fluids***, Vol. 28, pp. 571-600, 1998 (with P.M. Carrica, D. Drew and F. Bonetto).

"The Analysis of Void Wave Propagation in Adiabatic, Monodispersed Bubbly Two-Phase Flows using an Adiabatic, Ensemble-Averaged, Two-Fluid Model," ***Int. J. Multiphase Flow***, Vol. 24, No. 7, pp. 1205-1244, 1998 (with J-W. Park and D.A. Drew).

"A Polydisperse Model for Bubbly Two-Phase Flow Around a Surface Ship," ***International Journal of Multiphase Flow***, Vol. 25, No. 2, pp. 257- 305, 1999 (with P.M. Carrica, D. Drew, and F. Bonetto).

"A Moving-Boundary Nodal Model for the Analysis of the Stability of Boiling Channels," ***International Journal of Heat & Mass Transfer***, Vol. 42, No. 19 ,pp. 3575-3584, 1999 (with V. Garea and D.A. Drew).

"An Analysis of Phase Distribution and Turbulence in Dispersed Particle/Liquid Flows," ***Chemical Engineering Communications***, Vol. 174, pp. 85-133, 1999 (with A. Alajbegovic and D.A. Drew).

"On the Use of Nonlinear Filtering, Artificial Viscosity and Artificial Heat Transfer for Strong Shock Computations," ***Journal of Computational Physics***, Vol. 153, pp. 575-595, 1999 (with S. Bae).

"Lateral Forces on Spheres in Turbulent Uniform Shear Flow," ***International Journal of Multiphase Flow***, Vol. 25, Nos. 6-7, 1999 (with F.J. Moraga and F.J. Bonetto).

"An Experimental Study of Phase Distribution and Turbulence Structure for Solid/Fluid Flow in Horizontal Pipes," ***Chemical Eng. Communications***, Vol. 179, pp. 149-179, 2000 (with A. Assad and F. Bonetto).

On the Forced Oscillations of a Small Gas Bubble in a Spherical Liquid-Filled Flask, ***J. Fluid Mech.***, Vol. 414, pp. 47-73, 2000 (with R.I. Nigmatulin, I. Sh. Akhatov, and N.K. Vakhitova).

"An Experimental Study of Dispersed Liquid/Liquid Two-Phase Upflow in a Pipe," ***Chemical Engineering Communications***, Vol. 182, pp. 47-73, 2000. (with T. Nigmatulin, F. Bonetto, A. Larreteguy, and J. McQuillen).

"Role of Very High-Frequency Excitation In Single Bubble Sonoluminescence," ***Physical Review-E***, Vol. 62, No. 2, pp. 2233-2237, 2000 (with F. Moraga, R. Taleyarkhan and F. Bonetto).

The Analysis of Two-Phase Flow and Heat Transfer using a Multidimensional , Four Field , Two-Fluid Model, ***Nuc. Eng. & Design*** ,Vol. 204 , Nos.1-3 , pp. 29-44 , 2001 (with D. A. Drew).

"Evidence for Nuclear Emissions During Cavitation" , ***Science*** , Vol. 295, pp. 1868-1873 , 2002 (with Taleyarkhan et al).

"The Relationship Between the Method of Acoustic Excitation and the Stability of Single Bubble Sonoluminescence for Various Noble Gases," ***Chemical Eng. Communications***, Vol. 189 , pp. 786-802 ,2002 (with G. Delgadino and F. Bonetto).

"Deuterium-Deuterium Nuclear Fusion during Cavitation" , ***Heritage of the Academy of Sciences - Republic of Bashkortostan***, Vol.7 No.4 , pp.3-25,2003 (with R. Nigmatulin and R. Taleyarkhan)

"Assessment of Turbulent Dispersed Models for Bubbly Flows", ***Int. J. Multiphase Flow***, Vol.29 ,No.4,pp.655-673, 2003 (with F. Moraga , A.

Larreteguy and D. Drew).

"The Modeling of Lift and Dispersion Forces in Two-Fluid Model Simulations of a Bubbly Jet", ***J. Fluids Engineering***, Vol. 126(4), 2004 (with M. Lopez de Bertodano, F. Moraga and D.A. Drew).

"The Evidence for Nuclear Emissions during Acoustic Cavitation Revisited", ***J. of Power and Energy***, Vol. 218(A), 345, 2004 (with R.I. Nigmatulin and R.P. Taleyarkhan).

"An Analytical Study on Interfacial Wave Structure Between the Liquid Film and Gas Core in a Vertical Pipe" , ***Int. J. Multiphase Flow***, Vol. 30, 829, 2004 (with F. Inada and D.A. Drew).

"Additional Evidence of Nuclear Emissions during Acoustic Cavitation," ***Physical Review-E***, Vol. 69, 036109, 2004 (with R.P. Taleyarkhan, J. Cho, C. West, R.Nigmatulin, R. Block).

"On the Multidimensional Analysis of Two-Phase Flows," ***Multiphase Science & Technology***, Vol. 15 (1-5), 1, 2004 (with D. A. Drew).

"Update and Clarifications on Experimental Studies for Nuclear Emissions during Acoustic Cavitation," ***J. Acous. Soc. Am.***, Vol. 113, 2205, 2004 (with R. Nigmatulin, R. P. Taleyarkhan, C. West).

"Update and Clarifications on Experimental Studies for Nuclear Emissions during Acoustic Cavitation," ***J. Acous. Soc. Am.***, Vol. 113, 2223, 2004 (with R. P. Taleyarkhan, C. West, J. Cho, R. Block, R. Nigmatulin).

"Sonoluminescence and the Search for Sonofusion," ***IEEE Spectrum***, May issue ,2005 (with R. Taleyarkhan, R. Nigmatulin).

"The Simulation of Multidimensional Multiphase Flows," ***Nuc. Eng. & Design***, Vol.235(10-12),1043, 2005.

"The Analysis of Interfacial Waves," ***Nuc. Eng. & Design***, Vol. 235 (10-12),1283, 2005 (with A. Galimov, D. A. Drew).

"Analysis of Void Wave Propagation and Sonic Velocity using a Two-Fluid Model" , ***Multiphase Science & Technology***, Vol. 17 Issue 4 , 293-320 , 2005 (with J. Yin, P. Tiwari).

"The Analysis of Linear and Nonlinear Bubble Cluster Dynamics" , ***Multiphase Science & Technology***, Vol.17 Issue 3 , 225-256,2005 (with I. Akhatov, R. Nigmatulin).

"The Design of Acoustic Chambers for Bubble Dynamics Research" , ***Multiphase Science & Technology***, Vol. 17 Issue 3 , 257-291 , 2005 (with S, Cancelos, F. Moraga, P. Bouchilloux).

"Bubble Nuclear Fusion Technology - Status and Challenges" , ***Multiphase Science & Technology***, Vol. 17 Issue 3 , 191-224 ,2005 (with R. P. Taleyarkhan, R. Nigmatulin).

"The Theory of Supercompression of Vapor Bubbles and Nano-Scale Thermonuclear Bubble Fusion" , ***Physics of Fluids***, Vol.17 , 107106-1 , 2005 (with R. Nigmatulin, I. Akhatov, A. Topolnikov, R. Bolotnova, N. Vakhitova).

"Computation of Incompressible Bubble Dynamics with a Stabilized Level Set Method", ***Computer Methods in Applied Mechanics and Engineering***, Vol.194 (42-44), 4565-4587,October ,2005 (with S. Nagrath and K. Jansen).

"Nuclear Emissions During Self-Nucleated Acoustic Cavitation" , ***Physical Review Letters***, Vol.96 , 034301-1, 2006(with R. Taleyarkhan ,C. West , R, Nigmatulin ,R. Block , Y. Xu).

"Modeling Wall-Induced Forces on Bubbles for Inclined Walls" , ***Multiphase Science & Technology***, Vol. 18 Issue 2 , 111-133 ,2006 (with F. Moraga, S. Cancelos).

"An Analysis of Interacting Instability Modes" , ***Multiphase Science & Technology,*** Vol. 18 Issue 4 , 305-333 , 2006 (with J. Yin, M. Podowski, M. Jensen).

"A Center-Averaged Two-Fluid Model for Wall-Bounded Bubbly Flows", ***J. Computers and Fluids***, Vol.35 (4) , 429-461, 2006 (with A. Larreteguy, F. Moraga, D. A. Drew).

"Hydrodynamic Simulation of Air Bubble Implosion using a FEM-based Level Set Approach", ***J. Comp. Physics***, Vol.215 (1), 98-132,2006 (with S. Nagrath, K. Jansen , I. Akhatov).

" Response to the PRL paper of Naranjo et al." , **Phys. Rev. Lett.** , Vol. 97 , 149404 , 2006 (with R. Taleyarkhan , R. Block , R. Nigmatulin and Y. Yu).

" Response to the PRL paper of A. Lipson" , **Phys. Rev. Lett.** , Vol.97 , 149402 , 2006 (with R. Taleyarkhan , R. Block , R. Nigmatulin and Y. Yu).

"The Effect of Buoyancy on Phase Distribution in Dispersed Two-Phase Flows", **Chemical Engineering Communications**, Vol.194, 507-536, 2007 (with M. Singhal , D.A. Drew).

"Sonofusion Technology Revisited" , **Nuclear Engineering & Design**, Vol.237 (15-17), 1571-1585, 2007 (with R.P.Taleyarkhan , R. I. Nigmatulin).

"A Sub-Grid Air Entrainment Model for Breaking Bow Waves and Naval Surface Ships" , **J. Computers and Fluids** , Vol.37, 281-298, 2007 (with F. J. Moraga , P. M. Carrica , D.A. Drew).

"Modeling , Analysis and Prediction of Neutron Emission Spectra from Acoustic

Cavitation Bubble Fusion Experiments" ,**Nuc. Eng. & Design**, Vol.238, 2779-2791,2008 (with R.P. Taleyarkhan, J. Lapinskas, Y. Xu, J.S. Cho , C. D. West, R.C. Block , R. I. Nigmatulin).

"Stability Analysis of a Uniformly Heated Channel with Supercritical Water" , **Nuc. Eng. & Design**, Vol.238(8), 1930-1939, 2008 (with T. Ortega-Gomez, A. Class, T. Schulenberg).

" A Spectral Turbulent Cascade Model for Single and Two-Phase Uniform Shear Flows", **J. of Turbulence**, Vol. 9 (26), 1-18, 2008 (with I.A. Bolotnov, D.A. Drew, K. E. Jansen, A.A. Oberai).

