Current challenges with digital technologies in nuclear power plant I&C systems

Janos Eiler

Obninsk, 27 June 2019

IAEA
International Atomic Energy Agency

The Paks Nuclear Power Plant in Hungary

IAEA

The start-up of Paks Unit 1 in 1982

IAEA

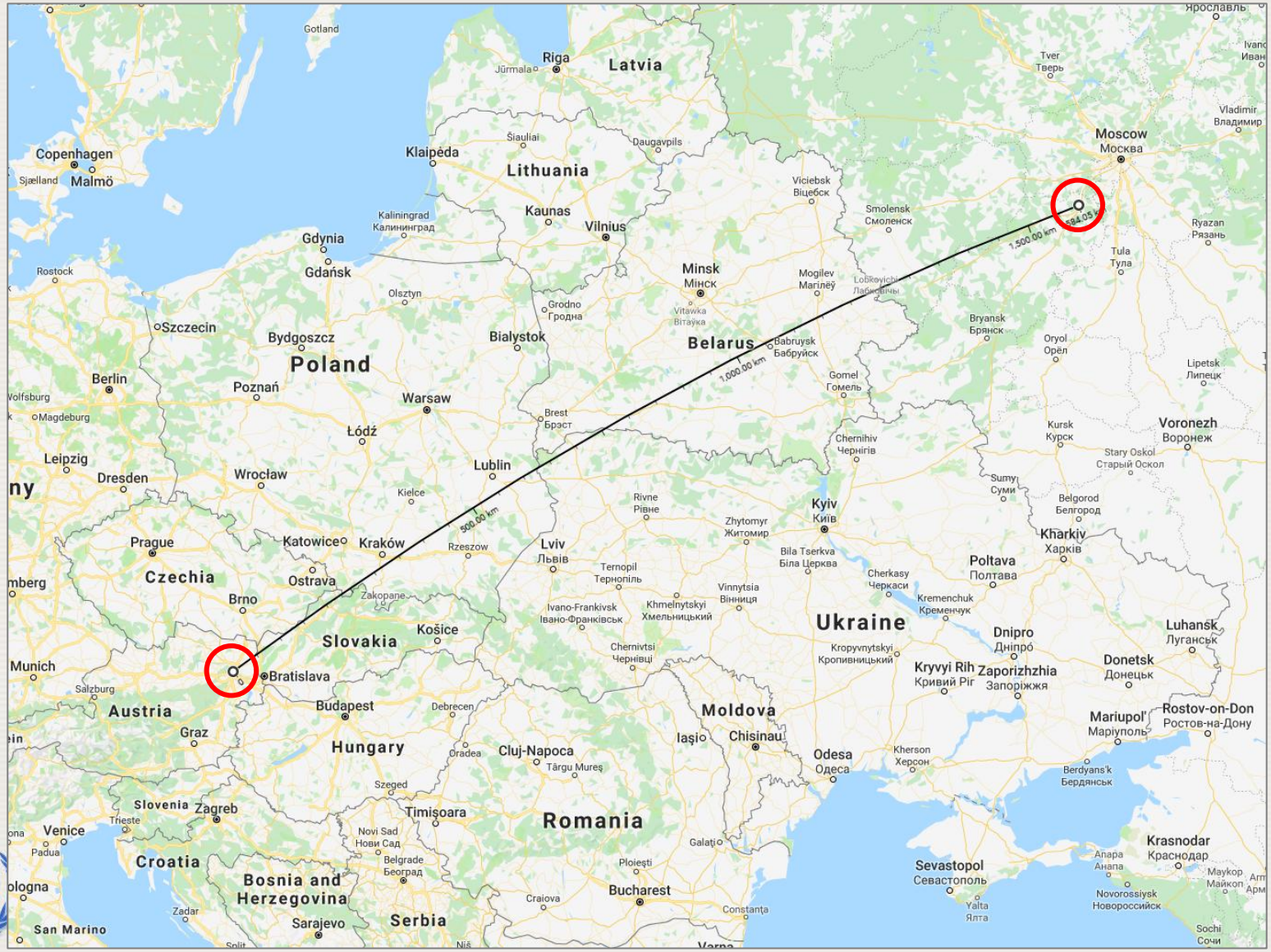
Outline

- Introduction to the IAEA and a global nuclear power outlook
- Most significant issues and challenges in the nuclear instrumentation and control area today
- Related IAEA activities

The IAEA in a nutshell and a global nuclear power outlook

IAEA
International Atomic Energy Agency

Vienna – Obninsk



Vienna City Hall

Downtown Vienna

St-Petersburg in Jun 2015

IAEA workshop in St-Petersburg in Jun 2015

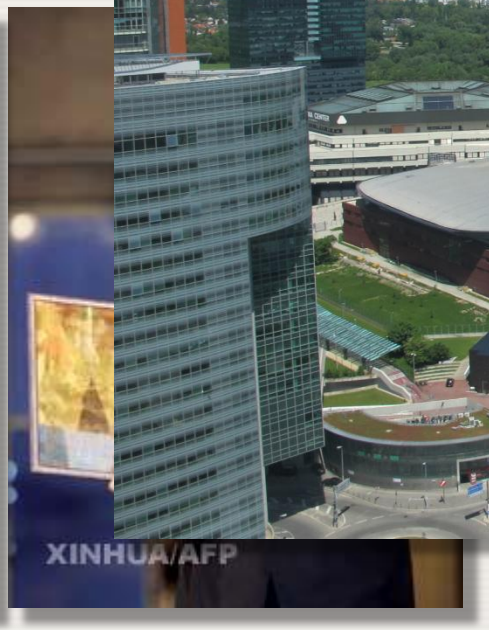
IAEA workshop in St-Petersburg in Jun 2015

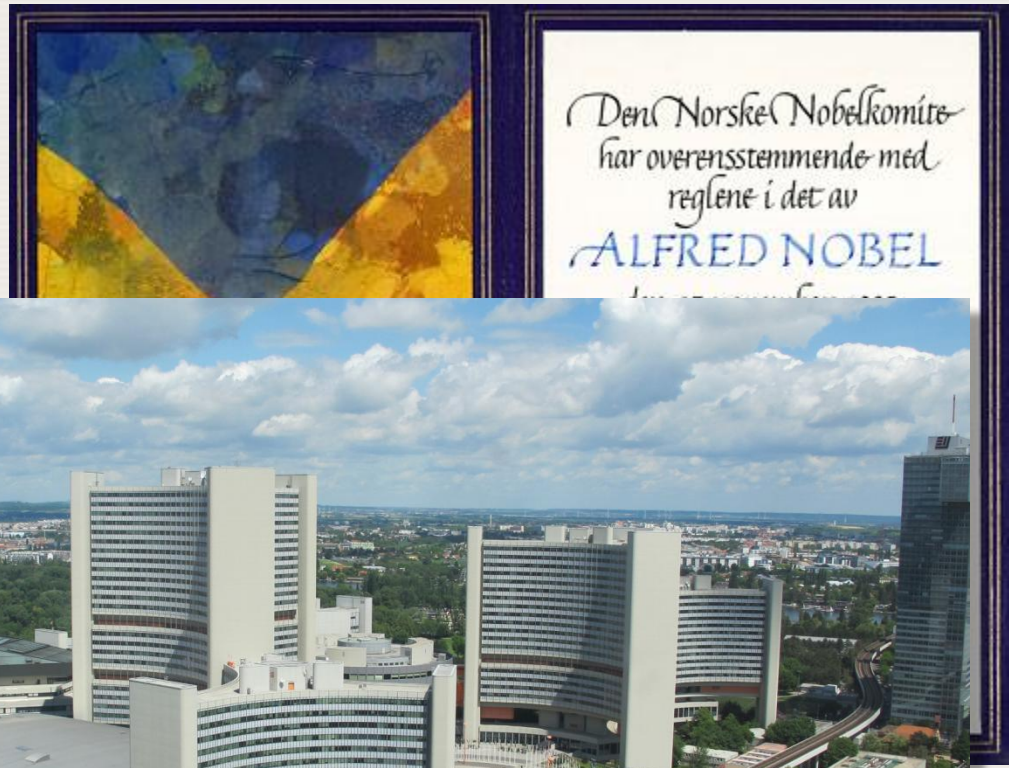
IAEA workshop in St-Petersburg in Jun 2015

IAEA workshop in St-Petersburg in Jun 2015

IAEA at a glance

- Founded in 1957
- 171 member states
- New member in 2019
  - Saint Lucia
- ~2500 staff
- Nobel Peace P





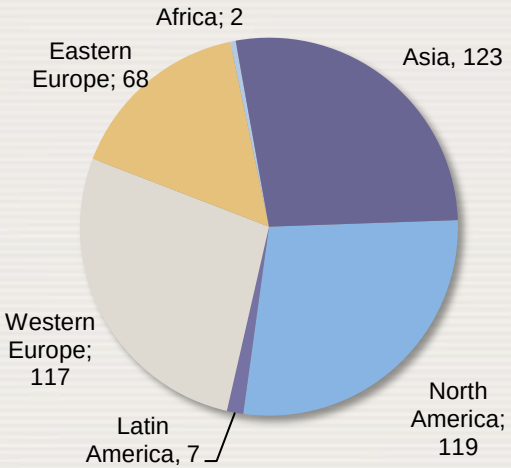
Global nuclear power status

452 reactors in operation (~400 GW_e)

