

Lawrence E. Eiselstein, Ph.D., P.E.
Principal Engineer

Professional Profile

Dr. Lawrence Eiselstein is a Principal Engineer in Exponent's Silicon Valley Office specializing in failure analysis, accident reconstruction, risk analysis, and materials science (corrosion, metallurgy, composites, polymers, ceramics, and glass) as applied to product design, manufacture, intellectual property issues, and materials testing and evaluation.

Dr. Eiselstein has more than 30 years of experience assisting clients in the areas of design and failure analysis of a wide range of commercial and civil structures. His research includes the mechanical behavior of materials (strength, fracture, fatigue, and creep), armor development, corrosion science, and testing as applied to material selection, coating evaluation, breakdown potential, repassivation, polarization, galvanic, stress corrosion cracking (SCC), and hydrogen embrittlement issues.

Dr. Eiselstein's medical device consulting includes: aerosol delivery devices, anastomosis devices, catheters, cochlear implants, delivery systems, electrosurgical tools, feeding tubes, fertility control devices, guidewires, heart valves, heart valve repair devices, aneurysm repair devices, orthopedic devices, hypodermic needles, batteries, intra-aortic balloon pumps, pacemakers, stents and stent grafts, syringe, trocars, as well as other medical devices. His consulting includes design analysis and testing for FDA approval of implantable devices manufactured from plastics, ceramics, stainless steel, superelastic nitinol (NiTi), elgiloy and MP35N, support for 510K and PMA submissions to FDA as well as FMEA (failure modes and effect analysis) for medical devices, failure analysis of implantable medical devices, and intellectual property issues.

Dr. Eiselstein has applied his materials, corrosion, and forensic science skills to investigate and prevent accidents involving chemical releases, fires, and explosions. He has extensive experience dealing with fatigue, deformation and fracture of materials, fractography, electronic and microelectronic failure analysis, and all aspects of corrosion (including corrosion fatigue, environmentally assisted cracking, hydrogen embrittlement) as applied to bridges, chemical and power plant components, construction industry, condensers, boilers, consumer products, electrical and electronic products, fire and explosion investigations, oil and gas pipelines, plumbing and piping, pressure vessels, reactor vessels, steam turbines, solder joints, thermal interface, underground storage tanks, and welds and brazing.

Prior to joining Exponent, Dr. Eiselstein was a metallurgist with SRI International, worked as a Research Associate at Stanford University, was a consultant for EPRI, and worked at Huntington Alloys, an INCO company.

Academic Credentials and Professional Honors

Ph.D., Materials Science, Stanford University, 1983

M.S., Materials Science, Stanford University, 1976

B.S., Metallurgical Engineering, Virginia Polytechnic Institute (*with distinction*), 1974

Tau Beta Pi; Sigma Xi; Alpha Sigma Mu; International Nickel Company Scholarship; Townsend Fellowship; Wire Foundation Competition Prize; A.O. Smith-Inland Company 4th Annual Ferrous Powder Metallurgy Competition prize winner; Biomaterials Session Chairman, Golden Gate Materials and Welding Technologies Conference, 1997; Guest Lecturer: School of Engineering, Stanford University, Member of National Academy of Science Committee for Assembled Chemical Weapons Alternatives Committee to Assess Designs for Pueblo and Blue Grass Facilities, 2003; Member of Editorial Advisory Board for *Engineering Failure Analysis*

Licenses and Registrations

Registered Professional Corrosion Engineer, California, #1067; Registered Professional Metallurgical Engineer, California, #1779; Registered Professional Engineer, Alabama, #28612-E

Book Chapters

Eiselstein LE, Huet R. Chapter 1: Corrosion Failure Analysis with Case Histories. In: Uhlig's Corrosion Handbook, Third Edition, Editor: R. Winston Revie, The Electrochemical Society, Inc., John Wiley & Sons, Inc., 2011.

Eiselstein LE. Chapter 38: Corrosion of Shape Memory Alloys. In: Uhlig's Corrosion Handbook, Third Edition, Editor: R. Winston Revie, The Electrochemical Society, Inc., John Wiley & Sons, Inc., 2011.

Corlett N, Eiselstein LE, Budiansky N. Chapter 29. Types of Corrosion in Liquids: Crevice Corrosion in Shreir's Corrosion. Vol. 2, Editor: T. Richardson, Elsevier, 2010, pp. 753–771.

Publications

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Eiselstein LE, et al. Acceptance criteria for corrosion resistance of medical devices: statistical analysis of nitinol pitting in in vivo environments. J Mater Eng Perform 2009; 18(5-6):768–780.

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Eiselstein LE, Caligiuri RD. Ion leaching from implantable medical devices, Thermec 2009, Berlin, Germany, Materials Science Forum Vols. 638-642, pp. 754–759, 2010.

Guyer EP, Eiselstein LE, Verghese P. Accelerated testing of active implantable medical devices. Paper No. 09464, Corrosion 2009, NACE International, 2009.

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Eiselstein LE, Proctor DM, Flowers TC. Trivalent and hexavalent chromium issues in medical implants. *Materials Science Forum* 2007; 539–543:698–703.

Eiselstein LE, James BA. Medical device failures. 2nd International Conference on Engineering Failure Analysis, Toronto, Canada, September 12–15, 2006.

Beaudet RA, Berkowitz JB, Doherty RM, Eiselstein LE, Gekler WC, Gollin M. Review and assessment of the proposals for design and operation of designated chemical agent destruction pilot plants (DCAPP-Blue Grass II). National Research Council of the National Academies, July 2006.

Caligiuri RD, Eiselstein LE, Schmidt CG, Giovanola JH. Stable deformation at very high strain rates in UHCS. THERMEC'2006, International Conference on Processing and Manufacturing of Advanced Materials, Chandra T (ed), Trans Tech Publications, July 2006.

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James B, Wood L, Murray S, Eiselstein LE, Foulds J. Compressive damage-induced cracking in nitinol. Proceedings, International Conference on Shape Memory and Superelastic Technologies, Baden-Baden, Germany, October 3–7, 2004; ASM International, pp. 117–124, 2006.

Eiselstein LE, Sire RA, James BA. Review of fatigue and fracture behavior in NiTi. Proceedings, Materials and Processes for Medical Devices Conference, Boston, MA, November 14–16, 2005; ASM International, pp. 135–147, 2006.

James BA, Foulds J, Eiselstein LE. Failure analysis of NiTi wires used in medical applications. Journal of Failure Analysis and Prevention 2005; 82–87.

