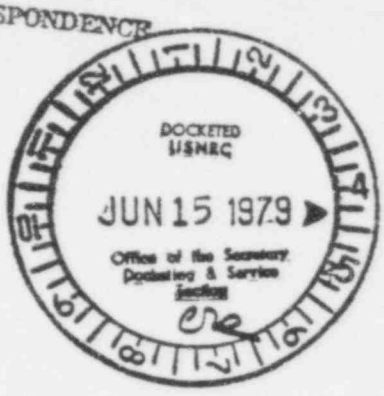
RELATED CORRESPONDENCE



UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	Docket No. 50-272
PUBLIC SERVICE ELECTRIC & GAS COMPANY	)	
(Salem Nuclear Generating Station, Unit #1)	)	Proposed Issuance of Amedment to Facility Operating License No. DPR-70

TESTIMONY OF EARL A. GULBRANSEN, Ph.D., P.E.
IN RESPECT TO BOARD QUESTIONS #1,#2, #3,
OF ORDER DATED APRIL 18, 1979

My analysis of the accident of Three Mile Island and the potential involvement of the spent fuel pool and how that relates to Salem 1, necessarily involves some discussion of my opinions as to the use of Zirconium Alloys as cladding for the uranium dioxide fuel pellets in nuclear reactors.

I believe the reactor at Three Mile Island underwent a major temperature excursion during which, from available information, I would conclude that 10% - 15% of the Zircaloy cladding reacted with steam to form Zirconium dioxide and hydrogen. This reaction furnished most of the hydrogen in the bubble at the reactor head.

Part of the hydrogen probably penetrated the oxide film on the Zircaloy II cladding to dissolve in the metal and to form zirconium hydride, $ZrH_{1.4}$. This hydride has low hydrogen equilibrium pressures at the normal operating temperature of the reactor. Such reacted hydrogen obviously cannot be vented. I have prepared papers reported in the literature which described my work on this reaction. This work showed that hydrogen gas rapidly penetrates the oxide. At defects and edges spalling of the hydride and oxide could occur. I suggest that this reaction may have occurred in the reactor absorbing the hydrogen bubble. With or without spalling embrittlement of the cladding must have occurred with serious damage to the Zircaloy in the reactor. The spalled zirconium

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hydride and zirconium oxide would fall to the bottom of the reactor together with the fuel pellets. The circulating cooling water continues to react with the freshly spalled zirconim hydride sufaces forming more zirconium dioxide and hydrogen. I predict that this reaction will continue until all of the Zircaloy II cladding is reacted.

As a result of the above analysis, I suggest the following procedures:

1. Hydrogen in the cooling water should be burned catalytically to prevent build up of another hydrogen buble in the reactor.

2. The low temperature Zircaloy II - water reaction will continue as noted above. All released gases must be filtered and trapped before burning to remove radioactive gases and radioactive particulates. The only safe chemical and conditions after an accident like that at Three Mile Island is to have all of the Zircaloy II reacted to the oxide.

3. Hydrogen in the circulating cooling water must be monitored and removed until a near zero value is attained to insure that no metal and hydride remains. A temperature excursion with unreacted metal and hydride in the reactor could lead to reformation of the hydrogen bubble. Hydrogen gauges of high sensitivity are now available or could be made in a short time.

4. I am much concerned about the effect of hydrogen on the reactor vessel and piping. I strongly recommend that experiments be made on hydrogen embrittlement of the alloys used in the reactor and piping under conditions simulating those which occurred in the reactor.

5. I strongly recommend that experiments should be made on the effect of hydrogen in the cooling water at high pressure on pre-oxidized Zircaloy II to evaluate the penetration and pick-up of hydrogen as a function of temperature and pressure.

6. I recommend calculations on how much of a rapid Zircaloy II - steam or water reaction could occur before the hydrogen formed embrittles the cladding and ruins the reactor.

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7. Sensitive hydrogen gauges should be installed on the primary and secondary loops and on the reactor itself to monitor the Zircaloy II - steam and water reaction.

I should like to repeat that these suggestions are based on extensive research in the field of gas-metal reactions. My own basic research on zirconium began in 1947 before the formation of the Westingnouse Bettis Atomic Power Laboratories. Twenty years of nearly continuous research was conducted on the reactions of zirconium, Zircaloy II, Zircaloy IV and the other zirconium alloys with oxygen, air nitrogen and water vapor over a temperature range of 25°C to 800°C and at pressures of a few torr to over 100 atmospheres. This work was reported in 25 papers and many research reports to the Westinghouse Electric Corporation.

