**Paul E. Cantonwine, Ph.D.**

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I have 20+ years of cradle-to-grave experience in nuclear fuels. In my career, I have provided both technical and managerial leadership to develop, license and implement new BWR and PWR fuel technology (including a new BWR fuel channel material, a new lower tie plate filter, and a new cladding coating technology), evaluate fuel performance under dry storage conditions, receive NRC approval to transport new fuel technology, respond to customer concerns regarding fuel performance, and develop and implement process improvements and solutions for quality excursions in manufacturing nuclear fuel. I also have extensive experience in project management of technical work.  I am currently doing research on the disposition of used nuclear fuel at Oak Ridge National Laboratory. In 2013, I published a collection of Admiral Rickover’s essays in the ANS book “The Never-Ending Challenge of Engineering: Admiral H.G. Rickover in His Own Words,” which gave me insights into how many of the approaches Rickover took in developing nuclear power technology for the Navy are still relevant today.

**Education:**

**Ph.D. Materials Science and Engineering,** University of Virginia, Charlottesville, VA (1999)

**M.S. Materials Science and Engineering,** University of Virginia, Charlottesville, VA (1993)

**B.S. Metallurgical Engineering**, Purdue University, West Lafayette, IN (1990)

**Experience:**

**Distinguished R&D Staff Member,** Used Fuel & Nuclear Material Disposition, Oak Ridge National Laboratory (7/21 – Present)

Responsible for providing technical leadership in areas of nuclear fuel testing and fuel performance modeling for dry storage, transportation and geological repository conditions.

**Principal Engineer, Fuel Performance,** GE, Wilmington, NC (11/19 – 7/21)

Responsible for providing technical leadership for performance of BWR fuel with a focus on the thermal-mechanical performance during normal operation, anticipated operational occurrences, design basis accidents and storage after discharge. As part of the accident tolerant fuel program within GNF, I am directing the technical work supporting a licensing topical report to extend exposures beyond current limits. Additional activities include a fuel aging analysis of an Al-U fuel element for a research reactor, dry storage analyses of BWR fuel at high exposure, authoring a licensing compliance report for fuel design and qualification in Canada for BWRX-300, writing proposals for fuel inspections at plant sites, planning fuel design work for a sodium-cooled fast reactor and representing GNF in international collaborative industry programs.

**Manager, Fuel Performance and Design**, GE, Wilmington, NC (3/15 – 11/19)

Responsible for managing a team of engineers that varied in size from 10 to 15 people. The scope of work included the mechanical design of fuel components for both BWR and PWR fuel assemblies, the performance of those components during in-reactor operations and dry storage conditions, and development of new nuclear fuel technology. In addition, the Fuel Performance and Design (FP&D) group is responsible for working with supplier quality to help ensure vendors are meeting component specifications, working with manufacturing and quality on continuous improvement projects and quality excursions, and working directly with business functions to support customers.

Some key accomplishments of the FP&D team under my leaderships: (1) completed the GNF3 new fuel assembly design, (2) developed the Defender PLUS lower tie plate filter, which was completed in one year from conception to delivery to the customer (likely the fastest technology development program in GNF history), (3) developed the ARMOR coating for zirconium-alloy cladding that is resistant to fret failures and improves oxidation resistance (development included insertion of ARMOR lead test assemblies in 2018), (4) submitted and received NRC approval of the PRIME transient methodology, (5) completed all mechanical design, material evaluations, and fuel rod performance evaluations of the TVS-K PWR fuel assembly supporting the delivery of a Technical Evaluation Report (TER) to a customer supporting insertions of Lead Test Assemblies into a US PWR plant; this included updating the PRIME thermal-mechanical code to enable application to PWR fuel rods, and (6) hired and trained 8 new engineers.

**Technical Leader, Fuel Performance and Design**, GE, Wilmington, NC (3/14 – 3/15)

Responsible for leading a group of materials and thermal-mechanical experts. Scope of work included both manufacturing and performance of components made of zirconium alloys, nuclear fuel, and fuel rod performance in-reactor and during dry storage. Provided technical guidance to the team and communications of work status to upper management. Mentored less experience engineers.

**Senior Engineer, Fuel Performance and Design**, GE, Wilmington, NC (1/11 – 3/14)

Responsible engineer for BWR fuel channel performance, which includes performance models, interacting with nuclear design groups, providing status updates to management and customers, and providing customer support on channel issues.

Led a cross-functional team to introduce a new channel material called NSF that is resistant to in-reactor stress-free distortion and develop a lean channel manufacturing process. Responsibilities included being the primary author of the licensing topical report for NSF channels that requested and received NRC approval for full-reload applications.

