RIV000003
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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
ATOMIC SAFETY AND LICENSING BOARD

In the Matter of Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3)	Docket Nos. 50-247-LR and 50-286-LR

PREFILED WRITTEN TESTIMOY OF DR. JORAM HOPENFELD REGARDING RIVERKEEPER CONTENTION TC-2 – FLOW ACCELERATED CORROSION

On behalf of Riverkeeper, Inc. ("Riverkeeper"), Dr. Joram Hopenfeld submits the following testimony regarding Riverkeeper Contention TC-2.

Q. Please state your name and address.

A. My name is Dr. Joram Hopenfeld and my business address is 1724 Yale Place, Rockville Maryland, 20850.

Q. What is your educational and professional background?

A. I have received the following degrees from the University of California in Los Angeles: a B.S. and M.S. in engineering, and a Ph.D. in mechanical engineering. I am an expert in the field relating to nuclear power plant aging management. I have 45 years of professional experience in the fields of nuclear safety regulation and licensing, design basis and severe accidents, thermal-hydraulics, material/environment interaction, corrosion, fatigue, radioactivity transport, industrial instrumentation, environmental monitoring, pressurized water reactor steam generator transient testing and accident analysis, design, and project management, including 18 years in the employ of the U.S. Nuclear Regulatory Commission ("NRC"). My education and professional experience are described in my *curriculum vitae*, which is provided as Exhibit RIV000004.

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to provide support for, and my views on, Riverkeeper's Contention TC-2 related to the aging effects of flow-accelerated corrosion ("FAC") at Indian Point Generating Unit Nos. 2 and 3 during proposed 20-year extended operating terms. This contention was admitted by the Atomic Safety & Licensing Board ("ASLB") on July 31, 2008.[1] Riverkeeper asserts that Entergy Nuclear Operations, Inc. ("Entergy"), the owner of Indian Point, has failed to demonstrate that FAC will be adequately managed during the proposed periods of extended operation at the plant as required by 10 C.F.R. § 54.21(c).

Q. Please describe your professional experience specifically as it relates to FAC.

A. I have published numerous peer-reviewed papers in the area of corrosion, and hold patents related to monitoring of wall thinning of piping components. I have knowledge and expertise regarding the use of the CHECWORKS computer code, a program that was developed in an attempt to manage FAC at nuclear power plants. My familiarity with the CHECWORKS code dates back to 1988, when it was known as CHEC. 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 FAC and the use of CHECWORKS.

Q. Have you prepared a report in support of your testimony?

A. Yes, I prepared an expert report, provided as Exhibit RIV000005, which reflects my analysis and opinions.

Q. What materials have you reviewed in preparation for your expert report and testimony?

A. I have reviewed numerous documents in preparation of my expert report and testimony, including the following: the relevant section of Entergy's License Renewal Application ("LRA"), all of the pleadings involving Riverkeeper Contention TC-2, including Entergy's Motion for Summary Disposition of Riverkeeper's Contention TC-2 and supporting attachments thereto,[2] relevant portions of NRC Staff's Safety Evaluation Report pertaining to the Indian Point

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[1] *See* In the Matter of Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3), Docket Nos. 50-247-LR and 50-286-LR, ASLBP No. 07-858-03-LR-BD01, Memorandum and Order (Ruling on Petitions to Intervene and Requests for Hearing) (July 31, 2008), at 161-62. In response to new metal fatigue evaluations performed by Entergy, Riverkeeper and NYS jointly filed an amended contention, NYS-26B/RK-TC-1B, which the ASLB admitted as superseding the previous contentions.

[2] Applicant's Motion for Summary Disposition of Riverkeeper Technical Contention 2 (Flow-Accelerated Corrosion) (July 26, 2010), ADAMS Accession No. ML102140430.

license renewal proceeding, hundreds of documents identified by Entergy as relevant to Riverkeeper's FAC contention, numerous relevant NUREG reports, scientific and scholarly reports and articles, industry guidance documents and reports, and other documents generated by NRC, Entergy, industry groups, and scientific organizations. I have used such documents to inform me of the relevant facts and derive my conclusions.

A list of the particular documents that I reference in my expert report, and which I rely upon in this testimony, is included at the end of the report. Those references have been provided as RIV000006 through RIV000033, (or have been previously been provided as exhibits by another party in the proceeding), in support of my testimony. To the best of my knowledge, these are true and accurate copies of each document that I referred to, used and/or relied upon in preparing my report and this testimony. In some cases where the document was extremely long and only a small portion is relevant to my testimony, an excerpt of the document is provided. If it is only an excerpt, that is noted on the cover of the Exhibit.

Q. What conclusions have you reached about Entergy's program for managing FAC at Indian Point during the proposed period of extended operation?

A. In my professional judgment, and as I describe in more detail below and in my report, Entergy has failed to demonstrate that the serious aging mechanism of FAC will be adequately managed throughout the proposed extended licensing terms at Indian Point. Entergy plans to rely far too heavily on the CHECWORKS computer code to manage FAC during the PEO. This leaves the FAC Aging Management Program ("AMP") at Indian Point fundamentally deficient, since CHECWORKS is not an effective tool for predicting and managing FAC at the plant. Entergy's AMP must contain sufficient details about how FAC will otherwise be monitored and addressed, but it does not. As a result, Entergy has failed to demonstrate that it has a program for handling FAC that meets all relevant criteria and standards.

