

12th International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies (NPIC & HMIT 2021)

Embedded with the 2021 ANS Virtual Annual Meeting

Online

14 – 17 June 2021

Volume 1 of 2

ISBN: 978-1-7138-4092-3

Printed from e-media with permission by:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571



Some format issues inherent in the e-media version may also appear in this print version.

Copyright© (2021) by American Nuclear Society
All rights reserved.

Printed with permission by Curran Associates, Inc. (2022)

For permission requests, please contact American Nuclear Society
at the address below.

American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60526
USA

Phone: (800) 323-3044
(708) 352-6611
Fax: (708) 352-0499

www.ans.org

Additional copies of this publication are available from:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2633
Email: curran@proceedings.com
Web: www.proceedings.com

Proceedings of the 12th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC&HMIT 2021)

Embedded with the 2021 ANS Virtual Annual Meeting

June 14–17, 2021

General Chair: Pradeep Ramuhalli (Scientist, ORNL)

Program Chair: Jamie Coble (Assistant Professor, University of Tennessee Knoxville)

1 12th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC&HMIT 2021) Plenary

3 Human Factors

5 Advances in Control Room Design

7 A Microworld Framework for Advanced Control Room Design—*Ronald L. Boring (INL), Thomas A. Ulrich (INL), Roger Lew (Univ. of Idaho), Anna C. Hall (Braveheart Solutions)*

15 User-Centered Scalability: Creating Cross-System Visualizations for Nuclear Power Applications—*Torrey Mortenson (INL)*

25 Operator Preferences in an Advanced Nuclear Control Operating Room—*Clara Alivisatos (Univ. of California Berkeley), Christopher Poresky (Univ. of California Berkeley), Per F. Peterson (Univ. of California Berkeley), Ronald L. Boring (INL), Thomas A. Ulrich (INL)*

36 Systems-Theoretic Hazard Analysis of Digital Human-System Interface Relevant to Reactor Trip—*Edward Chen (North Carolina State Univ.), Nam T. Dinh (North Carolina State Univ.), Han Bao (INL), Hongbin Zhang (INL), Tate Shorthill (Univ. of Pittsburgh)*

52 Guiding Transformation: The Role of a Design Philosophy—*Zachary A. Spielman (INL), Casey Kovesdi (INL), Katya LeBlanc (INL)*

63 General Topics in Human Factors and Human-Machine Interface

64 Xe-100 SMR Main Control Room Staffing: Analysis and Validation—*Héctor Martínez-Pinna (Tecnatom), Luis Rejas (Tecnatom)*

72 Human Factors Validation of Fire Related Events—*Nuria Bernal (Tecnatom), Luis Rejas (Tecnatom)*

- 79 Augmenting Field Operator Training Through Virtual Reality—*Hanna Koskinen (VTT Technical Research Centre of Finland), Jari Laarni (VTT Technical Research Centre of Finland), Marja Liinasuo (VTT Technical Research Centre of Finland), Tuisku-Tuuli Salonen (VTT Technical Research Centre of Finland), Satu Pakarinen (Finnish Institute of Occupational Health), Kristian Lukander (Finnish Institute of Occupational Health), Tomi Passi (Finnish Institute of Occupational Health)*
- 89 Cognitive Aging as a Human Factor: Age of Operator on Human Performance in the Nuclear Control Room—*Anna C. Hall (Braveheart Solutions), Ronald L. Boring (INL), Tina M. Miyake (INL)*
- 103 Managing Skill Fading and Maintenance for Critical Tasks—*Chris Ste-Croix (HumanSystems), Andrew Morton (HumanSystems), Harold Angel (HumanSystems)*
- 113 Enabling VERA Software Support for Reactor Diagnostics and Aging Management**
- 114 Modernization Strategies for the Main Control Room**
- 115 Panel Discussion on I&C and Human Factors Standards**
- 116 Real-Time Demonstration of the NuScale Control Room Simulator**
- 117 Advances in Human Factors and Human-Automation**
- 118 Human-Factors Engineering Enhancement Integrated with Human Reliability Analysis for Control Room Design of Nuclear Power Plant—*Kenji Mashio (Mitsubishi Heavy Industries, Ltd.)*
- 129 Using Artificial Intelligence to Mitigate Human Factor Errors in Nuclear Power Plants: A Review—*Meenu Sethu (San Jose State Univ.), Nesar Ahmed Titu (Univ. of Tennessee, Knoxville), Dingyu Hu (San Jose State Univ.), Mahboubeh Madadi (San Jose State Univ.), Jamie Baalis Coble (Univ. of Tennessee, Knoxville), Ronald L. Boring (INL), Klaus Blache (Univ. of Tennessee, Knoxville), Vivek Agarwal (INL), Vaibhav Yadav (INL), Anahita Khojandi (Univ. of Tennessee, Knoxville)*
- 142 MEDIC—Approach for the Evaluation of Technological Preventive Measures Against Erroneous Personnel Actions at Human Machine Interfaces of Digital I&C Systems—*Hervé Mbonjo (Gesellschaft für Anlagen- und Reaktorsicherheit), Patrick Gebhardt (Gesellschaft für Anlagen- und Reaktorsicherheit)*
- 152 Human-Automation Collaboration Concerning Task Information Presentation System (TIPS)—*R. Hill (INL), J. Oxstrand (INL)*
- 161 Latest Trends in Human Factors**
- 162 Addressing Human and Organizational Factors in Nuclear Industry Modernization: A Sociotechnically-Based Strategic Framework—*Marvin J. Dainoff (Marvin J. Dainoff, LLC), Lawrence Hettinger (Lawrence Hettinger, LLC), Lewis Hanes (Consultant), Jeffrey C. Joe (INL)*
- 171 The Xe-100 Human Factors Engineering Licensing Roadmap—*Borja Hervás (Tecnatom), Luis Rejas (Tecnatom)*
- 179 Key Constructs for Reasonable Confidence in System Validation Programs—*Robert B. Fuld (Consultant), Jeffrey C. Joe (INL), Ryan S. Flamand (NuScale Power)*
- 188 A Methodology to Support the Development of a New State Vision for the United States Nuclear Industry—*C. Kovesdi (INL), Z. Spielman (INL), R. Hill (INL), T. Miyake (INL), J. Mohon (INL)*
- 198 Qualified Display System (QDS): A Safety Class 1 HMI for Monitoring and Controlling Safety Nuclear I&C Systems—*Stéphane Nouketchessi Simo (Framatome), Mathieu Allory (Framatome)*
- 209 Instrumentation and Controls**
- 211 Data Analytics, Machine Learning, and Artificial Intelligence - I**
- 212 Automated Image Stitching of Down Channel Nuclear Reactor Fuel Channel Inspection Footage—*Michael Devereux (Univ. of Strathclyde), Paul Murray (Univ. of Strathclyde), Graeme West (Univ. of Strathclyde)*
- 222 An Innovative Crack Detection Algorithm to Support Automated Inspection of Nuclear Reactor Cores—*Efstathios Branikas (Univ. of Strathclyde), Paul Murray (Univ. of Strathclyde), Graeme West (Univ. of Strathclyde)*
- 232 Machine Learning of Flash Thermography Images for Detection of Early Stage Fatigue in Martensitic Steel—*Xin Zhang (Illinois Institute of Technology), Jafar Saniie (Illinois Institute of Technology), Thiago Seuaciuc-Osorio (Electric Power Research Institute), Sasan Bakhtiari (ANL), Alexander Heifetz (ANL)*
- 239 Gaussian Process Ensemble for Corrosion Modeling and Prediction in Molten Salt Reactors—*Elizabeth Sooby (Univ. of Texas San Antonio), Miltiadis Alamaniotis (Univ. of Texas at San Antonio), Alexander Heifetz (ANL)*
- 251 Automated Generation of Training Dataset for Crack Detection in Nuclear Power Plant Components—*Zhouxiang Fei (Univ. of Strathclyde), Graeme M. West (Univ. of Strathclyde), Paul Murray (Univ. of Strathclyde), Gordon Dobie (Univ. of Strathclyde)*