173 reactors in permanent shutdown

54 reactors under construction

Geographical distribution



As of May 2019

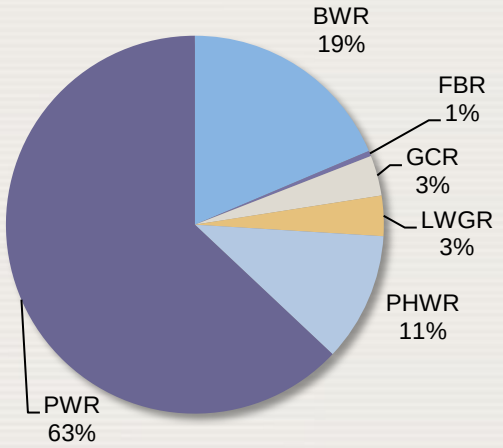
In 2012:

437 reactors in operation (371.7 GW_e)

143 reactor in permanent shutdown

67 reactors under construction

Reactor capacity by type



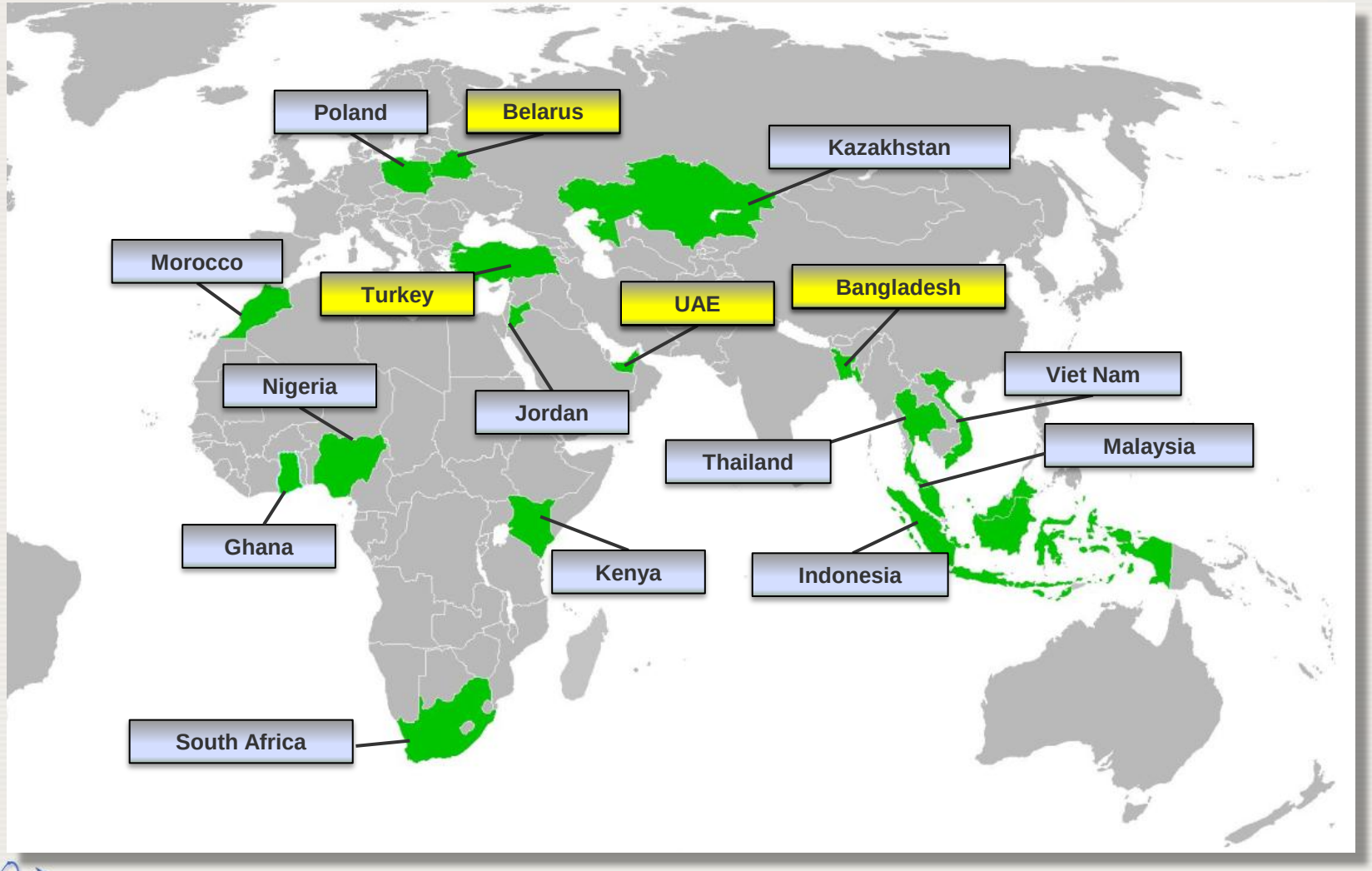
Latest connections to the grid (2 in 2019):

- SANMEN-1 and 2, 1000 MW PWR, China
- TAISHAN-1, 1660 MW PWR, China
- SHIN-KORI-4, 1340 MW, PWR, Korea, Rep. of
- NOVOVORONEZH 2-2, 1114 MW PWR, Russia

Website: http://www.iaea.org/pris/

IAEA

Who are the newcomers?



IAEA

Newcomers with first NPP under construction

UAE, Barakah, July 2012

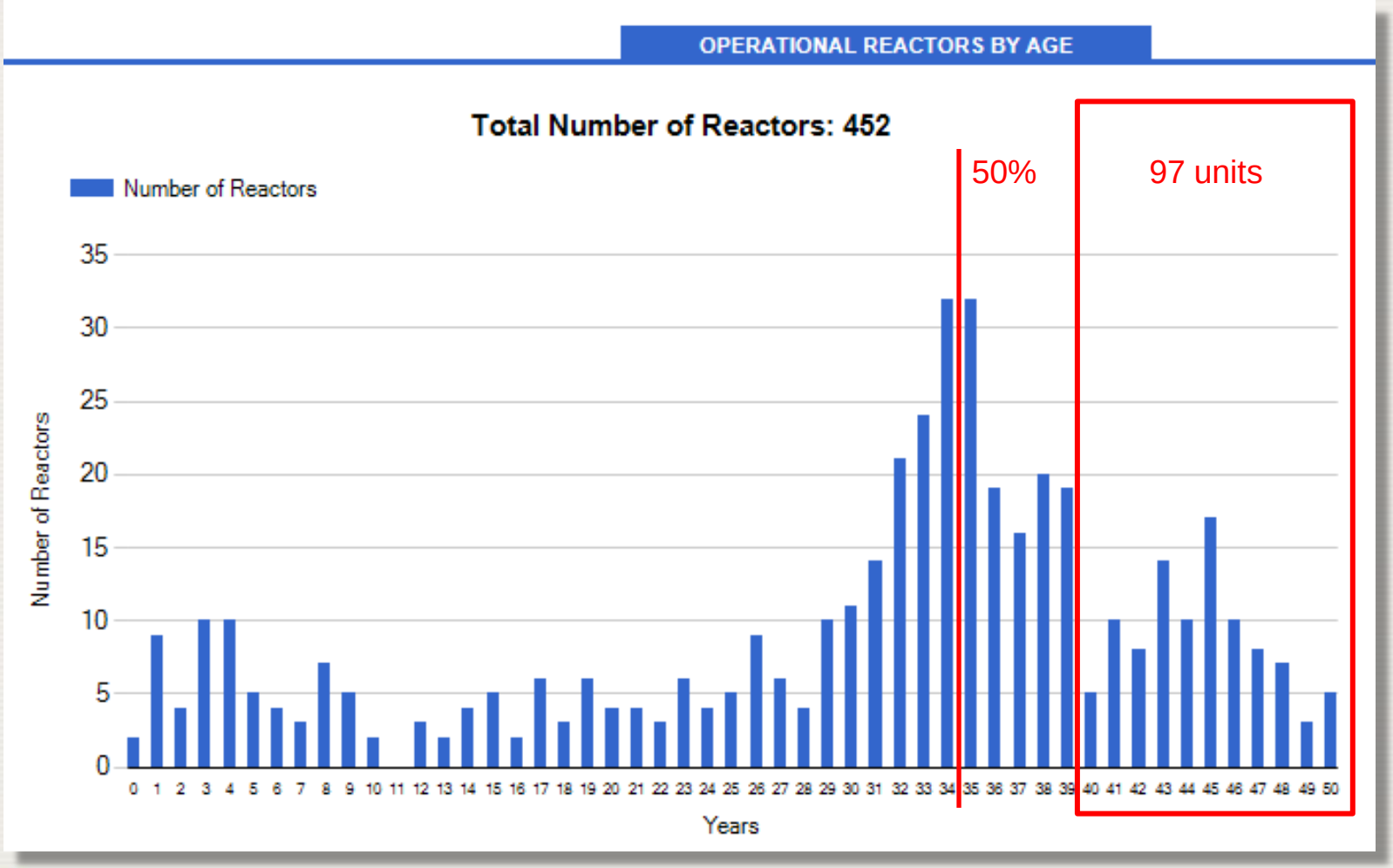
Belarus, Belarusian, Nov 2013

Bangladesh, Rooppur, Nov 2017

Turkey, Akkuyu, Apr 2018

IAEA

Age of operating reactors



As of May 2019

Current challenges

IAEA
International Atomic Energy Agency

Technical working group (TWG) photo, 2019

- I&C program for 2019 - 2023

Alternative TWG group photo from 2019

Russian speaker at the TWG meeting in 2019

- Mr. Aleksey Chernyaev of RASU

Current challenges in the nuclear I&C field

- Safety, security and licensing-driven issues
  - Enhancement of safety through improved systems and processes
  - Implementation of all necessary post-Fukushima improvements
  - Harmonization of standards, licensing practices, and safety classification schemes
  - Issues with software dependability (common cause failure)
  - Digital communications, independence, computer security
- Economic driven issues
  - Improvement of plant efficiency, increase of plant and personnel productivity for cost-effective operation -> competitiveness
  - Long term operation -> ageing management
  - Rapid evolution of digital technologies -> obsolescence management

