Application No.: 04-02-026
Exhibit No. : ________
Date: December 13, 2004
Witness: Dr. Joram Hopenfeld

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

Application of Southern California Edison Company (U 338-E) for Authorization: (1) to replace San Onofre Nuclear Generation Station Unit Nos. 2 & 3 (SONGS 2 & 3) steam generators; (2) establish ratemaking for cost recovery; and (3) address other steam generator replacement issues.	Application A.04-02-026 (Filed February 27, 2004)

TESTIMONY OF DR. JORAM HOPENFELD ON BEHALF OF CALIFORNIA EARTH CORPS

Sabrina D. Venskus
Attorney at Law
171 Pier Avenue, #204
Santa Monica, CA 90405
(310) 581-1180 (phone)
(310) 581-1183 (facsimile)
venskus@lawsv.com

For: CALIFORNIA EARTH CORPS

December 13, 2004

Q. For the record, please state your name and address.

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

Q. What is your educational and professional background?

A. I have received the following degrees in engineering from the University of California at Los Angeles: BS 1960, MS 1962, Ph.D 1967.

I have 40 years of experience in industry and government primarily in the areas of steam generator testing and licensing for the nuclear power industry. My major activities were focused on corrosion/erosion and thermal hydraulics in Coal Fired Plants, Sodium Cooled Nuclear Power Plants and Pressurized Water Reactors, ("PWRs"). I have managed a major international program on steam generator performance during accidents. I have funded and sponsored research and development work at the Engineering Department of the University of Virginia, which resulted in a novel method of measuring pipe wall thinning from erosion/corrosion. As a result of my work at the Nuclear Regulatory Commission, ("NRC") my position regarding the safety implication of steam generator tube degradation was adopted. Consequently, in 2001 the NRC launched a five-year major program on the effects of steam generator tube aging on core melt. This program is related to the recent reactor head failure at Davis-Besse. I have testified at great lengths before the Advisory Committee on Reactor Safety, ("ACRS") on steam generator tube degradation and related safety issues. In the last several years, I have consulted to a major law firm and a citizen group regarding steam generator issues.

I have published 14 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. I hold eight US patents. I am listed in the Engineers of Distinction published by the Engineers Joint Council and in American Men and Women in Science.

I am the owner and CEO of a small Maryland company, Noverflo, Inc., that is developing fiber optic sensors for the oil & gas, the transportation, and the environmental monitoring industries. I invent and develop new sensors, seek sponsors, and market the end products.

My employment history, the list of publications and the list of patents are provided in the Appendix.

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to provide the California Public Utilities Commission ("Commission") with perspective on issues associated with aging nuclear plant components and associated security risks. Based on my professional experience and information, it is my opinion that extending San Onofre Nuclear Generating Station's ("SONGS") operating lifetime to the end of its current licenses through Southern California Edison's ("SCE") proposed steam generator replacement project for Units 2 & 3, will require significant additional capital investments beyond those identified in SCE's application and testimony.

Q. What additional costs are not identified or considered in SCE's application and testimony?

A. In my opinion, the replacement of the steam generators allowing SONGS 2&3 to operate to the end of 2022 will require considerable more capital and O&M costs and power replacement costs than was identified in the SCE application. These additional costs are associated with three major uncertainties associated with the SCE cost-benefit analysis. The first uncertainty stems from the assumption that the cost associated with component aging in the entire plant, excluding the steam generators, would essentially remain at its present level. The other two uncertainties relate to increased security measure requirements and regulatory actions.

Q. Please elaborate on these three uncertainties.

1. COMPONENT AGING IN NUCLEAR POWER PLANTS

A. Let me start with plant component aging. It is a well-established fact that pressure vessels as well as mechanical and electrical components tend to fail at a high rate early in life and at the end of their life. The failure rate is relatively low during the rest of the time. This is called the "bathtub principle." The bathtub principle depicts a plot of the frequency of component failures versus time. Early in the life of the plant, the frequency of failure is high. The early failures occur due to fabrication, installation and design errors. As the plant ages, the frequency failure begins to decrease, until it flattens out for a while. Then, the frequency of failure rate begins to increase again, so that the frequency failure is high later in the plant's life. The later failures occur because components wear out, plain and simple.