259 Data Analytics, Machine Learning, and Artificial Intelligence - II

260 Semi-Automated Knowledge Capture and Representation for the Development of Knowledge Based Systems—*A. Young (Univ. of Strathclyde), G. West (Univ. of Strathclyde), B. Brown (Univ. of Strathclyde), B. Stephen (Univ. of Strathclyde), A. Duncan (The Alan Turing Institute), C. Michie (Univ. of Strathclyde), S. McArthur (Univ. of Strathclyde)*

272 Trusting Machine Learning in Nuclear Plant Control: A Reasoning-Based Discrepancy Checker—*Botros N. Hanna (New Mexico State Univ.), Linyu Lin (North Carolina State Univ.), Paridhi Athe (North Carolina State Univ.), Tran C. Son (New Mexico State Univ.), Nam T. Dinh (North Carolina State Univ.)*

285 Introduction of Analytics, Decision-Support, and Advanced Procedure Tool (ADAPT) and the Cultural Implications it Poses to the Nuclear Industry—*R. Hill (INL), C. Kovacs (INL), Z. Spielman (INL), J. Mohon (INL), T. Miyake (INL), K. Le Blanc (INL)*

293 Data Analytics, Machine Learning, and Artificial Intelligence - III

294 Detecting Fire with Machine Learning-Enabled Visual Monitoring for Nuclear Power Plant Environments—*L. Michael Griffel (INL), Brian Wilcken (INL), Ahmad Al Rashdan (INL), Roger Boza (INL)*

304 Sensor Degradation Detection Using Visual Timeseries and Deep Convolutional Neural Networks—*C. J. Wallace (Univ. of Strathclyde), S. D. J. McArthur (Univ. of Strathclyde)*

313 Monitoring of Thermal Mixing Tee Sensors with LSTM Neural Networks—*Victoria Ankel (ANL), Stella Pantopoulou (ANL), Matthew Weathered (ANL), Darius Lisowski (ANL), Anthonie Cilliers (Kairos Power), Alexander Heifetz (ANL)*

324 Object Detection in a Framework for Automated Nuclear Waste Classification—*Seonaid Hume (Univ. of Strathclyde), Gordon Dobie (Univ. of Strathclyde), Graeme West (Univ. of Strathclyde)*

335 Autonomous Control and Operation

336 Development of an In-Pile Facility to Demonstrate Autonomous Control of a Subcritical System—*Jarod Wilson (MIT), Jiankai Yu (MIT), Bren Phillips (MIT), Akshay J. Dave (MIT)*

346 Development of a Virtual System in Support of Demonstrating Autonomous Control of a Subcritical Facility—*Jiankai Yu (MIT), Jarod C. Wilson (MIT), Bren A. Phillips (MIT), Akshay J. Dave (MIT)*

355 Developments in Online Monitoring Technologies for Autonomous Microreactor Operations—*A. H. Hashemian (AMS), B. D. Shumaker (AMS), T. S. Gavin (AMS), R. A. Kettle (AMS), W. H. Ferrell (AMS)*

365 Route Operable Unmanned Navigation of Drones (ROUNDS)—*Ahmad Al Rashdan (INL), L. Mike Griffel (INL), Roger Boza (INL)*