IAEA

Current challenges in the nuclear I&C field (2)

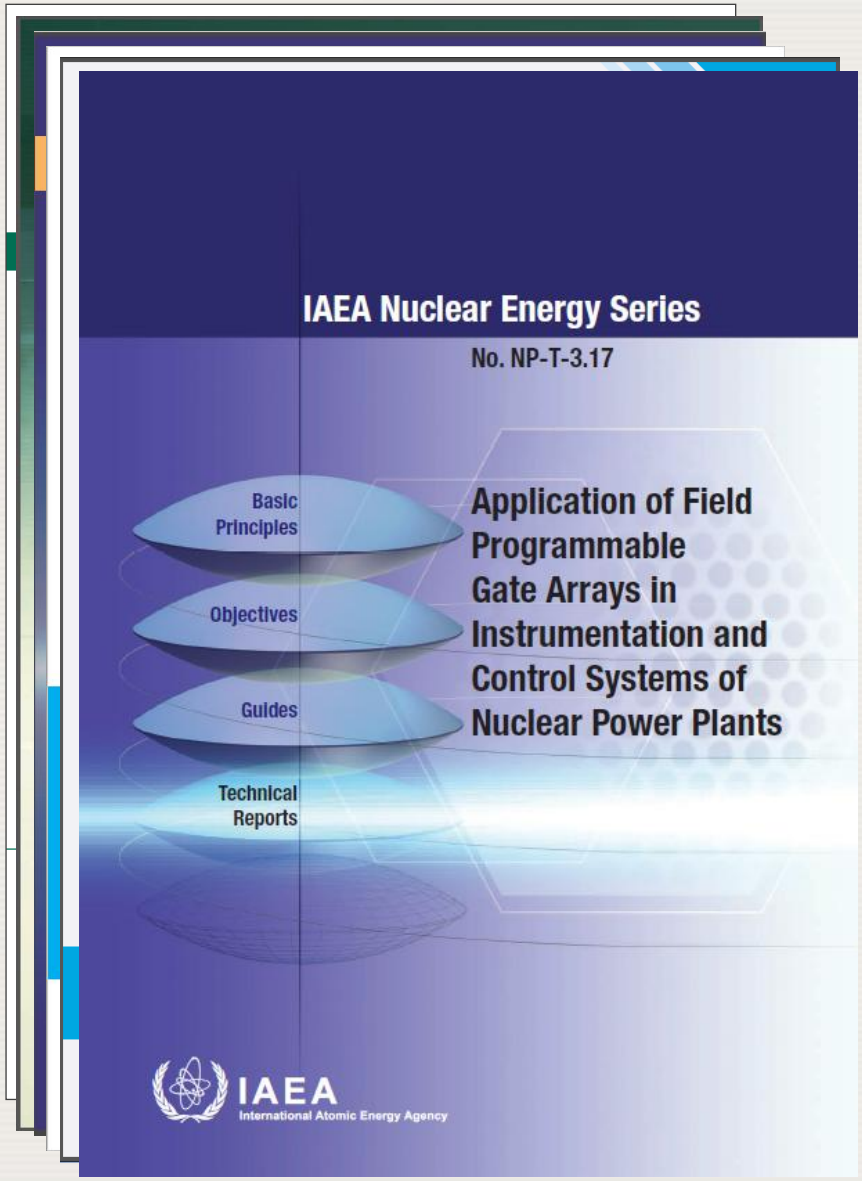
- Issues related to new technologies
  - Use of wireless technologies
  - Use of new information and communications technologies
  - Use of new Human Factors Engineering technologies
  - New reactor designs such as small modular reactors (SMRs)

Publications

IAEA
International Atomic Energy Agency

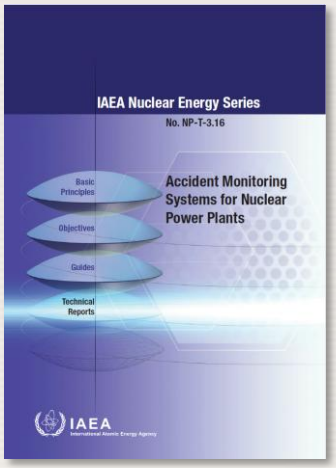
Publications

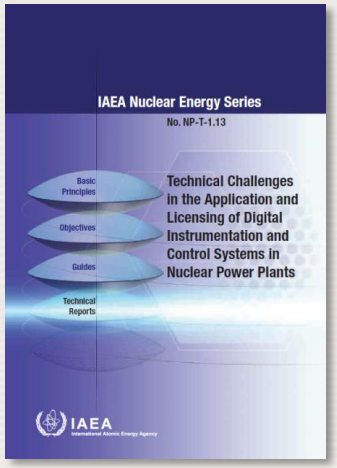
- Nuclear Safety Guides
- Safety Reports Series
- Nuclear Security Series
- Technical Reports Series
- TECDOCs
- Nuclear Energy Series

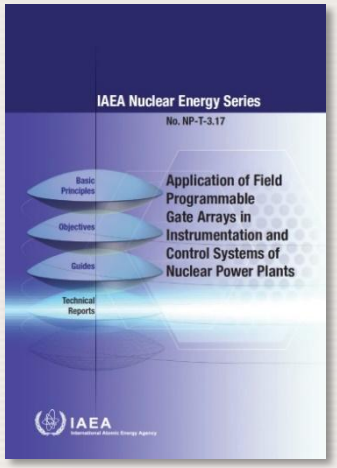


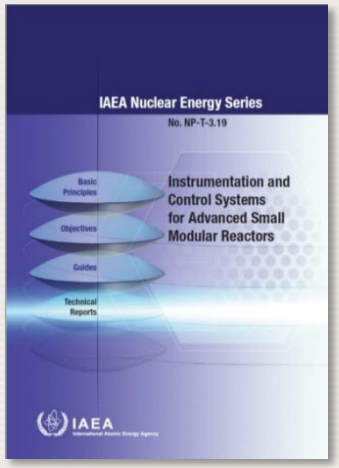
IAEA

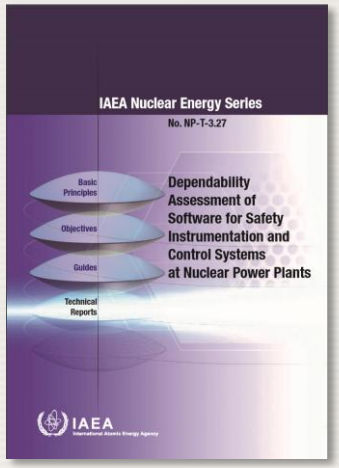
Recent Nuclear Energy Series publications

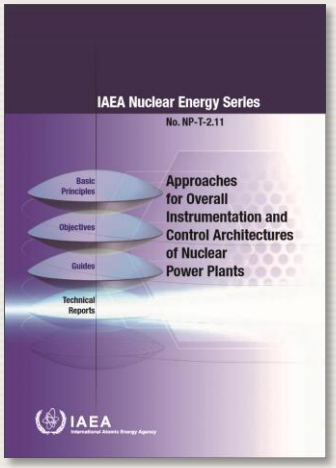


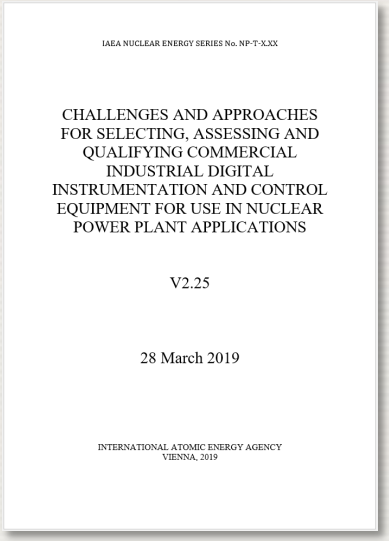










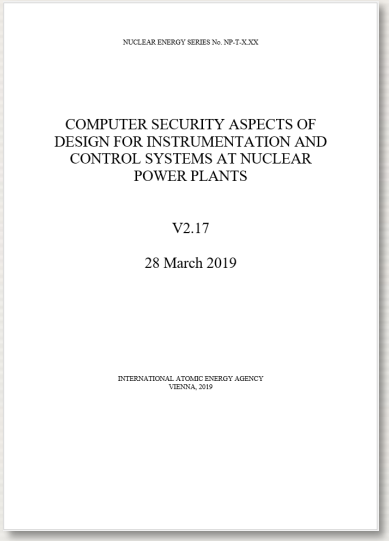

IAEA NUCLEAR ENERGY SERIES No. NP-T-X.XX

CHALLENGES AND APPROACHES FOR SELECTING, ASSESSING AND QUALIFYING COMMERCIAL INDUSTRIAL DIGITAL INSTRUMENTATION AND CONTROL EQUIPMENT FOR USE IN NUCLEAR POWER PLANT APPLICATIONS