Q. How does the above "bathtub principle" apply to your analysis of SCE's application in this case?

A. SONGS 2 & 3 began operation in 1983 and 1984, respectively. In 1991 the feed water distribution ring suffered severe erosion damage in both units 2 and 3. In its application, SCE indicates that the probability of steam generator failures in units 2 and 3 will increase very rapidly after 2009 because they will be approaching the end of their useful life. (Application, Figures III -1 & 2). This is why SCE must replace the steam generators and why SCE is before the Commission with this application. The steam generator behavior at SONGS clearly follows the classical "bathtub principle."

The balance of the plant (piping, reactor vessel, etc) has not yet reached the end of its useful life. However, experience with pressure vessels in fossil plants indicates that following the startup period, the probability of failure remains low for about 30 years, after which period failures start to increase largely due to formation of cracks at welds and wall corrosion.

With regard to SONGS, in 2013, four years following steam generator replacement, the balance of the plant in these units will be entering the last quarter of its 40-year design life. After 2013, an accelerated increase in component failures due to aging can be expected.

Q. Can you identify some components or systems that have a high probability of failure and that were not identified by SCE in their SGR application?

A. Yes. The components that have a high probability of failure that were not identified by SCE in the SGR application include large size pipe elbows and valves in the secondary loop as well as components made with Alloy 600 in both the primary and secondary loops. Large size pipe elbows and valves in the secondary loop are of concern because they share the same coolant with the steam generators. All components with Alloy 600 in both the primary and the secondary loops of the plant are of concern. These components are susceptible to erosion/corrosion, ("EC") and stress corrosion cracking ("SCC") which are the major contributors to component failures in nuclear power plants. They also are the major causes for the SGR. [1]

The failure of the feed ring units 2 & 3 strongly suggest that pipe thinning may be occurring in other parts of the secondary loop, and therefore may require replacement at some future time. The degradation of the steam generators is a precursor to degradation of other components in the plant.

Q. What are erosion/corrosion (EC) and stress corrosion cracking (SCC)?

A. EC occurs when materials are exposed to high flow velocities, above 20- 25 ft/second and when the material is not compatible with the coolant. SCC occurs when a given material is under high stress and is also incompatible with its fluid. Damage to piping from EC results in wall thinning, which if allowed to continue will cause the pipe to burst when its wall strength cannot withstand the internal pressure. Under sufficiently high stress, SCC cracks will propagate fast and cause a sudden component failure. SCC cracks are initiated at the surface as small indications, which are difficult to detect.

Q. Can you give some examples where EC and SCC have already occurred at SONGS?

A. Yes. The feed ring erosion discussed in NRC Information Notice 91-19, as well as the corrosion in the SONGS 2&3 steam generators as discussed in detail in SCE-2 "Condition of Steam Generators and Expectations for Continued Operation of Original Steam Generators," pages 7, 17-21.

Q. How do EC and SCC differ from other modes of component degradation?

A. Unlike general corrosion or fatigue crack propagation, the occurrence of EC and SCC are unpredictable. For this reason a good engineering practice dictates that materials be selected on the basis of a proven record of their ability to operate in the intended service environment. This is a difficult task in nuclear plants because of unforeseen local chemistry and stresses.

The selection of mill annealed Alloy 600 for steam generator tubes was a costly mistake. Both SONGS units use this material in their steam generators. For this reason, newer steam generators use

[1] NRC Information Notice 91-19, March 12, 1991 "Steam Generator Distribution Piping Damage" documents severe erosioı

thermally treated Alloy 600 and 690. However, recent experience in 2002 at the Seabrook Nuclear Power Plant indicates that even thermally treated Alloy 600 is less resistant to SCC than was previously believed.[2]

I would like to emphasize that EC and SCC related failures are not the only manifestation of plant aging. Electrical cables, valves, and instruments (especially those with moving parts), all deteriorate with age. I am focusing on EC and SCC because of their high potential for causing catastrophic failures.

Q. What are the consequences of EC and SCC unpredictability?

A. The inability of in-service inspection techniques to anticipate and prevent EC and SCC has been very costly almost from the beginning of nuclear power plant operation. For example, in December of 1986, an elbow of the feed water pipe at the inlet to the Surry steam generator ruptured suddenly, there were several fatalities; the reactor was down for several months. The cause of the elbow rupture was severe pipe wall thinning due to EC.[3] EC has also occurred in safety-related piping inside the containment structure. In 2002, the reactor vessel head at Davis-Besse was damaged due to SCC of Alloy 600 and only by luck was a Chernobyl-type disaster averted. The SCC cracks allowed the high pressure primary radioactive coolant to leak through the vessel walls.[4] The reactor was shut down for two years. In July 2004, several workers were killed at the Mihama nuclear power plant due to EC in the secondary loop.