Many important tehnical problems were solved including the solubility of hydrogen in zirconium, the crystal structure and range of homogeneity of zirconium hydride, $ZrH_{1.4}$, the rate of diffusion of hydrogen in zirconium, the role of oxide films on hydrogen adsorption, the rate of oxidation of zirconium in oxygen, the rate of nitride formation in nitrogen, the types of hydrogen reaction with zirconium intermetallic compounds, the rate of reaction of zirconium alloys in water at high pressure and the behaviour of Zircaloy II in fast flowing steam at temperatures above 1000°C.

After 25 years of research and development on the chemical and and metallurgical properties of metals and alloys used in nuclear power plants, I have come to the conclusion that the current design and materials cannot give us a safe and well-engineered nuclear power plant.

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The use of zirconium alloys as cladding material for the hot uranium oxide fuel pellets if a very hazardous design concept since zirconium is one of our most reactive metals chemically.

At the operating temperature of nuclear power reactors zirconium cladding alloys react with oxygen in water for form an oxide layer which partially dissolves in the metal embrittling and weakening the metal tubing. Part or the hydrogen formed in the zirconium metal reaction dissolves in the metal and may precipitate as a hydride phase also embrittling and weakening the metal tubing.

At temperatures above 1,100° Celsius (1980° Fahrenheit) zirconium reacts rapidly with steam with a large evolution of heat and the formation of free hydrogen, with most metals to form intermetallic compounds and with other metallic oxides to form its own oxide. Once zirconium is heated to 1,100° Celsius, which could occur in loss of coolant accidents, its is difficult to prevent further reaction, failure of the tubing and of the reactor.

There appears to be no way to overcome the inherent material problems associated with zirconium alloys and the current design of the reactor

Greater wall thickness for cladding and lower operating termperatures of the fuel may help but the chemical and metallurgical behaviour of zirconium alloys cannot be overcome. No backup or alternative design is available if the present design and materials prove unreliable.

Considering the potential and consequences of a meltdown or explosion as posed in the Board's question, it would be more consistent with the safety and health of the public to store spent fuel away from operating nuclear reactors. The storage of spent fuel in spent fuel pools at reactor

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sites in close proximity to operating nuclear reactors for long periods of time and in large quantities represents a significant involvement of large amounts of radioactive material in the event a serious nuclear accident.

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RECORD OF SCIENTIFIC AND ENGINEERING EXPERIENCE

Earl A. Gulbransen

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RECORD OF SCIENTIFIC AND ENGINEERING EXPERIENCE

Earl A. Gulbransen

ABSTRACT

0.0 Washington State College (now Washington State University), Pullman, Washington, graduated with honors, June, 1931, in Chemical Engineering and minors in Physics, Physical Chemistry and Mathematics. Teaching assistant and undergraduate research.

0.1 University of Pittsburgh, Pittsburgh, Pennsylvania, received Ph.D. degree in Physical Chemistry, August, 1934, with minors in Physics and Mathematics. Research work on thermodynamics of solutions. Teaching assistant in organic and physical chemistry.

0.2 University of California, Berkeley. National Research Council Post-Doctorate Fellowship in Physical Chemistry, September, 1934-August, 1935. Research Associate in Physical Chemistry, September, 1935-August, 1936. Research work on thermodynamics of gases and solutions.

0.3 Tufts College (now Tufts University), Medford, Massachusetts, September, 1936-June, 1940. Instructor in Chemical Engineering, Physical Chemistry and Analytical Chemistry. Research work on mass spectrometrically determined abundance ratios of carbon isotopes in nature.

0.4 Westinghouse Electric Corporation, Research and Development Center, Pittsburgh, Pennsylvania, July, 1940 to present.

0.4.1 July, 1940 to July, 1947 - Research Engineer in Chemistry Department. Research on gas-metal and gas-solid reactions and energy sources for underwater propulsion.

0.4.2 July, 1947 to July, 1966 - Advisory Engineer. Research on gas-metal and gas-solid reactions with special application to the nuclear power, lamp and electronic industries. Consulting work on chemical and metallurgical engineering processes.

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0.4.1.3 July, 1966 to Present - Consulting Scientist. Research on gas-metal and gas-solid reactions with special emphasis on applications in flash lamps, incandescent lamps, nuclear power and high temperature technology, hot corrosion of gas turbines and coal gasification. Extensive consulting activities with Westinghouse Divisions on corrosion, high temperature sintering of tungsten, getters for lamps, flash bulbs, hydrogen embrittlement, stress corrosion cracking and structure of surfaces.