"Turbulent Cascade Modeling of Single and Bubbly Two-Phase Turbulent Flows" , **International Journal of Multiphase Flow**, Vol.34(12), 1142-1151, 2008 (with I. A. Bolotnov , D. A. Drew, K. E. Jansen).

"On the Computation of Multiphase Flows", **J. Nuclear Technology**, Vol.167, 1-17, 2009.

"On the Direct Numerical Simulation of Two-Phase Flows", **Nuc. Eng. & Design**, Vol.239/5 , 867-879, 2009.

"Direct Numerical Simulation of Turbulent Channel Flows using a Stabilized Finite Element Method" , **J. Computers & Fluids**, Vol.38(4) ,924-938, 2009 (with A. Trofimova , A. E. Tejada-Martinez , K. E. Jansen).

" Spectral Cascade Modeling of Turbulent Flow in a Channel" , **Japanese J. of Multiphase Flow**, Vol.23(2), 190-204, 2009 (with I. Bolotnov, A. Oberai, D. Drew, K. Jansen).

" A Quantitative Sub-Grid Air Entrainment Model for Bubbly Flows" , **J. Computers & Fluids,** Vol. 39, 77-86, 2009 (with Jingsen Ma , A. Oberai , D. Drew, F. Moraga).

"Spectral Analysis of Turbulence based on the DNS of a Channel Flow", **J. Computers & Fluids** , Vol.39, 640-655, 2010.

"Parallel Adaptive Simulation of a Plunging Liquid Jet" , **Acta Mathematica Scientia**, Vol. 30(2) Series-B, 522-538, March, 2010 (with A.Y. Galimov, O. Sahni, M. Shephard, D.A. Drew , K.E. Jansen).

"An Analysis of Interacting Instability Modes in a Phase Change System" , in press, **Nuc. Eng. & Design** , 2010 (with W. Schlichting , M. Podowski).

" The Effect of Acoustically-Induced Cavitation on the Permeance of a Bullfrog Uinary Bladder", in press, **J. Acoustical Society of America**, 2010 (with Silvina Cancelos, Francisco Moraga, William shain, Robert Parsons).

"Recent Advances in Acoustic Inertial Confinement Fusion" , submitted , **Journal of Fusion Energy,** 2009 (with R. Taleyarkhan , R. Nigmatulin).

"A Comprehensive Sub-Grid Air Entrainment Model for RaNS Modeling of Bubbly Flows Near the Free Surface", submitted, **J. Computers & Fluids**, 2010 (with Jingsen Ma ,A. Oberai, D. Drew, M. Hyman).

"Evolution of Distortions from Spherical of a Cavitation Bubble during Acoustic Supercompression", submitted, **J. Fluid Mechanics** , 2010 (with R. I. Nigmatulin, A.A. Aganin, M.A. Ilgamov, D. Yu. Toporkov, R.I. Taleyarkhan).

" A Two-Way Coupled Polydispersed Simulation of Bubbly Flow Beneath a Plunging Liquid Jet", submitted, **J. Fluids Engineering**, 2010 (with Jingsen Ma . Assad Oberai, Donald Drew).

"Detached Direct Numerical Simulations of Turbulent Two-Phase Bubbly Channel Flow" , submitted, **Int. J. Multiphase Flow**, 2010, (with Igor A. Bolotnov, Kenneth E. Jansen, Donald A. Drew, Assad A. Oberai, Michael Z. Podowski).

Refereed Publications (Proceedings)

"Mixing, Flow Regimes, and Void Fraction for Two-Phase Flow in Rod Bundles," ASME Symposium Volume, Two-Phase Flow and Heat Transfer in Rod Bundles , November 1969 (with A. Schraub).

"Transient Flow Measurements with Sharp-Edged Orifices," ASME Paper 71-FE-30, 1971 (with B. Shiralkar).

"Diabatic Local Void Fraction Measurements in Freon-114 with a Hot Wire Anemometer," *ANS Transactions*, 15, No. 2, November 1972 (with B. Shiralkar).

"A Langrangian Analysis of Two-Phase and Nuclear-Coupled Density-Wave Oscillations," Paper B5.9, Proceedings of the Fifth International Heat Transfer Conference, Tokyo, 1974 (with G. Yadigaroglu).

"The Effect of Reduced Clearance and Rod Bow on Critical Power in Full-Scale Simulations of 8x8 BWR Fuel," ASME preprint 75-HT-69, 1975 (with B. Matzner).

"^{16}N Tagging of Water for Transient Flow Measurements," *ANS Transactions*, 27, December 1977 (with R.C. Block, M. Perez-Griffo and U.N. Singh).

"Critical Power in Boiling Water Nuclear Reactor Fuel Bundles," Proceedings of the ANS Topical Meeting on Thermal Reactor Safety, July 1977.

"The Effect of Non-Uniform Axial Heat Flux on Critical Power," Proceedings of the Conference on Heat and Fluid Flow in Water Reactor Safety, University of Manchester, September, 1977 (with J. Gonzalez-Santalo).

"The Status of Boiling Water Nuclear Reactor Safety Technology," ASME

Symposium Volume on *Thermal-Hydraulic Aspects of Nuclear Reactor Safety*, November 1977.

"An Experimental Technique for the Determination of Steam/Air Fraction," *ANS Transactions*, 27, December 1977 (with N. Saba and G. Krycuk).

"^{16}N Tagging for Two-Phase Flow Measurements," *ANS Transactions* , 30, 1978 (with M. Perez-Griffo and R.C. Block).

"Opportunities for University Contributions to BWR Thermal-Hydraulic Technology," *ANS Transactions*, 28, June 1978, San Diego, CA.

"Radial Phase Distribution Mechanisms in Two-Phase flow," Proceedings of the OECD/CSNI Specialists Meeting on Transient Two-Phase Flow," Paris, France, 6/12-14, 1978 (with D.A. Drew and S. Sim).

"A Turbine-Meeting Evaluation Model for Two-Phase Transients," ASME Symposium Volume, *Topics in Two-Phase Flow and Heat Transfer*, 1978 (with P.S. Kamath).

"A Mechanistic Subcooled Boiling Model," Proceedings of the 6th International Heat Transfer Conference, 1978, Toronto, Canada.

"The Development of a High Temperature Optical Void Probe," *ANS Transactions* , 30, 1978 (with M. Vince and H.E. Breed).

"Development of a Radio-Frequency Local Probe for Void Fraction Measurements, *ANS Transactions*, 30, 1978 (with S. Moreira and G. Krycuk).

"A High Intensity X-Ray System for Stochastic Measurements of Two-Phase Flow," *ANS Transactions*, 30, 1978 (with G. Krycuk and B.K. Malaviya).

"The Side-Scatter Gamma Technique for Local Density Measurements," *ANSTransactions* , 30, 1978 (with R.R. Gay and S. Schell).

"The Development of an Optical Digital Interferometer," Proceedings of the 2nd Multi-Phase Flow and Heat Transfer Symposium-Workshop, 4/16-18, 1979, Miami, FL (with M.A. Vince and G. Krycuk).

"The Analysis of Phase Distribution in Fully Developed Two-Phase Flows," Proceedings of the 2nd Multi-Phase Flow and Heat Transfer Symposium-Workshop, 4/16-18, 1979, Miami, FL (with D.A. Drew)

"An Evaluation of Interfacial Drag Models for Bubbly Two-Phase Flows," ASME Symposium Volume on Interfacial Transport Phenomena, 1979 (with S. Sim and D.A. Drew).

"The Analysis of Dynamic Bias in Gamma Densitometer Measurements," *ANS Transactions*, 32, 1979 (with T.J. Honan).

"The Evaluation of Static Error in Gamma Densitometry," *ANS Transactions* , 32, 1979 (with T.J. Honan).

"Scaling of the RPI Parallel Channel Effects Experiment," *ANS Transactions* , 32, 1979 (with W.M. Conlon).

"Current Light Water Nuclear Reactor Safety Concerns," *ANS Transactions* , 32, 1979.

"Dynamic Bias in Side-Scatter Gamma Density Measurements," *ANS Transactions* , 323, 1979 (with R.R. Gay).

"An Analytic Derivation of a Subchannel Void-Drift Model," *ANS Transactions* , 33, 1979 (with D.A. Drew).

"Dynamic Analysis of a Drag-Disk in Transient Two-Phase Flow," *ANS Transactions* , 33, 1979 (with P. Kamath).

"The Effect of Heater Rod Dynamics on CCFL Mechanisms," *ANS Transactions* , 33, 1979 (with K. Ohkawa).

"Modeling of Two-Phase Flow Manometric Oscillations," Proceedings of the 11th Annual Pittsburgh Conference on Modeling and Simulation, University of Pittsburgh, 1980 (with C.N. Shen and R.P. Taleyarkhan).

"An Assessment of Current LWR Thermal-Hydraulic Safety Concerns," Proceedings of 5th Indian Heat & Mass Transfer Conference, Hyderabad, India, 1980.

"An Analytical Approach to the Evaluation of Water Hammer Phenomena," *ANS Transactions*, 35, 1980 (with D.A. Drew).

"A Mixing Length Model for Fully-Developed Turbulent Two-Phase Flow," *ANS Transactions*, 35, 1980 (with D.A. Drew).

"The Measurement of Local Void Fraction with a Side-Scatter Gamma Technique," Proc. 26th International Symposium of the Instrument Society of America, Seattle, WA, May 1980 (with R.R. Gay and K. Ohkawa).

"The Analysis of a Drag-Disk in Transient Two-Phase Flow," Proceedings of the ANS/ASME Topical Meeting on Reactor Thermal-Hydraulics, NUREG/CP-0014, Saratoga Springs, NY, October 1980 (with M. Perez-Griffo and R.C. Block).

"Basic Two-Phase Flow Measurements Using ^{16}N Tagging Techniques," Proceedings of the ANS/ASME Topical Meeting on Reactor Thermal-Hydraulics, NUREG/CR-0014, Saratoga Springs, NY, October 1980 (with M. Perez-Griffo and R.C. Block).

"Analysis of the Error in Instantaneous Void Fraction Measurements by a Dual-

Beam X-Ray Technique," *ANS Transactions*, 34, 1980 (with B.K. Malaviya).

"The Analysis of LOFT Drag Disk Turbine Meter Rakes," *ANS Transactions*, 34, 1980 (with P.S. Kamath).

"Derivative Signal Thresholding for a Local Void Impedance Probe," *ANS Transactions*, 34, 1980 (with M. Vince).

"Flow Regime Identification Using a High Intensity X-Ray System," *ANS Transactions*, 34, 1980 (with M. Vince).