Beaudet RA, Barton C, Berkowitz JB, Doherty RM, Eiselstein LE, Forsen HK, Gekler WC, Gill CF, Roy CM, Smith KA, Stenstrom MK, Webler T. Interim design assessment for the blue grass chemical agent destruction pilot plant. Committee to Assess Designs for Pueblo and Blue Grass Chemical Agent Destruction Pilot Plants, Board of Army Science and Technology, National Research Council of the National Academies, The National Academies Press, Washington, DC, 2005.

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Eiselstein LE, Caligiuri RD. Particulate composite of white cast iron. Materials Science Forum, Trans Tech Publications, Switzerland, Vol. 426–432, pp. 895–900, 2003.

Caligiuri RD, Eiselstein LE. Superplastic densification of ultrahigh carbon steel powder compacts. Materials Science Forum, Trans Tech Publications, Switzerland, Vol. 426–432, pp. 877–882, 2003.

Andrew SP, Caligiuri RD, Eiselstein LE, Parnell TK. Evaluation of a failure in a chlorine production facility. Proceedings IMECE2001, ASME International Mechanical Engineering Congress and Exposition, New York, NY, November 2001.

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Eiselstein LE, Caligiuri RD. Atmosphere corrosion of the suspension cables on the Williamsburg Bridge. Degradation of Metals in the Atmosphere, ASTM STP 695, American Society for Testing and Materials, pp. 78–95, Philadelphia, PA, 1988.

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Guyer E, Eiselstein LE. Getting it right the first time: Accelerated testing of active implantable medical devices. Exponent Webinar, October 16, 2008.

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Eiselstein LE, Steffey D, Nissan A, Corlett N. Toward an acceptance criterion for the corrosion resistance of medical devices: A statistical study of the pitting susceptibility of Nitinol. Proceedings, ASM International Conference on Shape Memory and Superelastic Technologies, Tsukuba City, Japan, 2007.

Nissan A, Corlett N, Eiselstein LE, Steffey D. Effect of long-term immersion on the pitting corrosion resistance of Nitinol. Proceedings, ASM International Conference on Shape Memory and Superelastic Technologies. Tsukuba City, Japan, 2007.

Eiselstein LE, James B. Medical device failure analysis. Keynote Session VI – Failure Analysis (Fracture, Fatigue, Corrosion, and Materials Degradation), Materials, Medicine, and Nanotechnology Summit, ASM International, Cleveland, OH, October 20–25, 2006.

Eiselstein, LE, James B. Keynote lecture – medical device failures. 2nd International Congress on Engineering Failure Analysis, Toronto, Canada, September 12–15, 2006.

Eiselstein, LE. Medical device failures. Medical Device Seminar: Leaders and Visionaries, Stanford University, Stanford, CA, October 25, 1999.

Eiselstein, LE. Material considerations for biomedical devices. Golden Gate Materials and Welding Technologies Conference, San Francisco, CA, February 26–28, 1997.

Caligiuri RD, Eiselstein LE. Development of metallic laminate composites for heavy armor. Defense Advanced Research Projects Agency/Army/Marine Corps Armor/Anti-Armor Joint Program Office Information Exchange, Los Alamos National Laboratory, Los Alamos, NM, March 1990.

Caligiuri RD, Andrew SP, Eiselstein LE. A review of high strain rate properties and penetration mechanisms of depleted uranium and tungsten alloys. Army Research Development and Engineering Command/Army Research Office Workshop on Metallurgical Aspects of Deformation/Failure Mechanisms in “The Terminal Ballistics of Heavy Metal Kinetic Energy Penetrators,” Picatinny Arsenal, Dover, NJ, April 1990.

Reports

Eiselstein LE. Declaration of Lawrence Eiselstein in Support of Motion for Summary Judgment. Fireman’s Fund Insurance Company, Plaintiff, v Columbia Mechanical Contractors, Inc., Defendants, Exponent Report to William B. Waterman, October 2005 (Rule 26B Report).

Eiselstein L, Belanger J, Buehler C, Reza A, Ogle R, Adan M. Investigation of the explosion at Ultem Monomer production plant. Exponent Failure Analysis Associates, December 2003.

Eiselstein LE. Support of Plaintiff Microlife Intellectual Property GmbH’s Opposition to Defendant Atherm, Inc.’s Motion for Summary Judgment of Non-Infringement of U.S. Patent No. 6,419,388, Microlife Intellectual Property GmbH Plaintiff and Counter defendant, v Atherm Inc. Defendant and Counterclaimant. Civil Action No. C 03-1117 (SBA) in U.S.

District Court for Northern District of California, Oakland Division, September 2003 (Rule 26B Report).

Eiselstein LE. Supplemental Declaration of Lawrence E. Eiselstein, Marchon Eyewear, Inc. and Rothandberg, Inc., Plaintiffs, v Global Optical Resources, Inc., Defendant, Exponent Report to Frommer Lawrence & Haug LLP, June 2003 (Rule 26B Report).

Eiselstein LE. Stern tube corrosion and cathodic protection. Exponent Report to United States Coast Guard, Lockport, LA, May 2003.

Eiselstein LE. Declaration of Lawrence E. Eiselstein, Marchon Eyewear, Inc. and Rothandberg, Inc., Plaintiffs, v Global Optical Resources, Inc., Defendant, Exponent Report to Frommer Lawrence & Haug LLP, January 2003 (Rule 26B Report).

Eiselstein LE. Stern tube corrosion on 87-foot cutters. Exponent Report to United States Coast Guard, Alameda, CA, October 2002.

Eiselstein LE, Giddings V, Kennedy R, Mahnovski S, Medhekar S. Zelickson Patent Valuation. Enteric Medical Technologies and Boston Scientific, Exponent Report, August 2002.

Eiselstein LE. Valley Transit Authority (VTA) Rail Fracture. Exponent Report, June 2002.

Eiselstein LE. Equilon/Texaco Pipe Release. Expert Report to McCutchen, Doyle, Brown & Enerson, March 2002 (Rule 26B Report).

Eiselstein LE. Declaration of Lawrence E. Eiselstein, regarding underground corrosion of ARCO station piping, Report to O'Melveny & Myers LLP, September 2001 (Rule 26B Report).

Eiselstein LE. FSI International v Particle Measuring Systems, Exponent Report to Robins, Kaplan, Miller & Ciresi, August 2001 (Rule 26B Report).

Eiselstein LE. Rebuttal Expert Report, Varian Associates, Inc. v General Electric. Exponent Report to Farella Brawn & Martel, March 2001 (Rule 26B Report).

Eiselstein LE. Trident Weld Consumables Rebuttal Report. Exponent Report to Castro and Worthge, LLP, March 2001 (Rule 26B Report).