Mentored less experiences engineers

An expert in the performance of zirconium alloys prior-to, during and post in-reactor use.

**Lead Engineer, Fuel Performance and Design**, GE, Wilmington, NC (9/06 – 1/11)

Responsible for BWR fuel channel performance, which includes performance models, interacting with nuclear design groups, providing status updates to management and customers, and providing customer support on channel issues.

Provided technical justifications for dry storage of normal and potentially damaged Boiling Water Reactor fuel bundles.

**Senior Engineer,** Bettis Atomic Power Laboratory, West Mifflin, PA (8/99-9/06)

Developed performance limits for reactor materials and components using statistical correlation methods. This required a thorough understanding of the governing physical phenomenon (i.e., irradiation effects, hydrogen effects, etc.), knowledge of applying laboratory tests to component applications, and a clear understanding of how the performance limits are used to ensure safe operations and safe shipments of spent nuclear fuel

Used finite element models to simulate performance of reactor materials and components during both in-reactor use and after shutdown.

Evaluated materials response under several hypothetical design events to define potential configurations for designers to evaluate.

Received approval for a proposal to support a modeling, testing and characterization program at Ohio State University. Objective of work was to identify creep mechanism via the TEM to better develop physically based creep models of zirconium alloys that could be used in finite element models. Managed vendor contracts to perform work.

Received approval for a proposal for failure analysis on irradiated zirconium alloys that required work in a hot cell. This work provided new insights into the failure process that enabled failure criteria to be better defined for finite element modeling.

**Graduate Research Assistant**, University of Virginia, Charlottesville, VA (8/94-8/99)

Developed a continuous manufacturing process to infiltrate a 20%-50% loaded Al2O3 slurry into an Al2O3 fiber bundle (or tow) to fabricate a composite fiber. Process could produce hundreds of feet of this composite fiber, which were then coated with a Ni-based alloy via a plasma spray deposition process. This Al2O3/Al2O3 composite fiber was the cornerstone of a larger collaborative effort in developing low-cost high-temperature metal matrix composite materials. The project included approximately ten people working on the manufacture, testing and mechanics modeling of these novel and low-cost metal matrix composites.

After developing the composite fiber technology, I studied the effects of processing on the mechanical properties of this new fiber. I investigated the effects of sintering on mechanical performance. I used fracture mechanics to analyze the effect of processing defects in single filaments, and I extended current composite strength models to account for defects in fiber bundles.

**Visiting Scientist**, 3M Company, St. Paul, MN (8/93-9/94)

Lead engineer in manufacturing an innovative low-cost titanium matric composite using multi-filament Al­2O3 fibers. Processing experience included polymer infiltration into tow fibers, chemical vapor deposition of fiber coatings, physical vapor deposition of matrix coatings, and hot isostatic pressing for composite consolidation. Composite properties were maintained while costs dramatically decreased compared to traditional processing approaches

Performed characterization and testing of fibers and composites; related properties to processing and compared to model predictions

**Other Experience**

**Graduate Research Assistant**, University of Virginia, Charlottesville, VA (8/90-8/93)

**Co-op Engineering Student**, GE Motors, Fort Wayne, IN (8/86-1/89)

**Other Training**

1. Six Sigma Green Belt Certified
2. GE Building Essential Leadership Skills (2009)
3. GE Fundamentals for Technologists (2012)
4. INPO First Line Leadership Seminar (2015)
5. ANT International PWR Technology Seminar (2017)

**Technical Skills and Tool Sets:**

1. **Material Processing**: plasma spray deposition, chemical vapor deposition, physical vapor deposition, vacuum hot-pressing, hot-isostatic pressing (HIP), tape casting, slurry casting, heat treating, sintering; familiar with pilgering, welding, forming, and additive manufacturing
2. **Materials Characterization**: metallography, optical microscopy, scanning electron microscopy, fractography, NDE techniques (e.g., ultrasonic)
3. **Materials Properties**: tensile/compression, creep, single filament and bundle strength, failure by plastic instability, composite interface properties, brittle fracture, permeability
4. **Data Analysis/Modeling Methods**: Stochastic/Monte Carlo, Statistical Correlations of Empirical and Phenomenological Models, Finite Element Analysis
5. **Communication**: PowerPoint
6. **Additional training**: Fluid Flow and Heat Transfer in Nuclear Reactors, project management