372 Leveraging Distributed Control Systems to Achieve Greater Functionality in Nuclear Power Plants—*Joey Carman (Enercon Services), Cory Carmin (Enercon Services)*

379 Advanced Sensors and Measurement Technologies

380 A JFET-Based Radiation-Hardened Sensing and Communications Electronic System for Dry Cask Instrumentation—*F. Kyle Reed (ORNL), M. Nance Ericson (ORNL), N. Dianne Bull Ezell (ORNL), Roger Kisner (ORNL), Lei Zuo (Virginia Polytechnic Univ.), Haifeng Zhang (Univ. of North Texas)*

388 Non-Invasive Internal Monitoring of Dry Cask Storage Systems—*Ryan M. Meyer (Pacific Northwest National Laboratory), Morris S. Good (Pacific Northwest National Laboratory), Ericka L. Fors (Pacific Northwest National Laboratory), Christopher A. Hutchinson (Pacific Northwest National Laboratory), Francesco Luzi (Pacific Northwest National Laboratory), Samuel W. Glass (Pacific Northwest National Laboratory)*

398 Development of Ultrasonic Densimeter and Viscometer for Fluid Characterization—*Hongbin Sun (ORNL), Ryan C. Gallagher (ORNL), Vivek Rathod (ORNL), Pradeep Ramuhalli (ORNL)*

406 Effect of ZrO₂ Thin-Film Coatings on the Corrosion Resistance of AlN Piezoelectric Single Crystal Sensors—*Sean Kerrigan (NC State Univ.), Mohamed Bourham (NC State Univ.), Howuk Kim (NC State Univ.), Xiaoning Jiang (NC State Univ.)*

416 Ultrasonically Embedded Sensors for Microreactor Health Monitoring—*Christian M. Petrie (ORNL), N. Dianne B. Ezell (ORNL)*

425 Digital Twins

426 Validation of VERA Software for Nuclear Power Plant Life Extension Applications—*J. R. Houser (Analysis and Measurement Services Corp.), S. N. Tyler (Analysis and Measurement Services Corp.), T. J. Cole (Analysis and Measurement Services Corp.), W. H. Ferrell (Analysis and Measurement Services Corp.)*

437 A Recursive Data-Driven Approach to State Variable Selection and Digital Twin Derivation—*Haoyu Wang (ANL), Roberto Ponciroli (ANL), Richard B. Vilim (ANL), Andrea Alfonsi (INL), Cristian Rabiti (INL)*

447 Use of the Extended Kalman Filter for Cybersecurity Assessment in a Closed-Loop Digital Twin Testbed—*R. Busquim e Silva (IAEA), J. R. C. Piqueira (Univ. of Sao Paulo), R. P. Marques (Univ. of Sao Paolo)*

457 Explainable and Trustworthy Diagnostics Achievable Through Process-Based Automated Reasoning—*R. Vilim (ANL), T. Nguyen (ANL), R. Ponciroli (ANL)*

467 Latest Trends in Digital Instrumentation and Controls

- 468 Health Monitoring of Digital I&C Systems Using Online Electronic Measurements—*B. D. Shumaker (Analysis and Measurement Services Corp.), C. J. Kiger (Analysis and Measurement Services Corp.), D. E. McCarter (Analysis and Measurement Services Corp.)*
- 478 Applying Single Failure Criteria to Digital I&C Systems—*Richard J. Stattel (U.S. Nuclear Regulatory Commission)*
- 486 New Licensing Process for Major Nuclear Digital Safety System Upgrades—*Samir Darbali (U.S. Nuclear Regulatory Commission)*
- 496 SymPLe: A Complexity-Aware Approach for Realizing Verifiable FPGA-Based Digital I&C for Safety Critical Applications—*Richard Hite (Virginia Commonwealth Univ.), Christopher Deloglos (Virginia Commonwealth Univ.), Athira Jayakumar (Virginia Commonwealth Univ.), Smitha Gautham (Virginia Commonwealth Univ.), Aidan Collins (Virginia Commonwealth Univ.), Abhi Rajagopala (Virginia Commonwealth Univ.), Carl Elks (Virginia Commonwealth Univ.), Matt Gibson (Electric Power Research Institute)*

509 Advances in Sensors and Sensor Characterization

- 510 Dynamic Response Characterization of Temperature Sensors for Small Modular Reactors—*A. H. Hashemian (AMS Corporation), E. T. Riggsbee (Analysis and Measurement Services Corporation), S. N. Tyler (Analysis and Measurement Services Corporation), B. Arnholt (NuScale Power), N. Cetiner (Oak Ridge National Laboratory)*
- 520 Development and Testing of High Temperature Fiber Optic Sensors for Measurement of Heat Pipe Temperature in the eVinci,™ Micro Reactor—*Thomas Tweedle (Westinghouse Electric Co.), Yuqi Li (Univ. of Pittsburgh), Kevin Chen (Univ. of Pittsburgh)*
- 526 Microwave Resonant Cavity-Based Flow Sensor for Advanced Reactor High Temperature Fluids—*Alexander Heifetz (ANL), Victoria Ankel (ANL), Dmitry Shribak (ANL), Sasan Bakhtiari (ANL), Anthonie Cilliers (Kairos Power)*
- 534 Design, Fabrication, Installation and Operation of the In-Core Instrumentation for EPR Reactors—*Patrick Weidenauer (Framatome), Heiko Jasper (Framatome)*
- 544 The Transient Thermal Response of a Pressure-Driven Fabry-Pérot Cavity—*Daniel C. Sweeney (ORNL), Adrian M. Schrell (ORNL), Christian M. Petrie (ORNL)*

555 In-Pile Instrumentation

- 556 Radiation-Hard Electronics for Nuclear Instrumentation in Terrestrial Reactors—*N. Dianne Bull Ezell (ORNL), F. Kyle Reed (ORNL), M. Nance Ericson (ORNL)*

