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Session Organizer: Nathan Ka Ching Lau (Virginia Tech) **Chair:** P. O. Braarud

Human Performance Measures for the Evaluation of Nuclear Power Plant Control Room Interfaces: A Systematic Review **1211**

Jie Xu, Shilo Anders (Vanderbilt Univ), Arisa Pruttianan (Virginia Tech), Daniel J. France Vanderbilt Univ), Nathan Lau (Virginia Tech), Julie A. Adams (Oregon State Univ), Matthew B. Weinger (Vanderbilt Univ)

Experimental Study on Team Coordination of NPP Plant Operators based on the Simultaneous NIRS Measurements 1226

Makoto Takahashi, Fumiyasu Shirai, Ryuta Kawashima (Tohoku Univ), Kazukiyo Ueda (BWR Operator Training Center Cooperation)

Evaluating Situation Awareness in the Control Room: The Development and Initial Testing of the Process Awareness and Situation Understanding (PASU) Measure 1234

Per Oivind Braarud (OECD Halden Reactor Project)

Measures—II: Data Collection Methods and Challenges
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Technical Constraints to Conducting Operator Studies in a Reconfigurable Control Room Simulator 1242

Brandon Rice (INL)

A Summary Comparison of Design Evaluation Techniques 1249

Zachary Spielman, Rachael Hill (INL)

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C. Kovesdi, J. Joe (INL)

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Session Organizer: Johanna H. Oxstrand (INL) **Chair:** Katya Le Blanc (INL)

Development of Utility Generic Functional Requirements for Electronic Work Packages and Computer-Based Procedures 1272

Johanna Oxstrand (INL)

Supporting the Industry by Developing a Design Guidance for Computer-Based Procedures for Field Workers 1282

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Automated Work Package: Capabilities of the Future 1293

Ahmad Al-Rashdan, Johanna Oxstrand, Vivek Agarwal (INL)

Computer-Based Tools for Improving Operator and Plant Performance—II
Session Organizer: Johanna H. Oxstrand (INL) **Chair:** Jacques Hugo (INL)

Developmental Study of Advanced HIS Design Method for Digital I&C+HMIT of PWR Plant 1305

Hidekazu Yoshikawa (Harbin Eng Univ)

Human Factors Principles in Information Dashboard Design 1315

Jacques V. Hugo, Shawn St. Germain (INL)

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Yao-Hsien Huang (Shih Chien Univ), Tsung-Chieh Cheng (INER), Yuan-Yu Tsai (Asia Univ)

Safety Critical Software Development, Qualification, and V&V—I
Cochairs: Edward Quinn (Technology Resources), Janos Eiler (IAEA)

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Antti Pakonen (VTT Technical Research Centre of Finland), Topi Tahvonen (Fennovoima Ltd), Markus Hartikainen, Mikko Pihlanko (Fortum Power and Heat)

An Automatic Input/Output Test Experience of FPGA based Logic Controller with I/O Stimulator **1353**
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Safety Demonstration of a Class 1 Smart Device **1359**
Sofia Guerra, Eoin Butler, Sam George (Adelard LLP)

Test Based Reliability Assessment Method for a Safety Critical Software in Reactor Protection System **1369**
Sung Min Shin, Jaehyun Cho, Wondea Jung (KAERI), Seung Jun Lee (UNIST)

Safety Software Release Options to Support Plant Start-Up and Commissioning Activities **1377**
Jerry M. Stanley, Marc Kalo, Steve Leicher, Lori Richards (Westinghouse)

Digital Control System Applications
Chair: Hidekazu Yoshikawa (Harbin Eng. Univ)

A Novel Priority Selection System for Nuclear Power Plant **1387**
Shuo Wang, Qingwei Shi, Kelin Qi, Gang Ma, Dong Wang (CNPE)

The Problem Analysis of Data Processing Performance in Nuclear Power Plant Computerized Information and Control System **1397**
Jianwei Liu, Lixue Tang, Qingyu Yang (CNPE)