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damage in SONGS units 2 & 3. Indeed, the SCE application itself attributes SGR to SCC.

[2] NRC Information Notice 2002-021, Supplement 1: Axial Outside Diameter Crack Affecting Thermally Treated Alloy 600 Steam Generator Tubing.

[3] NRC Bulletin 87-01 "Thinning of Pipe Walls in Nuclear Plants."

[4] NRC Bulletin 2002-01 and www.nrc.gov, "Davis Besse Reactor Vessel Head Degradation," (ML003690021)

SCC-associated steam generator tube ruptures have occurred in seven plants since 1975. SCC in steam generators was a major factor in causing the permanent shut down of the Trojan Nuclear Power Plant in Oregon in 1992 after only less than 10 years of operation.

Q. What is being done to reduce the impact of EC and SCC?

A. The industry and the NRC have reacted with great speed to address safety concerns as events occur in nuclear plants. Following each event the NRC issues an Information Notice, ("IN") describing the event and its implications. The INs do not require any action, they are more or less an educational tool. The INs demonstrate that EC and SCC-related failures are unforeseen, not well understood, can go undetected, and are random. For this reason, SCE's application for SGR should include the costs of component replacement that is expected due to EC and SCC.

Q The NRC modified the SONGS licenses in March 2000 in response to a SCE request to allow Unit 2 to operate until 2013 and Unit 3 to operate until 2014. How did NRC address the question of whether the plant could be operated safely for this extended duration of the licenses?

A. From an aging perspective, the NRC did not require SCE to address the question of whether the plant could be operated safely for the extended duration of the licenses. The NRC has a policy called "license recapture" in which the NRC allows nuclear plant owners to "reset" the clock on the original 40-year operating licenses. In other words, the original clock started during plant construction, but delays in construction result in a large chunk of the 40-year license to be "used up" before the reactor even began operating. NRC's policy of "license recapture" resets the timing of the 40-year operating license initiation to when the plant started operation. The ultimate result is that the overall license term extends beyond the original 40-year operating license period. In the case of SONGS, the original license terms expired on October 6, 2013 for Unit 2, and July 19, 2014 for Unit 3, and the clock was "reset" for an additional 8 years.[5]

The NRC review of SCE (ML003690021) for SONGS 2 & 3 operating conditions was insufficient from the standpoint of evaluating aging components issues. The NRC neither required the submission of, nor did it review, condition monitoring program information for the 2000 SONGS licensing changes because those recaptures were not reviewed and approved pursuant to Title 10 of the Code of Federal Regulations, section 54.

The NRC does not provide assurance of the ability of a plant to operate safely and reliably during the license renewal period.[6] Therefore, SCE cannot justify its failure to include costs related to aging components degradation and associated operation failures in its SGR application, based on an argument that safety issues were addressed during the NRC 2000 re-licensing process.

Q On the basis of your review of SCE's application and testimony, do you have any concerns about whether the costs SCE estimates to extend SONGS 2&3 operating lifetime are identified and estimated properly?

A. Yes. SCE discounts age-related degradation of components other than that associated with steam generators themselves. The steam generators are not the only items vulnerable to age-related degradation and potential adverse impact on plant performance during its operating lifetime.

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[5] Letter from L. Raghaven, NRC to H. Ray, SCE, (March 9, 2000), SONGS 2&3 licenses February 16 and November 2022, respectively.

Q. Do you have any particular concerns about aging components at SONGS?

A. Yes. SONGS appears to have experienced more EC problems than the typical nuclear plant. The same or similar environment, (coolant chemistry) that caused the already mentioned damage to the feed ring in units 2&3 exists elsewhere in the secondary loop. Depending on the local velocity and flow turbulence sometimes these problems appear early but sometimes they can appear late especially if the velocities are relatively low. I am particularly concerned about thinning of pipe elbows because thinning may be very localized and only a fraction of the pipe is inspected during in-service inspection.