- 564 In-Core Neutron Flux, Temperature, and Pressure Instrumentation for the WIRE-21 Experiment in the High Flux Isotope Reactor—*Padhraic L. Mulligan (ORNL), N. Dianne B. Ezell (ORNL), Kurt Smith (ORNL), Kara Godsey (ORNL), Daniel C. Sweeney (ORNL), Christian M. Petrie (ORNL), Jorge Carvajal (Westinghouse Electric Co.), Shawn Stafford (Westinghouse Electric Co.), Jeff Arndt (Westinghouse Electric Co.)*
- 575 Magnetostrictive Ultrasonic Waveguide Transducer for In-Pile Thermometry—*Shane Palmer (Boise State Univ.), Alex Draper (Boise State Univ.), Zhangxian Deng (Boise State Univ.)*
- 585 A First Principle Look at the Electromotive Force Generation from Molybdenum and Niobium Alloys—*Richard Skifton (INL)*
- 592 Irradiation Characterization of Pressure Transducers—*Dan C. Floyd (Univ. of Tennessee, Knoxville), Richard T. Wood (Univ. of Tennessee, Knoxville), N. Dianne B. Ezell (ORNL)*

601 Electromagnetic Compatibility and Wireless Technology

- 602 Methods for Automating Electromagnetic Compatibility Testing—*G. W. Morton (Analysis and Measurement Services Corp.), B. D. Shumaker (Analysis and Measurement Services Corp.), D. E. McCarter (Analysis and Measurement Services Corp.)*
- 613 Introduction to the Electromagnetic Pulse Issue in the Nuclear Power Industry—*Richard Supler (Enercon Services), John Livingston (Enercon Services), Connor Armstrong (Enercon Services), Omran Samadi (Enercon Services)*
- 626 Securing Wireless Technologies in Nuclear Facilities—*Kurt W. Derr (INL), Christopher D. Becker (INL)*
- 639 Perspectives on Secure Communications with Advanced Reactors: Ultrasonic and Millimeter Waves Classical and Quantum Communications—*Alexander Heifetz (ANL), Madeleine Roberts (ANL), Sasan Bakhtiari (ANL), Derek Kultgen (ANL), Xin Hunag (Illinois Institute of Technology), Jafar Sanii (Illinois Institute of Technology), Miltiadis Alamaniotis (Univ. of Texas at San Antonio)*
- 649 Electromagnetic Interference and Material Degradation Concerns with Ultraviolet Germicidal Irradiation in Nuclear Power Plant Control Rooms—*C. J. Kiger (Analysis and Measurement Services Corp.), A. H. Hashemian (Analysis and Measurement Services Corp.), T. A. Toll (Analysis and Measurement Services Corp.), K. M. Ryan (Analysis and Measurement Services Corp.), S. M. Lopez (EPRI)*

659 Productivity/Efficiency Improvement

- 660 Nuclear Power Fault Diagnostics and Preventative Maintenance Optimization—*Cody Walker (INL), Vivek Agarwal (INL), Nancy Lybeck (INL), Pradeep Ramuhalli (ORNL), Mike Taylor (EPRI)*