**Invited Presentations**

1. “Underway on Nuclear Power: A Retrospective – Panel,” Invited Speaker, “Why Rickover is Still Relevant,” ANS Winter Meeting, Orlando, FL, Nov. 11-15 (2018).
2. “Reactor Physics Challenges in Current LWR Fleet – Panel,” Invited Speaker, “Fuel Performance Issues at Extended Burnup,” ANS Winter Meeting, Washington, D.C., Oct. 29 – Nov. 2 (2017).
3. “New Nuclear Construction Around the World,” Invited Speaker, “Admiral H.G. Rickover: The Never-Ending Challenge of Engineering,” ANS Winter Meeting, Las Vegas, NV, Nov. 6-10 (2016).
4. “Shadow Corrosion-Induced Bow of Zircaloy-2 Channels,” Eastern New York ASM International Chapter’s Symposium hosted by GE Global Research Center in Schenectady, NY, May 18-19 (2010).

**Publications: Books**

1. *The Never-Ending Challenge of Engineering: Admiral H.G. Rickover in His Own Words*, Compiled by Paul E. Cantonwine, American Nuclear Society (2013).

**Publications: Journal/Conference Papers**

1. P. Cantonwine and B. Rand, “Rethinking PCMI Failures under Transient Conditions,” TOPFUEL 2022, Raleigh, NC, ANS, 678-684, Oct. 9-13, 2022.
2. P. Cantonwine, O. Martinez, and R. Montgomery, “The Mechanical Response of High-Burnup 17x17 PWR Fuel Rods under Bending,” TOPFUEL 2022, Raleigh, NC, ANS, 738-746, Oct. 9-13, 2022.
3. P. Cantonwine and B. Rand, “Irradiation Performance: Light Water Reactor Fuels,” Encyclopedia of Nuclear Energy, Volume 2, edited by Ehud Greenspan, Elsevier, 377-391, 2021.
4. R. Schneider, D. Lutz, P. McCumbee, and P. Cantonwine, “GNF Fuel Reliability and Channel Performance: 2019 Update,” Proceedings of Top Fuel 2019, Seattle, Washington, USA, Sept. 22-26, 2019.
5. Y-P. Lin, R. Fawcett, P. Cantonwine, M. Yilmaz, R. Rebak, R. Dunavant, N. Satterlee, S. DeSilva, R. Rand, D. Lutz, P. Davis, “Paths Towards Industrialization of Enhanced Accident Tolerant Fuel,” Proceedings of TOPFUEL 2018, Prague, Czech Republic, Sept. 30-Oct. 4, 2018.
6. P. Cantonwine, R. Schneider, Y-P. Lin, D. Lutz, P. McCumbee, “GNF Fuel Reliability and Channel Performance: 2018 Update,” Proceedings of TOPFUEL 2018, Prague, Czech Republic, Sept. 30-Oct. 4, 2018.
7. P.Cantonwine, D. Lutz, D. White and Y-P. Lin, “The Performance of NSF in BWR Operating Conditions,” *18th Symposium on Zirconium in the Nuclear Industry*, ASTM STP 1597, 909-937, R. Comstock and A. Motta, ASTM International, Hilton Head, South Carolina, USA, May 15-19, 2016.
8. M. Christensen, W. Wolf, C. Freeman, E. Wimmer, R. Adamson, L. Hallstadius, P. Cantonwine and E. Mader, “Understanding Irradiation Growth through Atomistic Simulations: Defect Diffusion and Clustering in α-Zirconium and the Influence of Alloying Elements,” *18th Symposium on Zirconium in the Nuclear Industry*, ASTM STP 1597, 645-675, R. Comstock and A. Motta, ASTM International, Hilton Head, South Carolina, USA, May 15-19, 2016.
9. P. Cantonwine, R. Schneider, R. Dunavant, K. Ledford, and R. Fawcett, “GNF Fuel Performance 2015 Update,” Proceedings of TOPFUEL 2015, Zurich, Switzerland, Sept. 13-17, 2015.
10. D. Lutz, Y-P. Lin, P. Cantonwine, J. Varela, A. Kucuk, and K. Edsinger, “Test Reactor Evaluation of Zirconium Alloy NMCA Corrosion Behavior,” Proceedings of TOPFUEL 2015, Zurich, Switzerland, Sept. 13-17, 2015.
11. D. Lutz, Y-P. Lin, P. Cantonwine, J. Varela, A. Kucuk, K. Edsinger, and M. McGrath, “Test Reactor Evaluation of Zirconium Alloy Shadow Corrosion Behavior,” Proceedings of TOPFUEL 2015, Zurich, Switzerland, Sept. 13-17, 2015.
12. M. Christensen, W. Wolf, C. Freeman, E. Wimmer, R.B. Adamson, L. Hallstadius, P.E. Cantonwine, E.V. Mader, “Diffusion of point defects, nucleation of dislocation loops, and effect of hydrogen in hcp-Zr: Ab initio and classical simulations,” J. Nucl. Mater., Vol. 460, pp. 82-96, 2015
13. P. Cantonwine, R. Schneider and B. Hunt, “Global Nuclear Fuel Launches GNF3 and NSF: The Most Reliable BWR Fuel Just Got Better,” Nuclear España, April, 2015
14. M. Kinoshita, Y. Iwamoto, K. Ledford, and P. Cantonwine, “Finite element analysis of BWR fuel channel buckling during a seismic event,” Proceedings of WRFPM 2014, Sendai, Japan, Sept. 14-17, 2014.
15. M. Christensen, W. Wolf, C.M. Freeman, E. Wimmer, R.B. Adamson, L. Hallstadius, P.E. Cantonwine and E.V. Mader, “H in alpha-Zr and in zirconium hydrides: solubility, effect on dimensional changes, and the role of defects,” J. Phys.: Condens. Matter 27 (2015) 025402.
16. M. Christensen, W. Wolf, C.M. Freeman, E. Wimmer, R.B. Adamson, L. Hallstadius, P.E. Cantonwine and E.V. Mader. “Effect of alloying elements on the properties of Zr and the Zr-H system,” Journal of Nuclear Materials 445 (2014) 241-250.