Feature Selection based on PCA and the Transient Identification in Nuclear Power Plants **1405**
Shuqiao Zhou, Chao Guo, Xiaojin Huang (Tsinghua Univ)

Improving Nuclear Power Plant Safety and Operating Margins through Linear Quadratic Estimation **1412**
R. Steven Black (AREVA Inc.), Michael Smith (AREVA Federal Services LLC)

Integration and Assessment of Component Health Prognostics in Supervisory Control Systems **1423**
Pradeep Ramuhalli, Chris Bonebrake, Gerges Dib, Surajit Roy (PNNL), Sacit M. Cetiner (ORNL)

I&C Modernization Experience—I
Chair: Graham Walford (Univ of Tennessee)

Comparative Requirements, Stakes and Deployment for 2 Ongoing Major I&C Modernization Projects **1432**
Arnaud Duthou, Jean-Michael Palaric (Rolls-Royce Civil Nuclear)

Identifying Requisite Changes to Support Modern Maintenance Practices **1443**
Zach Welz, Jamie Coble, J. Wesley Hines (Univ of Tennessee)

BWR Modernization Project: Installation of a New Digital Feedwater Control System **1452**
Javier Lasierra, Cristina Corrales, Mateo Ramos (Tecnatom S. A.)

Electric Actuator Modification on a Turbine Driven Feedpump at Calvert Cliffs Nuclear Power Plant 1461
Brian T. Vilicka, Steve D. Whaley, Louis W. Gaussa, Ryan S. Blinn, Timothy J. Pasko (Westinghouse), Jim M. Bonner, Jonathan L. Allen (Exelon)

Integrated Emergency Control Board Including Design Extended Conditions for Krško NPP 1470
Luis Rejas, Nicolás Moyano, Fernando Ortega, Sara Fernandez (Tecnatom S.A)

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I&C Lessons Learned from Fukushima
Chair: Cristina Corrales (Tecnatom S.A.)

Enhanced Electrical Penetration Components Meet the Higher Safety Standards Required for China's HTR-PM Shidaowan and Generation mPower Small Modular Reactors 1479
Thomas Fink (Schott AG, BU Electronic Packaging), Shi Qi (Chinergy Co, LTD), Edward L. Quinn (Technology Resources), James F. Gleason (GLSEQ, LLC)

Instrumentation, Control, and Human System Interface Contributions to Historical Severe Accidents 1488
Gary L. Johnson (Independent Consultant)

New Intrinsically Smart Severe Accident Instrumentation Saves Costs and Enhances Severe Accident Management 1500
James Gleason, Patrick Gleason (GLSEQ, LLC)

Diversity and Defense in Depth (D3)—I
Chair: Michael Becker (Northrop Grumman)

Impacts of Common Cause Failure Regulatory Requirements on Protection System Architectures 1506
Mark Burzynski (NewClear Day, Inc.)

Graded Approach for Assessing Digital System Failure Susceptibilities 1517
R. Torok (EPRI), D. Blanchard (Applied Reliability Eng)

Diversity for Safety and Security of NPP I&C: Post NUREG/CR 7007 Stage 1528
Vyacheslav Kharchenko, Eugene Babeshko (Center for Safety Infrastructure-Oriented Research and Analysis), Kostyantyn Leontiiev (RPC Radiy), Vyacheslav Duzhy (National Aerospace Univ)

Addressing Embedded Digital Devices in Safety-Related Systems of Nuclear Power Plants 1537
Richard Wood (Univ of Tennessee), Jerry Mauck (JLM Eng and Technology Resources), Edward L. Quinn (Technology Resources)

Measures—III: Eye Tracking Applications and Methods
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Eye Tracking Studies based on Attentional-Resource Effectiveness 1557
Jun Su Ha, Young-Ji Byon, Chung-Suk Cho (Khalifa Univ. of Science, Technology and Research), Seongkeun Kang, Poong Hyun Seong (KAIST)

Experience with Control Room Modernization—I
Session Organizer and Chair: Ken Thomas (INL)

