Importance of modern instrumentation and control systems in nuclear power plants

16th International Workshop on Nuclear Safety and Simulation Technology

Oszvald Glöckler

Beijing, China

November 24 | 2013

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Outline

- Modernization of instrumentation and control (I&C) systems and components in nuclear power plants (NPPs);
- Applications of Field Programmable Gate Arrays (FPGAs) in NPPs;
- I&C related activities of the International Atomic Energy Agency (IAEA).

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Modernization of I&C systems

- More than 50% of the world's 435 operating NPPs in 30 countries, have had some level of digital I&C upgrade to systems important to safety.

- 71 new nuclear reactors, currently under construction around the world, will have either completely digital I&C technology for their control and safety systems, or a modern hybrid system of digital and analog components.

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http://www.iaea.org/PRIS/WorldStatistics/Operatio

PRIS - Miscellaneous report...

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IAEA | PRIS Power Reactor Information System

World Statistics | Country Statistics | Publications | Glossary | About PRIS

REACTOR STATUS REPORTS
- Operational & LTS
- Under Construction
- Permanent Shutdown

LAST THREE YEAR FACTORS
- Energy Availability
- Unit Capability
- Unplanned Capability Loss

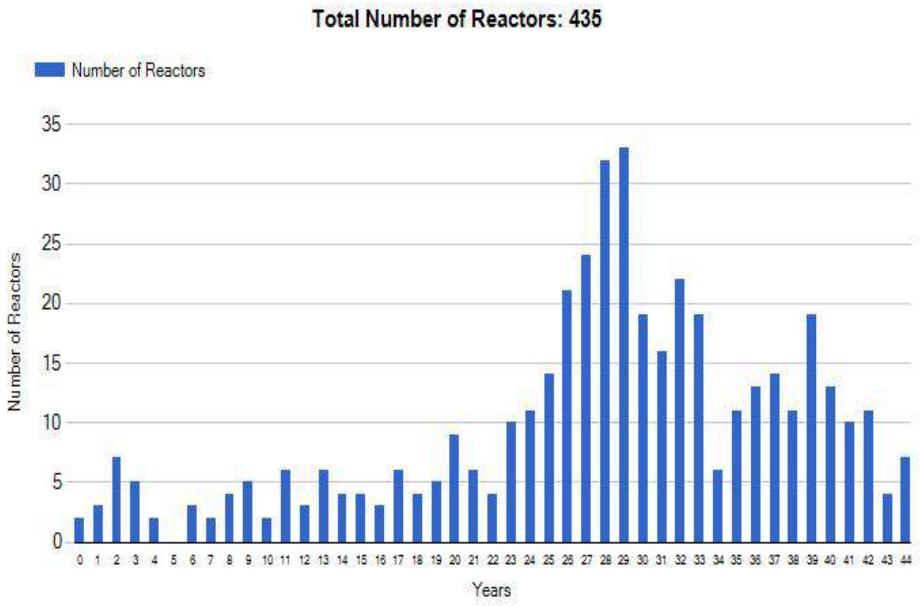
LIFETIME FACTORS
- Energy Availability
- Unit Capability
- Unplanned Capability Loss

TREND REPORTS
- Nuclear Power Capacity
- Energy Availability
- Unit Capability
- Unplanned Capability Loss
- Load Factor
- Electricity Supplied

MISCELLANEOUS Reports
- Nuclear Share

Operational Reactors by Age

OPERATIONAL REACTORS BY AGE



Age of reactor is determined by its first grid connection. Reactors connected in current year are assigned with the age 0 years.