- 670 Exelon-Fitzpatrick Nuclear Power Plant Risk-Informed Surveillance Frequency Control Program for Instrumentation and Control Systems—*Karim Habayeb (James A. Fitzpatrick NPP), Jeremy Torrez (James A. Fitzpatrick NPP), Andrew Bratek (James A. Fitzpatrick NPP), David Poulin (James A. Fitzpatrick NPP), Anthony Yost (James A. Fitzpatrick NPP), Edward L. (Ted) Quinn (Technology Resources)*
- 680 Approach to Crediting Self-Diagnostic Features of Digital Instrumentation & Control to Achieve Technical Specifications Surveillance Test Interval Extension—*Garill Coles (PNNL), Pradeep Ramuhalli (ORNL), Edward (Ted) Quinn (Technical Resources), Ron Jarrett (Technical Resources), Vivek Agarwal (INL)*
- 690 Topical Report on Implementation of Online Monitoring to Extend Calibration Intervals of Pressure Transmitters—*H. M. Hashemian (Analysis and Measurement Services Corp.), G. W. Morton (Analysis and Measurement Services Corp.), B. D. Shumaker (Analysis and Measurement Services Corp.), M.J. Burzynski (NewClear Day, Inc.), R. Olson (Southern Nuclear Operating Co.)*
- 701 Advances in Instrumentation and Controls Systems**
- 702 I&C System Architectures in a New Light—*Mark Burzynski (SunPort S.A.), Sean Kelley (SunPort S.A.)*
- 714 In-Core Monitoring System (ICMS) for VVER Reactors: 25 Years Later—*Alexander Vereschaka (NRC Kurchatov Institute), Viacheslav Nebolsin (NRC Kurchatov Institute), Alexander Musikhin (NRC Kurchatov Institute), Andrey Kalinushkin (NRC Kurchatov Institute)*
- 723 Sensor Technology for Molten Salt Reactor Off-Gas Systems—*Hunter Andrews (ORNL), Joanna McFarlane (ORNL), David Holcomb (ORNL), Dianne Bull Ezell (ORNL), Kristian Myhre (ORNL), Amanda Lines (PNNL), Samuel Bryan (PNNL), Heather Felmy (PNNL)*
- 737 How Plug & Play Technology Solves Metering Obsolescence and Reduces Spare Inventory—*Otto P. Fest (Otek Corp.), Chris Foster (Otek Corp.)*
- 747 Application and Research into the Use of EDDs**
- 748 Embedded Digital Device Considerations in Commercial Grade Dedication—*John R. Hendricks (Curtiss-Wright Nuclear), Mike Wooldridge (Curtiss-Wright Nuclear)*
- 756 Software Reliability Testing of Digital Devices for Nuclear Power Applications—*B. D. Shumaker (Analysis and Measurement Services Corp.), R. T. Wood (Univ. of Tennessee Knoxville), C. Elks (Virginia Commonwealth Univ.), C. Smidts (Ohio State Univ.)*
- 764 EPRI Guidance on Designing and Managing Embedded Digital Components—*Matt Gibson (EPRI)*
- 769 Operating Experience and its Relationship to Embedded Digital Devices in Safety Systems—*M. D. Muhlheim (ORNL), D. S. Halverson (U.S. NRC), W. P. Poore (ORNL)*
- 780 The Role of Certification in the Safety Demonstration of COTS EDDs—*Sofia Guerra (Adelard), Luke Hinde (Adelard)*
- 791 Safety Critical Software Development, Qualification, and V&V**
- 792 Model-Checking I&C Logics - Insights from Over a Decade of Projects in Finland—*Antti Pakonen (VTT Technical Research Centre of Finland)*
- 802 Accessible Formal Verification for Design Assurance of Model Based Critical I&C Systems—*Smitha Gautham (Virginia Commonwealth Univ.), Athira Varma Jayakumar (Virginia Commonwealth Univ.), Abhi D. Rajagopala (Virginia Commonwealth Univ.), Carl Elks (Virginia Commonwealth Univ.)*
- 812 A Pseudo-Exhaustive Software Testing Framework for Embedded Digital Devices in Nuclear Power—*Athira Varma Jayakumar (Virginia Commonwealth Univ.), Richard Kuhn (National Institute of Standards and Technology), Brandon Simons (Virginia Commonwealth Univ.), Aidan Collins (Virginia Commonwealth Univ.), Smitha Gautham (Virginia Commonwealth Univ.), Richard Hite (Virginia Commonwealth Univ.), Raghu Kacker (National Institute of Standards and Technology), Abhi D. Rajagopala (Virginia Commonwealth Univ.), Carl Elks (Virginia Commonwealth Univ.)*
- 824 Model-Based Design Assurance and Verification in the Context of IEC-61508 SIL- 4 Standard—*Smitha Gautham (Virginia Commonwealth Univ.), Athira Varma Jayakumar (Virginia Commonwealth Univ.), Richard Hite (Virginia Commonwealth Univ.), Christopher S. Deloglos (Virginia Commonwealth Univ.), Ashraf Tantawy (Virginia Commonwealth Univ.), Matt Gibson (EPRI), Abhi D. Rajagopala (Virginia Commonwealth Univ.), Carl Elks (Virginia Commonwealth Univ.)*
- 837 General Sessions in I&C**
- 838 Resilient Micro and Nano Silicon-Based Electromechanical Relays for Nuclear Power Applications—*Benjamin Horstmann (Virginia Commonwealth Univ.), Kai Ding (Virginia Commonwealth Univ.), Md Ataul Mamun (Virginia Commonwealth Univ.), Carl Elks (Virginia Commonwealth Univ.), Gary Atkinson (Virginia Commonwealth Univ.), Umit Ozzur (Virginia Commonwealth Univ.), Vitaliy Avrutin (Virginia Commonwealth Univ.)*
- 850 Advantages of a Digital Wide-Range Neutron Instrumentation System—*Arnaud Duthou (Rolls-Royce Civil Nuclear), Pierre Vignollet (Rolls-Royce Civil Nuclear), Gael de Cargouet (Rolls-Royce Civil Nuclear), Stéphane Fargues (Rolls-Royce Civil Nuclear)*