V2.25

28 March 2019

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

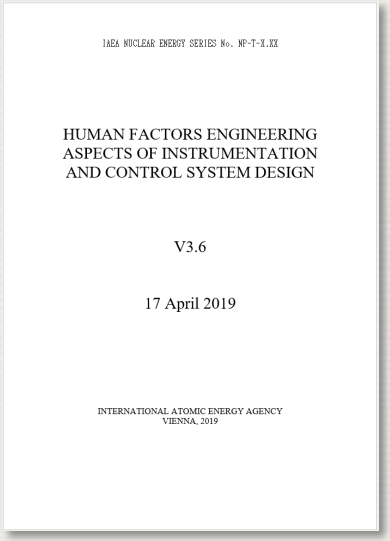

NUCLEAR ENERGY SERIES No. NP-T-X.XX

COMPUTER SECURITY ASPECTS OF DESIGN FOR INSTRUMENTATION AND CONTROL SYSTEMS AT NUCLEAR POWER PLANTS

V2.17

28 March 2019

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019


IAEA NUCLEAR ENERGY SERIES No. NP-T-X.XX

HUMAN FACTORS ENGINEERING ASPECTS OF INSTRUMENTATION AND CONTROL SYSTEM DESIGN

V3.6

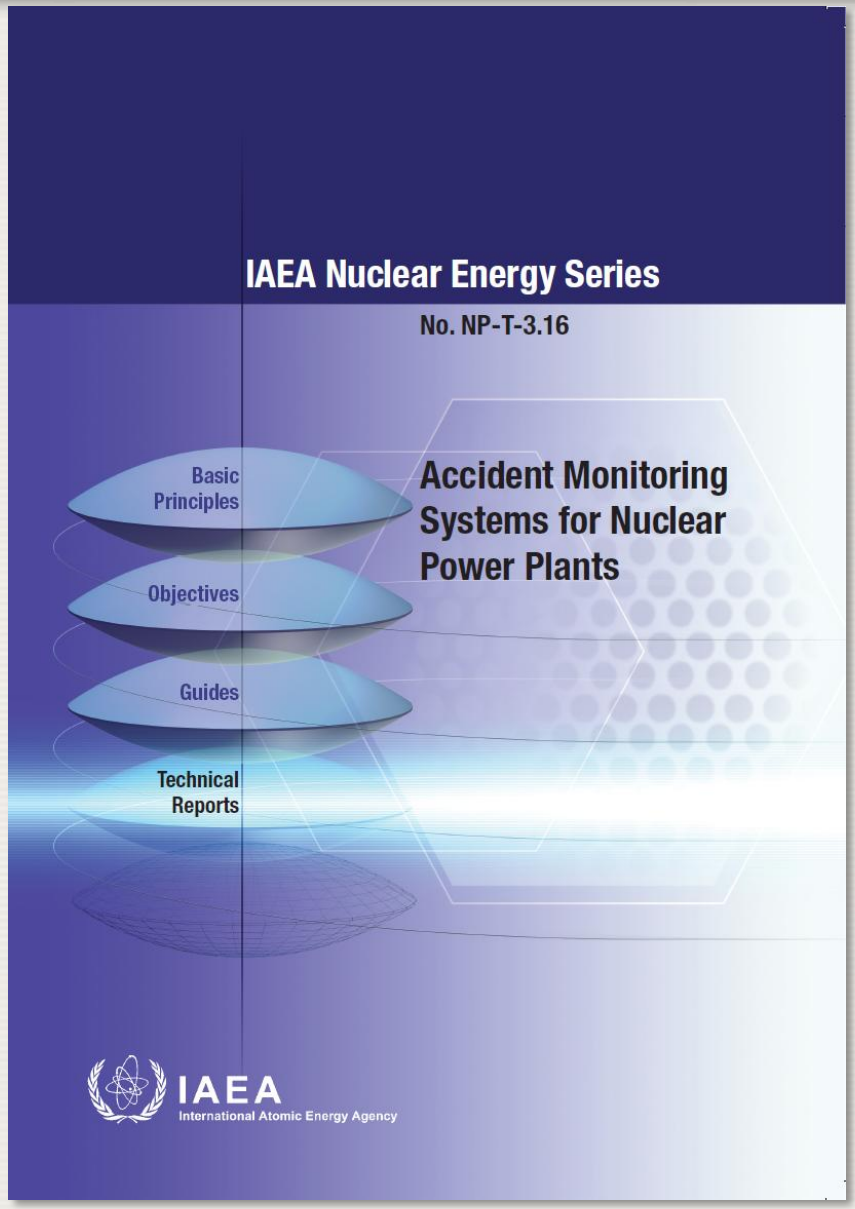
17 April 2019

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

IAEA

Accident monitoring systems for nuclear power plants

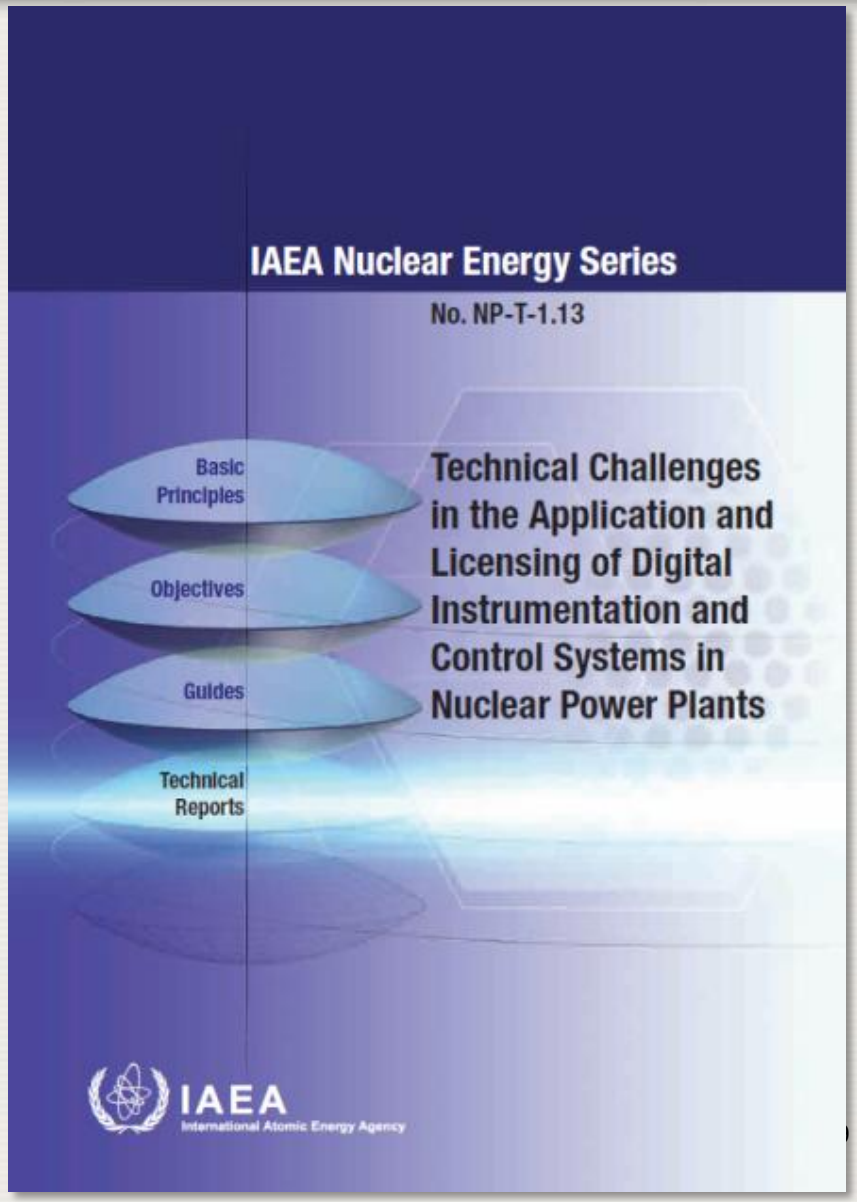
- Introduction
- Accident management for nuclear power plants
- Selection of plant parameters for accident monitoring
- Establishing criteria for designated accident monitoring instrumentation
- Design and implementation considerations for accident monitoring instrumentation
- Technology needs for accident monitoring
- Summary and conclusions



IAEA

Technical challenges in the application and licensing of digital I&C systems

- Products accepted by regulators in one country are frequently difficult to obtain acceptance by another regulator
- Harmonization efforts are underway but progress is very slow
- IAEA publication addresses 17 important issues encountered in digital I&C system design, licensing and implementation



IAEA

The 17 challenges identified in NP-T-1.13

Issue No. 1: Self-diagnostics within a digital instrumentation and control platform

Issue No. 2: Independent verification and validation

Issue No. 3: Management of the functional requirements specification

Issue No. 4: Development of and adherence to configuration management

Issue No. 5: Common cause failure, diversity and defence in depth.

Issue No. 6: Use of smart devices

Issue No. 7: Safety classification schemes

Issue No. 8: Computer security

Issue No. 9: Harmonization of standards.

Issue No. 10: Taking credit for on-line monitoring

Issue No. 11: Environmental qualification of safety system platforms.

Issue No. 12: Impact of hardware description language programmable devices

Issue No. 13: Digital communications

Issue No. 14: Safety classification and function of a soft controller.