Eiselstein LE. Stress Corrosion Cracking of CAP Wire. Exponent Report to Rogers, Joseph, O'Donnell & Quinn, July 2000.

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Eiselstein LE and Haussmann G. Investigation of the October 23, 1995 Chemical Release at Gaylord Chemical, Bogalusa, Louisiana. Exponent Report, September 1998.

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Eiselstein LE, Wachob HF, Mimmack GF. Failure Analysis Report of Limit Switch. Failure Analysis Associates Report to Puget Sound Naval Shipyard, Bremerton WA, November 1997.

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Project Experience

General Failure Analysis

Power Plant Steam Explosion—Investigated a steam explosion at a fossil fueled power plant that killed four plant personnel. One of the plants main steam lines had been severed as a result of a large primary air draft fan failure that was used to blow crushed coal into the boiler. Fractography, fracture mechanics, material testing, and metallurgy were used to help investigate the cause of this accident. Pieces of the fan were put back together to identify the origin. The failure was traced to a weld crack. These results were presented to the plant personnel concerned about plant safety.

Power Steam Turbine Experience—Investigated the corrosion mechanisms associated with stress corrosion cracking (SCC) of steam rotor materials for EPRI (Electric Power Research Institute). This research included measurements of initiation and growth of SCC cracking in low pressure steam turbine disks. Performed a probabilistic based risk analysis of LP steam turbine disk cracking for a large number of units operating at a mid-west power plant.

New York City Williamsburg Suspension Bridge—Investigated the atmospheric corrosion damage that had occurred over the 80-year life (now over 100 years old) to the Williamsburg Suspension Bridge main suspension cables. This bridge was opened to traffic in 1903 and the four main support cables are composed of 7,696 high carbon patented steel wire. These wires were ungalvanized but given a protective organic coating when installed. Wire samples were removed from the cables and evaluated for corrosion damage and mechanical properties. Mechanical properties had been degraded. Accelerated corrosion tests were used to estimate the current rate of corrosion.

Atmospheric Corrosion of Copper Coated Stainless Steel Architectural Material—Investigated the nature of corrosion failures that was occurring on copper coated stainless steel sheet that was being used as roofing, gutters and siding on homes and businesses. In some cases the atmospheric corrosion of the electroplated stainless steel sheet had corroded sufficiently to expose the underlying stainless steel. In other cases, the stainless steel sheet had undergone pitting to such an extent to allow water to leak through. Atmospheric corrosion rates that can be expected for copper in various environments such as marine or coastal, urban, and rural areas were reviewed. The potential for galvanically assisted pitting of the stainless steel was also

investigated. The acidic condensation from chimneys and flues was found to rapidly strip off the copper plating.

LM2500 Gas Turbine Failure—Investigated the reason for the failure of a LM2500 turbine. Turbine bolting manufactured from Inconel 718 that had been plated with silver for anti-galling (low friction) had failed while the unit was at full power. Issues were turbine operating temperature, creep-fatigue, and hot corrosion (sulfur and chloride).

Steam Turbine Rotor Straightening—Investigated the reasons for the warpage (bowing) of HP/IP rotors manufactured from Ni-Cr-Mo-V steel. The effect of turning gear failure, creep during time at temperature while stationary, the effect of thermal gradient induced thermal stresses (from rubbing or loss of turning gear) on plastic and creep deformation, and the resulting residual stresses induced by these permanent deformation were considered along with the effectiveness of proposed straightening methods.

Fertilizer Plant Explosion—Investigate the December 13, 1994 massive explosions that leveled portions of a Port Neal, Iowa, ammonium nitrate plant owned by Terra Industries. Four plant workers were killed, eighteen others suffered serious injury, and damage to the plant and surrounding community was estimated in the hundreds of millions of dollars. Reviewed the events surrounding the accident, analyzed the plant's process data for reliability, and conducted extensive research regarding ammonium nitrate properties and decomposition mechanisms. Also completed analytical modeling and experimental testing to resolve the conflicting accident theories, and inspected and performed metallurgical analysis of various artifacts from the explosion site. The investigation revealed that the detonations occurred due to unsafe plant operations, including poor maintenance and inadequate employee training. Specifically, plant operators allowed the ammonium nitrate within their 18,000-gallon-capacity neutralizer vessel to become contaminated and highly acidic. Operators then injected superheated steam directly into the neutralizer vessel, precipitating a runaway chemical reaction.

Inconel 718 Fuel Nozzle Cracking—A commercial airliner experienced an in-flight engine fire and shutdown in Paris that was linked to the failure of the superalloy Inconel 718 forged fuel spray nozzle used in certain Rolls Royce engines installed on Airbus and Boeing aircraft. This led to the worldwide replacement of thousands of fuel spray nozzles on hundreds of aircraft. We investigated the nature of the aircraft fuel nozzle cracking, the forging procedures (forgability limits, forging temperature), ingot size, and inspection and manufacturing techniques used to make these nozzles.

Ammonium Perchlorate Plant Explosion—Investigated the cause of a series of explosions that destroyed a solid rocket oxidizer plant (ammonium perchlorate manufacturing facility) in Henderson NV. The largest of five individual explosions at PEPCON was equivalent to 1.5 million pounds of TNT, and another explosion was equivalent to 500,000 pounds of TNT. Assessed the role that ERW weld defects in a 16-inch high pressure natural gas pipeline that traversed the plant and was damaged by the explosions may have played in the incident.

Oil Well Perforation Gun Explosion—Investigated a perforation gun explosion at the Halliburton Industries assembly plant in Kenai, Alaska that killed one employee and seriously injured five others. Perforation guns are used in oil well completion to perforate the oil well casings to allow oil to flow into the well. A perforation gun consists of numerous explosive shaped charges aligned within a pipe. The explosion occurred and workers were injured during the shop assembly of the perforation gun. Exponent’s forensic investigation involved detailed examination of the remaining fragments, combined with mapping of the fragment locations after the explosion, to determine the sequence of events that led to the explosion. The evidence indicated that an employee accidentally ignited the shaped charges or the detonation cord within the gun.

Drill String Failures—Investigated the cause of several drill string failures. These failures involved complete separation of the string at the threaded coupling, rather than the more commonly observed washout failures that occur in the main pipe segment. These failures occurred at various depths and total drilling hours. Testing and finite element analysis was performed to determine if these failures were a result of stress corrosion cracking (SCC) or from fatigue from stresses in the shoulder of the coupling.