Q. What is Flow-Accelerated Corrosion?

A. FAC is a pipe wall thinning phenomenon in which the thinning rate is accelerated by flow velocity. When the metal is exposed to flowing liquid, flow velocity has a significant effect on metal removal. FAC includes wall thinning by impingement corrosion, electrochemical corrosion, erosion-corrosion, cavitation-erosion, and chemical dissolution. FAC is affected mainly by turbulence intensity, steam quality, material compositions, oxygen content, and coolant pH. The rate of FAC depends upon the local geometry, local metal composition, and local turbulences. FAC can manifest in the formation of round holes and grooving. Once local corrosion has begun, geometrical changes may cause FAC to increase in a non-linear rate.

Q. What are the safety implications of FAC?

A. Undetected FAC can pose a significant safety risk at nuclear power plants. In order to ensure that the pipes susceptible to FAC will operate safely throughout their lifetime, they are designed with a corrosion allowance that is added to the minimum design wall thickness, commonly known as Tcr. When FAC reduces wall thickness of a component *below* the minimum design value, the potential exists for the component to rupture. In many cases, this will be preceded by a leak, which can be detected before catastrophic rupture. A FAC-induced rupture of a high pressure component or pipe may have very serious safety consequences. For this reason, the ASME code, specifically requires that components and pipes do not operate below design limit wall thicknesses.[3] Numerous instances of undetected FAC have previously resulted in catastrophic events, including several fatalities at the Surry nuclear power plant in 1986 due to a feed water pipe elbow rupture, and several fatalities at the Mihama nuclear power plant as a result of FAC in the secondary loop.

Q. What is the CHECWORKS computer code?

A. In the wake of several industry FAC events, the CHECWORKS computer code was developed to assist utilities in preventing FAC-related failures. The goal of the CHECWORKS software is to predict what locations may succumb to FAC-induced wear before wall thinning reaches unacceptable levels. Due to the inherent unpredictability of FAC, CHECWORKS is based on statistics, meaning, a collection of selected data which represents only a fraction of the total flow area. Accordingly, CHECWORKS is not a reliable predictive tool unless it is adequately benchmarked for each component and for relevant plant parameters. Changes in plant parameters necessitate appropriate re-calibration of the CHECWORKS code. Updating the model is especially important in the event of a power increase, since power changes affects

[3] ASME B31.3; ASME Code Section III, Paragraph NB-3200.

various plant parameters, including velocities, temperatures, coolant chemistry, and steam moisture. The Electric Power Research Institute ("EPRI") has recognized that power uprates, even small ones, can significantly affect the rate of FAC.[4]

Q. Please describe Entergy's program for managing FAC during the PEO, as you understand it.

A. Entergy's LRA sections § A.2.1.14 and B.1.15 indicate that its FAC program is based on an EPRI guidance document, EPRI, *Recommendations for an Effective Flow-Accelerated Corrosion Program*, and involves determining critical locations, performing inspections, and undertaking corrective action if necessary. The LRA further indicates that Entergy believes its FAC AMP is consistent with NUREG-1801, *Generic Aging Lessons Learned (GALL) Report* ("*GALL Report*"). Based on my review of EPRI's guidance document, as well as Entergy's program implementation documents,[5] it is apparent that Entergy's FAC management program is largely based on the use CHECWORKS to predict timing and locations of wall thinning.

Q. What is your opinion regarding Entergy's use of CHECWORKS to manage FAC during the PEO?

A. Entergy's dependence on CHECWORKS to select components for wall measurements and to determine the time between successive thickness measurements is misplaced, because CHECWORKS will fail to assure that timely detection of FAC-related wall thinning will occur during the proposed PEO. This is primarily because CHECWORKS is not properly benchmarked and fails to provide reliable predictive results at Indian Point.

Q. How did you reach the conclusion that CHECWORKS is not properly benchmarked at Indian Point?

A. Entergy provided and I reviewed more than 6,500 data points, contained in Indian Point-specific CHECWORKS modeling reports. These reports memorialize CHECWORKS-related results from FAC-related inspections which occur during plant outages. The data I reviewed was collected in relation to more than 10 outages at Indian Point, from both before and after power

[4] EPRI, Recommendations for an Effective Flow-Accelerated Corrosion Program, NSAC-202L-R3, at p.4-5.