"Involvement in Nuclear Public Information Activities at RPI," *ANS Transactions*, 34, 1980 (with B.K. Malaviya, H. Burdock and R.M. Ryan).

"The Analysis of Two-Phase Level in a PWR Core During Conditions of Severely Reduced Liquid Mass Inventory," Proceedings of the ICHMT Seminar, Dubrovnik, Yugoslavia, 1980.

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

"The Analysis of Vent Clearing," *ANS Transactions*, 35, 1980 (with Z.M. Khalid).

"The Effect of Radial Nonuniformity on BWR Stability Margins," *ANS Transactions*, 35, 1980 (with G. Park and M. Becker).

"Non-Uniform Tagging and Flow Structure Effects in PNA Measurements," *ANSTransactions*, 35, 1980 (with M. Perez-Griffo and R.C. Block).

"Interfacial Dissipation in Two-Phase Flow," ASME Symposium Volume, *Basic Mechanisms in Two-Phase Flow and Heat Transfer*, 1980 (with D.A. Drew).

"Analytical Modules for Nuclear Reactor Simulators," Proceedings of USNRC/EPRI Symposium on Simulation Methods for Nuclear Power Systems, EPRI Report WS-81-212, 1981.

"The Effect of Virtual Mass on the Prediction of Critical Flow," Proceedings of 3rd CSNI Specialists Meeting on Transient Two-Phase Flow, Cal. Tech., 1980.

"The Adaptation of a Non-Equilibrium Vapor Generation Model into MAYU4a," *ANS Transactions*, 38, 1981 (with C.E. Hardie and R.R. Gay).

"The Analysis of System Pressure Drop Characteristics During Flow Boiling," *ANS Transactions*, 38, 1981.

"Stability Analysis for a Nonuniformly Heated Boiling Channel," *ANS Transactions*, 38, 1981 (with R. Taleyarkhan and M. Podowski).

"Thermal-Hydraulic Instrumentation for LWR Experiments A Review," *ANS*

Transactions, 38, 1981.

"A State Variable Model and Stability Criterion for Density-Wave Oscillations in Boiling Water Reactors," Proceedings of the 12th Annual Pittsburgh Conference on Modeling and Simulation," University of Pittsburgh, 4/30-5/1, 1981 (with C.N. Shen and J. Balaram).

"A State Variable Formulation of Density-Wave Oscillation in Boiling Water Reactors," *ANS Transactions*, 36, 1981 (with C.N. Shen and J. Balaram).

"A Mechanistic Analysis of LOFT Pulsed Neutron Activation Data," *ANS Transactions* , 38, 1981 (with M.L. Perez-Griffo and R.C. Block).

"An Analytical Solution for BWR Channel Flow Split," *ANS Transactions* , 39, 1981 (with R. Beauman).

"Flow Regime Effects on Integral and Local Slip in Vertical Two-Phase Flows," *ANS Transactions*, 39, 1981 (with M.A. Vince).

"An Interactive Graphics Based Multi-Purpose Nuclear Power Plant Simulator," *ANS Transactions*, 39, 1981 (with F.E. Wicks).

"A Review of Some Selected Nonintrusive Nuclear and Optical Techniques for the Determination of Void Fraction, Flow Regime and Two-Phase Flow Rate," *ANS Transactions*, 39, 1981.

"Thermal-Hydraulic Stability of Interconnected Boiling Channels," *ANS Transactions*, 39, 1981 (with R. Taleyarkhan and M. Podowski).

"The Use of Microprocessors for the Evaluation of the Thermal-Hydraulic Stability of Boiling Systems," *ANS Transactions*, 39, 1981.

"An Improved Model for the Stability Analysis of BWRs," *ANS Transactions* , 39, 1981 (with G.C. Park, J.K. Park, M. Becker and M. Podowski).

"The Effect of Heater Wall Dynamics on Density-Wave Oscillations in a Boiling Channel," Proc. 7th International Heat Transfer Conference, Munich, Germany, 1982 (with R. Taleyarkhan and M. Podowski).

"Ventilated Channel Instability Analysis," ASME Preprint 82-WA/HT-3, 1982 (with R. Taleyarkhan and M. Podowski).

"The Modeling of Density-Wave Oscillations in Boiling Water Nuclear Reactors," Proc. NATO Advanced Workshop on Two-Phase Flows and Heat Transfer," August 31-September 3, 1982, Spitzingsee, Germany (with G.C. Park, M. Podowski and M. Becker).

"Density-Wave Oscillations," Proc. 9th U.S. National Congress of Applied Mechanics, Cornell University, June 1982 (with M. Podowski).

"Some Physical Problems Involving Large Moving Gradients," Proc. of 10 th IMACS World Congress on Systems Simulation and Scientific Computation, Concordia University, Montreal, Canada, August 1982.

"An Analysis of BWR Flow Transients," *ANS Transactions*, 41, 1982 (with S. Peng and D.A. Drew).

"An Analysis of a Hypothetical BWR Inlet Flow Blockage," *ANS Transactions*, 41, 1982 (with M.E. Nissley and R.R. Gay).

"On the Relationship Between Ledinegg and Density-Wave Instability Analysis," *ANS Transactions*, 41, 1982 (with G. Yadigaroglu).

"The Stability Analysis of BWR Recirculating Loops," *ANS Transactions*, 41, 1982 (with G.C. Park, M. Podowski and M. Becker).

"Virtual Mass Effects in Two-Phase Flows A Review," *ANS Transactions*, 41, 1982.

"The Interaction of Neutronics and Thermal-Hydraulics in the Evaluation of BWR Stability," Proc. ANS Topical Meeting on Advances in Reactor Physics and Core Thermal-Hydraulics, 1982 (with M. Becker, J.K. Park, G.C. Park and M. Podowski).

"Pulsed Neutron Activation for Single- and Two-Phase Flow Measurements," Proc. of Institute of Physics Conference on the Neutron and Its Applications, Cambridge, England, Sept. 1982 (with M.L. Perez-Griffo and R.C. Block).

"Multivariable Approach to Boiling Water Nuclear Reactor Stability," Proc. 13th Annual Pittsburgh Conference on Modeling and Simulation, 1982 (with J. Balaram and C.N. Shen).

"A Heat Transfer Model for LWR Fuel Rods During Hypothetical Core Meltdown Accidents," *ANS Transactions*, 42, 1982 (with T. Ikeda, M. Podowski and B. Koh).

"Multivariable Stability Margins for Boiling Water Nuclear Reactors," Proc. of 21st IEEE Conference on Decision and Control, Orlando, FL, December 8-10, 1982 (with J. Balaram and C.N. Shen).

"Wave Dispersion Effects in Two-Phase Flow," Proc. of 2nd International Topical Meeting on Reactor Thermal-Hydraulics, Santa Barbara, CA, January 1983 (with L. Cheng and D.A. Drew).

"The Development of a Nodal Method for the Stability Analysis of Ventilated Boiling Channels," Proc. of 2nd International Topical Meeting on Reactor Thermal-Hydraulics, Santa Barbara, CA, January 1983 (with R. Taleyarkhan and M. Podowski).

"Scaling of BWR Parallel Channel Effects," Proc. NRC Meeting on Basic Thermal-

Hydraulic Mechanisms in LWR Analysis, Bethesda, MD, September 1983 (with W.M. Conlon).

"Multichannel Stability Analysis of BWR Recirculating Loops," *ANS Transactions*, 44, 1983 (with G. Park, M. Becker and M. Podowski).

"Channel-to-Channel Instabilities in Parallel Channel Boiling Systems," *ANS Transactions*, 44, 1983 (with M. Podowski and R.P. Taleyarkhan).

"The Modeling of Heat Transfer in a Degraded BWR Core," AIChE Symposium Series, 79, 1983 (with M. Podowski and R. Taleyarkhan).

"Annular Two-Phase Flow Measurements in a Horizontal Pipe using the Pulsed Photon Activation Technique," *ANS Transactions*, 45, 1983 (with O.C. Jones, Jr., T.F. Lin and R.C. Block).

"The Analysis of Subcooled Boiling Dynamics in Boiling Water Nuclear Reactors," Proc. of ASME/JSME Thermal Engineering Joint Conference, Honolulu, Hawaii, 1983 (with G.C. Park, M. Becker, and M. Podowski).

"An Analysis of Molten Material Relocation and Rubble Bed Formation in Degraded BWR Cores," ASME Symposium Volume, Thermal-Hydraulic Aspects of Nuclear Reactor Safety, 1983 (with M. Podowski and R. Taleyarkhan).

"An Analysis of Feed-and-Bleed Mode of PWR Emergency Core Cooling," *ANS Transactions*, 45, 1983 (with A. Salame-Alfie).

"The Two-Phase Flow Measurements Using a Pulsed-Photon-Activation (PPA) Technique," Proc. of the IUTAM Symposium on Measuring Techniques in Gas/Liquid Two-Phase Flows, Nancy, France, 1983 (with T.F. Lin, R.C. Block, O.C. Jones, Jr. and M. Murase).

"An Analysis of Density-Wave Oscillations in Ventilated BWR Fuel Rod Bundles," Trans. Of the 3rd Multi-Phase Flow & Heat Transfer Symposium Workshop, 1983, Miami Beach, Florida (with M. Podowski and R. Taleyarkhan).

"NUFREQ-NP: A Computer Code for the Stability Analysis of Boiling Water Reactors," *ANS Transactions*, 46 and 2nd Proceedings on Nuclear Thermal Hydraulics, Annual Meeting of American Nuclear Society, New Orleans, Louisiana, 1984 (with S.J. Peng and M. Becker).

"The Modeling of Emergency Core Cooling (ECCS) in a Degraded BWR Core," *ANS Transactions*, 46 and 2nd Proceedings on Nuclear Thermal-Hydraulics, Annual Meeting of American Nuclear Society, New Orleans, LA , 1984 (with B.R. Koh, R.P. Taleyarkhan and M. Podowski).

"Film Thickness and Non-Intrusive Void Fraction Measurements in Horizontal Annular Flows," Proceedings of International Symposium on Two-Phase Annular and Dispersed Flows, Pisa, Italy, 1984 (with T.F. Lin, O.C. Jones, Jr., R.C. Block and M. Murase).

"Local Void Fraction Measurements Techniques in Two-Phase Bubbly Flows Using Hot-Film Anemometry," Proc. 22 ASME/AIChE National Heat Transfer Conference, Niagara Falls, NY, August 5-8, 1984.

"Mathematical Modeling of U-Tube Steam Generator Dynamics for Slow Transients and Small Break Loss-of-Coolant Accidents," Proceedings of International Conference on Power Plant Simulation, Cuernavaca, Mexico, 1984.