A Review of Human-System Interface Design Issues Observed during Analog-to-Digital and Digital-to-Digital Migrations in U.S. Nuclear Power Plants 1568
C. Kovesdi, J. Joe (INL)

Study on Main Control Room and Human-System Interface of Generation III in China 1581
Shi Ji, Liu Qianzhong (China Nuclear Power Plant Design Co., LTD)

Optimized Application of Regulatory Human Factors Engineering Guidelines 1592
Asriel Eisinger, Wolfgang Krause (AREVA NP)

Human Factors and Modeling Methods in the Development of Control Room Modernization Concepts 1598
Jacques V. Hugo (INL), Lorenzo Slay III, John Hernandez (APS)

Advanced Sensors and Measurement Technologies—II
Chair: Anton Andrashov (RadICS LLC)

A Novel Technique Applying Spectral Estimation to Johnson Noise Thermometry 1611
N. Dianne Bull Ezell, Charles Britton, Nance Ericson, David Holcomb (ORNL), M. J. Roberts, Seddik Djouadi, Richard Wood (Univ of Tennessee)

Continuous Measurement of the Boron Concentration in a Nuclear Power Plant: Why is it Essential for a Safe and Efficient Operation? 1620
Miriam Jimenez, Patrick Pirat (Rolls-Royce)

Severe Accident: Hardening of Standards and Qualification Requirements for Nuclear Pressure Transmitters 1628
H. Fabbro, R. Desgeorge, J. C. Peres (Rolls-Royce)

Safety Critical Software Development, Qualification, and V&V—II
Chair: Nguyen Thy (EdF)

Test Case Selection Procedure for Simulation-Assisted Automation Testing 1635
V.-M. Tikkala, A. Rantakaulio (Fortum Power and Heat Oy)

Extension of Mutation Testing for the Requirements and Design Faults 1644
Boyuan Li, Carol Smidts (Ohio State)

An Operation Verification Strategy Against Network Attack of DCS in Nuclear Power Plant 1651
Chao Guo, Jianghai Li, Zhe Dong, Xiaojin Huang (Tsinghua Univ)

Virtualized Hardware Environments for Supporting Digital I&C Verification 1658
Frederick E. Derenthal IV, Carl Elks, Tim Bakker, Mohammadbagher Fotouhi (Virginia Commonwealth Univ)

On-line Monitoring for Maintenance Optimization—I
Chair: Stylianos Chatzidkis (ORNL)

On-Line Monitoring of I&C Transmitters and Sensors for Calibration Verification and Response Time Testing was Successfully Implemented at ATR 1671

Phillip A. Erickson (INL), Ryan O'Hagan, Brent Shumaker, H. M. Hashemian (AMS), invited

On-Line Monitoring to Detect Sensor and Process Degradation under Normal Operational Transients **1679**
Samuel Boring, Jamie Coble, (Univ of Tennessee)

Bayesian Inference for High Confidence Signal Validation and Sensor Calibration Assessment **1688**
Anjali M. Nair, Jamie Coble (Univ of Tennessee, Knoxville)

On-Line Monitoring for Static and Dynamic Performance Verification of I&C Systems at Sizewell B Nuclear Power Station **1698**
P. Goffin (EDF Energy Generation), B. Shumaker, A. Hashemian, G. Morton (AMS)

Framework for Structural Online Health Monitoring of Aging and Degradation of Secondary Piping Systems due to Some Aspects of Erosion **1706**
Andrei V. Gribok, Vivek Agarwall (INL)

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Advanced Surveillance, Diagnostics, and Prognostics— IV
Chair: Mitch McCrory (SNL)

Nuclear Power Plant Risk-Informed Surveillance Frequency Control Program Implementation at the Duke Catawba Nuclear Plant with a Focus on Instrumentation and Control Systems **1716**
Heather Szews (Duke Energy), James K. (Jim) Liming (ABSG Consulting Inc.), Edward L. (Ted) Quinn (Technology Resources)

Estimation of LOCA Break Size Using Cascaded Support Vector Regression **1725**
Kwae Hwan Yoo, Man Gyun Na (Chosun Univ), Goen Pil Choi (KAERI)