[5] EN-DC-315, Revision 3, *Flow Accelerated Corrosion Program* (March 1, 2010).

uprates that occurred at Unit 2 in 2004 and Unit 3 in 2005. The data plots CHECWORKS wear predictions of component wall thickness relative to actual measurements. The data I reviewed, excerpted from Entergy's CHECWORKS modeling reports, has been included in support of my testimony as RIV00016A and RIV00016A. Based on my extensive analysis of Entergy's data, it is my professional opinion that the CHECWORKS computer code produces highly unreliable and non-conservative component wear predictions. Specifically, the data shows that CHECWORKS has consistently been inaccurate at Indian Point. There is a complete lack of correlation between component wear predictions and actual wall thickness measurements. Allow me to explain. Each graph shows three lines: a central 45° line, and lines designated +50% and -50%. With a perfect correlation, all the data would fall on the 45° line. However, Entergy's data shows that very few points fall on the 45° line. Generally, the graphs exhibit a wide scatter. The data points that fall between the 45° line and the abscissa, i.e., the zero wear prediction x-axis, represent non-conservative predictions. My review of all of Entergy's plotted data points reveals that CHECWORKS has yielded non-conservative predictions about 40-60% of the time. I have documented this finding in relation to the different data sets I reviewed in Table 1, column (A) contained in my report. Additionally, with an ideal correlation each predicted point would have a single measured value. Instead, Entergy's data shows that a given prediction yields many widely different measured points. Furthermore, the data shows that the degree of inaccuracy of CHECWORKS' predictions has been quite large. While the +/-50% lines of each graph imply that CHECWORKS bounds the data within +/-50%, this is highly misleading and incorrect. The data falling within this range actually represents a much larger degree of imprecision. The +50% line represents conservative over-predictions in wear that vary by a factor of .7, while the -50% line represents non-conservative under-predictions of wear that vary by a factor of 2. Simply because this data appears within the arbitrary lines placed on these graphs does not indicate that the CHECWORKS has an appropriate degree of accuracy. In any event, many data points fall outside the arbitrary +/-50% lines, which indicates that CHECWORKS cannot even bound the data conservatively within a factor of 2. I have documented the degree to which data fell outside the +/-50% lines in Table 1, column (B) in my expert report. My review of the data reveals that CHECWORKS can over or under predict actual measured FAC by more than a factor of 10. The over-prediction or under-prediction of the data by a factor of 10 exhibited by a significant number of components clearly demonstrates that the CHECWORKS model employed at Indian

Point cannot predict FAC to any degree of accuracy or precision. Instead, CHECWORKS can only predict an overall range of corrosion rate that is far too wide for practical applications, especially when the consequences of component failure are safety related. The consistent inaccuracy of CHECWORKS, from before the power uprates at Indian Point, to well after, demonstrates that the CHECWORKS model has never been properly benchmarked, that the model is certainly not currently benchmarked to account for changes in plant operating parameters as a result of the power increases.

Q. The graphs plotting the CHECWORKS data you reviewed all contain an "LCF." Can you explain what this means?

A. Based on my review of Entergy's CHECWORKS reports, it is my understanding that LCF stands for "line correction factor." According to Entergy, this indicates the degree of CHECWORKS' under- or over- predictions.[6] Entergy uses the LCF to "adjust" the predictions to match the inspection data.[7] While an LCF of 1 would represent an exact agreement between CHECWORKS predictions and actual wall thickness measurements, Entergy considers the LCF to be acceptable if it is between 0.5 and 2.5.[8] Interestingly, the only graphs showing an LCF of 1, are those figures with no data in them. Based on my review of Entergy's documentation, there is no justification to support the conclusion that an LCF within the range of 0.5 to 2.5 is acceptable or that an LCF within this range would be an indication that CHECWORKS can be used to accurately predict inspection locations. In any event, the CHECWORKS data I reviewed reveals many instances where the LCF was outside the range that Entergy claims is acceptable. I have documented this in Table 1, column (c) in my expert report. Based on Entergy's own criteria, it is apparent that CHECWORKS is unreasonably failing to predict wear rates.

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[6] CSI, Technologies, Inc., Indian Point Unit 3 CHECWORKS SFA Model, Calculation No. 0705.100-01, Revision 2, August 2, 2011, at p.26.

[7] Applicant's Motion for Summary Disposition of Riverkeeper Technical Contention 2 (Flow-Accelerated Corrosion) (July 26, 2010), ADAMS Accession No. ML102140430, at Attachment 2, ¶ 48.

[8] CSI, Technologies, Inc., Indian Point Unit 3 CHECWORKS SFA Model, Calculation No. 0705.100-01, Revision 2, August 2, 2011, at p.26.

Q. Are there any limitations to your review of the CHECWORKS data that Entergy provided?

A. Yes. Despite the fact that CHECWORKS has been in use since the early 1990s when EPRI sold the program to nuclear power plant operators, Entergy has no CHECWORKS related documentation related to Indian Point Unit 2 generated prior to the year 2000.[9] Further, Entergy did not provide any CHECWORKS related documentation related to Indian Point Unit 3 generated prior to 2001, since "locating such documentation, to the extent it exists, would be extremely burdensome."[10] Thus, the data analyzed represents only a fraction of the total plant data that was allegedly used to benchmark CHECWORKS at Indian Point. The available data, however, is sufficient to show that the model is not adequately benchmarked for use at Indian Point.

Q. You indicated that you participated in the Vermont Yankee license renewal proceeding in relation to FAC and the use of CHECWORKS. Are you aware of the ASLB determination in that proceeding relating to benchmarking of the CHECWORKS model at Vermont Yankee?

A. Yes, it is my understanding that the ASLB in the Vermont Yankee license renewal proceeding determined that, at Vermont Yankee, a prolonged period of benchmarking of CHECWORKS at VY was not necessary.