"An Analysis of Core Meltdown Accidents for BWRs," Proceedings of the Fifth Int. Meeting on Thermal Nuclear Reactor Safety, Karlsruhe, Germany, 1984 (with S.H. Kim, M. Podowski and R.P. Taleyarkhan).

"Mathematical Modeling of U-tube Steam Generator Dynamics for Slow Transients and Small Break Loss-of-Coolant Accidents," Proceedings of 85 Eastern Simulation Conference, Norfolk, VA, March 3-8, 1985 (with J.S. Petzold and M. Podowski).

"Modeling Two-Phase Flow Division at T Junctions," Proc. 2nd Int. Conf. On Multiphase Flow, BHRA, London, 1985 (with B. Azzopardi and M. Cox).

"The Analysis of Degraded BWR Core Thermal-Hydraulics," ANS Proceedings, 1985 National Heat Transfer Conference, Denver, CO, August 6-9, 1985 (with M.Z. Podowski, S.H. Kim, B.R. Koh and R.P. Taleyarkhan).

"A Stability Analysis of Ventilated Boiling Channels," *ANS Proceedings* , 1985 National Heat Transfer Conference, Denver, CO, 1985 (with R. Taleyarkhan and M. Podowski).

"BWR Linear Stability Analysis," *ANS Proceedings*, 1985 National Heat Transfer Conference, Denver, CO, 1985 (with S.J. Peng and M.Z. Podowski).

"The Hydrodynamic Development Length for Lateral Void Distribution in a Triangular Conduit," ASME Symposium Volume, Multiphase Flow and Heat Transfer, Denver, CO, August 6-9, 1985 (with S.H. Kim).

"An Assessment of the Severe Core Damaged Predictive Capabilities using MELRPI," Proceedings of the Third International Topical meeting on Reactor Thermal-Hydraulics, Newport, RI, October 15-18, 1985 (with S.H. Kim and M.Z. Podowski).

"An Analytical Model for the Prediction of Two-Phase Level During Bottom Reflooding of a Heated Channel," Proceedings of the Third International Conference on Nuclear Reactor Thermal-Hydraulics, Newport, RI, 1985 (with M.R. Fakory).

"Stability Margin Evaluation in Boiling Water Nuclear Reactors," Proceedings of the Third International Topical Meeting on Reactor Thermal-Hydraulics, Newport, RI, October 15-18, 1985 (with M.Z. Podowski and S.J. Peng).

"The Effect of Fuel Rod Dynamics on BWR Stability Margin," Proceedings of the

Third International Topical Meeting on Reactor Thermal-Hydraulics, Newport, RI, October 15-18, 1985 (with R.P. Taleyarkhan and M.Z. Podowski).

"An Experimental Investigation of BWR/4 Long-Term Cooling with Either Intact or Broken Jet Pump Seals," Proceedings of the Third International Topical Meeting on Reactor Thermal-Hydraulics, Newport, RI, October 15, 1985 (with M. Fakory).

"MELRPI Code Assessment and Its Application to Severe Core Damage Accident Analysis," Proceedings of the ANS Topical Meeting on Thermal Reactor Safety, San Diego, CA, February, 1986 (with S. Kim and M. Podowski).

"A Study of Using Simulants for Assessments of LWR Meltdown Models," *ANS Transactions*, 52, 1986 (with S. Kasprzak and M. Podowski).

"An Analysis of Siphon Dynamics," *ANS Transactions*, 52, 1986.

"Subchannel Measurements of the Equilibrium Quality and Mass Flux Distribution in a Rod Bundle," Proceedings of the Eighth International Heat Transfer Conference, Vol. 5, San Francisco, CA, August 17-22, 1986.

"An Analysis of BWR-Core Degradation and Meltdown Progression Using the MELPRI Computer Code," Proceedings of the ANS Topical Meeting on Advances in Reactor Physics and Safety, NUREG/CR-0080, Vol. 1, Saratoga Springs, NY, September 1986 (with A. Sozer, S.H. Kim and M.Z. Podowski).

"Current Challenges in Nuclear Reactor Safety," Proceedings of the ANS Topical Meeting on Advances in Reactor Physics and Safety, NUREG/CP-0080, Vol. 1, Saratoga Springs, NY, September 1986.

"Experimental Simulations and Analytical Modeling of Impinging-Jet-Induced Plate Melting," Proceedings of the ANS Topical Meeting on Advances in Reactor Physics and Safety, NUREG/CP-0080, Vol. 1, Saratoga Springs, NY, September 1986 (with S. Kasprzak and M.Z. Podowski).

"The Modeling of Molten Fuel Relocation Phenomena in a Degraded BWR Core," Proceedings of the ANS Topical Meeting on Advances in Reactor Physics and Safety, NUREG/CP-0080, Vol. 1, Saratoga Springs, NY, September 1986 (with El-K. SiAhmed and M.Z. Podowski).

"An Investigation of Sound Propagation in Bubbly Air-Water Flows," Proceedings of the ASME WAM International Symposium on Multi-Phase Fluid Transients, Anaheim, CA, December 7-12, 1986 (A.E. Ruggles and H.A. Scarton).

"Bubble Size and Velocity Distribution in Bubbly Two-Phase Flows," Proceedings of the 4th Miami International Symposium on Multi-Phase Transport & Particulate Phenomena, Miami Beach, FL, December 15-17, 1986 (with K.M. Bukhari).

"Finite Element Analysis of Two-Dimensional Single and Two-Phase Flows," Proceedings of the 4th Miami International Symposium on Multi-Phase Transport & Particulate Phenomena, Miami Beach, FL, December 15-17, 1986 (with K.M.

Bukhari).

"Phase Separation Phenomena in Multiphase Systems," Proceedings of the 4 th Miami International Symposium on Multi-Phase Transport & Particulate Phenomena, Miami Beach, FL, December 15-17, 1986.

"A Dual Loop Jet Pump Model for BWR Stability Analysis," *ANS Transactions* , 53, 1986 (with S.J. Peng and M.Z. Podowski).

"The Modeling of BWR Thermal-Hydraulics for Severe Accident Analysis," Proceedings of the Second ASME/JSME thermal Engineering Joint Conference, Honolulu, Hawaii, March 22-27, 1987 (with B.R. Koh and M.Z. Podowski).

"A Study of Using Simulant Materials to Model Core Meltdown Accidents," Proceedings of the Second ASME/JSME Thermal Engineering Joint Conference, Honolulu, Hawaii, March 22-27, 1987 (with S.J. Peng and M.Z. Podowski).

"Interfacial Transport Phenomena During Simulated Reactor Meltdowns," submitted to the 6th International Conference on PhysicoChemical Hydrodynamics, England, April 6-8, 1987 (with M.Z. Podowski and S. Kasprzak).

"Turbulence and Phase Distribution Phenomena in Two-Phase Flow," Proceedings of the ICHMT Seminar on Transient Phenomena in Multiphase Flow, Hemisphere Press, Dubrovnik, Yugoslavia, May 24-30, 1987.

"A Linear Model to Study Fluid Dynamics Instabilities in Boiling Channels Due to Density Wave Oscillations," Proceedings of the 5th Congresso Nazionale sul Trasporto del Calore (UIT), Torino, Italy, June 25-27, 1987 (with F. DAuria, N. DeSanctis, P. DiMarco and M.Z. Podowski).

"The Relationship Between Standing Waves, Pressure Pulse Propagation and Critical Flow Rate in Two-Phase Mixtures," ANS Proceedings of the National Heat Transfer Conference, Pittsburgh, PA, August 9-12, 1987 (with A.E. Ruggles, D.A. Drew and H.A. Scarton).

"Transient Two-Phase Channel Flow for Nonuniform Axial Heat Fluxes," ANS Proceedings of the National Heat Transfer Conference, Pittsburgh, PA, August 9-12, 1987 (with G. Arnold).

"The Modeling of Reactor Vessel Failure Modes During Core Meltdown Accidents of BWRs," ASME Preprint: 87-HT-70, 1987 (with D.H. Kim and M.Z. Podowski).

"The Impact of Transient Single-Phase Heat Transfer Modeling on Predicted BWR Fuel Stability Margins," *ANS Transactions*, Vol. 55, 1987 (with R. Taleyarkhan, A. McFarlane and M.Z. Podowski).

"An Application of the APRIL Code to the Analysis of BWR Core Meltdown Accidents," *ANS Transactions*, Vol. 55, 1987 (with S.H. Kim and M.Z. Podowski).

"Transient Two-Phase Channel Flow for Nonuniform Axial Heat Fluxes," *ANS*

Transactions, Vol. 55, 1987 (with G. Arnold).

"A Study on Single and Two-Phase Pressure Drop in Branching Conduits," Proceedings of the AIChE Winter Meeting, New York, NY, November 15-20, 1987 (with S.T. Hwang).

"The Modeling of BWR Thermal-Hydraulics for Severe Accident Analysis," AIChE Symposium Volume No. 257, Vol. 83, 1987 (With B. Koh and M.Z. Podowski).

"The Analysis of Two-Phase Drop in Branching Conduits Using a Two-Fluid Model," *ANS Transactions*, Vol. 56, 1988 (with S. Kalkach-Navarro and S-J. Lee).

"Derivation of Constitutive Equations for Interfacial Force and Reynolds Stresses for a Suspension of Spheres using Ensemble Cell Averaging," ANS Proceedings of the 25th NHTC, HTC-Vol. 3, 1988 (with G. Arnold and D. Drew).

"Finite Element Analysis of Fully Developed Turbulent Two-Phase Flow in Triangular Conduits," ANS Proceedings of the 25th NHTC, HTC-Vol. 3, 1988 (with S.K. Sim and J.E. Flaherty).

"A Linear Analysis of Channel-to-Channel Instability Modes," ASME Proceedings (Vol-2) of the 25th NHTC, HTD-Vol. 96, 1988 (with M.Z. Podowski, A. Clausse and N. DeSanctis).

"An Experimental Investigation of Phase Distribution in an Eccentric Annulus," Proceedings of the 2nd International Symposium on Two-Phase Annular and Dispersed Flows Oxford, England, 1988.

"The Prediction of Two-Phase Turbulence and Phase Distribution Phenomena Using a Reynolds Stress Model," Fundamentals of Gas/Liquid Flows, FED-Vol. 72, ASME, NY, NY, 1988 (with M. Lopez de Bertodano, S.J. Lee and D.A. Drew).

"The Analysis of Choking in Two-Phase Flow," *ANS Transactions*, Vol. 57, 1988.