Issue No. 15: Formal methods of software development

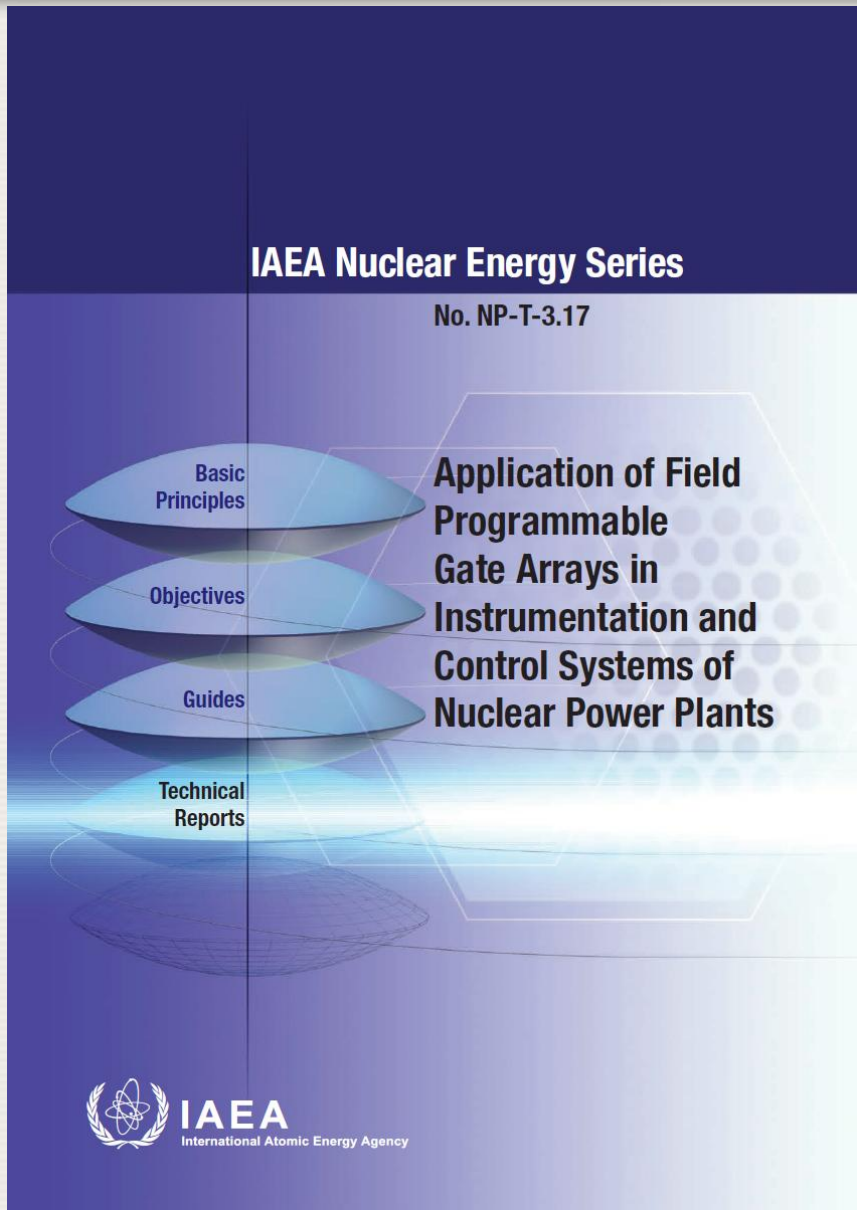
Issue No. 16: Use of wireless technology

Issue No. 17: Reliability (taking credit for digital systems in probabilistic risk assessment).

IAEA

Application of PGAs in I&C systems of NPPs

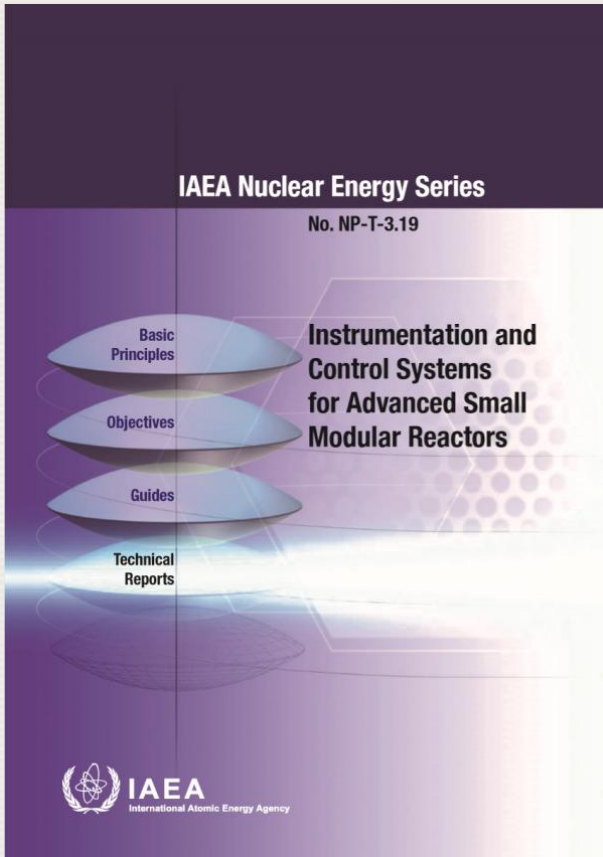
- Introduction to FPGA technology
- Methods and tools for development and verification
- Licensing
- Replacement systems and new NPP designs



IAEA

I&C systems for SMRs

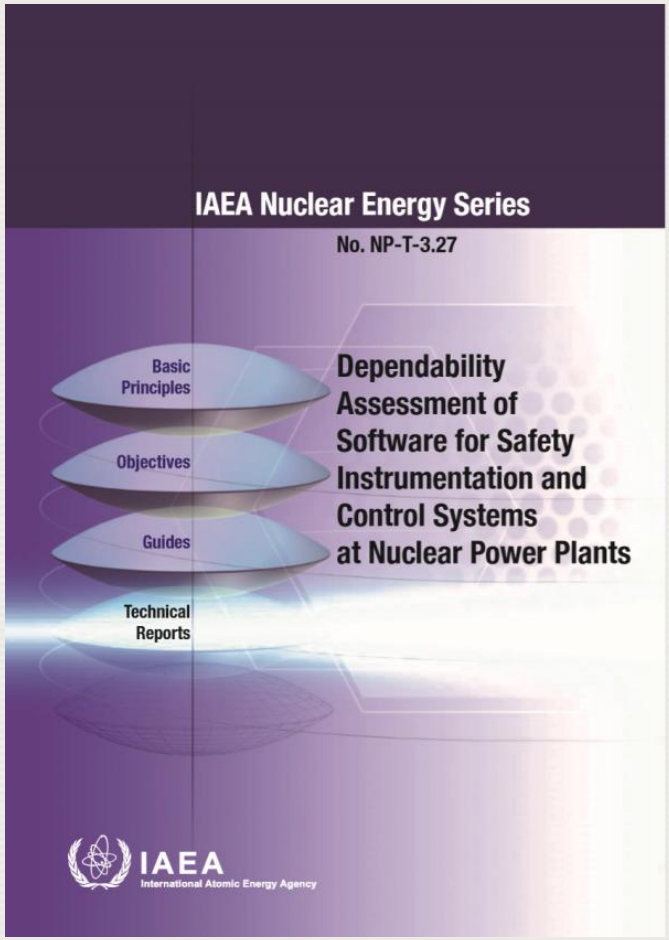
- General SMR objectives and characteristics affecting I&C
  - Measurement characteristics specific to advanced SMRs
  - Operational characteristics specific to advanced SMRs
  - Maintainability characteristics specific to advanced SMRs
  - Economic considerations affecting I&C usage
  - Regulatory considerations
- Distinctive I&C features and issues
  - Approach to design
  - I&C architecture, technology and equipment
  - Fabrication and site integration issues
  - Concepts important for operation of SMRs
  - Maintenance



IAEA

Issues with software dependability

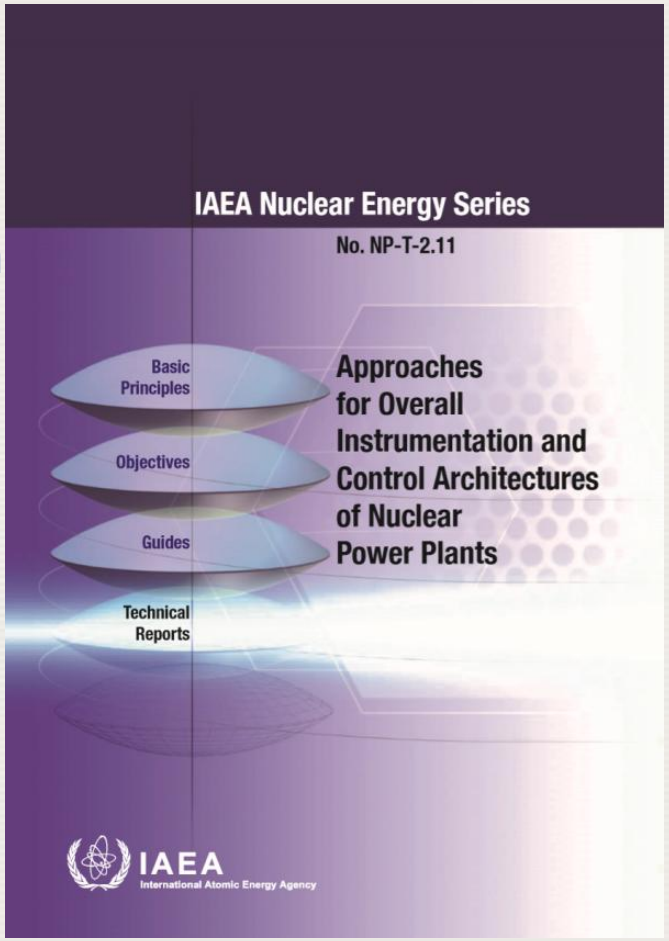
- The evaluation and dependability assessment of software important to safety is an essential and difficult aspect of digital systems safety justification
- The concern is with detecting and removing residual design errors
- These errors might be a risk of common-cause failure (CCF) that could defeat redundancy or defence-in-depth
- To provide adequate confidence, extensive work is under way worldwide
- A new IAEA publication covers relevant aspects of software evaluation and dependability assessment