Q Are there examples of aging components-related damage at SONGS other than EC and SCC?

A. Yes. On February 3, 2001, Unit 3 was restarting from a refueling outage when an electrical breaker experienced a fault that started a fire. The reactor tripped and the unit experienced a loss of offsite power. When a battery powered lubricating pump failed to start, the lack of lubricating oil to the main turbine shaft caused extensive damage that required the reactor to remain shut down for several months.[7]

Q. Are there other costs associated with age-related degradation, besides the actual costs of repairing or replacing aging components?

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[6] The Hatch Nuclear Plant is an example where despite the NRC review and approval of a plant's condition monitoring program, failures occurred subsequent to the license renewal, resulting in a forced shutdown of the plant. It is another illustration of the costly discovery of age related problems in the nuclear industry.
[7] NRC, "San Onofre Nuclear Generating Station Special Team Inspection Report No. 50-362/01-05," (April 20, 2001).

A. Yes. As the number of problems increase with plant age, the probability of outages caused by age-related failures also increases. Nuclear plants must be taken off-line for repairs. In some cases, resulting outages have been extensive. For example, age-related degradation of a reactor vessel head kept the Davis-Besse nuclear plant shut down from March 2002 through March 2004.

Q. Has SCE allowed for potential long outages such as the recent Davis-Bessee outage in its cost-benefit analysis?

A. No. SCE evaluations neglect the potential for prolonged reactor outages, whether voluntary or NRC-mandated. Over the past twenty years, twenty-seven reactors have encountered delays of a year or more in restarting, due to problems unrelated to a steam generator age-related problem.

Q. Apply this nuclear industry experience SONGS.

A. If this nuclear industry experience applied to the two reactors at SONGS 2&3, the probability that one of the SONGS 2&3 reactors will experience a year-plus outage by the year 2022 is about 39.4%.

Q. In your opinion, what information should SCE provide to the Commission so that the Commission can make a fully informed decision as to the cost-effectiveness of the SGR?

A. SCE should include in its costs analysis a factor of probability that one of the reactors at SONGS 2 & 3 will experience at least a two year outage between 2009 and 2022. The following table presents the probabilities, based on actual industry performance over the past 20 years, that one of the reactors will experience a year-plus outage between 2009 and 2022.

Year	Probability that one of SONGS 2&3 reactors has a year-plus outage
2009	14.6
2010	16.9
2011	19.0
2012	21.1
2013	23.2
2014	25.2
2015	27.1
2016	29.0
2017	30.9
2018	32.7
2019	34.4
2020	36.1
2021	37.8
2022	39.4

Actual industry experience demonstrates that outages of at least one year frequently occur. SCE's cost analysis assumed no chance that an outage of at least one year will occur. This is an unreasonable assumption, as the above table indicates. There is a 39.4% probability that an outage of at least one year will occur at one of the reactors at SONGS 2&3.

With regard to aging components-related repair and replacement costs, by using their in-service records, SCE should identify the systems and subsystems in the plant that are subject to aging, and then quantify the aging factor and estimate the relevant uncertainties based on SCE and industry experience.

2. <u>NUCLEAR PLANT VULNERABILITY TO TERRORISM</u>

Q. What is your criticism of SCE's application and testimony with regard to increased security costs due to the threat of terrorism?

A. In its cost-benefit analysis, SCE lumped the increase of security-related costs with increases associated with NRC scrutiny, plant conditions and industry events. The corresponding increases in capital and O&M costs were 50% and 20% respectively over a base line cost for the years 2004-2008.[8] SCE provides no justifications or the origin for these assumptions. It appears from SCE's application and testimony that they don't seriously consider these issues. SCE recognizes the issues, but doesn't ascribe any actual numbers. In my opinion, the cost of reducing SONGS' vulnerability to terrorist attacks may be significant because the main steam lines may have to be redesigned.