"An Experimental and Theoretical Investigation of Melt Propagation in a Rubble Bed, with Application in Severe Accident analysis," Proceedings of the ANS Winter Meeting, Washington, DC, Oct. 30 to Nov. 4, 1988 (with El-K. SiAhmed and M.Z. Podowski).

"Benchmarking and Qualification of the NUFREQ-NPW Code for Best Estimate Prediction of Multi-Channel Core Stability Margins," 4th Proc. of Nuclear Thermal-Hydraulics, ANS Winter Meeting, Washington, DC, 1988 (with R. Taleyarkhan, F.A. McFarlane and M.Z. Podowski).

"Finite Element Analysis of Fully Developed Single-Phase Turbulent Flows in Triangular Conduits," Proceedings of the Third International Meeting on Nuclear Power Plant Thermal-Hydraulics and Operations, Seoul, Korea, 14-17 Nov. 1988 (with S.K. Sim and J.E. Flaherty).

"The Analysis of Phase Separation and Phase Distribution Phenomena using Two-Fluid Models," Proceedings of the Third International Meeting on Nuclear Power Plant Thermal-Hydraulics and Operations, Seoul, Korea, 14-17 Nov. 1988.

"Modification of the BNL Plant Analyzer (HIPA) for the Nine Mile Point-1 Nuclear Power Station," Proceedings of the Third International Meeting on Nuclear Power Plant Thermal-Hydraulics and Operations, Seoul, Korea, 14-17 Nov. 1988 (with M.E. Bryam, M.Z. Podowski and S. Cheng).

"An Analysis of Void Wave Propagation in Bubbly Flows," Proceedings of the 5th Miami International Symposium on Multiphase Transport & Particulate Phenomena, 1988 (with A.E. Ruggles and D.A. Drew).

"The Influence of Gravity on Density-Wave Instabilities in Boiling Channels," Proceedings of the 5th Miami International Symposium on Multiphase Transport & Particulate Phenomena, 1988 (with A. Clausse).

"A Lumped Parameter Model for Linear and Non-Linear Analysis of Excursive and Density-Wave Instabilities in Boiling Channels," Proceedings of 7 th EUROTHERM

Thermal Non-Equilibrium in Two-Phase Flow, Seminar Proceedings Technical Rome, Italy, 1989 (with P. DiMarco, A. Clausse and D.A. Drew).

"The Analysis of Core Meltdown Progression in BWRs," Proceedings of the 4 th International Meeting on Nuclear Reactor Thermal-Hydraulics, Karlsruhe, FRG, 1989 (with M.Z. Podowski and J.M. Burger).

"Chaos and Non-Linear Dynamics of Density-Wave Instabilities in a Boiling Channel," AIChE Symposium Series 269, Vol. 85, 1989 (with A. Clausse and P. DiMarco).

"Void Wave Dispersion in Bubbly Flows," ANS Symposium Volume, HTC Vol. 4, 1989 (with J-W. Park and D.A. Drew).

"The Modeling of Aerosol Dynamics During Degraded Core Events," *ANS Transactions* , Vol. 60, 1989 (with A. Clausse).

"Experimental Simulation and Theoretical Analysis of Molten-Corium/Structure Interaction," *ANS Transactions*, Vol. 60, 1989 (with M.Z. Podowski, S. Kasprzak and D.H. Kim).

"Modeling and Calculation of Corium/Concrete Interaction in a MARK-I Containment," *ANS Transactions*, Vol. 61, 1990 (with H. Jia, S.J. Lee and M.Z. Podowski).

"An Analysis of Nonlinear Void Waves in Bubbly Flows," Proceedings of the Ninth International Heat Transfer Conference, Vol. 6, pp. 9-14, Jerusalem, Israel, August 19-24, 1990 (with J-W. Park and D.A. Drew).

"An Investigation of Periodic and Strange Attractors in Boiling Flows Using Chaos Theory," Proceedings of the Ninth International Heat Transfer Conference , Vol. 2, pp. 3-8, Jerusalem, Israel, August 19-24, 1990 (with A. Clausse).

"The Effect of CRD Flow on Severe Accident Mitigation in BWRs," *ANS Transactions* , Vol. 62, 1990 (with D.H. Kim and M.Z. Podowski).

"An Analysis of Chugging Loads in Containment Systems," *ANS Transactions* , Vol. 62, 1990 (with P.M. Lahey and D.A. Drew).

"The Analysis of Chaotic Instabilities in Boiling Systems," Proceedings of the 16th Eurotherm Seminar: Natural Circulation in Industrial Applications, October 11-12, 1990, Pisa, Italy (with A. "Clausse and D. Delmastro).

"The Current State-of-the-Art in the Modeling of Vapor/Liquid in Two-Phase Flows," ASME Preprint 90-WA/HT-13, 1990 (with D.A. Drew).

"Applications of Fractal & Chaos Theory in the Field of Two-Phase Flow and Heat Transfer," Proceedings of the 1990 ASME Winter Annual Meeting, Advances in Gas-Liquid Flows, HTD- Vol. 155, Dallas, TX, November 25-29, 1990.

"The Prediction of Phase Distribution using Two-Fluid Models," Proceedings of the 3rd ASME/JSME Thermal Engineering Joint Conference, March 17-22, 1991, Reno, NV (with M. Lopez de Bertodano).

"The Analysis of S/RV Loads in Pressure Suppression Containment Systems," *ANS Transactions*, Vol. 63, pp. 304-306, 1991 (with P.M. Lahey and D.A. Drew).

"The Analysis of Chaotic Density-Wave Oscillations," *ANS Transactions* , Vol. 63, pp. 197-198, 1991 (with N. Takenaka and M.Z. Podowski).

"A Model of Radionuclides Transport in BWR Systems," Proceedings of the 27th NHTC, Minneapolis, MN, July 28-31, 1991 (with C.S. Cho and M.Z. Podowski).

"A Model of BWR Containment Thermal-Hydraulics under Severe Accident Conditions," Proceedings of the 27th NHTC, Minneapolis, MN, July 28-31, 1991 (with S-W. Kim and M.Z. Podowski).

"A Characteristic Analysis of Void Waves using Two-Fluid Models," Proceedings of the International Conference on Multiphase Flow, Tsukuba, Japan, Sept. 24-27, 1991.

"A Model of Radionuclides Transport in BWR Systems," Proceedings of 7th Nuclear Thermal-Hydraulics Symposium , *ANS Trans.*, pp. 332-342, 1991 (with C.S. Cho and M.Z. Podowski).

"The Analysis of Phase Distribution in Turbulent Two-Phase Flows," Proceedings of the 4th International Lecture Course on Waves and Turbulence in Multiphase Flow, and Its Application, 1991.

"A Aplicacao do Modelo de Deslizamento na Determinacao da Fracao de Vazio em Escoamento Horizontal Estratificado e Anular," Proceedings of the 11 th ABCM Mech. Eng. Eonf., Sao Paulo, Brazil, Dec. 1991 (with Fr. Franca).

"The Relationship Between Void Waves and Flow Regime Transition," Proceedings of the International Symposium on Instabilities in Multiphase Flows, Rouen, France, May 11-14, 1992 (with D.A. Drew, S. Kalkach-Navarro and J-W. Park).

Phase Distribution in Complex Geometry Conduits," Proceedings of the Japan/US Seminar on Two-Phase Flow Dynamics, Berkeley, CA, July 5-11, 1992 (with M. Lopez de Bertodano and O.C. Jones, Jr.).

"The Analysis of Void Waves in Two-Phase Flow," Proceedings of the Japan/US Seminar on Two-Phase Flow Dynamics, Berkeley, CA, July 5-11, 1992 (with J-W. Park and D.A. Drew).

"Interfacial Area Density, Mean Radius and Number Density Measurements in Bubbly Two-Phase Flow," Proceedings of the 28th NHTC, San Diego, CA, Aug. 9-12, 1992 (with S. Kalkach-Navarro, D.A. Drew and R. Meyder).

"Simulation of Ablation Heat Transfer During Corium/Concrete Interaction," Proceedings of the 28th NHTC, San Diego, CA, Aug. 9-12, 1992 (with V. Garea, S. Kasprzak and M. Podowski).

"Multidimensional Effects During Corium Spreading in a MARK-I Containment," Proceedings of the 28th NHTC, San Diego, CA, Aug. 9-12, 1992 (with S. Kasprzak, H. Jia, M.Z. Podowski and R. Lilquist).

"Turbulent Bubbly Two-Phase Flow in a Triangular Duct," Proceedings of the NURETH-5, Salt Lake City, September 21-24, 1992 (with M. Lopez de Bertodano and O.C. Jones, Jr.).

"Numerical Simulation of DF-4 and CORA-16/17 Severe Fuel Damage Experiments Using APRIL.MOD3," Proceedings of the NURETH-5, Salt Lake City, September 21-24, 1992 (with S.W. Kim and M.Z. Podowski).

"The Assessment of Two Fluid Models Using Critical Flow Data," Proceedings of the ANS/ENS 1992 International Conference, Chicago, IL, November 15-20, 1992 (with B. Shome).

"Prediction of Critical Heat Fluxes Using a Hybrid Kohonen-Back Propagation Neural Network," Intelligent Engineering Systems Through Artificial Neural Networks, Vol. 2, pp. 853-858, Proceedings of Artificial Neural Networks in Engineering (ANNIE), November 15-18, 1992 (with T.C. Yapo, M.J. Embrechts and S.T. Cathey).

"The Application of Neural Networks to Two-Phase Flow Regime Identification," Intelligent Engineering Systems Through Artificial Neural Networks , Vol. 2, pp.

865-870, Proceedings of Artificial Neural Networks in Engineering (ANNIE), November 15-18, 1992 (with M.J. Embrechts and T.C. Yapo).

"Chaotic Phenomena in Density-Wave Oscillations," Presented at the New Bases for Engineering Science Algorithm, Dynamics & Fractal Symposium, November 23-28, 1992 (with C.J. Chang, F.J. Bonetto and D.A. Drew).

"The Application of Neural Networks to Flow Regime Identification," Presented at the Annual Meeting of the American Power Conference, April 13-15, 1993, sponsored by Illinois Institute of Technology (with M.J. Embrechts and T. C. Yapo).

"A Numerical Simulation of Two-Phase Jet Spreading Using and Euler-Lagrangian Technique," Proceedings of the International Symposium on Gas-Liquid Flows , ASME Spring Meeting, Washington, DC, June 20-23, 1993 (with F. Bonetto and D.A. Drew).

"The Measurement of Void Waves in Bubbly Two-Phase Flows," Proceedings of NURETH-6, Grenoble, France, October 5-8, 1993 (with J-W. Park and D.A. Drew).