Q. Is there any reason to believe that the ASLB determination in the Vermont Yankee license renewal proceeding about the benchmarking of CHECWORKS at Vermont Yankee has any relevance to the use of CHECWORKS at Indian Point?

Q. No, not at all. In fact, there several key differences between the use of CHECWORKS at Vermont Yankee versus Indian Point. First, at Vermont Yankee, there was no post-power uprate data to assess when the FAC program was under review. Instead the ASLB assumed that future updates to the CHECWORKS model before Vermont Yankee entered a proposed PEO would

[9] *See* In the Matter of Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3), Docket Nos. 50-0247-LR and 50-286-LR, ASLBP No. 07-858-03-LR-BD01, Order (Ruling on Riverkeeper's Motion to Compel) (November 4, 2010), at 3.

[10] *See* In the Matter of Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3), Docket Nos. 50-0247-LR and 50-286-LR, ASLBP No. 07-858-03-LR-BD01, Order (Ruling on Riverkeeper's Motion to Compel) (November 4, 2010), at 4.

benchmark the model. My review of three post-power uprate data sets for Indian Point Unit 2 and three post-power uprate data sets for Indian Point Unit 2 already shows that CHECWORKS has not been adequately benchmarked despite ample post-power increase model updates. In addition, at Vermont Yankee, prolonged benchmarking was found not to be necessary because the plant had the benefit of data dating back to 1989. There is no such historical data at Indian Point. Third, in Vermont Yankee, CHECWORKS was determined to be only a small part of the FAC management program. At Indian Point, Entergy's FAC program relies integrally upon CHECWORKS for determining inspection locations.

Additionally, a plant specific evaluation is prudent and necessary in order to account for unique differences in flow velocities, temperatures, geometry, material, and coolant chemistry. An evaluation of a nuclear power plant operator's use of CHECWORKS necessarily depends upon plant specific data. Accessibility for inspections, past history with respect to the number of components and frequency of wall measurements that were used in the calibration of CHECWORKS, the quality of the correlation of predictions with measurements, and the number of component failures from wall thinning, will necessarily vary depending on the facility. Indian Point is a much larger facility in comparison to Vermont Yankee, and a different and more susceptible type of reactor. As such, it is not appropriate to simply assume that the power uprate that occurred at Vermont Yankee bounds the one that occurred at Indian Point.

Based on these numerous differences in the circumstances surrounding the use of CHECWORKS at Vermont Yankee versus Indian Point, the findings made in the Vermont Yankee proceeding are not relevant to whether CHECWORKS is adequately benchmarked for use at Indian Point.

Q. Please summarize your conclusions relating to whether the CHECWORKS model is adequately benchmarked in relation to the operation of Indian Point.

A. The available universe of CHECWORKS comparison data demonstrates very poor predictive accuracy of the CHECWORKS model at Indian Point. The data further reveals no signs that predictions are improving with time. The highly erratic predictive behavior of the CHECWORKS model renders the CHECWORKS code useless for objective quantitative assessments. The failure of the CHECWORKS code to produce accurate or useful results at Indian Point despite decades of use unmistakably shows that the model continues to lack adequate benchmarking, and will not be properly calibrated before Indian Point enters the rapidly approaching proposed PEO. The lack of adequate benchmarking renders CHECWORKS an ineffective tool for selecting and prioritizing piping and piping component locations at Indian Point for inspections and wall thickness measurements during outages to timely detect and mitigate FAC during the proposed PEO.

Q. What are the implications of CHECWORKS' poor predictive accuracy due to inadequate benchmarking?

A. CHECWORKS predictions of wall thinning by FAC at the plant are by far too inaccurate to prevent pipe wall thickness from being reduced below minimum design values. Non-conservative predictions affect plant safety because they fail to indicate when a component is reaching a critical wall thickness and thereby result in untimely component inspection and replacement. I have discussed some examples to illustrate this point in my expert report. Wear rates, initial pipe wall thickness, and minimum design thickness vary widely, and even small changes in the corrosion rate can result in unacceptable levels of FAC and unsafe plant operations. As such, the inaccuracy of CHECWORKS is likely to allow many components to operate outside allowable critical design limits during the PEO. The increase in operating life from 40 to 60 years represents a significant potential for pipe wall thicknesses to fall below designated minimum critical design levels during extended operations, and one would expect that more and more components would become prone to failures after 40 years of service. In my professional opinion, the non-conservative nature of the CHECWORKS code will result in unacceptable FAC occurring during the PEO, which could pose serious safety issues.

In addition, conservative predictions may also affect plant safety. Entergy's documentation indicates that Entergy often attributes findings of "negative time to Tcr" (i.e., a finding that a component has low remaining life and should be replaced), to an "often overpredicted," meaning conservative, wear value by CHECWORKS.[11] However, CHECWORKS generally produces

[11] *See* CSI, Technologies, Inc., Indian Point Unit 3 CHECWORKS SFA Model, Calculation No. 0705.100-01, Revision 2, August 2, 2011, IPEC 00238096, at Appendix K – Components with Negative Time to Tcrit.

non-conservative wear predictions. Additionally, Entergy's apparent assumption is highly problematic from a safety perspective: if predictions are commonly perceived to be based on conservative estimates, component replacement could be erroneously postponed potentially resulting in an excessive wall thinning.