Q. Please describe why the main steamlines may have to be redesigned.

A. The main steam lines between the containment and the turbine building are located above the ground and are unprotected. Their temperature is above the temperature of the environment and they can be seen from outside the plant boundaries. These steam lines are about 2.5 ft in diameter with a design wall thickness of approximately 0.75-inch. Laser-aimed shoulder fired missiles and other readily available terrorist weapons, as well as a small aircraft loaded with high-energy explosives, can penetrate the unprotected pipes. A breach of the pipeline walls would cause an instantaneous steam depressurization of the secondary side of the steam generators leading to tube failures. This will

[8] SCE-4 "Cost Effectiveness Study," pages 38 and 45 (February, 2004).

cause the radioactive reactor cooling water to blow out of the broken steam lines directly to the environment. Eventually the cooling water would be depleted and the reactor core would be uncovered. The core melt would be followed by an extremely large direct and unfiltered offsite radioactivity release, especially if the attack occurs at the end of a PWR plant fuel cycle when decay heat is greatest.

Core melt could occur from a few hours to several days depending on operator action and the number of ruptured tubes. Because the containment is bypassed, large amounts of radioactivity will be continuously released to the environment even prior to core melt.

Q. The Nuclear Regulatory Commission (NRC), the Nuclear Energy Institute (NEI) and Entergy Nuclear testified before the Subcommittee on National Security on March 10, 2003 on the assessment of public safety and security measures at nuclear power facilities. The NRC and the NEI stated in that testimony that nuclear plants present a hard target to terrorism and that there is no difference, in regard to public safety, between terrorist attacks and equipment failure from other causes. Why should SCE change their estimates of security-related costs for the SGR?

A.. The government and the nuclear industry position that nuclear plants, even if attacked by terrorists, are not likely to endanger the public, is based on the invalid premise that the plants were designed to withstand accidents whether they were caused by equipment malfunction or by terrorism. Nuclear plants were designed against a standard that required protection from malfunction of only a single component at any given time. For example, the plants were designed to withstand a main steam line break ("MSLB") but they were not designed to withstand a concurrent failure of the steam line and the steam generator tubes.

Q. Why should an MSLB event trigger steam generator tube ruptures?

A. Following the MSLB event, the primary to secondary pressure will exceed the specified design value by as much as 1000psi. This force would cause the tube sheet and the support plates to move relative to the tubes and further increase the potential for tube damage. If more than ten tubes were to be damaged the core will melt, accompanied by a massive radioactivity release bypassing containment. If emergency-cooling water is not available, a core melt may occur even if only one tube ruptures. Since the refueling water storage tank and its service components are unprotected, a terrorist attack could disable the emergency water supply to the plant.

Each steam generator contains thousands of tubes that are only one millimeter thick. Some tubes may contain partially or through-the-wall tight SCC cracks that may leak to a varying degree when the secondary side is depressurized during the steam line break event. Steam generator replacement does not ensure that all the tubes will stay free of SCC cracks.

Q. What is the government doing about nuclear plant vulnerability?

A. It is my understanding that the NRC addresses this issue on a plant by plant basis. They have placed a veil of secrecy over their activities in this area. Following 9/11, the nation's efforts on improving home land security were highly focused on air transportation. Now shipping containers are receiving increasing attention. While nuclear power and chemical plants have received relatively little attention, it is likely that these plants will receive more attention and the government will ultimately require increased security measures on these plants.

Q What would be required at SONGS for purposes of increased security measures to protect against terrorist attacks?

A. At a minimum, the main steam lines outside containment, the turbine building and the refueling storage tank will need to be shielded from missile penetrations. Therefore, costs associated with shielding the main steam lines should be included in the SONGS SGR cost analyses.

B. REGULATORY UNCERTAINTIES

Q. What is your criticism of SCE's application and testimony with regard to costs associated with regulatory uncertainties?

A. Regulatory uncertainties accompany unforeseen events. If a major unforeseen event were to occur at SONGS 2 &3 it could take considerable time for the regulators to decide what to do. Such delays can be driven by management indecisiveness and political pressures.

Q. Do you have any examples that illustrate this point?

A. Yes. Two reactor case histories illustrate this point. In 1991 the steam generator tubes at Trojan, early in the plant's life, developed a massive number of SCC cracks. When one of the steam generators developed a non SCC-related leak in late 1992, the reactor was shut down and lengthy debates at the NRC delayed the scheduled reactor startup. When an internal technical report was leaked to the press, the Trojan owners decided to shut down the reactor permanently instead of dealing with regulatory uncertainties and steam generator replacements.[9]

Following repairs of a tube rupture which occurred in January, 2000 at the Indian Point-2 Nuclear Power Plant in New York, the plant owners, ConEd, wanted to restart the reactor as originally scheduled but later disallowed by the NRC. The Office of the Inspector General investigation relative to NRC's role in contributing to the accident and ensuing political pressures caused the NRC to reverse its original position regarding plant start-up. ConEd was forced to replace their steam generators at an earlier date than originally scheduled thereby suffering a large cost penalty.