Identification of NPP Transients Using Artificial Intelligence **1733**
Young Do Koo, Ju Hyun Back, Man Gyun Na (Chosun Univ)

Data Analysis for Valve Leak Detection of Nuclear Power Plant Safety Critical Components **1742**
Jung-Taek Kim, Hyeonmin Kim, Wan Man Park (KAERI)

Frequency Spectrum Analysis Code for Nuclear Noise Based on Improved Wavelet Algorithm **1752**
Baoxin Yuan, Herong Zeng, Wankui Yang (CAEP)

Cyber Security in Digital I&C—IV
Chair: Roberto Ponciroli (ANL)

Behavior-Based Approach to Misuse Detection of a Simulated SCADA System **1761**
Brien A. Jeffries, J. Wesley Hines (Univ of Tennessee), Kenny C. Gross (Oracle Physical Sciences Research Center)

Nuclear Power Plant Instrumentation and Control Cyber Security Common Vector Access Leading to Relational Common Cause Failures **1772**
Phillip L. Turner, F. Mitch McCrory, Lon A. Dawson (SNL)

Enhancing Power Plant Safety through Simulated Cyber Events **1779**
Phillip L. Turner, Susan S. Adams, Stacey M. Hendrickson (SNL)

Risk Informed Cyber Security for Nuclear Power Plants 1786
Phillip L. Turner, Timothy A. Wheeler (SNL), Matt Gibson (EPRI)

Supporting the Development, Practice, and Integration of Human Factors Engineering
Session Organizer: Dina Notte (ERGODIN)**Chair:** Paula Savioja (STUK)

Training and Certification of Human Organizational Factors Designers in Nuclear Plant Engineering 1791
Wolfgang Krause, Asriel Eisinger (AREVA GmbH)

How Systems Engineering and Human Factors Can Assist SMR Vendors with the Licensing Process 1797
Yasamin Dadashi, Chris Oberholzer, Glenn Archinoff (Candesco)

Developing a Human Factors Toolkit to Cope with Multi-Project Situation 1803
Fei Song, Qiuyu Wang, Zhong Yuan, Shuhui Zhang (SNERDI)

Early Implementation of Digital Upgrades on Simulators 1812
Vincent Gagnon, Bernard Gagnon (L3 MAPPS)

Experience with Control Room Modernization—II
Session Organizer and Chair: Ken Thomas (INL)

Migration to a Fully-Integrated Control Room 1822
Ken Thomas (INL), Ken Scarola (Nuclear Automation Engineering, LLC), John Hernandez, Tom Lambdin (APS)

A Human Factors Engineering Meta Model for U.S. Nuclear Power Plant Control Room Modernization 1833
Jeffrey C. Joe (INL)

A Human Factors Engineering Process to Support Human-System Interface Design in Control Room Modernization 1843
C. Kovesdi, J. Joe, R. Boring (INL)

A Business Case for Nuclear Plant Control Room Modernization 1856
Ken Thomas (INL), Sean Lawrie, Joe Niedermuller (ScottMadden Management Consultants), Michael Grigsby, John Hernandez, Brian Flynn (APS)

Field Programmable Gate Array (FPGA)—I
Chair: Brent Shumaker (AMS)

Development of a Systematic Approach for the Safety Analysis of PLD based Equipment of I&C Systems 1866
Ewgenij Piljugin, Claudia Quester, Manuela Jopen (GRS GmbH)

V&V Techniques for FPGA-Based I&C Systems—How They Compare with Techniques for Microprocessors? 1876
Sam George, Sofia Guerra (Adelard LLP)

Implementing a Control Application on FPGA Platform 1886
Jérôme Pizel, Alain Ourghanlian (EdF)

Development and Application of FPGA-Based Logic Controller 1895
Yoonhee Lee, Sedo Sohn, Jaehee Yun (KEPCO E&C), Seungkweon Jeong (Woori Technology, Inc.)