IAEA

I&C architectural approaches

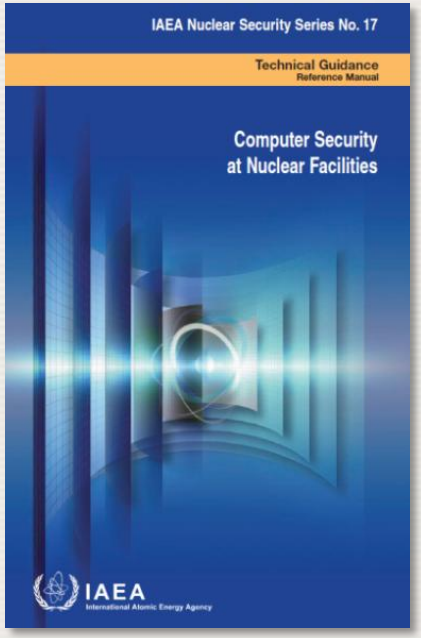
- Description of overall I&C architectures
- Main overall I&C architecture principles
- Development of the overall I&C architecture
- Specific technical considerations for the design of overall I&C architectures
  - Defence in depth
  - Independence among levels of defence in depth
  - Functional specification for I&C and safety classification of I&C systems
  - Computer security
  - I&C failure postulates
  - Dynamic aspects of overall I&C architectures
  - Features supporting testing and diagnostics
  - Architecture design to facilitate future upgrades and modernization

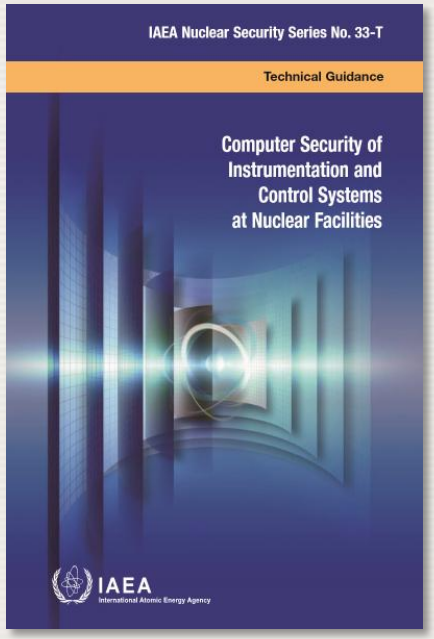


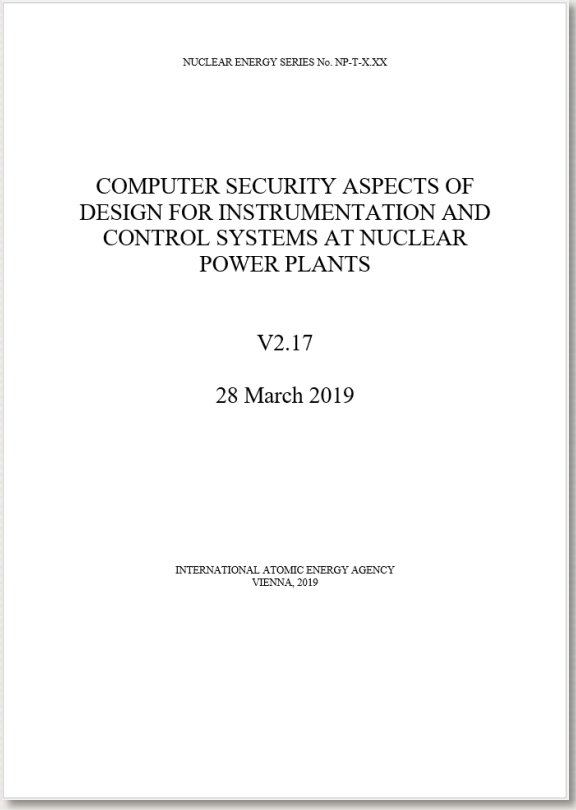
IAEA

Computer security (in printing)

- IAEA guidance aims to overlay security considerations on top of the systems' safety function to meet safety and security objectives at the same time
  - Key concepts for computer security for NPP I&C systems
  - Risk informed approach to computer security
  - Computer security in the I&C system life cycle






NUCLEAR ENERGY SERIES No. NP-T-X.XX

COMPUTER SECURITY ASPECTS OF DESIGN FOR INSTRUMENTATION AND CONTROL SYSTEMS AT NUCLEAR POWER PLANTS

V2.17

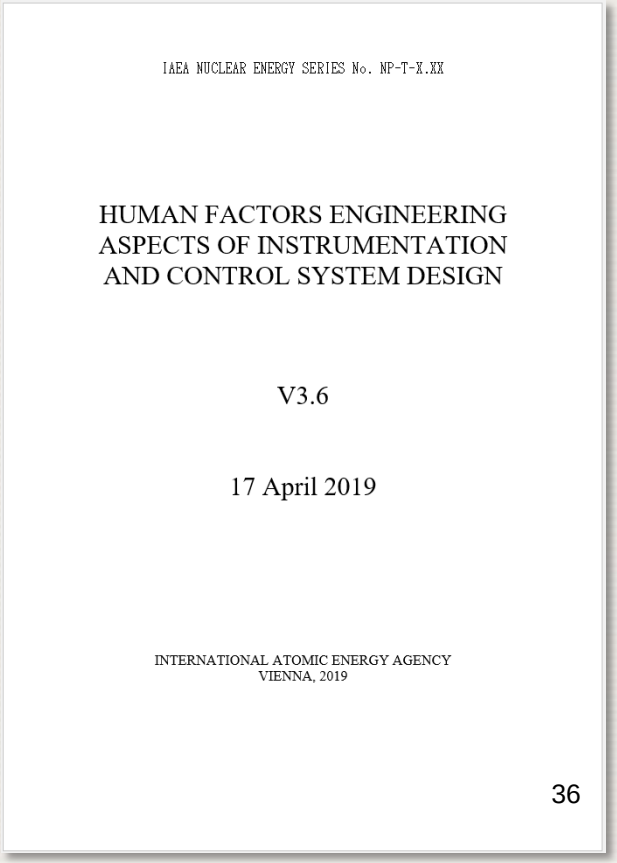
28 March 2019

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

IAEA

Human factors engineering vs. I&C design (in final review)

- Endpoint vision and planning
- I&C system design basis
- HFE analyses output supporting I&C design
- HSI design process and specification
- HFE in the procurement of equipment
- Verification, validation, implementation and operation


IAEA NUCLEAR ENERGY SERIES No. NP-T-X.XX

HUMAN FACTORS ENGINEERING ASPECTS OF INSTRUMENTATION AND CONTROL SYSTEM DESIGN

V3.6

17 April 2019

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

Use of commercial smart devices (in printing)

- Challenges associated with commercial industrial digital I&C equipment
- Strategy for the justification of commercial industrial I&C equipment
- Justification process
- Maintenance of justification
- Regulatory aspects

IAEA NUCLEAR ENERGY SERIES No. NP-T-X.XX

CHALLENGES AND APPROACHES FOR SELECTING, ASSESSING AND QUALIFYING COMMERCIAL INDUSTRIAL DIGITAL INSTRUMENTATION AND CONTROL EQUIPMENT FOR USE IN NUCLEAR POWER PLANT APPLICATIONS

V2.25

28 March 2019

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

Definition of “smart devices” in IEC 62671

- Key features:
  - Programmable electronic device
    - Including, for example, a microprocessor or an FPGA
  - Limited functionality
  - Typically commercial off the shelf
- IEC 62671

a) The device is a pre-existing digital device that contains pre-developed software or programmed logic (e.g. an HPD) and is a candidate for use in an application important to safety.

b) The primary function performed is well-defined and applicable to only one type of application within an I&C system, such as measuring a temperature or pressure, positioning a valve, or controlling speed of a mechanical device, or performing an alarm function.

c) The primary function performed is conceptually simple and limited in scope (although the manner of accomplishing this internally may be complex).

d) The device is not designed so that it is re-programmable after manufacturing nor can the device functions be altered in a general way so that it performs a conceptually different function: only pre-defined parameters can be configured by users.

e) If the primary device function can be tuned or configured, then this capability is restricted to parameters related to the process (such as process range), performance (speed or timing), signal interface adjustment (such as selection of voltage or current range), or gains (such as adjustment of proportional band).

IAEA

Key features and challenges for smart devices

- Increased functionality compared to non-smart devices
  - E.g. signal processing, communications, diagnostics
- Additional complexity of the component, multifunction, primary and support functions
- Development to non-nuclear standards
  - May need reverse engineering in certain instances
- Potential new failure modes and hazards
  - Additional risk of common cause failures
- Frequent design changes by manufacturers may cause previous testing to be invalidated
  - Unsure of how to evaluate software revision or sub-component changes on previous test data

IAEA

Key features and challenges for smart devices (cont'd)

- Cyber security
  - New vulnerabilities
  - How to address the potential presence of a virus or malicious code
- Counterfeit, fraudulent and suspect items
  - Digital sub-components are highly vulnerable to counterfeiting
- Engagement with manufacturer
  - Access to documentation, processes, source code can be problematic
  - Identification of embedded digital devices with undeclared content

Commercial grade dedication

- An acceptance process of the suitability and correctness of commercial industrial I&C equipment for their intended nuclear applications, which should confirm that:
  - They meet the functional requirements,
  - Are free from systematic faults and
  - No anticipated external effects can result in an unsafe operation of their principal functions