- 858 Nuclear Cogeneration Plant of Electricity and Hydrogen Using Methane Steam Reforming—*Junyi Li (Tsinghua Univ.), Zhe Dong (Tsinghua Univ.), Bowen Li (Tsinghua Univ.)*
- 867 Natural Ageing of Solder Joints in Old Electronic Assemblies—*Laurent Cretinon (EDF - DIPNN)*
- 876 Survivability of Low-Voltage Cable Insulations in Small Modular Reactor Environments—*C.R. Ferree (Analysis and Measurement Services Corp.), P.R. Ward (Analysis and Measurement Services Corp.), T. A. Toll (Analysis and Measurement Services Corp.)*
- 887 Cybersecurity Simulation, Testbeds, and Experiments**
- 888 Integration of the Asherah NPP Simulator into a Closed-Loop Digital Twin Environment for Cybersecurity Assessment—*R. Busquim e Silva (IAEA), J.R.C. Piqueira (Univ. of Sao Paulo), R. P. Marques (Univ. of Sao Paulo)*
- 897 Development of a Hardware-in-the-Loop Fancy Testbed to Support Cybersecurity Research, Training, and Education for Nuclear Power Plants—*Fan Zhang (Univ. of Tennessee), Christopher Spirito (INL), Ronald Boring (INL), Stacy Baskin (Southern Nuclear Operating Co.), Jamie Coble (Univ. of Tennessee), Scott Ruoti (Univ. of Tennessee)*
- 905 Developing a Compact Cybersecurity Testbed Using Raspberry Pi Emulated PLC—*Fan Zhang (Univ. of Tennessee), Trent Payne (Univ. of Tennessee), Blake Childress (Univ. of Tennessee)*
- 915 Automated Cyber Security Testing Platform for Industrial Control Systems—*Andrew Hahn (Sandia National Laboratories), Daniel R. Sandoval (Sandia National Laboratories), Raymond E. Fasano (Sandia National Laboratories), Christopher Lamb (Sandia National Laboratories)*
- 925 Creation of a Condenser Testbed for Hardware in the Loop Testing Using the Asherah Simulator—*Joel Strandburg (Univ. of Massachusetts Lowell), Collin Duffley (Univ. of Massachusetts Lowell), Sukesh Aghara (Univ. of Massachusetts Lowell)*
- 933 Digital Considerations for Safety Applications**
- 934 Best Estimate and Uncertainty Analysis for Safety Analysis and Plant Margins—*K. Ivanov (NINE LLC), W. Marquino (NINE LLC), M. Modro (NINE LLC), M. Cherubini (NINE LLC), A. Petruzzi (NINE LLC), E. L. Quinn (NINE LLC)*
- 945 Preliminary Insights on Digital Instrumentation and Control Regulatory Lessons from the Boeing 737 MAX 8 Crash Events—*Michael Waters (U.S. Nuclear Regulatory Commission), David Rahn (U.S. Nuclear Regulatory Commission), Ismael Garcia (U.S. Nuclear Regulatory Commission)*
- 957 Novel Integration of Field Sensors to Reactor Protection Systems—*Tighe Smith (Paragon Energy Solutions), Gregg Clarkson (Rock Creek Innovations), Ted Quinn (Technology Resources)*
- 961 Advanced Surveillance, Diagnostics, and Prognostics**
- 962 Artificial Reasoning System for Symptom-Based Conditional Failure Probability Estimation Using Bayesian Network—*Xingang Zhao (ORNL), Michael Golay (MIT)*
- 976 Nuclear Power Prognostic Model Assessment for Component Health Monitoring—*Pradeep Ramuhalli (ORNL), Cody Walker (INL), Vivek Agarwal (INL), Nancy Lybeck (INL)*
- 987 Multi-Fault System Prognostics of Maintenance Dependent Processes in Nuclear Power Plants—*Hang Xiao (Univ. of Tennessee Knoxville), Alex Hines (Univ. of Tennessee Knoxville), Fan Zhang (Univ. of Tennessee Knoxville), Jamie B. Coble (Univ. of Tennessee Knoxville), J. Wes Hines (Univ. of Tennessee Knoxville)*
- 997 Combining System Architecture Modelling with Dynamic Process Simulation for Early Stage Fault and Effect Analysis—*Joonas Linnosmaa (VTT Technical Research Centre of Finland), André A. Hauge (Institute for Energy Technology), Fabien Sechi (Institute for Energy Technology), Miki Sirola (Aalto Univ.)*
- 1007 A Process to Assess Latent Failure Risk in Sequential Control Logic During a FMEA—*M. McCarthy (Kinectrics), D. K. Masrani (Kinectrics), A. Vieira (Kinectrics)*
- 1017 OLM Implementation for Surveillance Frequency Extensions**
- 1018 Beyond Piecemeal Plant Modernization - The Digital Challenge for Total Plant Transformation**
- 1019 Addressing Common Cause Failure and Future Regulatory Challenges**
- 1020 Harsh Environment Electronics For Terrestrial Reactor Applications: Needs, Technologies, and Future Directions**
- 1021 I&C for Autonomous Operations and Online Maintenance in the Next Generation of Reactors**
- 1022 New Developments in EMC / Wireless Implementation in Equipment and Process Condition Monitoring, Diagnostics, and Prognostics**
- 1023 Transformational Challenge Reactor (TCR) - Transforming the Paradigm of Instrumentation and Controls for Future Nuclear Systems**
- 1025 Maintenance Planning and Optimization**
- 1026 An Exact Method for Maintenance Schedule Optimization in Nuclear Power Plants—*Jamie Coble (Univ. of Tennessee Knoxville), Ethan Deakins (Univ. of Tennessee Knoxville), Tim Gallacher (Univ. of Tennessee Knoxville), Anahita Khojandi (Univ. of Tennessee Knoxville), James Ostrowski (Univ. of Tennessee Knoxville), Diego Mandelli (INL)*