0.5 Other Activities. The complete record details my publications, patents, scientific societies, awards and other scientific and engineering activities.

0.6 Summary. For the 26 years between July, 1947 to the present I have been responsible for scientific and engineering work on a wide variety of chemical and metallurgical problems. I have had a total of 39 years of independent and supervisory scientific and engineering work experience.

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AMPLIFIED RECORD OF SCIENTIFIC AND ENGINEERING EXPERIENCE

Earl A. Gulbransen

1.0 Washington State University, Pullman, Washington. Bachelor of Science in Chemical Engineering with honors with minors in Physical Chemistry and Mathematics, June, 1931.

Between September, 1930 and June, 1931, I worked as a laboratory assistant in analytical chemistry. My supervisor was Dr. Lyle Gilbertson.

2.0 University of Pittsburgh, Pittsburgh, Pennsylvania; Department of Chemistry. Ph.D. in Physical Chemistry with minors in Mathematics and Physics, August, 1934.

Between September, 1931 and August, 1934, I was a graduate assistant in organic chemistry under the supervision of Professor Lowy (deceased) and in physical chemistry under the supervision of Professor Stegeman (deceased).

2.1 Thermodynamic Properties of Dilute Solutions

My research supervisor was Professor A.L. Robinson (deceased). Professors Robinson and Stegeman encouraged me to work in the field of Chemical Thermodynamics. I have followed their suggestions and I have contributed extensively to the field. My thesis work was concerned with the thermodynamics of dilute solutions of aqueous electrolytes. To carry out this program I assembled the first precision adiabatic differential calorimeter in the United States. My thesis work was published in the Journal of the American Chemical Society, Vol. 56, 2637 (1934) and is referred to as paper number 1 in Section 6.

3.0 University of California, Berkeley, California; Department of Chemistry.

In the summer of 1934 I was awarded a National Research Council Post-Doctroate Fellowship in Physical Chemistry. I chose to work at the Chemistry Department of the University of California headed by Professor G.N. Lewis (deceased).

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3.1 Thermodynamic Properties of Solids, Liquids and Gases

At the University of California I conducted research work in Professor Giaque's Low Temperature Laboratory and with Professor Randall. Together with Dr. E. Long, I determined the data of state equation for phosphine. This work was published in the Journal of the American Chemical Society, Vol. 58, 203 (1936). I worked also in the field of thermodynamics of solutions and especially in non-aqueous solutions. I continued my post-doctorate education by attending and participating in study seminars on radiochemistry, theoretical physics, thermochemistry and theory of solutions.

4.0 Tufts University, Medford, Massachusetts; Department of Chemistry and Chemical Engineering.

Between September 1, 1936 and July 1, 1940, I was instructor in Chemical Engineering teaching Unit Processes, Chemical Engineering Thermodynamics, Gas Analysis and Analytical Chemistry. I also supervised the research activities of 10 senior chemical engineering students. Chairmen of the department, in chronological order, were Professor Durkee (deceased) and Professor Baker (deceased).

4.1 Geochemical Research

At Tufts University I began a new field of research on geochemical and geophysical processes in nature. This became possible by the rapid development of mass spectrometric measurement of abundance ratios of the elemental isotopes. I initiated, together with Dr. A. O. Nier of Harvard University, a comprehensive study of the abundance ratios of C^{12} and C^{13} of naturally occurring carbon compounds. This was a pioneering work and led to the use of C^{12}/C^{14} ratios for dating of matter. The work was published in the Journal of the American Chemical Society, Vol. 61, 697 (1936).

4.2 National Research Council Committee on the Determination of Geologic Time

The head of this committee was Professor A.C. Lane (deceased) of Tufts University. Professor Lane was later called the forgotten man of atomic energy. I worked with Professor Lane for 3 years developing research programs on the use of isotopes not only for geologic time evaluation but for developing new methods for following geochemical reactions.

4.3 Closure

In summary, I spent 4 years at Tufts University doing independent teaching and creative research. During this period I maintained

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close communication with the teaching and research staff at Harvard University and Massachusetts Institute of Technology by attending weekly seminars and by attending local scientific society meetings. None of my supervisors were Registered Professional Engineers.

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5.0 Westinghouse Electric Corporation, Research and Development Center, Pittsburgh, Pennsylvania. July 1, 1940 to Present.