Q. What if anything, should SCE do to consider costs related to regulatory uncertainties?

A. Instead of lumping NRC regulatory uncertainties with security-related costs, SCE should consider regulatory uncertainties separately and provide the basis for SCE's rationale for attributing identified costs. NRC regulatory uncertainties should be considered as part of plant aging cost because as the plant ages it can be expected that the frequency of unforeseen events will increase. The uncertainty of how the NRC would react to any given event similarly increases.

Q. In summary, what are your conclusions regarding the SCE SGR application and testimony?

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[9] Inside NRC, Vol. 15, No. 2, (January 25, 1993). NRC, San Onofre Nuclear Generating Station Special Team Inspection Report No. 50-362/01-05 (April 20, 2001).

A. A substantial body of experience in nuclear and fossil power plants, pipelines, refineries and chemical processing plants indicates that age-related degradation of components is a major increase in capital and O&M costs.

SCE has focused too narrowly on the steam generators as the exclusive source of potential adverse plant performance and associated regulatory attention. Without a serious analysis of aging-related degradation, together with its associated repair and/or replacement costs as well as associated power replacement costs, SCE application is deficient. SCE approach, of counting all such costs as essentially zero, is unreasonable and highly speculative.

In its cost-benefit analysis, SCE included the increase in cost due to potential increases in security and NRC scrutiny. However, SCE does not identify the key assumptions in their projections; it appears that the assumed cost increases were quite arbitrary.

There is a significant likelihood that providing for the safe operation of SONGS 2&3 for another 13 years following SGR will require significant additional costs beyond those included in SCE's SGR application and testimony.

Since SCE does not address the three uncertainties in their cost-benefit analysis, the SCE application does not provide sufficient information to evaluate the magnitude of the risk that is involved in requiring the rate-payer to absorb the costs of SGR.

In summary, SCE did not supply the Commission with enough information regarding actual potential costs associated with the SGR to allow the Commission to make a reasoned decision about its cost-effectiveness. Without adequate information about all related costs and contingencies, the Commission is in no position to make a decision about the cost-effectiveness of SGR at this time.

APPENDIX

EMPLOYMENT HISTORY

1962- 1971 –Corrosion testing of materials for the design and operation of liquid metal cooled nuclear reactors. Atomics International, Canoga Park, Calif.

1971- 1973- Participated in the resolution of design issues as related to material corrosion and thermal hydraulics of nuclear reactors. Atomic Energy Commission

1973 – 1978 Project Manager for the safety evaluation and testing of steam generators for liquid metal reactors. Department of Energy (and its predecessor ERDA).

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. Department of Energy.

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

PUBLICATIONS IN PEER REVIEWED JOURNALS

1. Distributed Fiber Optic Sensors for Leak Detection In Landfills, Proceeding of SPIE Vol 3541 (1998)
2. Continuous Automatic Detection of Pipe Wall Thinning, ASME Proceedings of the 9th, International Conference on Offshore Mechanics and Arctic Engineering. Feb. 1990
3 Iodine Speciation and Partitioning in PWR Steam Generators, Nuclear Technology, March 1990
4. Comments on "Assessment of Steam Explosion Induced Containment Failures" Letter to the Editor, Nuclear Science and Engineering, Vol. 103, Sept. 1989
5. Experience and Modeling of Radioactivity Transport Following Steam Generator Tube Rupture, Nuclear Safety, 26,286, 1985

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

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

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

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

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

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

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

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

14. 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)

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 4,922,748
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 (Patent pending, February 2005).

CERTIFICATE OF SERVICE

I hereby certify that I have this day served a copy of TESTIMONY OF DR. JORAM HOPENFELD ON BEHALF OF CALIFORNIA EARTH CORPS in A.04-02-026.

A copy has been mailed First Class U.S. Mail and e-mailed to all known parties of record in the proceeding who have provided addresses.

Executed in Santa Monica, California, on the 13th day of December, 2004.

Sabrina D. Venskus