17. M. Christensen, W. Wolf, C.M. Freeman, E. Wimmer, R.B. Adamson, L. Hallstadius, P.E. Cantonwine and E.V. Mader, “Effect of Hydrogen on Dimensional Changes of Zirconium and the Influence of Alloying Elements: First-Principles and Classical Simulations of Point Defects, Dislocation Loops, and Hydrides,” *17th Symposium on Zirconium in the Nuclear Industry*, ASTM STP 1543, R.J. Comstock and P. Barbéris, Eds., ASTM International, Hyderabad, Andhra Pradesh, India February 03–07, 2013.
18. Cantonwine, P. et al., “BWR Corrosion Performance of NSF Channels,” Proceedings from TopFuel 2013 International Meeting on LWR Fuel Performance, Charlotte, NC, American Nuclear Society (2013).
19. Dunavant, R., Lutz, D. and Cantonwine, P. “Performance Considerations for Used BWR Fuel in Dry Storage and Transportation,” *TopFuel 2013 International Meeting on LWR Fuel Performance*, Charlotte, NC, American Nuclear Society (2013).
20. Karve, A., Cantonwine, P. et al., “Plant Statistics with Updated CFM and NSF Channels in Reload Cores,” *TopFuel 2013 International Meeting on LWR Fuel Performance*, Charlotte, NC, American Nuclear Society (2013).
21. Cantonwine, P. et al., “Performance of an Updated Cell Friction Methodology For Mitigating Channel – Control Blade Interference,” *TopFuel 2012 International Meeting on LWR Fuel Performance*, Manchester, England, European Nuclear Society (2012).
22. Yueh, K, Cantonwine, P., et al., “Silicon Carbide Composite for BWR Channel Application,” *TopFuel 2012 International Meeting on LWR Fuel Performance*, Manchester, England, European Nuclear Society (2012).
23. Mader, E., Cantonwine, P., et al. “EPRI BWR Channel Distortion Program,” *2011 Water Reactor Fuel Performance Meeting*, Chengdu, China, September (2011).
24. Mahmood, S., Cantonwine, P., et al. “Shadow Corrosion-Induced Bow of Zircaloy-2 Channels,” *16th International Symposium on Zirconium in the Nuclear Industry*, ASTM STP 1529, 954-989, P. Barbéris and M. Limbäck, Chengdu, China, May9-13, 2010.
25. Cantonwine, P., et al. “Channel – Control Blade Interference in GE Boiling Water Reactor, D-Lattice Plants with Zircaloy-2 Channels,” *Proc. Of LWR Fuel Performance/TopFuel/WRFPM*, Paper 079, Orlando, Florida, USA, September (2010)
26. Ledford, K., Cantonwine, P., et al., “GNF Defense in Depth 2009 Update,” *Proc. Of LWR Fuel Performance/TopFuel/WRFPM*, Paper 106, Orlando, Florida, USA, September (2010)
27. Cantonwine, P., et al. “ Channel – Control Blade Interference Management at LaSalle 1 and 2 during 2007 and 2008,” *Proc. Of Top Fuel 2009*, Paper 2154, Paris, France, September (2009)
28. Lingenfelter, A., Cantonwine, P., et al., “GNF Defense in Depth 2009 Update,” *Proc. Of Top Fuel 2009*, Paper 2124, Paris, France, September (2009)
29. Cantonwine, P., A.A. Karve, Y.P. Lin, S.T. Mahmood, D.W. White, and D. C. Crawford, “GNF Channel Performance and Success in Mitigating Channel Distortion and Cell Friction,” *Proc. of the 2008 Water Reactor Fuel Performance Meeting*, Paper 8078, Secretariat for the WRFPM2008, Seoul, Korea (2008).
30. Moon, J., Cantonwine, P. E., Anderson, K.R., Karthikeyan, S. and Mills, M, *Characterization and Modeling of Thermal Creep in Zircaloy-4*, *J. Nucl. Mater*., Vol. 353, 3, pp. 177-189, July (2006)
31. Cantonwine, P. E., *Educating Materials Engineers, Advanced Materials and Processing*, ASM International, March (2006)
32. Brady, V., Cantonwine, P., and Kvidahl, L., *Contemplating What Makes a Good Materials Engineer*, Proceedings of Symposium on What Makes a Good Materials Engineer and How Best to Educate Them, MS&T2005, TMS/ASM (2005)
33. Cantonwine, P. E., *Strength of Thermally Exposed Alumina Fibers: Part I Single Filament Behavior, J. Mater. Sci.* 38, pp. 461-470 (2003)
34. Cantonwine, P. E., *Strength of Thermally Exposed Alumina Fibers: Part II Bundle Behavior, J. Mater. Sci.* 38, pp. 471-480 (2003)
35. Cantonwine, P. E. and Wadley, H. N. G., in Advanced Ceramic-Matrix Composites IV, Proceedings from The American Ceramic Society Annual Meeting, p. 51 (1999)
36. Cantonwine, Paul and Deve, Herve, *Longitudinal Stress/Strain Response of Al2O3/Ti 6Al 4V Continuous Fiber Composites*, Recent Advances in Titanium Metal Matrix Composites, edited by F.H. Froes and J. Storer, The Minerals, Metals and Materials Society, pp. 201-212, (1995)
37. Cantonwine, Paul and Wadley, Haydn N.G., *The Effect of Fiber-Matrix Reactions on the Interface Properties in a SCS-6/Ti-24Al-11Nb Composite*, Composites Engineering, Vol. 4, No. 1 pp. 67-80 (1994)