Due to difficulties in financing research work at Tufts, I decided to leave Tufts University and join the Westinghouse Research Laboratories. Westinghouse, at that time, was attracting many good people with opportunities to work on basic research problems of interest to the electrical manufacturing industry.

5.1 Between July 1, 1940 and about July 1, 1947, I was employed as a Research Engineer in the Chemistry and Metallurgy Department. My supervisors were, chronologically: Messrs. A.A. Bates, Manager, Chemistry and Metallurgy Department, and R.W. Auxier, Manager, Chemistry Department. Neither were Registered Professional Engineers.

5.1.1 Oxidation of Metals

My primary project was (1) to develop methods for the study of gas-metal reactions, (2) to use these methods for the study of the oxidation of a variety of the common metals and alloys and (3) to develop theoretical models to explain the experimental results. I developed for these studies a very sensitive microbalance which was placed in the reaction system for determining the kinetics of oxidation of metals. I developed a special electron diffraction camera for the study of the surface structure of the oxide films formed on metals at temperatures up to 1000°C. I also developed with my co-workers methods for using the newly developed electron microscope for the study of the crystal habit of oxide films formed on metals during oxidation.

Twenty basic papers were published during this period on (1) the kinetics of oxidation, (2) the crystal structure of the oxide films and (3) the crystal habit of the oxide films. These papers are listed as papers number 4-23 in Section 6. The vacuum microbalance method has been duplicated and used throughout the world for gas-metal studies. We have also contributed extensively to present understanding of the crystal structure and crystal habit of oxide films on metals.

5.1.2 Consulting Activities

During this period I acted as a consultant to the Westinghouse Lamp Division on metal problems. I also consulted with the electronics department, metallurgy department and chemical department at our Laboratories.

5.1.3 World War II Work

During the period of 1942 - 1945, I worked on new methods of under-

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water propulsion, including rocket and jet propulsion, primary batteries, chemical power plants and gas turbines. I also carried out, with the help of technicians, experimental work on duct propulsion for torpedoes.

My suggestions on primary batteries led to a large contract with the government for the production of a new type of battery powered torpedo. This work was terminated in 1945 at the end of the war.

5.1.4 Closure

During this seven year period I worked as an independent research engineer. For part of the time I supervised the work of 1-4 professionals and technicians.

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5.2 July 1, 1947 to July 1, 1966, Advisory Engineer

My supervisors were, in chronological order: R. Auxier, Manager, Chemistry Department, and W.T. Lindsay, Jr., Manager, Physical Chemistry Department. Neither were Registered Professional Engineers.

On July 1, 1947, I was promoted to the position of Advisory Engineer. In this position, I conducted basic research projects directly and with the help of other professionals and technicians. I was primarily responsible for the administration, conduct and reporting of basic research activities in the area of surface reactions of gases with metals, alloys, non-metals and oxides and the corrosion of metals and alloys. I reported directly to the manager of the Chemistry Department.

Our research activities were of three types: (1) programs developed in cooperation with Divisions of Westinghouse, (2) programs sponsored by U.S. Government agencies and (3) basic research programs initiated to solve long-range research objectives of the company. The apparatus, methods and treatment of the problem were essentially the same for the three types of research activities.

5.2.1 Gas Reactions of Carbon 300 - 1500°C

This work was done for Bettis Atomic Power Division and Astronuclear Division to provide basic information on the reactivity of carbon at high temperature in the various nuclear power devices. Extensive studies were made on the reaction of pure graphite, pyrolytic carbon and doped carbon materials with oxygen, air, hydrogen, carbon dioxide and helium at temperatures of 300° to 1500°C, over a wide pressure range from a fraction of a torr to 76 torr and under a wide range of flow rates.

This work was done over the fifteen year period of 1950 to 1965. The results were of immediate value to the Divisions. In addition, the work led us to a new understanding of gas-solid reactions where the reaction product also was a gas. This work was reported in papers number 44, 45, 46, 47, 113, 116, 117, 122, 123, 124, 125, 126, 127, 135, 143, and 157 of the papers listed in Section 6.

5.2.2 Reaction of Zirconium and Zirconium Alloys with Oxygen, Hydrogen, Nitrogen and Water Vapor

This work was done for the Atomic Energy Commission, Bettis Atomic Power Laboratories and our Commercial Atomic Power Divisions. The work was begun as a basic research program in 1947 before the formation of Bettis Atomic Power Laboratories. Twenty years of nearly continuous research effort was carried out on the reactions of zirconium, Zircaloy II, Zircaloy IV and numerous other zirconium alloys

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with oxygen, air, hydrogen, nitrogen and water vapor over a temperature range of 25° to [illegible]0°C and pressures of a few torr to over 100 atmospheres. This work was reported in 25 papers which are referred to in Section 6 as papers number 35, 56, 56a, 59, 61, 62, 66, 68, 69, 70, 72, 73, 75, 77, 78, 79, 92, 132, 136, 137, 138, 142, 143, 146 and 151.