Steel Structural Steel Beam Cracking—Investigate reported incidents of cracked galvanized structural beams found in buildings over the last few years. Although cracking of steel beams in galvanizing baths is not a new phenomenon, there is a concern that the rate of cracking, although still small, has increased since 2000. The observed cracking is due to a mechanism known as liquid metal assisted cracking (LMAC) LMAC is a form of liquid metal embrittlement (LME). LMAC is a result of the simultaneous application of a high stress, a potentially deleterious environment (the galvanizing alloy) and a susceptible material (the steel) used for the structural beam. Several variables can affect LMAC, which makes predicting how and when it will occur challenging. Selecting an appropriate nondestructive testing (NDT) technique for inspection of beams containing LMAC cracks requires careful consideration as they can be filled or covered with the zinc (Zn) galvanizing alloy. This makes visual and dye penetrant testing impossible. It may be possible to use a modified magnetic particle testing technique, or even ultrasonic testing (UT) or eddy-current testing (ECT), to detect such cracks.

Natural Gas Fitting Failure and Explosion—Investigated a natural gas explosion that occurred in a mobile clinic. Examined a broken copper natural gas fitting on the clinics heater to determine the cause of failure. The failure was found to be a result of fatigue and not stress corrosion cracking.

Refrigerator Compressor Failures—Excessive field failures were observed a few years after introduction of a new type of refrigerator compressors. The investigation included engineering analysis of wear in the compressor parts as well as statistical analysis to determine the factors associated with field failures.

Home High Efficiency Furnace—Examined the corrosion damage to the enameled steel heat exchanger used in a condensing home furnace. X-ray photoelectron spectroscopy (XPS also known as ESCA) was used to characterize the pitting damage.

Armor/Anti-Armor—Worked on various armor and anti-armor projects. Designed, manufactured, and ballistically tested these armor systems (metallic laminates and ceramics) against a variety of threats from small caliber to shaped charges and kinetic energy penetrators. Manufacturing techniques included roll bonding, superplastic solid-state pressure induced diffusion bonding, electron beam welding, hot isostatic pressing (hipping) and other techniques.

Welds and Welded Connections

Steel Moment Frame Weldment Failures—Investigated the causes of failed steel moment frame welds after the Northridge Earthquake in Los Angeles, CA. Investigation included metallurgical examinations of failed welds removed from buildings, chemical analysis of weld material, and analysis of the potential for hydrogen induced weldment cracking.

Stainless Steel Piping Welds—Investigated the corrosion damage to stainless steel piping and welds in a semiconductor equipment manufacturing facility that had a hydrochloric acid (HCl) spill. The heat affected zone of the welded stainless steel piping was inspected for pitting and stress corrosion cracking. Methods for cleaning and passivating the stainless steel piping in place were evaluated.

Residual Stress in Space Satellite Fuel System—Investigated the effect of residual stress in an electron beam (EB) welded component used in a satellite fuel system. The failures appeared to be the result of low-cycle fatigue.

ERW Weld Corrosion Attack—The electrical resistance weld in steel piping used to pipe water to and from the cooling tower in an HVAC system was analyzed to determine if it was defective.

Ceramic-to-Metal Seal Braze—An exploding bridge wire detonator used in the aerospace industry was analyzed for reliability. The thermal stresses resulting from the difference in thermal expansion coefficient between the low expansion alloys used (Kovar and Invar), alumina, and the brazing alloy were analyzed.

Failure Analysis of EB and Laser Welded Inconel 718 Nickel-Hydrogen Battery—Some batteries used for an aerospace application developed a leak while in service after various charge/discharge cycles which cyclically pressurize and depressurize the battery. The manufacturing methods and materials used to manufacture nickel hydrogen battery were reviewed. Micro-fissuring grain boundaries during welding, niobium enrichment, delta phase precipitation, deep drawing and heat treatment variations, hydrogen assisted crack growth, caustic SCC, and other factors were considered as a potential causes for leaks.

Cracking of Nickel 200 Spot Welds on Cathodes in a Clorox Chlor-Alkali Plant—Examined some Nickel 200 spot welds that were found cracked in the cathode portion of chlor-alkali production cells at a chlorine production facility and determined the nature of this cracking. The nickel was exposed to 32-wt% caustic at 90°C. These cracks occurred in the heat-affected zone of the welds and therefore were not associated with defects in the weld metal, such as solidification porosity or hot tearing. The cracking was intergranular with little, if any,

indication of ductile rupture. The location of the intergranular cracking in the heat affected zone of the spot welds may indicate that this cracking is associated with precipitation of a carbon film (or graphite), or segregation of sulfur, antimony, tin or some other known embrittling trace element in the Nickel 200, at the grain boundaries during cooling. It is also at or near the maximum stress location. This cracking is most consistent with hydrogen embrittlement cracking driven by hydrogen charging at the cathode, potentially exacerbated by mechanical embrittlement from graphite precipitation or metalloids segregation in the grain boundaries.

Pipelines, Piping, and Plumbing

Hot Water Recirculation Systems—Investigated the reasons for copper piping leaks in a housing development. The failure investigation indicated the reason was too high a flow rate of the water in the hot water recirculation system that caused erosion-corrosion of the copper piping that was comprised of both hard and soft copper lines.

Pitting of Copper Tubing in HVAC System—Investigated the cause of through wall pitting of aluminum finned copper tubing used in a large data center's chilled water system. This system containing both steel and copper piping in the computer room air handlers (CRAHs) had been originally run with a nitrite based water chemistry with the addition of tolyltriazole as the copper corrosion inhibitor. The system ran for about 5 to 11 months prior to leaking. The copper coils leaked as a result of internal pitting corrosion as a result of microbiological influenced corrosion (MIC) of the copper. The presence of MIC was supported by the corrosion morphology (isolated pits under deposits), DNA/RNA testing showing denitrifying and nitrifying bacteria. The use of nitrite in an open loop system that can allow oxygen ingress that will convert the nitrite to nitrate may have provided a food source for the nitrifying-denitrifying bacteria. In addition, the lack of a biocide would allow MIC to occur. The very thin wall of the copper tubes makes them very susceptible to corrosion induced leaks.

Crude Oil Pipeline Release—Investigated, performed a failure analysis, and provided testimony regarding the adequacy of the corrosion protection (coating and cathodic protection) of a crude oil line that leaked.

Natural Gas Pipeline Rupture and Explosion—Investigated the cause of a 36-inch natural gas transmission pipeline rupture that occurred in Carlsbad, NM. This investigation including evaluation of the effects of internal corrosion and assessed the extent to which water ingress into the transmission line from third party producers and the pipeline configuration may have contributed to the observed internal corrosion.