IAEA

Justification process

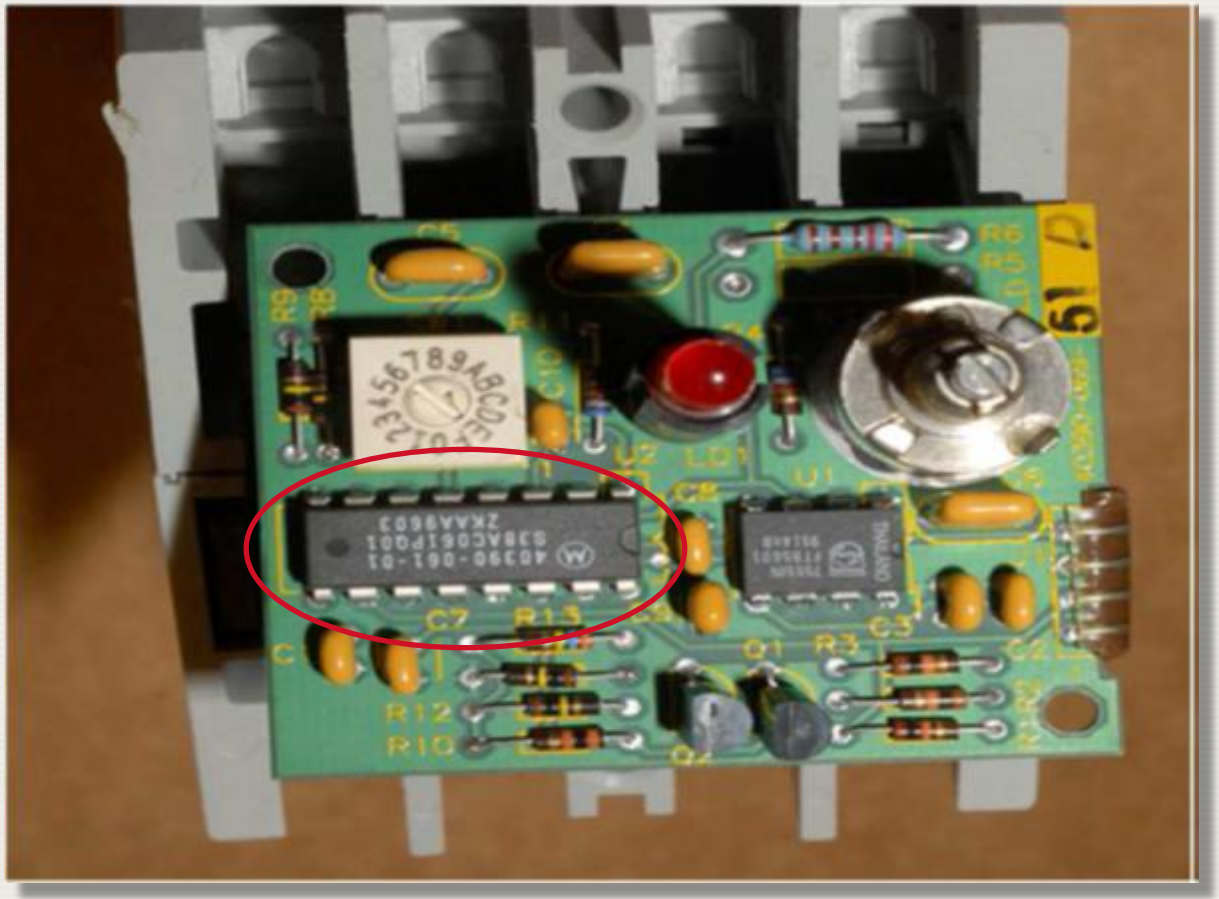
- Step 1: Definition of requirements and prerequisites
- Step 2: Selection of candidate devices
- Step 3: Manufacturer information and support
- Step 4: Planning
- Step 5: Assessment
  - Quality assurance, development and manufacturing processes
  - Functional, performance and dependability assessment
  - Vulnerabilities and failure modes assessment
  - Environmental and seismic qualification
  - Independent complementary assessment
- Step 6: Identification of lifetime issues
- Step 7: Justification documentation package

Undeclared digital content

- What is undeclared digital content (UDC)?
  - When a basic component that is being dedicated is believed to contain analog devices only contains a digital device
- Why is the identification of UDC important during the qualification and dedication process?
  - Commercial manufacturers are constantly updating their products to include digital content to reduce cost, improve reliability and increase their competitive advantage
  - The commercial manufacturer may not declare the change in their literature or marketing materials and may not require a part number change, especially when the form, fit and function is the same as seen through the commercial viewpoint
  - UDC may introduce failure modes that should be evaluated during the qualification and dedication process. For example,
    - EMI/RFI
    - Software change control

Industry example

- The commercial manufacturer (Allen Bradley) originally designed the 700 series timing relay with a digital logic board that had a custom integrated circuit



IAEA

Industry example (cont'd)

- As technology improved, the custom IC was replaced with a CPLD board which contained a "programmable" integrated circuit chip. This chip is programmed at the factory prior to installation in the relay

IAEA

Industry example (cont'd)

- The change in the relay was not discovered since it was not visible during dedication
- The new CPLD chip was susceptible to EMI and failed in the plant
- If a component with UDC causes a failure in the plant, the cost is extremely high
- It is cheaper by orders of magnitude to do the evaluation up front then to deal with a problem after installation
- Requires EMI/RFI testing and FMEA evaluation/test program to complete dedication

How to detect if a component may contain UDC

- By carefully reviewing product literature for key words or standards reference
  - Any device with any of the following key words in the description, datasheet, manual or catalog literature:
    - Programmable
    - Configurable
    - Timer
    - Controller
    - Solid state
    - Wireless
    - SMART
    - External connection (i.e.; USB, Ethernet port)
- All items identified as high risk may need a destructive test sample that is torn down to inspect for UDC

Conclusion for the application of COTS

- Use of COTS digital devices is important in maintaining and operating our plants in a safe and reliable manner
- Digital content may change over time within a product due to availability and technology development
- Components that have been previously qualified and dedicated may contain undeclared digital content
  - Clearly identify the application for which a smart device is needed
  - Assess whether a non-smart device option is possible
  - Consider the justification of the device in the context of the overall I&C architecture
    - Identify failure modes associated with the device
    - Assess whether there are common cause constraints in the selection of the device

IAEA

Coordinated Research Projects

IAEA

International Atomic Energy Agency

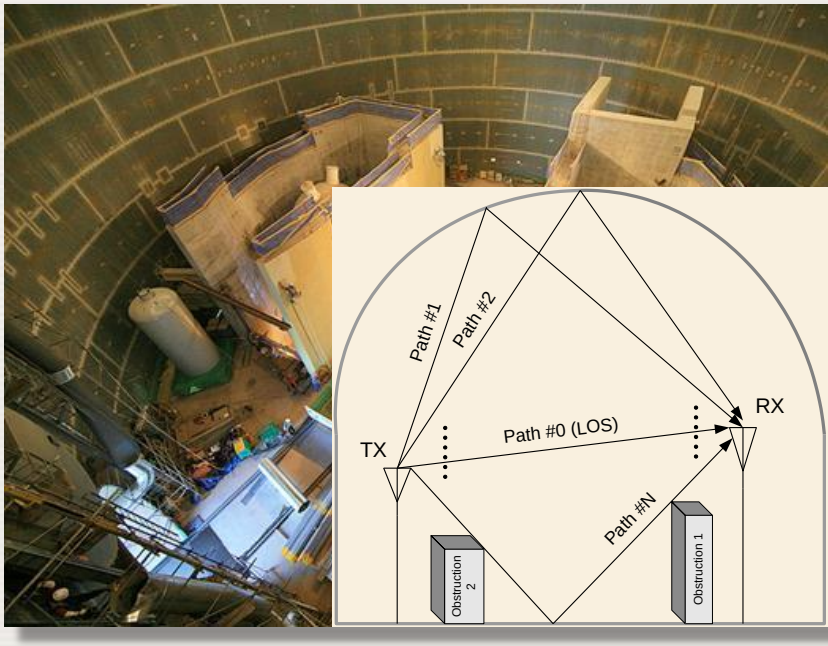
Coordinated Research Projects

- CRPs in general
  - The Coordinated Research Projects (CRPs) bring together research institutes in Member States to collaborate on research topics of common interest
  - Research is supported when it addresses areas where coordination by the IAEA would provide significant added value or represents a unique contribution
  - Results of research activities supported by the Agency are disseminated to all Member States
- CRP contract or agreement
- Chief Scientific Investigators (CSIs)
- Research Coordination Meetings (3 to 4 years)
- CRP Report and Benchmarking

IAEA

Application of wireless technologies in NPP I&C systems

- The technology is finding its way in a wider scope of applications in the nuclear power industry
  - Saving cable costs and installation time
  - Increased flexibility of information gathering through temporary sensor deployment
- IAEA coordinated research project conducted during 2015 to 2018
  - The overall objective was to develop and demonstrate techniques of advanced wireless communication in I&C systems of NPPs that can be used for transferring process and diagnostic information in a nuclear specific environment



IAEA

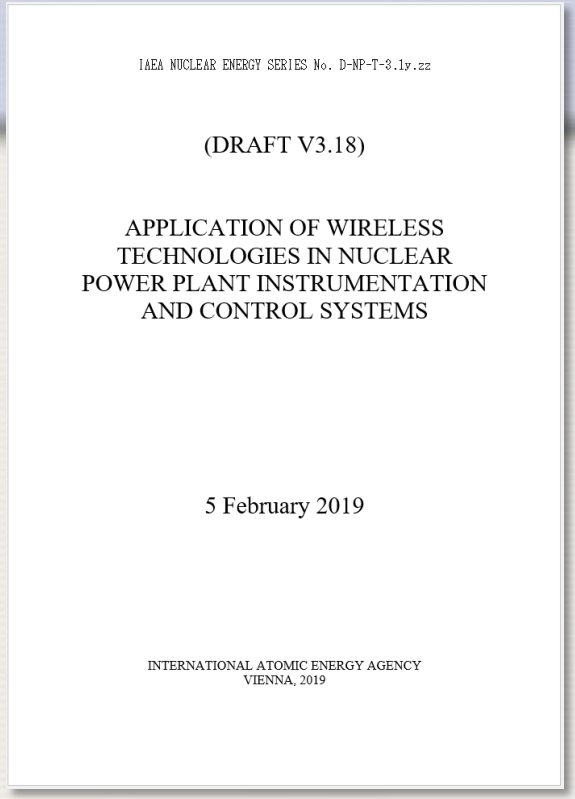
Research coordination meeting at RASU

IAEA

Research coordination meeting at RASU

CRP report on wireless technologies (in printing)