- 1036 Dynamic Scheduler for Nuclear Power Plant Outages—*Ozan Sert (Virginia Polytechnic Institute and State Univ.), Rahil Dugrani (Virginia Polytechnic Institute and State Univ.), Mitali Shah (Virginia Polytechnic Institute and State Univ.), Subhash C. Sarin (Virginia Polytechnic Institute and State Univ.)*
- 1046 Impact of Schedule Risk Indices and Visualizations for Re-allocating Resources for Emergent Work—*Anirudh More (Virginia Polytechnic Institute and State Univ.), Nathan Lau (Virginia Polytechnic Institute and State Univ.), Shilo Anders (Vanderbilt Univ.)*
- 1056 Advantages of Using Computer-Based Procedures During Outages—*Javier Barroso (Tecnatom), Javier Gil (Tecnatom), Mateo Ramos (Tecnatom)*
- 1062 Maintenance Needs and Power Losses Identification Through Heat Rate Monitoring Systems—*Javier González (Tecnatom), Mariano Martín (Tecnatom), Javier Barroso (Tecnatom)*
- 1073 Instrumentation and Controls Regulations, Standards, and Guidelines**
- 1074 Assessment of I&C Products vs. IEC SC 45A Standards—*Ricardo García (Tecnatom), Héctor Martínez-Pinna (Tecnatom), Luis Rejas (Tecnatom)*
- 1084 Development of an Update to ISA S67.04 and RP67.04: “Setpoints for Nuclear Safety-Related Instrumentation for Nuclear Power Plants”—*Wayne Marquino (GE Hitachi Nuclear Energy), Edward L. Quinn (Technology Resources), Ryan Hoover (Westinghouse Electric Co.), Ron Jarrett (Technology Resources), Kirklyn R. Melson (Melson Engineering and Technical Services), David Rahn (US Nuclear Regulatory Commission)*
- 1094 Development of a Standard for Platform Qualification—*Horst Miedl (TüV Rheinland Industrie Service), Raimund Heigl (TüV Rheinland Industrie Service)*
- 1100 The IEC Standard Series on Cybersecurity for I&C and Electrical Systems in Nuclear Power Plants—*Edward L. Quinn (Technology Resources), Ludovic Pietre-Cambacedes (EDF-DIPNN), Thomas Walter (Preussen Elektra), Juergen Bochtler (Siemens Energy)*
- 1111 Development of a New IEC Technical Report on Cybersecurity Risk Management for I&C and ES in Nuclear Power Plants—*Michael T. Rowland (Sandia National Laboratories), Edward L. Quinn (Technology Resources), John Sladek (Canadian Nuclear Safety Commission)*
- 1121 I&C Technologies for Space Reactors and Microreactors**
- 1122 Development of H ∞ Controllers for Nuclear Thermal Rocket Engines—*Dan C. Floyd (Univ. of Tennessee Knoxville), David M. Sikorski (Univ. of Tennessee Knoxville), Richard T. Wood (Univ. of Tennessee Knoxville), Seddik M. Djouadi (Univ. of Tennessee Knoxville)*
- 1132 A Reduced Order Nuclear Thermal Rocket Engine Model as a Research Development Platform—*David M. Sikorski (Univ. of Tennessee Knoxville), Richard T. Wood (Univ. of Tennessee Knoxville)*
- 1140 Development of a Non-Nuclear Test Bed for Advanced Control Algorithms—*Hayden Sutton (Univ. of Tennessee Knoxville), Richard Wood (Univ. of Tennessee Knoxville), Bart Murphy (ORNL), N. Dianne Bull Ezell (ORNL)*
- 1147 Instrumentation for Microreactor Non-Nuclear Testbed Facilities—*Troy Unruh (INL), Joshua Daw (INL), Kelly McCary (INL), Richard Skifton (INL)*
- 1153 Instrumentation to Support Monitoring and Situational Awareness**
- 1154 Physics-Based Automated Reasoning for Health Monitoring: Sensor Set Selection—*R. Vilim (ANL), T. Nguyen (ANL), R. Ponciroli (ANL), H. Wang (ANL)*
- 1164 A Parallel Capability Using Genetic Algorithm for Sensor Assignment Optimization with Process-Constrained Data-Analytic Diagnosis—*Yuxuan Liu (Univ. of Michigan), Brendan Kochunas (Univ. of Michigan), Tat Nghia Nguyen (ANL), Hubert Ley (ANL), Richard Vilim (ANL)*
- 1175 A Model-Based Symbolic Inference for Sensor Deployment Optimization for Fault Detection of the EBR-II Reactor—*Xiaoxu Diao (The Ohio State Univ.), Pavan Kumar Vaddi (The Ohio State Univ.), Boyuan Li (The Ohio State Univ.), Wei Gao (The Ohio State Univ.), Carol Smidts (The Ohio State Univ.)*
- 1185 Physics-Informed Machine Learning-Aided System Space Discretization—*Junyung Kim (Rensselaer Polytechnic Institute), Asad Ullah Amin Shah (Rensselaer Polytechnic Institute), Hyun Gook Kang (Rensselaer Polytechnic Institute), Xingang Zhao (ORNL)*
- 1195 Regulatory Applications and Guidance for the Use of EDDs**
- 1196 Overview of Approaches to the Use and Licensing of COTS Digital Devices in Safety Critical Industries—*Sofia Guerra (Adelard), Gareth Fletcher (Adelard)*
- 1205 Regulation of Smart Devices for Nuclear Safety: Lessons Learned in the UK—*Paolo Picca (Office For Nuclear Regulation), Mark Bowell (Office for Nuclear Regulation), Steve Frost (Office for Nuclear Regulation)*
- 1216 Use of Smart Devices for Safety-Related Applications in Canadian Nuclear Power Plants—*Kevin Douglas McKay (Ontario Power Generation)*
- 1221 Regulatory Requirements, Guidance, and Review of Embedded Digital Devices in Safety Systems—*D. S. Halverson (U.S. Nuclear Regulatory Commission), M. D. Muhlheim (ORNL), W.P. Poore (ORNL)*

1233 Cybersecurity in Nuclear Installations - I

- 1234 Development of a Cyber Response Strategy Establishment Method for Minimizing the Potential Risk from Cyber-Attacks in NPPs—*Chanyoung Lee (KAIST), Young Ho Chae (KAIST), Poong Hyun Seong (KAIST)*
- 1242 Cyber-Informed Engineering Case Study of an Integrated Hydrogen Generation Plant—*Shannon Eggers (INL), Katya LeBlanc (INL), Robert Youngblood (INL), Tim McLunkin (INL), Konor Frick (INL), Daniel Wendt (INL), Robert Anderson (INL)*
- 1252 Cyber Risks to the Operational Technology Architectures of Next Generation Nuclear Reactors—*Ray Fasano (Sandia National Laboratories), Chris Lamb (Sandia National Laboratories), Mike Rowland (Sandia National Laboratories)*
- 1267 Cybersecurity Threat Scenario for a Hypothetical Nuclear Power Plant Facility—*Krystian Szeffler (National Centre for Nuclear Research), Marcin Dudek (National Centre for Nuclear Research), Jacek Gajewski (National Centre for Nuclear Research), Kinga Pankiewicz (National Centre for Nuclear Research), Jakub Suchohab (National Centre for Nuclear Research), Joanna Walkiewicz (National Centre for Nuclear Research)*
- 1277 Enhancing Safety and Security of Digital Instrumentation and Control System by Event Aggregation—*Robert Altschaffel (Otto von Guericke Univ.), Fan Zhang (Univ. of Tennessee Knoxville), Jianghai Li (Tsinghua Univ.), Jonas Hielscher (Otto von Guericke Univ.), Tamas Holczer (Budapest Univ. of Technology and Economics), Wen Si (Tsinghua Univ.), Kevin Lamshöft (Otto von Guericke Univ.)*