"Numerical Simulation of Gas-Flow-Induced Circulation and Heat Transfer in a Liquid Pool Near an Inclined Wall," Proceedings of NURETH-6, Grenoble, France, October 5, 8, 1993 (with H. Jia, M. Lopez de Bertodano and M.Z. Podowski).

"Prediction of Two-Phase Sonic Velocity Using Two-Fluid Models," *Proceedings of the ANS*, TANSAO-69, 1993 (with C. Chang).

"Two-Fluid Modeling of the Bubbly/Slug Flow Regime Transition," *Proceedings of the ANS*, TANSAO-69, p. 495-496, 1993. *Mark Mills Award, Invited Lecture* (with S. Navarro-Valenti and D.A. Drew).

"Prospects for Bubble Fusion" , Proceedings of NURETH-7 , NUREG/CP-0142, 1995 (with R. I. Nigmatulin).

"Near- and Far-Field CFD for a Naval Combatant Including Thermal-Stratification and Two-Fluid Modeling," Proceedings of Twenty-first Symposium on Naval Hydrodynamics, Trondheim, Norway, June 1996 (with E.G. Paterson, M.C. Hyman, F. Stern, P.M. Carrica, F.J. Bonetto, and D.A. Drew).

"Bubble Fusion Reactor Technology," Proceedings of the Japan/U.S. Seminar on Two-Phase Flow Dynamics, Fukuoka, Japan, July 1996.

"A Geometrical Analysis of Interfacial Area Density for a Sinusoidal Wave and a Taylor Bubble in a Vertical Tube," Proceedings of AIChE Conference, Houston, TX, August 1996 (with T. Nigmatulin, and D.A. Drew).

A CFD Analysis of Multidimensional Phenomena in Two-Phase Flow using a Two-Fluid Model," Proceedings of AIChE Conference, Houston, TX, August 1996 (with A. Alajbegovic, N. Kurul, M. Podowski, and D.A. Drew).

"Mechanistic Modeling of CHF in Forced-Convection Subcooled Boiling," Proceedings of Conference on Convective Flow and Pool Boiling, Irsee, Germany, May 18-23, 1997 (with M.Z Podowski, A. Alajbegovic, N. Kurul and D.A. Drew).

"A Polydisperse Approach to Two-Phase Flow Around a Ship," Proceedings of ASME Fluids Engineering Division Summer Meeting, Vancouver, June 22-26, 1997 (with P.M. Carrica, F. Bonetto, and D.A. Drew).

"A New Mechanistic Model of Critical Heat Flux in Forced-Convection Subcooled Boiling," Proceedings of NURETH-8, Kyoto, Japan, Sept. 30-Oct. 4, 1997 (with A. Alajbegovic, N. Kurul, M.Z. Podowski and D.A. Drew).

"A Mechanistic Model of the Ebullition Cycle in Forced Convection Subcooled Boiling," Proceedings of NURETH-8, Kyoto, Japan, Sept. 30-Oct. 4, 1997 (with R.M. Podowski, D.A. Drew and M.Z. Podowski).

"An Analysis of a Wavy Interface Between a Liquid Film and Gas Core in a Vertical Circular Channel," Proceedings of German-Japanese Symposium on Multi-Phase Flow, Tokyo, Japan, September 1997 (with F. Inada and D.A. Drew).

"Interfacial Area Density in a Four Field Model," Proceedings of the International Symposium of Multiphase Flow, Beijing, China, October 7-11, 1997 (with T.R. Nigmatulin and D.A. Drew).

"On the Theory of Supercompression and Sonoluminescence of a Gas Bubble in a Liquid-Filled Flask," Proceedings of the International Symposium of Multiphase Flow, Beijing, China, October 7-11, 1997 (with R.I. Nigmatulin, I.S. Akhatov and N.K. Vakhitova).

"The Development of Multidimensional Modeling Capabilities for Annular Flows," Proceedings of the ICMF-Lyon, France, June 8-12, 1998 (with S. Antal, N. Kurul and M.Z. Podowski).

"Dynamics of a Small Gas Bubble in a Spherical Liquid Filled Flask," Proceedings of the ICMF-Lyon, France, June 8-12, 1998 (with R. Nigmatulin, I. Akhatov and N. Vakhitova).

"A Polydispersed Approach to the Two-Phase Flow Around a Ship," Proceedings of the ICMF-Lyon, France, June 8-12, 1998 (with P. Carrica, F. Bonetto and D.A. Drew).

"Three-Phase Flow Measurements Using a Hot-Film Anemometer," Proceedings of the Symposium on Optical Measurement Techniques Applied to Heat and Mass Transfer, Multiphase Flow and Combustion, Garching, FRG, September 23-24, 1999 (with S. Mayo).

"The Analysis of Two-Phase Flow and Heat Transfer Using a Multidimensional, Four Field, Two-Fluid Model," Proceedings of NURETH-9, San Francisco, CA, October 3-7, 1999 (with D.A. Drew).

"Hydrodynamics , Acoustics and Transport in Sonoluminescence Phenomena" ,L.A. Crum et al (Eds.), Sonochemistry and Sonoluminescence , pp. 127-138 , Kluwer Publishers , 1999 (with R. Nigmatulin , I. Akhatov ,and N. Vakhitova).

"A Center-Averaged Two-Fluid Model for Wall-Bounded Bubbly Flows," Proceedings of MECOM 99, Argentina, 1999 (with A.E. Larreteguy and D.A. Drew).

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

"Applications of Laser Anenometry in Experimental Studies of Two-Phase Flows", Proceedings of the International Conference on Multiphase Systems (ICMS-2000), Ufa, Russia, June 15-17, 2000 (with T.R. Nigmatulin and R.J. Bonetto).

"Experimental and Analytical Investigations on the Role of Multifrequency Excitation on Enhancing Sonoluminescence in Air/Water Mixtures", Proceedings of the International Conference on Multiphase Systems (ICMS-2000), Ufa, Russia, June 15-17, 2000 (with F.J. Moraga, R.P. Taleyarkhan, and F.J. Bonetto).

"An Analysis of Wavy Annular Flow ", Proceedings of the International Conference on Multiphase Systems (ICMS-2000) , Ufa , Russia , June 15-17 , 2000 (with T.J. Nigmatulin and D.A. Drew).

"CFD Analysis of Dispersed Two-Phase Flows", Proceedings of the International Symposium of Multiphase Flow & Transient Phenomena (MFTP-2000), Antalya, Turkey, November 5-10, 2000.

"Modeling Turbulence Non-Isotropy in Dispersed Particle/Liquids Flows", Proceedings of the International Symposium on Multiphase flow & Transient Phenomena (MFTP-2000), Antalya, Turkey, November 5-10, 2000 (with A. Alajbegovic and D.A. Drew).

"A Multidimensional Analysis of Bubbly Two-Phase Flow", Proceedings of the 2nd International Symposiumon Advances in Computational Heat Transfer (CHT01), Palm Cove, Queensland, Australia, May 20-25, 2001.

"Acoustic Excitation and the Stability of Single Bubble Sonoluminescence for Various Noble Gases", Proceedings of the 5th World Conference of Experimental Heat Transfer, Fluid mechanics and Thermodynamics (ExHFT-5), Thessaloniki, Greece, September 24-28, 2001.

"Assesment of Turbulent Dispersion Models for Bubbly Flows", Proceedings of the 4th Int. Conf. On Multiphase Flow (ICMF-2001), New Orleans, LA, May 27-June 1, 2001 (with F. Moraga, A. Larreteguy and D. Drew).

"Thermonuclear Fusion in Collapsed Microbubbles" , Proceedings of EUROTHERM-74 , March 23-26 , Eindhoven , Netherlands , 2002 (wilh R. Nigmatulin , I. Akhatov and R. Taleyarkhan).

"A Center-Averaged Two-Fluid Model for Wall-Bounded Bubbly Flows", Proceedings of the 5th Int. Symposium on Numerical Methods for Multiphase Flow , ASME/European FED Conference , Montreal,Canada,July 14-18 , 2002 (with A.E. Larreteguy and D. A. Drew).

"Sonoluminescence and the Search for Bubble Fusion " , Proceedings of HEAT-2002 , Kielce , Poland , June 24-27 , 2002 (with R. I. Nigmatulin and R. P. Taleyarkhan).

" The Analysis of Bubble Fusion" , *ANS Trans.* , June 9-13 , 2002 (with K.E. Jansen and S. Nagrath).

"Dynamics of Collapsing Bubbles : Sonoluminescence and Bubble Fusion", Proceedings of the 16th Int. Symposium on NonLinear Acoustics (ISNA-16) , Moscow , Russia , August 19-23 , 2002 (with R. Nigmatulin , I. Akhatov , A. Topolink , R. Bolotnova and R. Taleyarkhan).

" An Analytical Approach to Bubble/Slug Flow Regime Modeling using a Multi-Field , Two-Fluid Model" , Proceedings of the 6th ASME/JSME Conference , Kona ,Hawaii ,March 16-20 , 2003 (with D. Drew).

"Update and Clarifications on Experimental Studies for Nuclear Emissions during Acoustic Cavitation" , Proceedings of the 145th Meeting of the Acoustic Society of America , Nashville , TN , April 28-May 2 , 2003 (with R.P. Taleyarkhan , C.D. West , J.S. Cho , R.C. Block , and R. I. Nigmatulin).

"Update and Clarification on Analytical Studies for Nuclear Emissions during Acoustic Cavitation" , Proceedings of the 145th Meeting of the Acoustic Society of America , Nashville , TN , April 28-May 2 , 2003 (with R.I. Nigmatulin , R.P. Taleyarkhan , and C.D. West).

"The Modeling of Bubbly Flows around Naval Surface Ships at High Reynolds Numbers", Proceedings of the 2nd MIT Conference of Computational Fluid and Solid Mechanics, June 17-20 , 2003 (with F. Moraga , A. Larreteguy and D.A. Drew).

"The Design of Acoustic Resonant Chambers by Numerical Simulation",Proceedings of the 2nd MIT Conference of Computational Fluid and Solid Mechanics, June 17-20 , 2003 (with S. Cancelos , F. Moraga , I. Akhatov and R.H. Parsons).

"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

1968.

"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.

"Transit Time Techniques," Proceedings of Stanford Summer Course on Two-Phase Flow Instrumentation, 1980.

"The Design of Photon Attenuation and Scattering Systems," Proceedings of Stanford Course on Two-Phase Flow Instrumentation, 1980.