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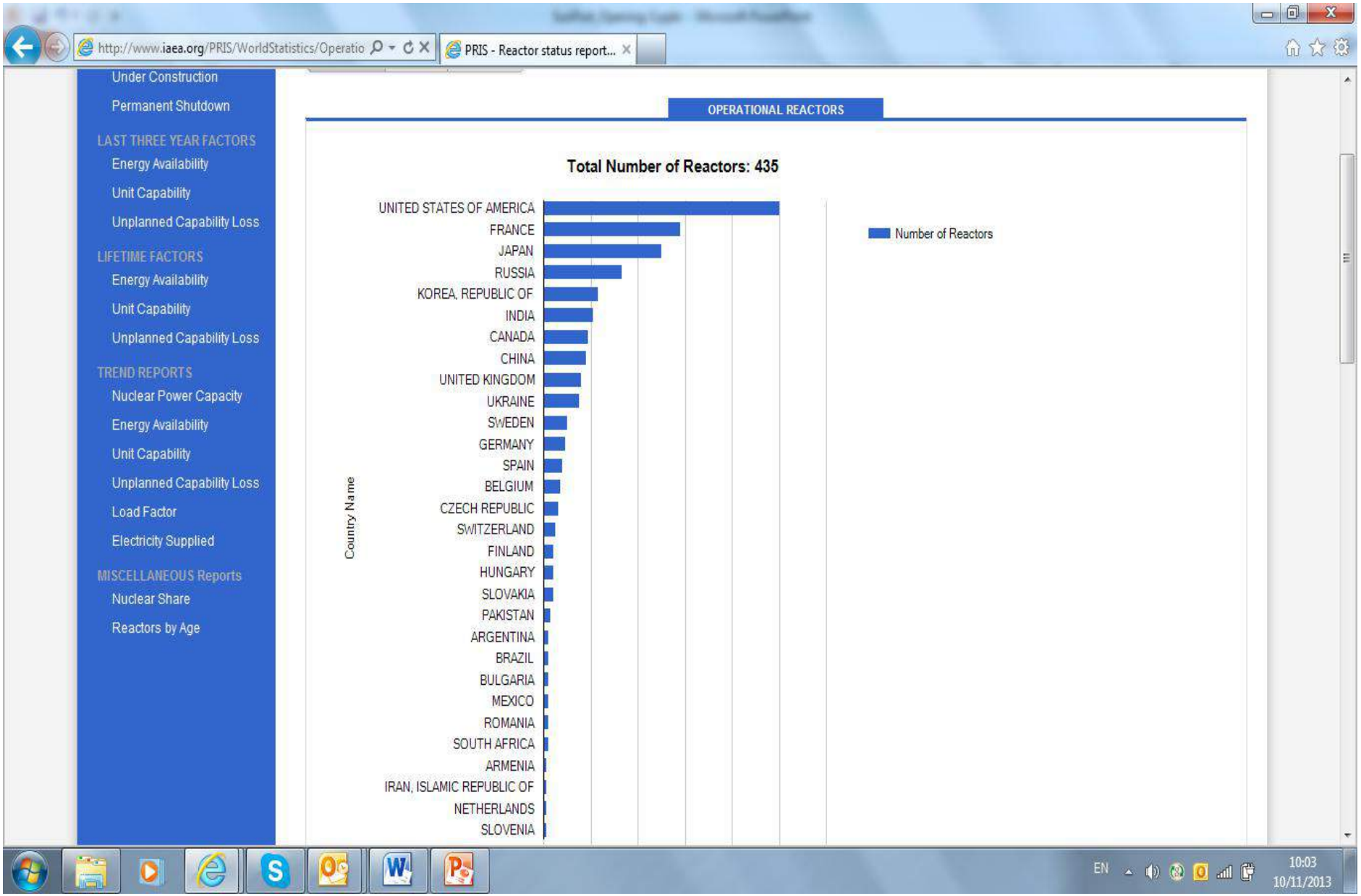
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TREND REPORTS
Nuclear Power Capacity
Energy Availability
Unit Capability
Unplanned Capability Loss
Load Factor
Electricity Supplied
MISCELLANEOUS Reports
Nuclear Share
Reactors by Age
OPERATIONAL REACTORS
Total Number of Reactors: 435
Country Name
UNITED STATES OF AMERICA
FRANCE
JAPAN
RUSSIA
KOREA, REPUBLIC OF
INDIA
CANADA
CHINA
UNITED KINGDOM
UKRAINE
SWEDEN
GERMANY
SPAIN
BELGIUM
CZECH REPUBLIC
SWITZERLAND
FINLAND
HUNGARY
SLOVAKIA
PAKISTAN
ARGENTINA
BRAZIL
BULGARIA
MEXICO
ROMANIA
SOUTH AFRICA
ARMENIA
IRAN, ISLAMIC REPUBLIC OF
NETHERLANDS
SLOVENIA
Number of Reactors
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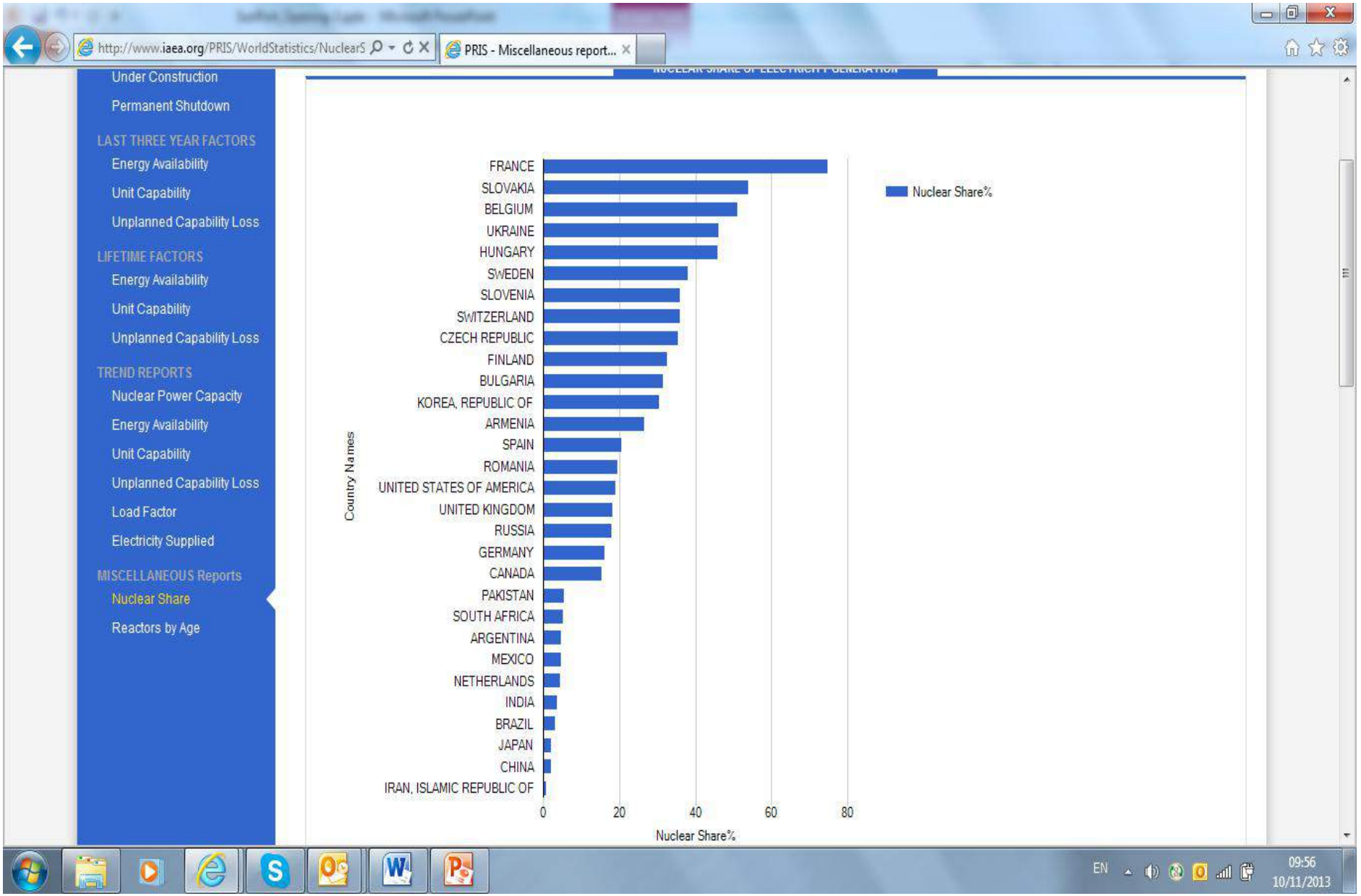
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Electricity Supplied
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Reactors by Age
FRANCE
SLOVAKIA
BELGIUM
UKRAINE
HUNGARY
SWEDEN
SLOVENIA
SWITZERLAND
CZECH REPUBLIC
FINLAND
BULGARIA
KOREA, REPUBLIC OF
ARMENIA
SPAIN
ROMANIA
UNITED STATES OF AMERICA
UNITED KINGDOM
RUSSIA
GERMANY
CANADA
PAKISTAN
SOUTH AFRICA
ARGENTINA
MEXICO
NETHERLANDS
INDIA
BRAZIL
JAPAN
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IRAN, ISLAMIC REPUBLIC OF
Country Names
0
20
40
60
80
Nuclear Share%
Nuclear Share%
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http://www.iaea.org/PRIS/WorldStatistics/UnderCo