Q. Aside from assessing the degree to which CHECWORKS is benchmarked, is there any other way to evaluate the effectiveness of the model at Indian Point?

A. Yes. To employ CHECWORKS in the face of evidence of inadequate benchmarking, it would be necessary to prove that the model has an adequate track record of performance at actually predicting and preventing FAC. Thus, an assessment of the number and severity of actual component and pipe failures, including leaks and ruptures, that have occurred at Indian Point over the years since CHECWORKS was introduced will also be indicative of whether or not the program is useful and effective.

On an industry-wide basis, CHECWORKS has not been successful at predicting FAC-induced wall thinning. This was recognized by the Advisory Committee on Reactor Safeguard ("ACRS") Subcommittee on Thermal Hydraulics in 2005.[12] In addition, NUREG/CR-6936, PNNL *16186,Probabilities of Failure and Uncertainty Estimate Information for Passive Components - a Literature Review* (May 2007) indicates that rate of FAC-related failures at pressurized water reactors did not decrease, and actually went up, during the period of time after CHECWORKS was introduced. In fact, in the years since the nuclear power plant industry began using CHECWORKS, incidents of undetected FAC, including leaks and pipe ruptures, have continued to be reported at numerous nuclear power plants across the United States. While there have been no recent catastrophic events resulting from FAC, this is not permission for the plant to operate with pipes of unknown and unacceptable wall thickness. The "leak-before-break" concept is not an excuse for operating with excessively worn-out components. There is simply no evidence to suggest that CHECWORKS has been a reliable tool in the industry for predicting and preventing FAC.

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[12] Statement by Dr. F. Peter Ford, transcript of January 26, 2005 meeting of the ACRS Subcommittee on Thermal Hydraulics (January 26, 2005), at 198, ADAMS Accession No. ML05040At 0613.

At Indian Point, a history of incidents demonstrate that, to date, CHECWORKS has not been successful in mitigating the effects of FAC. My review of documents provided by Entergy as relevant to Riverkeeper Contention TC-2 indicates that numerous leaks and reports of excessive wall thinning in mechanical systems at Indian Point have been reported.[13] Entergy has documented many instances where FAC has caused component wall thickness to decrease below acceptable code limits. There have also been numerous FAC-induced leaks. The long and consistent history of such occurrences at Indian Point clearly indicates that CHECWORKS has not been successful at predicting where unacceptable FAC is likely to manifest.

While it is not possible to assess whether the number of failures has increased since the owners of Indian Point began using CHECWORKS in the 1980s due to the fact that data for years prior to approximately 2000 is "unavailable," it is clear that FAC-related failures continue to occur despite the use of CHECWORKS at the plant. As Indian Point continues to age past 40 years, it is reasonably foreseeable that more and more components will be prone to thinning and failure.

Entergy's own documentation irrefutably shows that there is currently no track record of performance of the CHECWORKS code at Indian Point. The model has not been able to preventatively detect FAC before component wall thickness dips below minimum design requirements. Numerous such instances demonstrate the Entergy's use of CHECWORKS violates the ASME code, and poses tangible safety related concerns, as manifested by the various leaks that have occurred at Indian Point due to undetected FAC. Entergy's failure to demonstrate that the computer model has a demonstrated record of performance is further evidence that CHECWORKS cannot be considered an appropriate or useful tool for managing FAC at Indian Point during the PEO.

[13] *See* Entergy Engineering Report, Operating Experience Review Report, IP-RPT-06-LRD05, Rev. 3 (2008), IPEC00186046; Daily DER Report, DER-01-01522, April 25, 2001, IPEC00020501; Entergy Operations, Inc., Condition Report List, IPEC00185743; Entergy Operations, Inc., Condition Report List, IPEC00092552; Entergy Condition Report CR-IP2-2001-10525, IPEC00092616; Entergy Condition Report CR-IP3-2006-02270, IPEC00025699.

Q. What is your understanding regarding whether Entergy has any other methods, aside from CHECWORKS, for managing the aging effects of FAC during the PEO?

A. I understand that Entergy has stated its position that it does not solely rely upon the use of CHECWORKS to manage FAC. In particular, Entergy has stated that the FAC program at Indian Point will be effective because "CHECWORKS is only *one* of several bases used by Entergy to select and schedule in-scope components for inspection."[14] Entergy believes that the FAC program at Indian Point would be effective even without CHECWORKS because inspection scope is also based on (1) actual pipe wall thickness measurements from past outages, (2) industry experience related to FAC, (3) results from other plant inspection programs, and (4) engineering judgment.[15]

Q. Please evaluate the effectiveness of these other "tools" for managing FAC during the PEO.

A. These other tools that Entergy apparently relies upon do not demonstrate the effectiveness of Entergy's FAC AMP. This is because these additional criteria cannot be viewed as tools that would independently establish an accurate FAC inspection scope. In fact, they largely depend upon CHECWORKS. For example, actual pipe wall thickness measurements from past outages are only useful when used in combination with a predictive tool which would prevent the wall thickness of a given component from being reduced to below the minimum design thickness while in service. In other words, this is a required input for the use of CHECWORKS. It certainly cannot be classified as a stand-alone tool for component selection. In addition, if a component is initially selected to be inspected because of a CHECWORKS prediction, than, necessarily, future decisions about inspection scope based on actual wall thickness measurements, and wear rate trending of the actual inspection results, depend upon use of the CHECWORKS computer model.