"Local Void Probes," Proceedings of Stanford Summer Course of Two-Phase Flow Instrumentation, 1980.

"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).

"Two-Fluid or Not Two-Fluid," Guest Column, ***Heat Transfer and Fluid Flow Service***, UKAEA, UK, 1981.

"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.

The Modeling of Two-Phase Flow Around Ship Hulls
$900,841 July 1, 2001 - June 30 , 2006

The Modeling of Two-Phase Flow Around Ship Hulls
$1,1280,000. July 1, 2006 - June 30 , 2010.

EG&G

An Investigation of Turbine-Meter Drag Disc Devices in Transient Two-Phase Flow
$11,000 10/1/76-9/30/77.

Analysis of BWR Inlet Flow
$20,000 10/1/77-9/30/78.

An Investigation of Turbine-Meter Drag Disc Devices in Transient Two-Phase Flow
$121,764 10/15/76-9/30/79.

Analysis of BWR Inlet Flow
$78,549 2/1/80-1/31/81.

The Analysis of PNA Techniques
$29,323 2/1/80-2/28/81.

The Development of a Global Transient Model for DTT Rakes
$55,764 10/1/78-9/30/79.

The Analysis of BWR Inlet Flow Blockage using MAYU-4B
$81,258 1/1/80-12/31/80.

NSF

Three-Dimensional Turbulence Structure Measurement in Two-Phase Flow

$218,000 3/1/81-11/30/83.

Three-Dimensional Turbulence Structure Measurements in Two-Phase Flow
$78,800 5/1/82-4/30/83.

Three-Dimensional Turbulence Structure in Two-Phase Flow Measurements
$77,700 5/1/83-4/20/84.

Phase Separation Mechanisms in Branching Conduits
$175,000 12/1/84-1/31/87.

Phase Distribution Phenomena in Complex Geometry Conduits
$85,655 3/1/88-2/28-89.

A Study of Phase Separation in Branching Conduits
$95,000 2/1/89-1/31/90.

Phase Distribution Phenomena in Multiphase Systems
$88,446 9/1/89-8/31/90.

The Modeling of Two-Phase Turbulence
$252,351 11/1/01 -10/31/04

ORNL

The Development of Mechanistic Models for the MARCH-based Analysis of BWR Cores
$30,950 9/1/81-8/31/82.

The Development of Mechanistic Models for the MARCH-based Analysis of BWR Cores
$117,990 9/1/81-8/31/83.

The Development of Mechanistic BWR Hydraulics and Structural Component Failure Models for the MARCH Code
$46,000 9/1/82-8/31/83.

Development of Improved Models for BWR Thermal-Hydraulics and Core Degradation Phenomena
$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.

Analysis of Sonoluminescence/Sonofusion Phenomena to Support ORNL Experiments
$164,784 , 7/28/99-7/27/2003.

Westinghouse

The Analysis of Thermal-Hydraulic Instabilities in Quad-Plus Fuel
$97,445 9/1/81-8/31/82.

EPRI

The Development of Analytical Modules for Nuclear Reactor Simulators
$49,085 6/1/81-5/31/82.

Workshop on Two-Phase Flow Fundamentals
$15,000 9/1/86-6/30/87.

ESEERCO

An Analysis of BWR/4 and BWR/5 Pressure Boundary Failure Modes During Core Meltdown and Its Impact on Mark-II Containment
$304,667 2/1/84-1/31/86.

The Propagation and Failure Modes in Severely Degraded BWR Cores
$210, 568 9/1/85-8/31/86.

Degraded BWR Code Modeling: Radionuclide Transport and Additional Thermal Hydraulics Models for the APRIL Code
$399,608 6/1/87-5/31/88.

Modeling and Analysis of Severe Accidents in BWRs Using the APRIL

Computer Code
$356,712 1/1/90-12/31/90.

Degraded BWR Code Modeling: The Upgrading and Validation of APRIL as an Interactive Computer Code for BWR Severe Accident Analysis
$428,862 1/1/92-12/31/92.

USDOE

An Analysis of the Closure Conditions for Two-Fluid Models of Two-Phase Flow
$115,000 4/1/86-3/31/87.

Workshop on Two-Phase Flow Fundamentals
$98.000 9/1/86-6/30/87.

An Investigation of the Closure Conditions for Two-Fluid Models of Two-Phase Flow
$120,000 4/1/87-3/31/88.

An Analysis of the Closure Conditions for Two-Fluid Models of Two-Phase Flow
$120,000 4/1/88-3/31/89.

The Continuum Modeling of Two-Phase Systems
$532,088 4/1/89-3/31/93.

A Nonintrusive Measurement System for Multiphase Flows
$134,549 6/30/89-6/29/90.

Analysis of Nuclear Reactor Instability Phenomena
$83,278 6/1/91-5/31/92.

The Continuum Modeling of Two-Phase Systems
$128,000 4/1/92-3/31/93.

Analysis of Nuclear Reactor Instability Phenomena
$88,384 4/15/93-4/14/94.

The Development of Multidimensional Two-Fluid Modeling Capabilities
$129,551 4/1/94-3/31/97.

Multidimensional Analysis of Bubble Dynamics Associated with Bubble Fusion Phenoma
$404,203 7/1/99-6/30/2002.

KAPL

The Development of Improved Models for BWR Thermal-Hydraulics and Core Degradation Phenomena

$50,000 9/1/85-8/31/85.

Turbulent Phenomena in Two-Phase Flows
$32,000 4/15/86-4/14/87.

The Development of Improved Models for BWR Thermal-Hydraulics and Core Degradation Phenomena
$14,997 9/1/86-8/31/87.

A Review of KAPL Methodology in the Area of Multiphase Flow and Heat Transfer
$30,163 7/8/91-7/7/92.

The Mechanistic Analysis of Critical Heat Flux Using Two-Fluid Models
$73,796 4/1/93-9/30/93.

The Mechanistic Analysis of Critical Heat Flux Using Two-Fluid Models
$184,529 10/1/93-9/30/94.

The Mechanistic Analysis of Critical Heat Flux Using Two-Fluid Models
$149,080 10/1/94-9/30/95.

The Mechanistic Analysis of Critical Heat Flux Using Two-Fluid Models
$80,300 12/1/95-4/30/96.

The Analysis of Annular Two-Phase Flows
$227,049 7/1/03-6/30/06

CAAPS

Enabling Technology for Multiphase Flow Food Processing
$48,927 9/1/92-8/31/93.

Enabling Technology for Multiphase Flow Food Processing
$51,305 9/1/93-8/31/94.

Enabling Technology for Multiphase Flow Food Processing
$54,333 9/1/94-8/31/95.

NASA

The Analysis of Phase Distribution Phenomena in Microgravity Environments
$119,438 5/1/92-4/30/93.

The Analysis of Phase Distribution Phenomena in Microgravity Environments

$120,000 12/1/93-11/30/95.

The Analysis of the Effect of Gravity on Multiphase Flows
$396,544 7/26/04 - 9/30/07

GE

Two-Phase Flow Analysis
$10,152 7/15/92-11/1/92.

Two-Phase Flow Analysis
$24,180 12/14/92-3/1/93.

The Development of Multidimensional Modeling Capabilities for Annular Flows in Heated Assemblies
$203,756 8/1/96-9/1/98.

Master's Degrees

Completed

- Vea, Henry W., "An Exact Analytical Solution of Pool Swell Dynamics During Depressurization by the Method of Characteristics" (1977)
- Kamath, Pradeep, "A Turbine Meter Evaluation Model for Two-Phase Transients" (1977)
- Sim, Suk Ku, "An Analysis of Phase Distribution Mechanisms in Turbulent Two-Phase Pipe Flow" (1977)
- Cheng, Lap-Yan, "Virtual Mass Effects in Two-Phase Flow" (1977)
- Saba, Nematollah, "An Experimental Technique for the Determination of Steam/Air Fraction" (1977)
- Ohkawa, Katsu, "The Analysis of BWR Inlet Flow Blockage" (1978)
- Schell, Susan, "The Development of A Sid-Scatter Gamma Ray Technique for the Measurement of Void Fraction" (1978)
- Lombardo, Nicholas, "The Instrumentation and Data Processing of a Large Freon Loop (1978)
- Honan, Timothy J., "Phase Separation in Wyes and Tees" (1978)
- Shum, Feibiu, "The Development of a 4-Equation Drift-Flux Computer Code (DRIFT-4)" (1978)
- Drozd, Andrew , "NUFREQ-S: A Frequency Domain Drift-Flux Technique for the Evaluation of the Thermal-Hydraulic Stability of Boiling Systems" (1980)
- Ostrogorsky, Alexander ,"The Analysis of Countercurrent Two-Phase Flow Pressure Drop and CCFL Breakdown in Diabatic and Adiabatic Conduits" (1980)
- Nissley, Mitchell ,"The Analysis of Proposed BWR Inlet Blockage Experiments Using MAYU-4b" (1981)
- Antal, Steven, "An Evaluation of Boiling Water Nuclear Reactor Stability Using Systems Pressure Perturbation (1982)
- Balaram, J., "Stability Margins for Boiling Water Nuclear Reactors: A Multi-Input Multi-Output Analysis" (1982)

- Shatas, Jr., Joseph F., "A Streak Photography Method for Use in Two-Phase Flow" (1982)
- Lee, Sung Jin, "The Development of a Digital Data Processing System for Two-Phase Turbulence Data" (1982)
- Sterner, R.W., "Air/Water Subchannel Measurements of the Equilibrium Quality and Mass Flux Distribution in a Rod Bundle" (1983)
- Petzold, J.F., "Mathematical Modeling of U-Tube Steam Generator Dynamics for Slow Transients and Small Break for Loss-of-Coolant Accidents (1983)
- Koh, Byung R., "The Model of Emergency Core Cooling Systems for Severe Accident Analysis of Boiling Water Reactors (BWRs)" (1984)
- Bryam, Morris, "Modification of Brookhaven National Lab BWR Plant Analyzer to Accommodate BWR-2 Design of Nine Mile Point-1 Nuclear Power Station" (1987)
- Campanella, Rick, "Wave Propagation Phenomena in Bubbly Two-Component Two-Phase Flows" (1988)
- Kalkach-Navarro, Susana, "A Mechanistic Analysis of Phase Separation in Branching Conduits Using Three-Dimensional Two-Fluid Models" (1988)
- Kimpland, Robert, "A Phenomenological Model for the Prediction of Phase Separation in Branching Conduits" (1990)
- Haley, Thomas C., "A Characteristic Analysis of Mathematical Models of Two-Phase Flow in One Space Dimension" (1990)
- Mayo, Stephen, "Void-Fraction and Velocity Measurements in Three-Phase Flow Using a Hot-Film Anemometer" (1994)
- Potterf, Samuel, "Modeling of Heat Transfer Through Stratified Multiphase Flow in a Horizontal Pipe Using Drift-Flux Techniques, with Special Applications to Aseptic Food Processing" (1995)
- Bolotnov, I., "A Non-Linear Spectral Model for Bubble-Induced Turbolent Viscosity in Bubbly Two-Phase Flow" (2003)
- Saglime, Frank, "Experimental Results for the RPI Bubble Fusion Project" (2004)
- Trofimova , Alisa, "The Direct Numerical Simulation of Turbulent Channel Flows" (2007)