General Sessions in I&C—III
Chair: Christian Petrie (ORNL)

In-Pile Measurements of Fuel Rod Dimensional Changes Utilizing the Test Reactor Loop Pressure for Motion **1905**
Richard S. Skifton, Kurt L. Davis (INL), John C. Crepeau (Univ of Idaho), Steinar Solstad (Inst for Energy Technology)

Preliminary Analysis of Effect of Vanadium Self-Powered Neutron Detectors on AP1000 Reactor Core Physical Parameters **1912**
Yeshuai Sun, Xing Wang, Changhui Wang, Junhong Lv, Hui Yu, Yixue Chen (State Power Investment Company Research Inst)

Upcoming Irradiation of Ultrasonic and Fiber Optic Sensors in the MITR **1921**
Joshua Daw (INL), Lance Hone (The Center for Space Nuclear Research), Jean-François Villard, Guillaume Laffont (CEA), Kevin Chen (Univ of Pittsburgh), Jack Illare, Alfred Margaryan, Ashot Margaryan (AFO Research, Inc.), David Carpenter (MIT)

Improving Plant Efficiency through the Installation of TecSOLCEP Online Monitoring System **1931**
F. Javier González Mariano Martin, Iván Juan, Mateo Ramos (Tecnatom)

Industry Analytics to Optimize Time Based Maintenance for I&C Components **1938**
Curtis Good, Dan Stiffler (Rolls-Royce)

On-line Monitoring for Maintenance Optimization—II
Chair: Dean Crumpacker (Sargent & Lundy)

Development of a Transient Signal Validation Technique via a Modified Kernel Regression Model **1943**
Ibrahim Ahmed, Gyunyoung Heo (Kyung Hee Univ)

I&C Regulations, Standards, and Guidelines—II
Chair: Alan Levin (DOE)

Verification of Severe Accident Management Guideline (SAmG) Entry Condition for OPR1000 **1952**
Young Gyu No, Poong Hyun Seong (KAIST)

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General Sessions in I&C—IV
Chair: Jamie Coble (Univ of Tennessee)

DCIS Integration Tests for Lungmen Nuclear Power Plant **1962**
Jiin-Ming Lin, Jeen-Yee Lee (Taiwan Power Co.)

A Multi-Mode State-Space Dynamic Model for Pyrofusion Neutron Sources **1972**
A. M. Darbyshire, K. D. Atkinson (Defence Academy of the United Kingdom)

Identification and System Parameter Estimation Methods for a Pyrofusion Neutron Source **1983**
A. M. Darbyshire, K. D. Atkinson (Defence Academy of the United Kingdom)

Wide-Range Fission Chambers Signal Simulator **1991**
I. V. Alyaev, N. A. Selyaev, Yu. A. Paryshkin, V. A. Fedorov (National Research Nuclear Univ «MEPhI»)

A Dynamic Model of Once Through Steam Generator (OTSG) for Prototypical Advanced Reactor 1999
Fan Zhang, Jamie Coble (Univ of Tennessee)

Diversity and Defense in Depth (D3)—II
Chair: Thomas Hunter (Lockheed Martin Corp./Lockheed Martin Energy)

Diversity and Defense-in-Depth Analysis for I&C Systems of Research Reactors: A Case Study on Two Research Reactors 2010
Seung Ki Shin, Yong Suk Suh, Sang Mun Seo (KAERI)

Advanced Licensing and Safety Engineering Method—ADLAS™ 2020
Pekka Nuutinen, Satu Sipola, Antti Rantakaulio (Fortum Oyj)

NRC Technical Basis for Evaluation of Its Position on Protection Against Common Cause Failure in Digital Systems Used in Nuclear Power Plants 2031
Steven A. Arndt, Rossnyev Alvarado, Bernard Dittman, Kenneth Mott (NRC), Richard Wood (Univ of Tennessee)

Development of a Diversity and Defense-In-Depth Strategy for the CNNC Fuqing Fangjiashan and Hainan Nuclear Plants 2046
Taha Ibrahim (Schneider Electric), Jerry Mauck (JLM Eng and Technology), Michael Howard (Zachry Group), Edward L. Quinn (Technology Resources)