Industry and plant experience includes information about wall thinning events at Indian Point as well as other plants, or changed plant parameters. These are also types of information that feed

[14] Applicant's Motion for Summary Disposition of Riverkeeper Technical Contention 2 (Flow-Accelerated Corrosion) (July 26, 2010), ADAMS Accession No. ML102140430, at 17.

[15] Applicant's Motion for Summary Disposition of Riverkeeper Technical Contention 2 (Flow-Accelerated Corrosion) (July 26, 2010), ADAMS Accession No. ML102140430, at 17 and Attach. 2, ¶¶ 39.

directly into the CHECWORKS model. These are not necessarily independent tools for identifying and specifying the inspection scope during outages. Again, the usefulness of such information for determining future inspections largely rests on how the CHECWORKS model processes the inputs and how such information affects the model over time.

The only tool that can be considered an independent method for managing FAC is engineering judgment. If actual pipe wall thickness, plant, and industry experience are not relying on CHECWORKS, they can only otherwise be characterized as inputs which assist the formulation of an engineering judgment. However, alone, this is not a sufficiently reliable tool for managing FAC at Indian Point. The development of the CHECWORKS computer model itself stemmed from the realization by the nuclear industry that engineering judgment alone was no longer enough to be able to detect unacceptable and unsafe wall thinning occurrences. Engineering judgment is problematic because it is intrinsically subjective. When engineering judgment is identified as an independent predictive tool, a very high degree of knowledge is required by those who conduct the assessment and specify the required steps for the prevention of component failures. However, even with the same input data, different assumptions could lead to different results because each assessment would depend heavily on the individual skill and experience of the responsible engineer. In order to assess the validity of the use of engineering judgment, it is imperative to fully understand how it is used and all relevant underlying assumptions informing any judgment related determinations.

Entergy's FAC program fails to clearly describe what exactly engineering judgment even means in relation to FAC inspections at Indian Point, and what role it actually plays in inspection scope selection. Entergy has not identified any kind of systematic methodology which demonstrates that engineering judgment is a separate predictive tool that would adequately manage FAC related component degradation during the PEO. In fact, based on my review of Entergy's numerous documents pertaining to its FAC program at Indian Point, it is apparent that Entergy fails to espouse several elements that are key to forming a sound engineering judgment about FAC. First, good documentation of historical FAC assessments is critical in order to ensure that engineering judgment will be based on sound knowledge of plant history. All aspects of the FAC experience at the plant must be maintained, including the accuracy of past predictions, repairs, and changes in plant operating conditions like water chemistry. At Indian Point, Entergy has lost more than half of the overall amount of CHECWORKS-related data and documentation. The lack of an institutional knowledge relating to FAC hinders sound engineering judgment. Second, good communication between the organization that conducts analytical assessments and the plant operators is essential to ensure that problems are identified early and appropriate actions are taken to resolve them. At Indian Point, despite anomalies in CHECWORKS results, the record of documents I reviewed did not show adequate discussions between Entergy and Entergy's vendor, CSI, Technologies, Inc. about the significance of such anomalies. It is not apparent that Entergy and its outside vendors have the level of communication necessary to yield an adequate engineering judgment. Third, to render a sound engineering judgment, the operator must have knowledge of FAC assessment methods. In other words, it is critical to understand the model employed, which at Indian Point, is predominantly, if not solely, CHECWORKS. However, this is difficult to accomplish. For example, one important way to understand the validity of CHECWORKS is to observe how the model responds to changes in plant parameters. While the opportunity to observes the model's response to input variables arose in 2004 and 2005 at Indian Point, a comparison to past performance is very limited in light of the fact that Entergy has lost most of the documentation and data. Additionally, Entergy has indicated its belief that historical documentation related to CHECWORKS is irrelevant for purposes of assessing the validity of the model. This is an inappropriate attitude for purposes of demonstrating the ability to exercise well-founded engineering judgment. Fourth and lastly, engineering judgment requires knowledge or risks and consequences. In other words, it is necessary to understand and take into account the varying safety risks posed by FAC. For example, a pipe rupture of a small pipe in the service water system does not pose a risk that could lead to a severe reactor accident, while a FAC-induced rupture of a main feedwater or steam line pipe may lead to an uncontrolled severe accident. The documents and information provided by Entergy do not reflect adequate consideration of inspection priorities of FAC-susceptible components relative to the safety risks posed due to a FAC-related failure.

Based on this assessment, Entergy has completely failed to demonstrate that engineering judgment alone will safely manage FAC at Indian Point.

In turn, it is apparent that Entergy does not employ any meaningful tools that, separate and apart from CHECWORKS, would sufficiently manage the aging effects of FAC at Indian Point. Rather, Entergy's program for managing FAC relies heavily on the unreliable CHECWORKS code.