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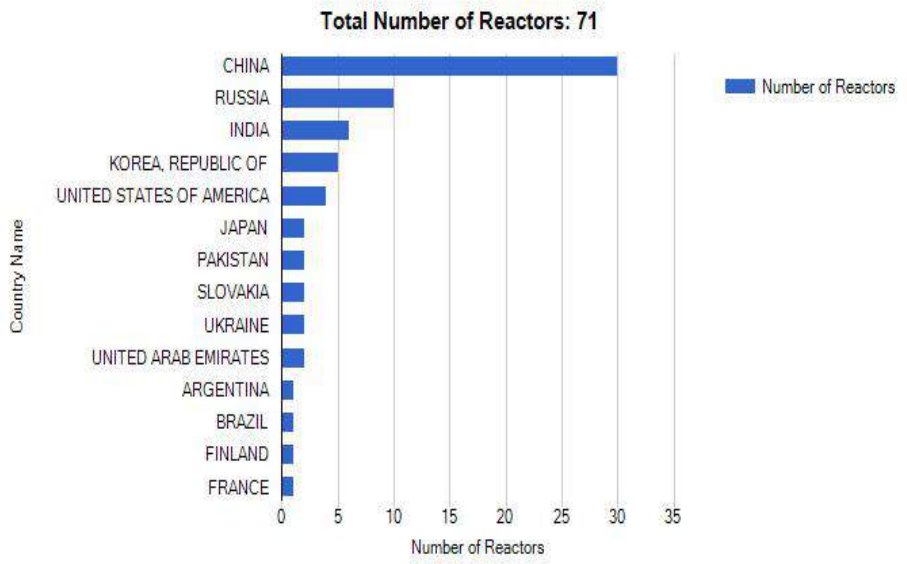
MISCELLANEOUS Reports
- Nuclear Share