- Codes, standards and regulatory guides
- Wireless technologies for nuclear applications
  - Components of a wireless sensor
  - RF communication considerations
  - Energy source considerations
  - Nuclear specific considerations
- Practice, experience and lessons learned
- Potential applications
- Emerging technologies and challenges
  - Wireless communication through existing apertures in walls and doors
  - Electromagnetic propagation estimation using ray tracing methods
  - Electromagnetic non-line of sight propagation
  - Optimum polarization wireless communication
  - Wireless power transfer
- 10 annexes on specific details of the research


IAEA NUCLEAR ENERGY SERIES No. D-NP-T-3.1y.zz

(DRAFT V3.18)

APPLICATION OF WIRELESS TECHNOLOGIES IN NUCLEAR POWER PLANT INSTRUMENTATION AND CONTROL SYSTEMS

5 February 2019

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

IAEA

Publications from the Nuclear Safety and Security Department

Safety:

- Safety Guides
  - SSG-39 Design of I&C systems for nuclear power plants (2016)
  - SSG-51 Human Factors Engineering for nuclear power plants (exp. 2019)
  - DS514 Equipment qualification for nuclear installations (exp. 2020)
- TECDOCs
  - Assessment of Equipment Capability to Perform Reliably Under Severe Accident Conditions (2017)
  - Criteria for Diverse actuation Systems for Nuclear Power Plants (2018)

Alex Duchac

Publications from the Nuclear Safety and Security Department

Security:

- NSS 33-T: Computer security for I&C systems at nuclear facilities (2018)
- NST045: Computer security for nuclear security (exp. 2019)
- NST047: Computer security techniques for nuclear facilities (exp. 2019)

Mike Rowland

Links to access IAEA publications on I&C

- For Nuclear Energy I&C webpage
  - https://www.iaea.org/topics/operation-and-maintenance/instrumentation-and-control-systems-for-nuclear-power-plants
- For Nuclear Energy I&C publications
  - https://www.iaea.org/topics/operation-and-maintenance/instrumentation-and-control-systems-for-nuclear-power-plants/iaea-publications
- For all Nuclear Energy Series publications
  - https://www.iaea.org/publications/search/type/nuclear-energy-series
- IAEA publications in general
  - https://www.iaea.org/publications

Review Missions

IAEA
International Atomic Energy Agency

IERICS missions

- IERICS: Independent Engineering Review of Instrumentation and Control Systems
  - To review the design, prototype, testing, operation, maintenance, and modernization of I&C systems
  - Conducted by a team of international experts from complementary technical areas
  - Based on appropriate IAEA documents, such as Safety Guides and Nuclear Energy Series Reports
  - Findings include a list of recommendations, suggestions and identified good practices
- IERICS mission website: https://www.iaea.org/services/review-missions/independent-engineering-review-of-ic-systems-ierics
- A forthcoming mission is considered by Iran

IAEA

IERICS missions completed to date

- Doosan Heavy Industries & Construction Co., RoK, 2010
- Research and Production Corporation Radiy, Ukraine, 2010
- Joint Stock Company VNIIAES, Russia, 2012
- Joint Stock Company SRPA “Impulse”, Ukraine, 2013
- China Techenergy Co. Ltd., China, 2016
- China Nuclear Control System Engineering Co. Ltd., China, 2016

IERICS mission at VNIIAES in 2012

VNIIAES IERICS mission final report

IAEA
International Atomic Energy Agency

IERICS-RUS-2013
Final version
Original: English
Distribution: Restricted

INTERNATIONAL ATOMIC ENERGY AGENCY

FINAL MISSION REPORT

INDEPENDENT ENGINEERING REVIEW OF INSTRUMENTATION AND CONTROL SYSTEMS (IERICS)

IAEA REVIEW OF THE VNIIAES COMPUTERIZED PROCESS CONTROL SYSTEM FOR AES-2006 (VVER-1200) NPPs

Moscow, Russia

Review Mission: 6 - 15 December 2012
Close-out Meeting: 15 to 17 October 2013

INDEPENDENT ENGINEERING REVIEW OF
INSTRUMENTATION AND CONTROL SYSTEMS
(IERICS)

IAEA REVIEW OF THE VNIIAES COMPUTERIZED PROCESS CONTROL SYSTEM
FOR AES-2006 (VVER-1200) NPPs

IAEA DEPARTMENT OF NUCLEAR ENERGY
DIVISION OF NUCLEAR POWER

FINAL MISSION REPORT

INDEPENDENT ENGINEERING REVIEW OF INSTRUMENTATION AND CONTROL SYSTEMS (IERICS)

IAEA REVIEW OF THE VNIIAES COMPUTERIZED PROCESS CONTROL SYSTEM FOR AES-2006 (VVER-1200) NPPs

REPORT TO
Joint Stock Company "VNIIAES"

Review Mission: 6 to 15 December 2012
Close-out Meeting: 15 to 17 October 2013
Moscow, Russia

Possible cooperation between IAEA and WANO

RASU by rosatom

WANO involvement to the digital I&C issues solutions: new tasks announced at BGM-2017

WANO 30 YEARS 1989-2019 GLOBAL LEADERSHIP IN NUCLEAR SAFETY

- Importance of digital I&C challenges was highlighted several times at BGM-2017 in Republic of Korea
- All new NPP Units and Units under modernization are mainly based on digital I&C
- This enhancement of the level of NPP automation brings new challenges for NPP operational safety performance
- Reliability of digital I&C has direct influence on reliability, effectiveness and safety of the NPP operation
- Assessment of digital I&C from the point of view of their influence on reliable and safe operation of NPP could be a new and very significant task of WANO performance (in possible cooperation with IAEA)

Slide: courtesy of V. Sivokon

Major events planned for 2019

- 27th Meeting of the Technical Working Group on Nuclear Power Plant Instrumentation and Control, 15-17 May 2019, Vienna, Austria
- Technical meeting on “Critical Challenges with Digital Instrumentation and Control Systems at Nuclear Power Plants”, 8-11 October 2019, Budapest, Hungary
- Eastern European Regional I&C Workshop, 19-22 November 2019, Bucharest, Romania
- Technical Meeting on “Management of Direct Current Power Systems and Application of Digital Devices in Safety Electrical Power Systems”, 2-6 December 2019, Vienna, Austria
- 12th International Workshop on the Application of FPGAs in NPPs, 14-16 October 2019, Budapest, Hungary
- World Nuclear Association’s Technical Workshop on Current Status and Difficulties of I&C Modernization, 29-31 October 2019, Erlangen, Germany

IAEA

Thank you for your attention!

IAEA
International Atomic Energy Agency

Nuclear Energy Series published 2008-2018

1. Approaches for overall I&C architectures of nuclear power plants
2. Dependability assessment of software for safety I&C systems at NPPs
3. Instrumentation and control systems for advanced SMRs
4. Application of Field Programmable Gate Arrays
5. Technical Challenges in the Application and Licensing of Digital Instrumentation and Control
6. Accident Monitoring Systems for Nuclear Power Plants
7. Advanced Surveillance, Diagnostic and Prognostic Techniques in Monitoring SSCs
8. Electric Grid Reliability and Interface with NPPs
9. Assessing and Managing Cable Ageing in NPPs
10. Core Knowledge of Instrumentation and Control Systems
11. Integration of Analog and Digital Instrumentation and Control Systems in Hybrid Control Rooms
12. Protecting Against Common Cause Failures
13. Implementing Digital I&C Systems in the Modernization of Nuclear Power Plants
14. The Role of I&C Systems in Power Uprating Projects
15. On-line Monitoring for Improving Performance of Nuclear Power Plants; Part 2: Process and Component Condition Monitoring and Diagnostics
16. On-line Monitoring for Improving Performance of Nuclear Power Plants; Part 1: Instrument Channel Monitoring

IAEA

Latest IAEA Technical Documents (TECDOC) 1998-2016

- Preparing and Conducting Review Missions of Instrumentation and Control Systems in Nuclear Power Plants
- Management of life cycle and ageing at nuclear power plants: Improved I&C maintenance
- Managing modernization of nuclear power plant I&C systems
- Solutions for Cost Effective Assessment of Software Based I&C Systems in Nuclear Power Plants
- Harmonization of the Licensing Process for Digital I&C Systems in Nuclear Power Plants
- Information Integration in Control Rooms and Technical Offices in Nuclear Power Plants
- Assessment and management of ageing of major nuclear power plant components important to safety: In-containment instrumentation and control cables
- Management of Ageing of I&C Equipment in NPPs
- Specification of Requirements for Upgrades Using Digital Instrument and Control Systems
- Modernization of Instrumentation and Control in NPPs

IAEA

IAEA Technical Report Series (TRS) 1984-2000

- Quality Assurance for Software Important Safety
- Modern Instrumentation and Control for Nuclear Power Plants: A Guidebook
- Verification and Validation of Software Related to Nuclear Power Plant Instrumentation and Control
- Development and Implementation of Computerized Operator Support Systems in Nuclear Installations
- Software Important to Safety in Nuclear Power Plants
- Nuclear Power Plant Instrumentation and Control: A Guidebook