Painted Steel Pipe Aqueduct —Investigated the condition of 10 miles of painted above ground steel piping with approximately half inch thick wall that had become submerged as a result of a flooding event. Pipe diameter varied from 65-inches to 87-inches. Some flood induced abrasion damage to the paint was noted on some of the pipelines. Biological growth was also observed on the paint on the undersides of the pipelines. There was little to no significant corrosion damage to the steel pipeline. Various alternatives were considered regarding how to bring the pipeline coatings to pre-flood conditions.

Underground Corrosion of Cast Iron Water Main—Investigated and testified on the reasons for a cast iron water main failure. The reasons were graphitic corrosion and lack of cathodic protection.

External Underground Corrosion of Copper Laterals—Investigate the reasons for through wall corrosion of copper laterals in a new housing development. Cathodic protection was recommended.

External Underground Corrosion of HVAC Supply/Return Water Piping—Investigate the reasons for through-wall corrosion of steel HVAC supply and return underground water piping to office building. Stray current effects were evaluated. Isolation and cathodic protection was suggested as remediation method.

PEX Plumbing System Failures—Leaks in many homes utilizing a cross linked polyethylene (PEX) plumbing. The majority of leaks occurred on the hot water supply line. The PEX plumbing joint is composed of PEX piping, a brass elbow or tee, and stainless steel crimp bands. The stainless steel bands are used to clamp PEX tubing to brass fittings. Some of these clamps had failed resulting in a leaking joint. Scale or deposits were found on the inside and outside of the incident brass fittings. Analysis of the corrosion deposits was done with energy dispersive spectroscopy (EDS) in a scanning electron microscope (SEM). The deposits were composed mainly of zinc, oxygen, and aluminum with traces of carbon, lead, iron, and nickel. SEM examination of the fractured stainless steel crimp bands indicated it failed from intergranular stress corrosion cracking (SCC). EDS analysis revealed chlorine present on the band near the fracture surface. The SCC of the stainless steel clamp appears to be the result of moisture and contaminants leaking through the wall of the dezincified brass.

Polybutylene Potable Water Pipe Failure—A landslide occurred on a steep hillside. A leak in polybutylene potable water fitting on supply main may have been the reason the landslide occurred after a long dry spell. Polybutylene (PB) pipe has a high susceptibility to chemical degradation, and a low resistance to cracking. The rate at which antioxidant are leached from the pipe interior, water chemistry, and the stress in the PB pipe at the rigid coupling, factors in environmental stress cracking (ESC) were considered. Fractography of the PB pipe fracture surface was performed to determine if the pipe failed as a result of ESC and thereby a cause of the landslide or from ductile overload and thereby a result of the landslide.

Ethylene Steam Pyrolysis Furnace—There was a sudden and unplanned shutdown of an ethylene steam cracker plant that caused immediate, and potentially latent damage, to the expensive nickel-chromium-iron (Ni-Cr-Fe) furnace tubes. Cast HP or Incoloy 800H tubes are sometimes used. Ethylene is obtained by flowing hydrocarbons (*e.g.* ethane) and steam inside tubes heated in a furnace; the reaction produces light alkenes (including ethylene) and hydrogen. The furnace is heated by gas burners; the tube temperature in service is about 1000°C (1800°F). At these temperatures the tube metal experiences a number of damage mechanisms that eventually result in tube failure and replacement. A byproduct of the reaction is the formation of a layer of coke (carbon) on the inner surface of the tube. This layer is detrimental for a number of reasons; in particular it acts as a thermal insulation barrier between the tube and the cooler gas inside the tube, thus increasing the tube metal temperature. If the coke buildup

severely restricts the flow of gas inside the tube or completely plugs it, the entire tube will overheat because it will no longer be cooled by the gas flow on the inside. As a result, the coke layer must be removed periodically by flowing only steam in the tubes, or steam and some air. This burns off the coke. The change between carburizing and decarburizing conditions at the tube inner surface contributes to surface damage. Decoking accelerates the tube degradation. The various damage modes and operating conditions leading to tube failures were investigated and include:

- Carburization during normal operation where carbon diffuses into the metal. Operating with thick coke deposits will increase tube temperature, accelerating carburization and shortening tube life.
- Oxidation and wear of the inside surface. Oxidation may occur during decoking cycles, eroding and consuming the metal matrix.
- Overheating and melting of the tubes if the coke deposits are too thick or if a tube becomes partially or completely plugged.
- Sulfidation: Hydrocarbon mixtures frequently contain some level of sulfur. Although sulfur may be used to the control of coking rates, iron- and nickel-based alloys are susceptible to accelerated high temperature degradation when exposed to sulfur compounds, as a result of the low melting temperature of various metal sulfides. For example nickel sulfide (Ni_3S_2) melts at 635°C .
- Creep, which is a phenomenon where metal under stress at high temperature will slowly deform and eventually crack.
- Thermal fatigue, due to cyclic stresses.
- Metal embrittlement due to formation of intermetallic phases or sigma phases.

Central Arizona Project (CAP) Pipe Failure—Investigated the reason for pre-stressing wire failures that occurred on the pipe used in the Central Arizona Project (CAP). CAP is a waterway transporting water from the Colorado River to central and southern Arizona. At the time of construction it was the longest single water transportation project ever authorized by the United States Congress; it combines an intricate system of canals, tunnels, pipelines and pumping stations. Where CAP crosses seven major riverbeds and washes, 6.4 m (21-foot) diameter inverted siphons are used. Six of these seven siphons, ranging in length from one quarter mile to almost two miles in length, were constructed from what was at the time, the largest precast prestressed concrete pipe ever manufactured, that is, pipe with an internal diameter of 6.4 m (252 inches), a wall thickness of 0.54 m (21 inches), and a length of 6.9 m (22.6 feet). Individual prestressed concrete pipe (PCP) sections weighted as much as 225 tons. The prestressing wire was high-strength patented steel wire (ASTM A648 Class III) and up to 35 km (22 miles) of wire was used to prestress each pipe segment. This prestressing placed the wire at approximately 75% of the wire's minimum ultimate tensile strength (UTS). The wire was then covered by a thin layer of mortar. The pipe sections were not coated or cathodically protected. Wire fractures and splits were the main symptoms of wire distress in the CAP pipes. While the mortar initially contained relatively low concentrations of chloride, evaporation led to a chloride concentration build-up to levels supporting SCC. Water sources included ground water and pipe joint leakage, both of which can contain chloride. Evaporation of the water, as it "wicked" up around the pipes through the mortar, deposited the chloride within the upper half of the siphon pipes, eventually concentrating it to levels exceeding the values necessary to initiate. Chloride levels in the wet/dry transition zone of the siphons appear to have been high enough to

cause SCC without any significant carbonation of the mortar or the core. These conditions would not have occurred in the absence of a frequent or continuous evaporation process, a direct result of the CAP geographic location and the size of the pipe, as well as the arid area soil characteristics.