Q. Aside from CHECWORKS and the four other tools Entergy claims inform the scope of FAC inspections, has Entergy identified any other details or program elements that would adequately manage FAC during the PEO?

A. No. Entergy's FAC program implementation documents rely heavily on the appropriate use of CHECWORKS. However, Entergy's use of CHECWORKS has not been successful and the model cannot be used to predict wall thinning during the PEO. Entergy has further failed to identify any other tools that operate independent from CHECWORKS that would adequately manage FAC. Accordingly, Entergy has failed to demonstrate that it has an adequate AMP to manage FAC during the PEO. In order to comply with the *GALL Report* and NUREG-1800, *Standard Review Plan for License Renewal Applications*, Entergy must provide sufficient details to address all relevant program elements, including the method for determining component inspections, frequency of such inspections, and attendant criteria for component repair and replacement.[16] Entergy cannot simply rely on procedural documents which depend upon the proper use of CHECWORKS. Instead, Entergy must provide sufficient details regarding inspection scope, frequency, component replacement and repair criteria, etc., to demonstrate that FAC will be appropriately managed. Entergy has not done this. Its FAC AMP lacks sufficient details to demonstrate that, aside from the use of CHECWORKS, the aging effects of FAC will be adequately managed throughout the proposed PEO.

Q. You indicated earlier that it is your understanding that Entergy believes that its FAC AMP complies with NRC's *GALL Report*. How would you assess that position?

A. Entergy's position that the FAC AMP at Indian Point complies with the guidance contained in the *GALL Report* is unfounded and wrong. The *GALL Report* clearly indicates that when a licensee uses CHECWORKS to predict wall thinning, the code must be properly benchmarked before it can be used as a management tool to control FAC. In fact, though

[16] *See* SRP-LR at § A.1.2.3.

Entergy ostensibly continues to rely on the *GALL Report*, Revision 1, the newest version of the *GALL Report*, Revision 2, makes this explicit. In particular, the *GALL Report*, Revision 2, indicates that CHECWORKS is acceptable if it provides a "bounding analysis," which the report defines as one that provides conservative results.[17] If the results are not conservative, CHECWORKS must be re-calibrate it accordingly.[18]

Notably, Entergy assigns very different criteria to the acceptability of CHECWORKS. According to Entergy, as long as CHECWORKS predicts wear within its +/-50% range, which is actually a much bigger margin than implied, or if the LCF is between a 0.5 and 2.5, CHECWORKS is acceptable. Under Entergy's criteria, much of the results could be non-conservative, but the use of the code still appropriate. This is not what is contemplated by the *GALL Report*, as clarified in the most recent version. This is also not what has been contemplated in a more general way by the NRC in using analytical tools to predict plant behavior. In particular, the NRC has stated that, "[i]n general, the analytical methods and codes are assessed and benchmarked against measurement data, comparisons to actual nuclear plant test data and research reactor measurement data. The validation and benchmarking process provides the means to establish the associated biases and uncertainties. The uncertainties associated with the predicted parameters and the correlations modeling the physical phenomena are accounted for in the analyses."[19]

By the applicable, and appropriate standard set forth in the *GALL Report*, Entergy's use of CHECWORKS at Indian Point is not acceptable, due to the predominately non-conservative wear results achieved at Indian Point. The CHECWORKS model at Indian Point has produced non-conservative results about 50% of the time, and many times data falls outside the broad range of what Entergy considered "bounding," i.e., the +/-50% lines. The model is, therefore, *not* properly calibrated and, according to *GALL*, Revision 2, it must be re-calibrated. However, years of apparent attempts to recalibrate CHECWORKS at Indian Point have not resulted in any improvement in the predictive capability of the code. CHECWORKS would have to be

[17] GALL Report, Rev. 2 at XI M17-1.
[18] GALL Report, Rev. 2 at XI M17-2.
[19] *See* Safety Evaluation by the Office of Nuclear Reactor Regulations Related to Amendment No. 229 to Facility Operating License No. DPR-28 Entergy Nuclear Vermont Yankee, LLC and Entergy Nuclear Operations, Inc. (Vermont Power Station, Docket No. 50-571), at § 2.8.7.1, p. 190, ADAMS Accession No. ML060050028.

recalibrated continuously in order to meet the standard in the *GALL Report*. Under such circumstances, CHECWORKS ceases to be a predictive tool. Calibration of CHECWORKS on a continuous basis would prevent plant operators from being able to determine whether the critical thickness of any given component will be reached before the next cycle, and, in turn, when component repair or replacement is necessary. Because CHECWORKS continues to produce non-conservative results after decades of use, there is no way to ensure appropriate calibration of the model prior to, or even during, the proposed period of extended operations at Indian Point. Thus, according to the *GALL Report*, Revision 2, which only condones the use of CHECWORKS if it produces conservative results or if can be re-calibrated to the extent results are not conservative, the use of CHECWORKS at Indian Point is not acceptable. In other words, Entergy's reliance upon CHECWORKS, does not demonstrate an AMP for FAC that is consistent and compliant with the *GALL Report*.