Many technical problems were solved in these studies including the solubility of hydrogen in zirconium, the crystal structure and range of homogeneity of zirconium hydrides, the rate of diffusion of hydrogen in zirconium, the role of oxide films in hydrogen adsorption, the rate of oxidation of zirconium in oxygen and in nitrogen, the types of hydrogen reaction with zirconium intermetallic compounds and the reaction of zirconium alloys in water at high pressure.

5.2.3 Oxidation of the Refractory Metals, Tungsten, Molybdenum, Rhenium, Niobium and Tantalum

This work was done for Wright-Patterson Air Force Laboratories, U.S. Army Office of Research, Durham, Westinghouse Lamp Division and for Westinghouse Basic Research programs.

Twenty-six years of research effort was carried out on the reactions of tungsten, molybdenum, rhenium, niobium and tantalum with oxygen, hydrogen and hydrogen-water vapor gas mixtures over a temperature range of 25° to 2700°C, a wide pressure range and in static and flow reaction environments. This work was reported in 20 papers which are referred to in Section 6 as papers number 17, 20, 21, 33, 37, 91, 106, 110, 111, 112, 113, 115, 117, 123, 129, 147, 156, 157, 159, 164 and 166.

The studies included kinetic studies on the oxidation reaction and the role of volatile oxide species on the rate of oxidation, the crystal structures of the oxide films, the mechanisms of oxidation and the thermochemical stability of the oxide species.

Many technical problems were solved in these studies. The work pointed out the difficulties inherent in using these materials in high temperature oxidizing gas environments due to the formation of volatile metal-oxide gas species. Studies on the sintering of silicon, aluminum and potassium doped tungsten ingots showed the important role of the oxygen potential of the hydrogen-water vapor gas mixture in controlling the composition and properties of the tungsten ingots. Vapor pressure studies on molybdenum oxides demonstrated the high volatility of the trimer $(MoO_3)_3$.

5.2.4 Localized Oxidation and Stress Corrosion Cracking of Metals

This work was started as a basic research program and later sponsored

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by the Office of Naval Research and the Westinghouse Stress Corrosion Cracking Committee. Eighteen years of research work was carried out on the nucleation of oxides on iron, the formation of oxide whiskers and blade-shaped and fan-shaped oxide platelets on iron and the mechanism of stress corrosion cracking of metals. This work was reported in 20 papers which are referred to in Section 6 as papers number 57, 58, 65a, 83, 86, 88, 89, 90, 103, 104, 105, 114, 121, 148, 149, 150, 153, 155, 158 and 165.

The results of this work has suggested new models for the oxidation of metals, new mechanisms for the rapid transport of metal in oxide structures and a new model for the stress corrosion cracking of metals.

5.2.5 Oxidation of Alloys

This work was started in 1945 as a basic research program since Westinghouse was interested in developing better heat resistant alloys for electric stoves, steam and gas turbines and for use in a wide variety of electrical apparatus. Twenty years of research was carried out on the kinetics of oxidation of type 304 stainless steel, nickel-chromium-aluminum and iron-chromium-aluminum alloys. Crystal structure and crystal habit studies on the oxide films was correlated with the kinetic observations. This work was reported in 16 papers which are referred to in Section 6 as papers number 15, 16, 17, 19, 25, 26, 27, 29, 31, 52, 55, 63, 80, 84, 85 and 97.

These studies were valuable in establishing the unique role of chromium, aluminum, manganese, silicon and trace impurities in high temperature oxidation.

5.2.6 Thermochemical Analyses

Thermochemical analysis was used as a discipline to guide us in planning and interpreting all of the research programs. In the early 1940's we searched the literature and assembled free energy and equilibria data on many oxide systems to evaluate the oxidation, reduction and sintering reactions of metals. This compilation of thermochemical information was one of the first and was very important in our own work and as a help to others in our laboratory and in Westinghouse Divisions. Three special studies were made to develop thermochemical quantities to help in our own studies: (1) vapor pressure of beryllium, paper number 38, (2) vapor pressure of chromium, papers number 50 and 67 and (3) vapor pressure of molybdenum trioxide, paper number 111. These papers helped us to develop models for the oxidation of beryllium, chromium and molybdenum.