1287 Safety-Related Applications of Advanced I&C

- 1288 Trends for Field Programmable Gate Array Technology and Implications for Safety Critical Applications in Nuclear Power Plants—*Mark Burzynski (SunPort), Sean Kelley (SunPort)*
- 1303 An Isolation Design Strategy for Implementing Secure and Safety-Critical Applications in FPGA—*Abhi D. Rajagopala (Virginia Commonwealth Univ.), Smitha Gautham (Virginia Commonwealth Univ.), Carl Elks (Virginia Commonwealth Univ.)*
- 1314 Safety Instrumentation and Control Technologies for Small Modular Reactors and Advanced Reactors—*Arnaud Duthou (Rolls-Royce Civil Nuclear)*
- 1323 Safety-Related Instrumentation and Control Pilot Upgrade: Initial Scoping Phase Implementation and Lessons Learned—*Paul Hunton (INL), Robert England (INL), Gerald Segner (Exelon Generation), Mark Samselski (Exelon Generation), David Herrell (MPR Assoc.), William Jessup (MPR Assoc.), Sean Lawrie (ScottMadden Inc.), Mike Kerrigan (ScottMadden Inc.)*
- 1333 Potential Use of Thinklogical's KVM Technology in Safety Applications—*Richard Turk (Technology Resources), Richard Cooper (Thinklogical), James Gleason (GLSEQ), David Herrell (MPR Assoc.)*

1339 Cybersecurity in Nuclear Installations - II

- 1340 Finding Cyber-Attack Path Considering the Impact of the Attack by Using Page Rank Algorithm—*Young Ho Chae (KAIST), Chanyoung Lee (KAIST), Poong Hyun Seong (KAIST)*
- 1349 A Framework for Describing Attacker Models—*Christopher Deloglos (Virginia Commonwealth Univ.), Ashraf Tantawy (Virginia Commonwealth Univ.), Carl Elks (Virginia Commonwealth Univ.)*
- 1361 Response of Programmable Logic Controllers of the Pressurizer in a Representative PWR Plant Following a False Data Injection—*Timothy Schriener (Univ. of New Mexico), Mohamed S. El-Genk (Univ. of New Mexico)*
- 1372 Automated Scenario Generation for Cyber Risk Assessments using CICAT—*Jackson Wynn (The MITRE Corp.)*
- 1383 Exploring Quantum Key Distribution for Nuclear I&C Cybersecurity—*Stylios Chatzidakis (Purdue Univ.)*

1393 Cybersecurity in Nuclear Installations - III

- 1394 Application of Information Harm Triangle to Inform Defensive Strategies for the Protection of NPP I&C Systems—*Michael T. Rowland (Sandia National Laboratories), Andrew J. Clark (Sandia National Laboratories)*
- 1408 Formal Approach to Use the Security Models for Design and Evaluation of the NPP I&C Security Architecture—*Vitaly Promyslov (Institute of Control Sciences of RAS), Edward L. Quinn (Technology Resources), Kirill Semenov (Institute of Control Sciences of RAS), Michael T. Rowland (Sandia National Laboratories), Christopher C. Lamb (Sandia National Laboratories), Jianghai Li (Tsinghua Univ.)*
- 1417 LOBO Nuclear Reactor Power Plants Cyber Security (LOBO NCS) Platform—*Mohamed El-Genk (Univ. of New Mexico), Timothy Schriener (Univ. of New Mexico), Andrew Hahn (Sandia National Laboratories), Raymond Fasano (Sandia National Laboratories), Christopher Lamb (Sandia National Laboratories)*
- 1427 Overview and Recommendations for Cyber Risk Assessment in Nuclear Power Plants—*Fan Zhang (Univ. of Tennessee Knoxville)*
- 1437 Nuclear Energy Agency's Consensus Position on the Impact of Cyber Security Features on Digital Instrumentation and Control Systems Important to Safety at Nuclear Power Plants - Evaluation Framework—*Ismael L. Garcia (U.S. NRC)*

1445 Digital I&C Modeling Approaches for PSA

- 1446 Integrated Risk Assessment of Digital I&C Safety Systems for Nuclear Power Plants—*Hongbin Zhang (INL), Han Bao (INL), Tate Shorthill (Univ. of Pittsburgh), Edward Quinn (Technology Resources)*

- 1458 **WGRISK DIGMAP: Comparison of PSA Modeling Approaches for Digital I&C**—*Markus Porthin (Paul Scherrer Institut), Sung-Min Shin (KAERI), Milan Jaros (ÚJV Řež), Jiri Sedlak (ÚJV Řež), Paolo Picca (Office for Nuclear Regulation), Richard Quatrain (EDF), Jeanne Demigné (EDF), Hans Brinkman (NRG), Venkat Natarajan (NRG), Tero Tyrväinen (VTT Technical Research Centre of Finland), Christian Müller (Gesellschaft fuer Anlagen- und Reaktorsicherheit), Ewgenij Piljugin (Gesellschaft fuer Anlagen- und Reaktorsicherheit)*
- 1468 **Risk Comparison Among Design Options of RPS with Diverse PLC and FPGA Systems**—*Hyun Gook Kang (Rensselaer Polytechnic Institute), Kwang-Seop Son (KAERI), Seung Hwan Seong (KAERI)*