Development of a Diversity and Defense-In-Depth Strategy for the TerraPower TWR-P Advanced Nuclear Power Plant 2052
Baofu Lu, Eric Williams (TerraPower), Jerry Mauck (Technology Resources), Michael Howard (CSA Inc.), Richard Wood (Univ of Tennessee), Edward L. Quinn (Technology Resources)

Soft Controls
Session Organizer and Chair: Lauren Reinerman-Jones (Univ of Central Florida)

Workload Response to Soft Controls Presented on Two Interfaces 2058
Lauren Reinerman-Jones, Jonathan Harris (Univ of Central Florida), Niav Hughes, Amy D'Agostino (NRC)

Design Themes for Future Hybrid Nuclear Power Plant Control Rooms 2069
Shilo Anders, Jie Xu, Dan France, Matthew B. Weinger (Vanderbilt Univ), Julie A. Adams (Oregon State Univ), Katya Le Blanc (INL)

Field Programmable Gate Array (FPGA)—II
Chair: Jerry Stanley (Westinghouse)

Development of Programmable Logic in a Rapid, Automated, and Repeatable Fashion for Safety-Related Applications 2077
Keith A. Harvey, Dan Ho, Phil Allen, Andrew Mortellaro, Louis Yu (Lockheed Martin Corp.)

Certification of RadICS FPGA-Based Platform under U.S. NRC Requirements 2085
Ievgenii Bakhmach, Olexandr Siora (Research and Production Corporation Radiy), Anton Andrashov (RadICS LLC), Vyacheslav Kharchenko, Andriy Kovalenko (Centre for Safety Infrastructure-Oriented Research and Analysis)

SymPLe 1131: A Novel Architectural Solution for the Realization of Verifiable Digital I&C Systems and Embedded Digital Devices 2093

Carl Elks (Virginia Commonwealth Univ), Matt Gibson (EPRI), Tim Bakker, Richard Hite, Smitha Gautham, Vidya Venkatesh (Virginia Commonwealth Univ), Jason Moore (The MathWorks, Inc.)

Toward Biologically Inspired Self Healing Digital Embedded Devices: BIO-SymPle) **2105**

Shawkat Khairullah, Tim Bakker, Carl R. Elks (Virginia Commonwealth Univ)

Digital System Reliability—II
Chair: Donald Chase (Curtiss Wright)

Analysis of, and Defense Against, Spurious Actuation and Other Incorrect Behaviors of Digital Control Systems **2120**

Nguyen Thuy (EdF)

Application of Quantitative Methods for Reliability Testing of a Nuclear Power Plant Digital Rod Position Indication Diagnostic System **2129**

G. W. Morton, B. D. Shumaker, D. E. McCarter, S. D. Caylor, J. T. Rich (AMS)

Recent Results from a Testbed for the Reliability of the Digital Instrumentation and Control Systems and Cyber-Security in Nuclear Power Plants **2139**

Yongkyu An, Calogero Sollima, Rizwan-uddin, Daniel Chen, Zbigniew Kalbarczyk (Univ of Illinois)

Fault Propagation and Effects Analysis for Designing an Online Monitoring System for the Secondary Loop of a Nuclear Power Plant Part of a Hybrid Energy System **2148**

Huijuan Li, Xiaoxu Diao, Xiang Li, Boyuan Li, Carol Smidts, (Ohio State), Shannon Bragg-Sittion (INL)

I&C Modernization Experience—II
Chair: Roy Ray (Mirion Technologies)

Diablo Canyon Power Plant Digital Process Protection System Replacement Licensing Experience Using ISG-06 **2160**

Kenneth J. Schrader (PG&E), Scott B. Patterson (Rock Creek Innovations, LLC), John W. Hefler (Altran US Corp), Edward (Ted) L. Quinn (Technology Resources)

Development of Functional Requirements Specification for Digital Instrumentation and Control Systems Upgrades Used at Nuclear Power Plants (NPPs) **2170**

Roger D. Wyatt, Richard Supler (Enercon Services)