Experimental thermochemical studies were also made for (1) zirconium-

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hydrogen system, papers number 59 and 62 and (2) columbium-hydrogen system, paper number 106. The results of this work were very valuable in using zirconium alloys as a cladding material in pressurized water nuclear power reactors.

5.2.7 Closure

All of the work during this period was under my direct supervision. I participated in the planning, carrying out of the experiments, in the interpretation of the results and in the write-up of the results. During this period I supervised the work of 4-[illegible] fessionals and 2-4 technicians.

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5.3.2 Oxidation of Silicon and Silicon Carbide

This work was begun by the Army Office of Research, Durham, and later continued as a basic research project. Studies were made on the behavior of silicon, silicon oxide and silicon carbide in oxidizing and reducing gas atmospheres and in high vacuum. These studies confirmed thermochemical predictions of two types of oxidation processes, active and passive. Very rapid oxidation (active, occurs in low pressure oxygen using high flow rates with loss of silicon monoxide and carbon monoxide. Very slow (passive) oxidation occurs in high pressure oxygen even in high flow rates with the formation of a protective oxide. Thermochemical analysis shows the equilibrium pressure of silicon monoxide at the silicon/silicon dioxide or silicon carbide/silicon dioxide interface determines the type of oxidation reaction.

The results of these studies were reported in papers number 133, 134, 156, 157, 158, 160, 161, 163 and 164 in Section 6. The results of these studies have led to a new understanding of high temperature oxidation of materials where volatile gases are formed at internal interfaces. Also, the success of the use of thermochemical analysis in the interpretation of oxidation has led to many new applications of thermochemical analysis in industry.

5.3.3 Hot Corrosion of Gas Turbine Alloys

This work developed from our interest in applying thermochemical analyses to high temperature corrosion processes in gas turbines. A lengthy paper entitled "General Concepts of Oxidation and Sulfidation Reactions -- A Thermochemical Approach" was written. This paper was published and is listed as paper number 160. This paper has led to further work with the Coal Gasification Project. Here, cleaned low BTU coal gas will be used in a gas turbine at 1600°F. Thermochemical analysis is being used to guide us in planning and interpreting the extensive experimental program.

5.3.4 Sintering of Tungsten for Incandescent Lamps

Extensive thermochemical analysis has been used to study the influence of temperature and dew point of the hydrogen gas used in the sintering process on the density and silicon, aluminum and potassium analysis of the tungsten. A special high temperature, high vacuum furnace was installed to carry out sintering reactions in high vacuum of 10^{-7} torr and in controlled hydrogen/water vapor gas mixtures at temperatures to 2700°C. This work demonstrated the important role of the dew point (oxygen potential) of the hydrogen gas on the density and silicon, aluminum and potassium levels. The experimental work confirmed the thermochemical predictions. This work has not been published.

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6.0 PUBLICATIONS

Dr. E. A. Gulbransen

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2. Data of State of Phosphine at Low Pressures and from 190 to 300 K. E. A. Long and E. A. Gulbransen. J. Am. Chem. Soc. 58, 203 (1936).

3. Variations in the Relative Abundance of Carbon Isotopes. A. O. Nier and E. A. Gulbransen. J. Am. Chem. Soc. 61, 697 (1936).

4. Thin Oxide Films on Iron. E. A. Gulbransen. Trans. Electrochemical Society 81, 327-339 (1942).

5. Some Observations on the Formation and Stability of Oxide Films. E. A. Gulbransen. Trans. Electrochemical Society 82, 375-389 (1942).

6. Transition State Theory of Formation of Thin Oxide Films on Metals. E. A. Gulbransen. Trans. Electrochemical Society 83, 301-317 (1943).

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9. The Oxidation and Evaporation of Magnesium at Temperatures from 400 to 500°C. E. A. Gulbransen. Trans. Electrochemical Society 87, 463-473 (1945).

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11. A Use of the Electron Microscope in Chemical Microscopy. E. A. Gulbransen. R. T. Phelps and Alois Langer. Ind. Eng. Chem. Anal. Ed. 17, 646-52 (1945).

12. An Electron Diffraction and Electron Microscope Study of Oxide Films Formed on Metals and Alloys at Moderate Temperatures I. Stripped Oxide Films of Metals. R. T. Phelps, E. A. Gulbransen and J. W. Hickman. Ind. Eng. Chem. Anal. Ed. 18, 391-400 (1946).