Brass Plumbing Failure—Several brass elbows from two different commercial installations had failed. The cracking on the female end was examined with optical microscopy and the fractures surfaces with SEM/EDS. Ion chromatography of debris, corrosion product, and solder flux found on piping and fittings was examined for contaminants that may be responsible for SCC. The evidence pointed to fitting failures from over tightening.

Intellectual Property Litigation

Nitinol Patent Infringement—Provided expert testimony in an intellectual property litigation involving whether or not multiple companies were infringing a patent involving superelasticity and shape memory properties of nitinol (NiTi). This effort included reviewing the patent, reviewing the court rulings, and testing exemplar materials to determine their shape memory and superelastic properties.

Stent Patent—Testified in an intellectual property dispute regarding whether a stent being manufactured and sold infringed on a stent patent. The issues involved both manufacturing methods as well as design issues.

Wafer Cleaning Patent Infringement—Review a new wafer cleaning apparatus to determine if there might be infringement of existing patents.

Mitral Valve Repair Patent—Reviewed a patent and a venture capital funded company's proposed mitral valve repair device to see if there would be infringement.

Gastroesophageal Reflux Disease (GERD) Patent—Developed a probabilistic economic model to estimate the present value of a GERD patent.

Digital Thermometer Patent—Performed inspections using microfocus x-ray radiography that demonstrated infringement on a patent.

Hazardous Chemical Releases

Ammonia Release—An injury resulted when a worker was overcome by ammonia that had been released from failed tubing that was part of the refrigeration system at a large frozen foods warehouse facility. This effort involved a microscopic examination of the failed part with scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) and a comparison with exemplar products. Issues considered were silver brazing, joint strength, vibration-induced fatigue, and whether or not there was a manufacturing defect present.

Chlorine Release from Rail Car—Two trains collided and a pressure tank car loaded with liquefied chlorine was punctured, releasing a vaporized cloud of chlorine gas about 700 feet in

radius prior to drifting away from the site. Three died as a result of this incident. I was asked to investigate the extent of corrosion or other environmentally induced damage, if any, done to property that was being transported on one of the two trains. This investigation included a thorough visual inspection and wipe sampling of all the consumer product products being transported.

Chlorine Release from Chlor-Alkali Plant—Investigated the root cause failure of a large chlorine release that occurred at a liquid chlorine production facility located in Henderson, NV. This release required the evacuation of areas surrounding the plant. This investigation reviewed the various plant processes, including the primary chlorine liquefier. Efforts included detailed metallurgical examination of corroded components, use of computational fluid dynamics to model the flow of liquid chlorine, and corrosion experiments in brine contaminated chlorine. Experiments and computational fluid mechanics were used to evaluate the erosion-corrosion where chilled brine entered the liquid chlorine stream at a hole that had developed in the primary liquefier. The corrosion rate of steel in liquid chlorine/brine mixtures at high flow velocities was measured to determine how fast this mixture would corrode through the rundown elbow, causing the chlorine release.

Chlorine Release from Train Collision—A train collided with a stationary train, which contained a liquefied chlorine rail car that was punctured. The resulting chlorine cloud killed several people and resulted in corrosion damage to the factory that was located at the site. The extent of corrosion damage to various plant equipment, structures, and electronics was evaluated through the use of wipe sampling, SEM/EDS, and atmospheric corrosion coupons.

Iodine Release from Drug Manufacturing Laboratory —A glass container stored in a laboratory refrigerator that contained an organic iodine compound came into contact with the plastic lining of the refrigerator, and then leaked onto the floor. It is likely that this compound decomposed into iodine and hydrogen iodine which caused extensive atmospheric corrosion damage to stainless steel and other equipment and facilities throughout the lab.

Corrosion Induced Nitrogen Tetroxide Release from Rail Car—Investigated the circumstances leading up to the failure of a carbon steel railcar which was transporting approximately 110,000 pounds of nitrogen tetroxide (N_2O_4), also known as dinitrogen tetroxide or nitrogen peroxide. Upon receipt, the end user found that the nitrogen tetroxide was contaminated with water. After partially draining the railcar (the plant personnel believed they had completely emptied the tank car contents) the contents were further diluted with water until the tank rupture occurred. The jacket head was blown 350 feet from the railcar, the inner tank liner ruptured and the railcar was propelled 35 feet in the opposite direction and derailed. A large reddish-brown cloud was released as a result of this rupture. The interior and exterior of the railcar was inspected along with components removed from the railcar including the vapor dome, dip tubes, and other components. A series of laboratory tests were conducted in Exponent's corrosion/chemistry laboratory to recreate conditions inside the railcar prior to its rupture. A chemical corrosion reaction between nitric acid and carbon steel inside railcar caused a dramatic and localized reduction in the wall thickness. This substantially decreased the pressure required for rupture. The gaseous products of this reaction overcame the limited ability of the scrubber to reduce the internal pressure in the railcar, which built up the point where the pressure relief valve opened

briefly and then partially closed. Nitric acid corrosion of the carbon steel railcar shell resulted in continued wall thinning and gas generation inside the tank car, ultimately causing the tank car end to fail.

Silane Release—Investigated the cause of cracking and leakage of a silane-producing chemical reactor vessel. Metallographic, corrosion, and mechanical property testing were performed on the Incoloy 800H hydrogenation reactor vessel material. ASTM G28 sensitization was performed on the vessel material. Both silicon tetrachloride and trichlorosilane were produced in this vessel. Cracks were located in both the weld and heat affected zones (HAZ). Intergranular carbides were present in both the base and HAZ material. The failure was likely the result of sensitization induced intergranular stress corrosion cracking.

Sodium Hydroxide Release—Investigate the stress corrosion cracking that occurred to steel and Nickel 200 used in a multiple-effect evaporator for sodium hydroxide. Both the first effect and 2nd effect vessels had experienced some levels of cracking.

Hydrogen Sulfide Release—Assessed the occurrence and cause of sulfide-induced stress corrosion cracking in small bore process piping welds that led to releases of hydrogen sulfide (H₂S) gas into the environment at an upstream oil and gas processing facility.

Electronic and Electrical Equipment and Consumer Goods

BGA Fatigue Failure—Investigated the reasons for the failure of an electronic consumer product. This investigation involved thermal management, ball grid array solder joints, low cycle fatigue, and under fill issues. Accelerate life testing, statistical analysis of field failure data, modeling of creep-fatigue and intermetallic compound formation, and finite element analysis (FEA) were used to help understand the reason for the BGA cracking.