### Awards:

Virginia Space Grant Fellow: 1996-1997

2012 NEI Top Industry Practice Award for BWR Fuel Channel Distortion Mitigation

2013 GNF Engineering Award: Outstanding Innovation

2016 NEI Top Innovative Practice Award for NSF Channel Introduction at Grand Gulf Nuclear Station

2016 John H. Schemel Best Paper Award for “Effect of hydrogen on dimensional changes of zirconium and the influence of alloying elements: first-principles and classical simulations of point defects, dislocation loops, and hydrides,” from *17th Symposium on Zirconium in the Nuclear Industry*, ASTM STP 1543, R.J. Comstock and P. Barbéris, Eds., ASTM International.

2017 NEI Top Innovative Practice Award for GNF2.02 Introduction at River Bend Station

### Patents

1. US 8,208,597, “Channel Confinement System and Method for Dry-Storage of BWR Fuel Bundles,” Granted June 26, 2012.
2. US 8,385,497, “Channel Confinement Method for Dry-Storage of BWR Fuel Bundles,” Granted February 26, 2012.
3. US 9,287,012, “Optimized Fuel Assembly Channels and Methods of Creating the Same,” Granted March 15, 2016.
4. US 9,564,249, “Spacers for Nuclear Fuel Assemblies,” Granted February 7, 2017.
5. US 9,646,722, “Method and Apparatus for a Fret Resistant Fuel Rod for a Light Water Reactor (LWR) Nuclear Fuel Bundle,” Granted May 9, 2017.
6. US 9,911,511, “Fuel Rods with Wear-Inhibiting Coatings and Methods of Making the Same,” Granted March 6, 2018.
7. US Application 20090285350, “Multi-Layer Fuel Channel and Method of Fabricating the Same,” Applied November 19, 2009.
8. US Application 20160099083, “Fast Flux Shield and Method of Reducing Fast Neutron Fluence at a Core Shroud of a Boiling Water Reactor Using the Same,” Applied April 7, 2016.

### Professional:

*American Nuclear Society (2011 – Present)*

*ASM International*: (1989-Present), Member Nuclear Materials Committee, Student Chapter President (1995)

*American Society of Ceramics*: (1999-2001)

*AFOSR:* Panel member reviewing Air Force Office of Scientific Research (AFOSR) mechanics grant proposals (2004)