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17. An Electron Diffraction Study of the Oxide Films Formed on Molybdenum and Tungsten at High Temperatures. J. W. Hickman and E. A. Gulbransen. AIME Inst. Metals Div. Trans. 171, 371-387 (1947).

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19. An Electron Diffraction Study of the Oxide Films Formed on Oxidation Resistant Alloys. J. W. Hickman and E. A. Gulbransen. Trans. Electrochemical Soc. 91, 605-620 (1947).

20. The Kinetics of the Oxidation, Reduction and Vacuum Behavior of Molybdenum and its Oxides. E. A. Gulbransen and W. S. Wysong. AIME Metals Div. 175, 628-47 (1948).

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7.0 PATENTS

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7.2 Photoflash Lamp and Multiple Flash Lamp System, July 4, 1972, U.S. 3,675,004, Earl A. Gulbransen, R. L. Tallman, K. F. Andrew, and B. T. Buzalski

7.3 Yttrium-Hydrogen Isotope Compositions for Radiochemical Reactions, February 13, 1973, U.S. 3,716,491, L. N. Yannopoulos, S. A. Jansson, and E. A. Gulbransen.

7.4 Yttrium Alloy Getter, September 29, 1971, Great Britain 1,248,184, S. A. Jansson, E. A. Gulbransen, and L. N. Yannopoulos.

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8.0 SCIENTIFIC SOCIETIES

8.1 American Chemical Society 1936 - Present

8.2 Electrochemical Society 1941 - Present

8.3 American Institute of Mining and Metallurgical Engineers - Institute of Metals Division 1946 - Present

8.4 Chemists Club of Pittsburgh

8.5 Former Member Electron Microscope Society, American Society of X-Ray and Electron Diffraction, American Association for the Advancement of Science.

9.0 AWARDS

9.1 American Institute of Mining and Metallurgical. Engineers Award for Outstanding Research - 1949.

9.2 National Association of Corrosion Engineers, Willis Rodney Whitney Award - 1952.

9.3 American Chemical Society, Pittsburgh Section Award - 1961.

9.4 Electrochemical Society, Acheson Award and Prize - 1964.

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10.0 OTHER SCIENTIFIC ACTIVITIES

10.1 International Conference on Surface Reactions - 1948 - Chairman and Organizer.

10.2 Gordon Research Conference, Metals Conference - 1952 - Chairman and Organizer.

10.3 Gordon Research Conference, Corrosion Conference - 1955 - Chairman.

10.4 Corrosion Research Council, Member 1958-1964 - Chairman 1963-1964.

10.5 AIME Conference on Physical Metallurgy of Stress Corrosion Fracture - 1959 - Program Chairman.

10.6 AIME Corrosion Resistant Metals Committee, Member 1957 - 1965.

10.7 American Chemical Society, Pittsburgh Section - Chairman 1959-1960.

10.8 Electrochemical Society, Pittsburgh Section - Chairman 1947.

10.9 Chemist Club of Pittsburgh, Chairman - 1956.

10.10 International Union of Pure and Applied Chemistry, Member Committee on Pure Metals.

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11.0 Summary

Thirty-three of my thirty-nine years of scientific and engineering experience have been in the field of gas-metal and gas-solid reactions including research, development, consulting and supervisory activities. The time span of 1940 - 1973 includes the period in which gas-metal reactions were just beginning to be studies in our universities to the present period where the study of gas-solid reactions is essential in the preparation and use of materials.

My first activities at Westinghouse were to develop new and improved instruments for the study of gas-metal reactions. We developed the vacuum microbalance method for the study of the kinetics of oxidation, medium and high voltage electron diffraction methods for the study of the crystal structure of thick and thin oxide films and electron microscope methods for the study of the crystal habit of oxide films. A combination of these methods was used to experimentally characterize a wide variety of oxidation, volatilization, hydrogen reduction and hydriding reactions.

A second phase of this work was to interpret the results of the experimental studies. We made important theoretical contributions to gas-solid reactions using thermochemical analyses, kinetic theory, transition state theory of chemical reactions, diffusion theory and classical diffusion rate theory.