In addition, CHECWORKS cannot be used to demonstrate that Entergy's FAC program will meet applicable acceptance criteria as discussed in the *GALL Report*, since CHECWORKS is not capable of accurately calculating the number of operating cycles remaining before a component will reach the minimum allowable wall thickness.[20] Notably, the inability to ensure the maintenance of minimum design wall thicknesses also violate the ASME code.

Furthermore, the use of CHECWORKS also fails to meet the guidance of the *GALL Report* because it does not ensure that all forms of FAC will be adequately managed. In particular, while the *GALL Report* does not limit the obligation of licensees to manage wall thinning by FAC, CHECWORKS is limited to predicting FAC caused only by electrochemical reaction. As explained above, there are various other forms of flow-induced wall thinning.

Q. What, if any, safety issues does the continued operation of Indian Point for an additional 20 years pose, given the inadequacy of Entergy's FAC AMP?

A. The delay of necessary pipe inspections, repairs, replacements, and/or other corrective action due to over-dependence on a demonstrably ineffective predictive tool could result in serious safety issues at Indian Point during the proposed period of extended operation. The

[20] *See* GALL Report, Rev. 1 at XI M-62; GALL Report, Rev. 2 at XI M17-2.

operation of the plant without an adequate knowledge of the degree to which the strength of various components have been degraded due to FAC-related wear poses significant safety concerns.

This is particularly important when Indian Point is subject to sudden transient loads where it may be too late to detect a leak and prevent a component failure. For example, the feed water distribution piping ring inside the steam generators is subjected to high local velocities, (greater than 20 feet per second), and turbulence. With severely degraded walls, this pipe may rupture under transient loads causing damage to other structures within the steam generators, like tubes. Notably, Entergy has not provided data on CHECWORKS predictions for components inside the steam generators.

In addition, undetected FAC during the extended operating terms at Indian Point also poses a risk of loss of coolant accidents ("LOCA") in violation of NRC's General Design Criterion ("GDC") 4, which requires plant structures, systems and components be able to handle such accidents, including equipment failures due to circumstances outside the plant.[21] Notably, when the original Indian Point probabilistic risk assessments ("PRAs") were developed, the effects of aging were not included, and it was assumed that pipes were in pristine conditions. In actuality, the probability of a pipe failing under a given load will be reduced when the walls have been degraded.

Adequate protection is particularly important at Indian Point because recent risk assessments show that Indian Point is vulnerable to core melts from earthquake loads. In fact, while the area around Indian Point is susceptible to earthquakes of up to 7.0 magnitude, an NRC report from August 2010 reveals that Indian Point Unit 3 has the highest risk of seismic related core damage than any other nuclear power plant in the country. Another important class of accidents that depends on reliable knowledge of wall thickness of various components are station blackouts, SBOs. The fact that Entergy has not demonstrated that it has any reliable method of predicting component wall thinning casts a doubt about Entergy's risk predictions from such accidents.

[21] 10 C.F.R. Part 50, Appendix A, General Design Criteria for Nuclear Power Plants, *Criterion 4—Environmental and dynamic effects design bases.*

Entergy should, but has failed to consider how the uncertainty related to pipe wall thickness at Indian Point will affect the integrity of components under transient loads other than plant transients, such as earthquakes and station blackouts. In addition, Entergy has not considered how the operation of Indian Point with such large uncertainties about pipe wall thicknesses will affect the likelihood of components succumbing to the effects of metal fatigue.

Pipes at Indian Point have already been reduced in strength due to almost 40 years of operation. Entering an extended period of operation with no valid tool to predict wall thinning limits Entergy's ability to determine the degree of pipe degradation and reduction in strength. Entergy has failed to show that despite such uncertainty, Indian Point would continue to operate in compliance with GDC 4, and without a severe accident occurring.

Q. Please summarize your opinions regarding whether or not Entergy has demonstrated that FAC will be adequately managed during the proposed period of extended operation as required by 10 C.F.R. § 54.21(c).

A. Based on my review of Entergy's documentation concerning FAC and other relevant documents, in my professional opinion, Entergy's has failed to demonstrate that the aging effect of FAC will be adequately managed during the PEO. Entergy intends to rely on CHECWORKS, which is not adequately benchmarked so as to be an effective tool for predicting FAC at Indian Point during the PEO, and which has no proven track record of performance. Entergy has revealed no other tools that are meaningfully independent of CHECWORKS that will assure that the aging effects of FAC will be sufficiently managed during the PEO. As a result, Entergy's AMP must contain, but does not, sufficient details about methods and frequency of component inspections, and criteria for component repair and replacement, to demonstrate that FAC will be appropriately managed throughout the entire PEO. Failure to do so poses serious safety concerns due to potential FAC if Entergy continues to operate Indian Point for an additional 20 years.

Q. Does this conclude your initial testimony regarding Riverkeeper Contention TC-2?

A. Yes.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
ATOMIC SAFETY AND LICENSING BOARD

In the Matter of Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3)	Docket Nos. 50-247-LR and 50-286-LR

DECLARATION OF DR. JORAM HOPENFELD

I, Joram Hopenfeld, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications are true and correct to the best of my knowledge and belief.

Executed in Accord with 10 C.F.R. § 2.304(d)

Joram Hopenfeld

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December 21, 2011