Lead Free Solder—Examined the effect of various board finishes, such as organic solder preservative (OSP), hot air solder leveling (HASL), electroless-nickel immersion gold (ENIG), and Immersion Silver (ImAg) on lead free (SAC) solder ball grid array (BGA) mounted device reliability.

Backup Alarm on Earthmoving Equipment—A fatality occurred when a grader backed up over an employee at a construction site. The backup alarm on the grader was not operating when inspected after the accident, because one of the wires had been cut. The cut wire was examined to determine the nature and timing of the cut. This investigation determined it was not cut with wire cutters. Examination of the cut wire with SEM/EDS could not reliably determine whether the cut had been made near the time of the accident or several years earlier.

Limit Switch Failure—Investigated a limit switch that reportedly failed to turn off and disengage the control circuit for an electric motor on a hoist on board a US Navy ship, resulting in a serious injury. The accident limit switch and exemplar switches were examined and tested electrically and mechanically. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were used to investigate the atmospheric marine corrosion that had developed on the various materials of construction, 6000 series aluminum, copper, and steel.

The primary cause of failure was that the wrong type of limit switch was specified and installed, however even if the appropriate limit switch had been used, the accident still may have occurred since the tab was incorrectly placed on the lever and the accumulation of corrosion debris from the marine atmospheric corrosion may have prevented correct operation.

Electric Power Line Arcing—Investigated the arc marks on an aluminum conductor from a high voltage transmission line that had broken and fallen along a road. The origin of a forest fire that destroyed many homes was near a tree where the downed line was found. The arc marks were found to be consistent with arcing between the tree limbs and the high voltage line.

Bus Transfer Criteria for Power Generating Stations—Computer simulation and mechanical analysis was used to see the effect of the ANSI C50.41-1982 criteria for bus transfer on electrical power generating equipment damage. Some methods of bus transfer result in all external sources of power being removed from auxiliary busses for a short period of time. Electric motor driven equipment will decelerate when all external power sources are removed. The rates of deceleration depend on the inertia of the drives and the synchronizing power. Data on motor-driven equipment, including pumps, fans, compressors, and pulverizers, and where possible their motors, was collected from various manufacturers. Single machine simulations showed that high-inertia fan drives were found to have limitations when transferred at or near the criteria limit. Multimachine simulations indicate that drives can be subjected to more transfer without concern for crack initiation due to torsional fatigue. In most cases, and particularly for high-inertia fan drives, the limiting component of the shaft system is the motor shaft keyway.

Handheld Consumer Electronic Manufacturing Issue—Discoloration was observed on a polished stainless steel part that was being developed for a hand held consumer electronic device. It was found that a lead free solder was used to attach a bracket and that the residual flux containing chloride had attacked the stainless steel substrate.

Marine, Maritime, and Shipping Failure Analysis

Stern Tube Corrosion—Investigated the reasons for a series of stern tube failures on 87-foot boats in a seawater environment. Issues involved the materials selected and inadequate cathodic protection.

Ship Propulsion Boiler Bolt Failures—Socket head bolts holding the surface blowdown valve bonnet to the valve body failed on a ship operated by the Military Sealift Command (MSC). I investigated the boiler water chemistries that had been used over the years. The first boiler water chemistry used was a coordinated phosphate program. This was changed to a continuous chelant treatment comprised of EDTA-hydrazine-phosphate. The boiler water treatment was then changed to a catalyzed hydrazine, disodium phosphate, and sodium hydroxide treatment. Fractography of the bolt fracture surfaces clearly showed that the fracture surface was almost entirely intergranular indicating caustic stress corrosion cracking was the reason for the failure. This failure mode was consistent with some of the prior water chemistries used (particularly the ones with high Na/PO₄ ratios) since when they concentrate can cause concentrated sodium hydroxide solutions to develop.

U.S. Coast Guard Cutter Hull Penetration—A 110-foot patrol boat steel hull is protected by epoxy and anti-fouling paint and an impressed-current cathodic protection (CP) system. Nonetheless, a corrosion hole occurred about eight inches below the waterline. The cathodic protection system was found to be in general working order but the paint in this location had been damaged.

Shipping Container Cargo Crane—Analyzed the reason for cracking observed on a newly build container handling gantry crane. This crane had recently been placed into service at one of the west coast ports. Cracks developed in the box beam structural elements. Investigate the design, methods of manufacture, and operating history to determine the reason for the cracking.

Fracture of Navy Ship Welds—The Navy's certification of HSLA-80 (ASTM A710 Grade A Class 3) for use in surface ship hull construction occurred in February 1984 and provided shipbuilders with their first new steel since the mid 1950s. This steel has been used as a replacement for martensitic HY-80 steel in the construction of U.S. Navy ships beginning with cruisers of the Ticonderoga class and the low carbon content of HSLA-80 makes it much less sensitive to hydrogen-assisted HAZ cracking, and therefore it is able to be welded without the expensive preheat and process controls required for HY-80. Research conducted at David Taylor Research Center (DTRC) on HSLA 80 base plate and HAZ microstructures and mechanical properties after the certification-program had been completed showed that the fracture properties of certain small grain-coarsened regions of the HAZ were much lower than those of the base plate material and raised the issue of whether these locally brittle zones could significantly increase the probability of fracture of welded plates. A probabilistic fracture mechanics (PFM) analysis was performed to quantify the influence of LBZs on the reliability of weldments in HSLA80 taking into account the considerable variability in LBZ location, size, and toughness and the wide variability in frequency and size of as-manufactured welding flaws.

Pretensioned Monel K-500 Propeller Bolts—Powerheads are used by the marine industry to install pretensioned Monel alloy K-500 ship propeller bolts. The Powerhead is manufactured from high strength steel. The LaQue Center for Corrosion Technology corrosion-fatigue tested the Powerhead and bolts in natural seawater. Both the Monel bolts and steel Powerheads were cathodically protected with zinc anodes during the corrosion-fatigue. The Powerhead and bolts were fatigue-cycled till fracture. Our investigation was to determine the location of the fracture origin and the mode of failure.

Identification of Debris on Ship Hull—I investigated debris that was found on an un-painted area of a ship hull docked in brackish water in order to determine if it was of a microbiological origin. Optical and scanning electron microscopy was used, along with EDS, to help characterize this material. No evidence was found that indicated a microbiological origin. The most likely origin of the debris was from the cathodic protection system that resulted in the formation of a calcareous deposit at this location.