In Progress

- None

Doctoral

Completed

- Vince, Mark A., "Flow Regime Identification and Void Fraction Measurement Techniques in Two-Phase Flow" (1980)
- Kamath, Pradeep, "The Transient Analysis of DDT Rakes" (1981)
- Saba, Nematollah, "Phase Separation Phenomena in Branching Conduits (1981)
- Perez-Griffo, Maria, "Analysis of the Pulsed Neutron Activation Technique (1981)
- Conlon, William M., "An Experimental Investigation of Boiling Water Nuclear Reactor parallel Channel Effects during a Postulate Loss-of-Coolant Accident (1982)
- Taleyarkhan, Rusi P., "An Analysis of Density-Wave Oscillations in Ventilated Channels (1982)
- Ohkawa, Katsuhiro, "The Development of a Gamma-Ray Scattering Densitometer and its Application to the Measurement of Two-Phase Density Distribution in an Annular Test Section" (1983)
- Cheng, Lap-Yan, "An Analysis of Wave Dispersion, Sonic Velocity and Critical Flow in Two-Phase Mixtures" (1983)

- Park, Goon C., "The Development of NUFREQ-N, an Analytical Model for the Stability of Nuclear Coupled Density-Wave Oscillations in Boiling Water Nuclear Reactors" (1983)
- Fakory, Mohammad, "Parallel Channel Effects and Long-Term Cooling During Emergency Core Cooling in a BWR/4" (1984)
- Peng, Shie-Jeng, "NUFREQ-NP - A Digital Computer Code for the Linear Stability Analysis of Boiling Water Nuclear Reactors" (1984)
- Lin, Thomas Fu Yuan, "An Application of Pulsed Photon Activation Technique in Single- and Two-Phase Flow Measurements (1984)
- Bukhari, Khalid M., "Phase Separation and Distribution Phenomena in a Two-Dimensional Test Section" (1985)
- Wang, Shou-Kong, "Three-Dimensional Turbulence Structure Measurements in Air/Water Two-Phase Flow" (1985)
- Koh, Byung R., "The Modeling of BWR Thermal-Hydraulics for Severe Accident Analysis (1986)
- Sim, Suk K., "Phase Distribution Phenomena in Triangular Conduits (1986)
- Hwang, Sun-Tack, "A Study on Phase Separation in Branching Conduits" (1986)
- Lee, Sung-Jin,"Turbulence Modeling in Bubbly Two-Phase Flows" (1986)
- Ruggles, Arthur E., "The Propagation of Pressure Perturbations in Bubbly Air/Water Flows" (1987)
- Kim, Seok H. ,"The Modeling and Analysis of BWR Severe Accidents (1987)
- Arnold, Gary S., "Entropy and Objectivity as Constraints Upon Constitutive Equations for Two-Fluid Modeling of Multiphase Flows" (1988)
- SiAhmed, El-Khider, "An Experimental and Theoretical Investigation of Melt Propagation in a Rubble Bed with Applications to Degraded Nuclear Reactor Cores" (1988)
- Kim, Dong-Ha, "An Analysis of Corium/Structure Interaction during Severe Accidents in Boiling Water Nuclear Reactors" (1990)
- Lopez de Bertodano, Martin, "Turbulent Bubbly Two-Phase Flow in a Triangular Duct" (1992)
- Park, Jee-Won, "Void Wave Propagation in Two-Phase Flow" (1992)
- Cho, Chang-Sok, "Modeling and Analysis of Radionuclide Transport during Severe Accidents in Boiling Water Nuclear Reactors" (1992)
- Valenti (Kalkach-Navarro), Susana, "The Mathematical Modeling of Flow Regime Transition in Bubbly Two-Phase Flows" (1992)
- Jia, Hong, "Multidimensional Effects During Corium Spreading and Corium-Concrete Interaction in BWRs" (1992)
- Yoon, Juh-Yeon,"A Streamline Upwinding Finite Element Method for Multiphase Flow and Heat Transfer Analysis" (1993)
- Antal, Stephen P., "Phase Distribution in Bubbly Two-Phase Flows" (1994)
- Alajbegovic, Ales, "Phase Distribution and Turbulence Structure for Solid/Fluid Upflow in a Pipe (1994)
- Chang, Chin-Jang, "The Analysis of Chaotic Instabilities in Boiling Systems" (1994)
- Kim , Shin-Whan, "Computer Simulation of Severe Accidents in Boiling Water Nuclear Reactors" (1994)
- Assad, Amir, "An Experimental Study of Phase Distribution and Turbulence Structure for Solid/Liquid Flow in Horizontal and Vertical Pipes" (1995)
- Garea, Veronica B., "Nodal Analysis of Two-Phase Flow Instabilities" (1998)
- Moraga, Francisco, "Lateral Forces on Rigid Spheres in a Turbulent Uniform Shear Flow" (1998)
- Nigmatulin, Tagir, "An Experimental and Theoretical Study of Interfacial Area Density for different Two-Phase Flow Regimes" (1999)
- Bae, Song H., "A Theoretical Investigation of the Dynamics of Single Bubble

Sonoluminescence" (1999)
- Delgadino, Gerardo, "The Dynamics of Single Bubble Sonolominescence" (1999)
- Singhal, Maneesh, "The Effect of Dispersed Phase Buoyancy on Phase Distribution" (2004)
- Yin, Juan, "Modeling and Analysis of Multiphase Instabilities" (2004)
- Cancelos , Silvina, "Effect of Acoustically-Induced Pressures on the Permeability of a Bullfrog Urinary Bladder" (2007)
- Galimov , Azat , "An Analysis of Interfacial Waves and Air Ingestion Mechanisms" (2007)
- Bolotnov, Igor , " Cascade Modeling of Single and Two-Phase Turbulence" (2008)
- Ortega-Gomez , Tino, "Stability Analysis for High Performance Light Water Reactor" - U. Karlsruhe , Germany (2008)
- Rodriguez , Joseph M., "Numerical Simulation of Two-Phase Annular Flow" (2009)
- Schlichting, William R. , " An Analysis of the Effect of Gravity on Interacting DWO/PDO Instability Modes" (2009)

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 9, 2010

Riverkeeper, Inc. provisionally designates

the attached Declaration of Dr. Joram Hopenfeld

dated September 9, 2010 as containing

Confidential Proprietary Information

Subject to Nondisclosure Agreement

REDACTED, PUBLIC VERSION

UNITED STATES
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

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Entergy Nuclear Indian Point 2, LLC, Entergy Nuclear Indian Point 3, LLC, and Entergy Nuclear Operations, Inc.	DPR-26, DPR-64 September 9, 2010

DECLARATION OF DR. JORAM HOPENFELD IN SUPPORT OF PETITIONERS STATE OF NEW YORK AND RIVERKEEPER, INC.'S NEW AND REVISED CONTENTION CONCERNING METAL FATIGUE

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 support of the State of New York and Riverkeeper's New and Revised Contention concerning Entergy's inadequate plan to monitor and manage the effects of aging due to metal fatigue on key reactor components.

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 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. I have also reviewed two Westinghouse proprietary documents provided by Entergy pursuant to the parties' mandatory disclosure obligation, entitled "Environmental Fatigue Evaluation for Indian Point Unit 2" and "Environmental Fatigue Evaluation for Indian Point Unit 3," which were received by Riverkeeper on August 23, 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.

Entergy's "Refined" Fatigue Evaluations

8. Entergy's LRA included two tables (4.3-13 and 4.3-14) containing values of environmentally adjusted cumulative usage factors ("CUFen") 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 CUFen.

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

10. However, the methodology employed to calculate Entergy's new CUFen calculations is, as yet, highly suspect and questionable, calling 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]

[redacted] *See* NUREG/CR-6909; EnvFat 1.0 User's Manual, Version 1.0 (May 2009), IPECPROP00056783[1]; 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 Fen 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 Fen 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 Fen 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). To appropriately apply such Fen 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 Fen values of 12 and 17 for stainless steel and carbon, respectively. To the contrary, Entergy continues to use unrealistically low Fen values that are, as yet, not justified in light of the wide range of parameters unaccounted for.

11. One of the largest uncertainties in determining appropriate Fen values is the concentration of dissolved oxygen (DO) in the water at the surface of each component during the transient. The Fen 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 Fen, 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 Fen 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 Fen for each component

[1] An excerpt of this document was provided to Riverkeeper on September 3, 2010.

during the transients; without an understanding of the DO levels used in each transient for the calculations of Fen, it is impossible to conclude that the claimed CUFen values, which Westinghouse and Entergy's recent refined analysis purport to predict to a ten-thousandth of a decimal point, are accurate.

12. Furthermore, Entergy's evaluation does not specify the heat transfer coefficients used for each component during the transients. The CUFen 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 CUFen. 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 CUFen. 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 CUFen remains highly questionable and it is impossible to conclude that Entergy's new CUFen calculations are accurate to the degree Entergy now claims.

13. Moreover, the number of transients that were used in the calculations directly affects the CUFen. 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 CUFen 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.

14. 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 CUFen 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.

15. Based on the foregoing, 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.

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

16. 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.*

17. In response to CUFen 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 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.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.

18. Given Entergy's previous findings in its initial April 2007 LRA that CUFen values for various components exceeded the regulatory threshold, and the questionable nature of the recently revised calculations to demonstrate that the CUFen 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 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).

19. The lack of a reliable, transparent, complete assessment of CUFen 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).

20. 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 CUFen 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 CUFen. Thus, Entergy's flawed methodology for calculating CUFen, 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.

21. 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

22. 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. 8, 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 Support of State of New York and Riverkeeper, Inc.'s New and Revised Contention Concerning Metal Fatigue (September 9, 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)

2005-2006

Technical consultant and expert witness 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.

B. Industry and Government Employment

1962- 1971 –Corrosion 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 destruction of SNAP fuel rods on reentry into the earth atmosphere. Atomics International, Canoga Park, Calif.

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