We have studied over a thirty-three year period a broad spectrum of gas-metal and gas-solid reactions. The oxidation reaction of the following elements and alloys have been studied: iron, nickel, cobalt, copper, aluminum, magnesium, chromium, beryllium, titanium, vanadium, zirconium, rhenium, silicon, niobium, tantalum, molybdenum, tungsten, uranium, stainless steels, nickel-chromium, iron-nickel-chromium, iron-chromium-aluminum, zirconium-tin, Zircaloy and a large number of zirconium-intermetallics. The hydrogen and nitrogen reactions of zirconium, titanium, niobium, tantalum, Zircaloy and the zirconium-intermetallics were studied. We have worked extensively on the oxidation, reduction and volatilization reactions of SiC, SiO_2, Al_2O_3, W-O, Mo-O and U-O systems.

Over the years the gas environments have changed from simple oxidation and reduction gas environments to complex environments of mixed gases such as hydrogen-water vapor gas mixtures, inert gases containing traces of water vapor, nitrogen, oxygen, etc. and air containing water vapor and traces of sulfur gases. Also, temperatures have risen from temperatures below 1000°C to temperatures up to 2800°C. These trends in more complex

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reaction environments and higher temperatures has required a great deal of care in the planning and interpreting of the data.

My professional activities have brought me into contact with a wide spectrum of products: nuclear reactors, steam generators, electrical generators, gas turbines, motors, transformers, furnaces, ovens, electrical heaters, incandescent lamps, flourescent lamps, automotive lamps, cameras, flash lamps, high temperature materials, ceramics, electrical heater alloys, magnetic alloys, protective coatings, electroplated coatings and corrosion resistant alloys.

From the beginning I have been affiliated with individuals and groups dedicated to solving technical problems using the best of modern theoretical and experimental methods. My scientific work has taken me to meetings and discussions all over the United States and in many foreign countries including Canada, England, France, U.S.S.R., Japan, Norway, Sweden, Switzerland and Italy. As a result I am familiar with scientific and engineering work in my area of competence in many countries and know most of the workers.

Carl A Gahlmann

Signed

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UNITED STATES OF AMERICA

RELATED CORRESPONDENCE

NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	:	
PUBLIC SERVICE ELECTRIC & GAS CO. (Salem Generating Station Unit #1)	:	DOCKET NO. 50-272
	:	

CERTIFICATE OF SERVICE

I hereby certify that copies of Earl A. Gulbransen's testimony on behalf of the intervenor, Township of Lower Alloways Creek, in response to the Board Order dated April 18, 1979

in the above captioned matter have been served upon the attached list by deposit in the United States mail at the post office in Northfield, N.J., with proper postage thereon, this 12th day day of June , 1979.

CARL VALORE, JR., Special Nuclear Counsel for the Intervenor, the Township of Lower Alloways Creek

Dated: June 12, 1979

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Gary L. Milhollin, Esq.
Chairman, Atomic Safety
& Licensing Board
1815 Jefferson Street
Madison, Wisconsin 53711

Glen O. Bright
Member, Atomic Safety
& Licensing Board
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dr. James C. Lamb, III
Member, Atomic Safety &
Licensing Board Panel
313 Woodhaven Road
Chapel Hill, N. C. 27514

Chairman, Atomic Safety and
Licensing Appeal Board Panel
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Chairman, Atomic Safety &
Licensing Board Panel
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Barry Smith, Esquire
Office of the Executive Legal Director
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Mark L. First, Esquire
Deputy Attorney General
Department of Law & Public Safety
Environmental Protection Section
36 West State Street
Trenton, N. J. 08625

Mark J. Wetterhahn, Esquire
for Troy B. Conner, Jr., Esq.
1747 Pennsylvania Avenue, N. W.
Suite 1050
Washington, D. C. 20006

Richard Fryling, Jr., Esquire
Assistant General Solicitor
Public Service Electric &
Gas Company
80 Park Place
Newark, N. J. 07101

Keith Ansdorff, Esquire
Assistant Deputy Public Advocate
Department of the Public Advocate
Division of Public Interest Advoc
P. O. Box 141
Trenton, New Jersey 08601

Sandra T. Ayres, Esquire
Department of the Public Advocate
520 East State Street
Trenton, N. J. 08625

Mr. Alfred C. Coleman, Jr.
Mrs. Eleanor G. Coleman
35 "K" Drive
Pennsville, N. J. 08070

Office of the Secretary
Docketing and Service Section
U. S. Nuclear Regulatory Commissi
Washington, D. C. 20555

June D. MacArtor, Esquire
Deputy Attorney General
Tatnall Building, P. O. Box 1401
Dover, Delaware 19901

Mr. Lester Kornblith, Jr.
Atomic Safety and Licensing Board
U. S. Nuclear Regulatory Commissi
Washington, D. C. 20555

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