Medical Device Investigations

Corrosion Evaluation for Various Implantable Medical Devices—Evaluated a wide range of medical devices and materials, for a wide variety of medical device manufacturers. These efforts have included evaluating the medical device's corrosion resistance and surface finish using long-term potential monitoring, ASTM F 2129 cyclic potentiodynamic testing, nickel ion release (leaching) rates, Auger electron spectroscopy, x-ray photoelectron spectroscopy (XPS), and other techniques. Devices and types of corrosion effects evaluated include:

- Passivated stainless steel stents with and without radiopaque markers such as platinum, tantalum, and gold markers
- Implantable neurostimulator and leads
- Electropolished nitinol (NiTi) coronary stents with and without radiopaque markers.
- Cobalt-chromium (CoCr), Elgiloy, Phynox MP35N, stainless steel, and nitinol stents that are overlapped for fretting and galvanic corrosion
- Nitinol (NiTi) with various organic and inorganic coatings
- Potential for crevice corrosion from markers or delaminated coatings
- Metallic components of mitral and aortic heart valves, both mechanical and tissue.
- Annuloplasty rings
- Various implantable chronic obstructive pulmonary disease (COPD) devices
- Various implantable devices to mitigate sleep apnea
- Evaluation of corrosion-fatigue strength of various implantable devices

Electronic Failure in Implantable Device—Performed a failure analysis, and suggested methods to prevent further such failures, for an electronic medical device that failed during clinical trials. The issue involved stress corrosion cracking of glass and laser sealing.

Accelerated Life Testing for Active Implantable Medical Devices—Helped a medical device manufacturer design a suite of HASL and accelerated life tests to assure reliability of a new design for an electrically active implantable medical device (AIMD). This effort involved considering potential failure modes and suggesting tests to determine acceleration factors for the accelerated life tests (ALTs). Mechanical (fatigue, shock, etc.), electrical, and chemical tests were considered.

Implantable Batteries—Various projects involving the testing and manufacture of different types of lithium batteries used for biomedical applications. Destructive and non-destructive failure analysis of primary lithium-silver vanadium oxide (Li-SVO) ICD batteries that exhibited less than expected life including x-ray computer tomography (CT), open circuit voltage (OCV), complex impedance, and swelling measurements.

Leaking Medical Devices—Helped various implantable medical device manufactures (cardiovascular and neurological) determine the reason for moisture ingress. Helium (He) leak checking, dye penetrant testing, metallography, SEM, microfocus x-ray radiography, x-ray microtomography (micro-CT), and residual gas analysis (RGA) and accelerated life testing have been utilized to solve these problems.

Tracheobronchial Stent Failure—A tracheobronchial stent fractured while implanted. Investigated design and manufacturing issues regarding this stent. The adequacy of accelerated life testing for mechanical fatigue (effect of coughing) and corrosion resistance and submissions to the FDA were reviewed; as were product quality management documents. This stent, manufactured from cobalt-chromium-nickel-molybdenum wire. Allegations of improper heat treatment were considered and dismissed based on micro-hardness measurements. It was determined that this stent had failed as a result of fatigue and the device was found to be free from material or manufacturing defects.

Electronic Control Module for a Medical Procedure—A printed circuit board assembly (PCBA) used in a medical procedure experienced a rapid thermal damage due to an electrical failure. Our analysis was to understand the cause and origin of the failure, the potential risk to patients and medical professionals from fire and smoke inhalation hazards, and provide recommendations to minimize future failures.

Instrumentation and Data Analysis for In-vivo Loading—Instrumented an implantable medical device to collect *in-vivo* biomechanical loading data on a heart repair device for fatigue life analysis of the device.

Failure Analysis of Pacemaker Leads—Investigate the reasons for pacemaker lead failures. Issues included corrosion-fatigue, fretting, how polymer materials were used, manufacturing changes, effects of residual stress, and *in-vivo* loading of the leads.

Failure of Periarticular Screws—Examined the periarticular system including tibial plates and two broken screws with a stereomicroscope and scanning electron microscope (SEM). The subject periarticular screws fractured due to low cycle fatigue crack initiation and growth. The fatigue fracture of the subject screws was due to cyclic *in-vivo* loads that exceeded those for which they were designed.

Safety and Hazard Analysis for Various Medical Devices—I have performed safety and hazard analysis such as failure modes and effects analyses (FMEAs) for various medical devices including fertility control devices, brain stem implants, needle incineration devices, plastic surgery devices, septal defect closure device, hearing aid, and a drug inhaler.

Stress and Fatigue Analysis of Various Implantable Medical Devices—I have performed stress and fatigue analysis of various implantable medical devices. Stress analysis has included estimating the loading conditions from biomechanical and medical literature reviews, measuring the *in-vivo* loads, modeling device and tissue interactions with finite element analysis (FEA). The calculated stresses, or strains, are then compared to fatigue life data generated from accelerated life testing in physiological solutions such as phosphate buffered saline (PBS), bile, Hanks, and Ringers. Devices analyzed include anastomosis fasteners, stents (coronary, iliac, carotid, biliary), abdominal aortic aneurysm (AAA) stent grafts, heart valves, septal defect closure device, vena cava filters, bifurcated stents, COPD devices, transjugular intrahepatic portosystemic shunt (TIPS). The effect of mean stress is accounted for by the modified

Goodman, Gerber, Soderberg, Haigh type of analysis. These results are generally used for PMA submissions to the FDA.

Great Toe implant Failure Analysis—Examined the issues regarding the development metallosis in a Ti-6Al-4V great toe joint implant. Device design, manufacture specifications, and quality control during manufacture were examined.

Failure of Electrical Circuit in Defibrillator—Helped a defibrillator manufacturer understand the reasons for a small number of circuit failures that were observed during manufacture.

Intra-aortic Balloon Pump Failure—Examined the reasons for the failure of the balloon used in an intra-aortic balloon pump. The balloon had developed a leak after many days of use. Fatigue, abrasion, and appropriate instructions for use were evaluated.

Laser Cutting of Stents—Evaluated two different laser-cutting processes to cut stents from Nitinol tubing. Metallography and scanning electron microscopy (SEM) were used to characterize the laser cut surfaces.

Broke Dental Needles—Evaluated several dental needle failures. Needles generally work reliably but occasionally fine gauge needles will break in use. Needle breakage in the oral cavity after local anesthesia is a common complication with possible serious complications. In the majority of cases needle fracture happened during inferior alveolar nerve block. It is generally considered to occur as a result of improper technique or the use of too thin a needle. Analysis of the fracture surface of the needle can provide evidence for the presence or absence of material or manufacturing defects.

Professional Affiliations

Surface Mount Technology Association (SMTA); The Wire Association International (member); American Water Works Association (member); American Society for Testing and Materials, Committee on Medical and Surgical Materials and Devices (member); American Society for Metals (member); American Institute of Mining and Metallurgical Engineers (member); National Association of Corrosion Engineers (member)