Under Construction Reactors

By Country | By Type | By Region

UNDER CONSTRUCTION REACTORS



The total Number of Reactors includes also 2 reactors in Taiwan, China

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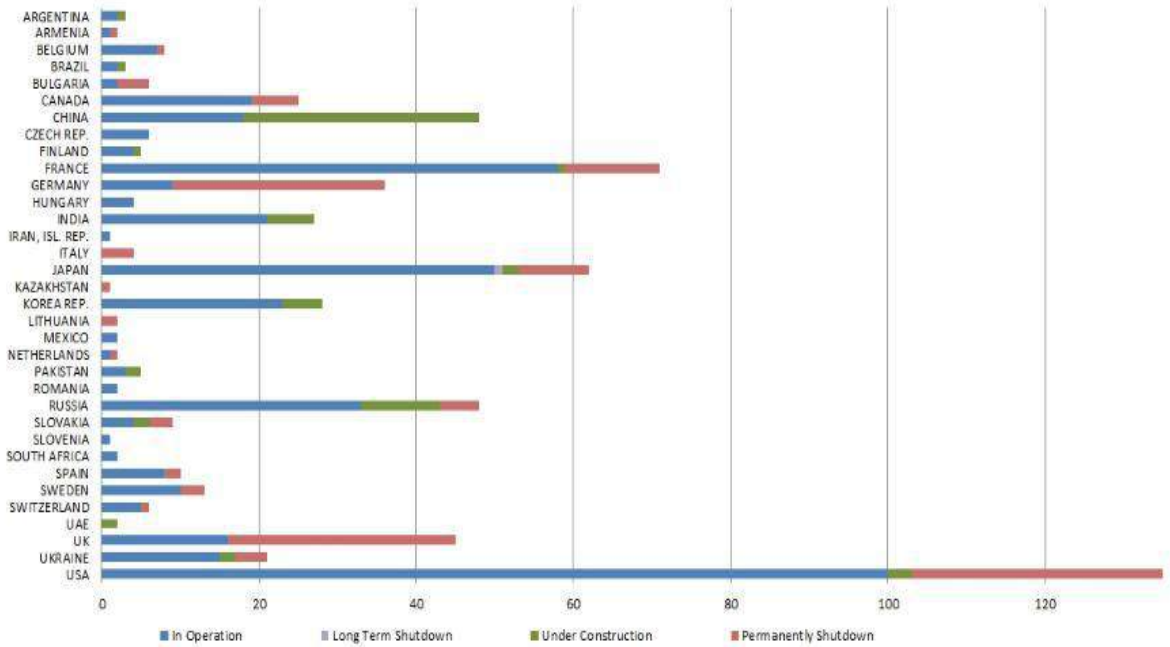
http://www.iaea.org/PRIS/CountryStatistics/Counti

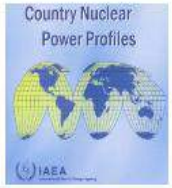
PRIS - Country Statistics

- Canada
- China
- Czech Republic
- Finland
- France
- Germany
- Hungary
- India
- Iran, Islamic Republic of
- Italy
- Japan
- Kazakhstan
- Korea, Republic of
- Lithuania
- Mexico
- Netherlands
- Pakistan
- Romania
- Russia
- Slovakia
- Slovenia
- South Africa
- Spain
- Sweden
- Switzerland
- Ukraine

Number of Power Reactors by Country and Status



COUNTRY NUCLEAR POWER PROFILES (CNPP)



The web-based Country Nuclear Power Profiles publication compiles information – updated annually - on nuclear power programmes in IAEA Member States and relevant legislative, regulatory and international frameworks.

Click here to view CNPP

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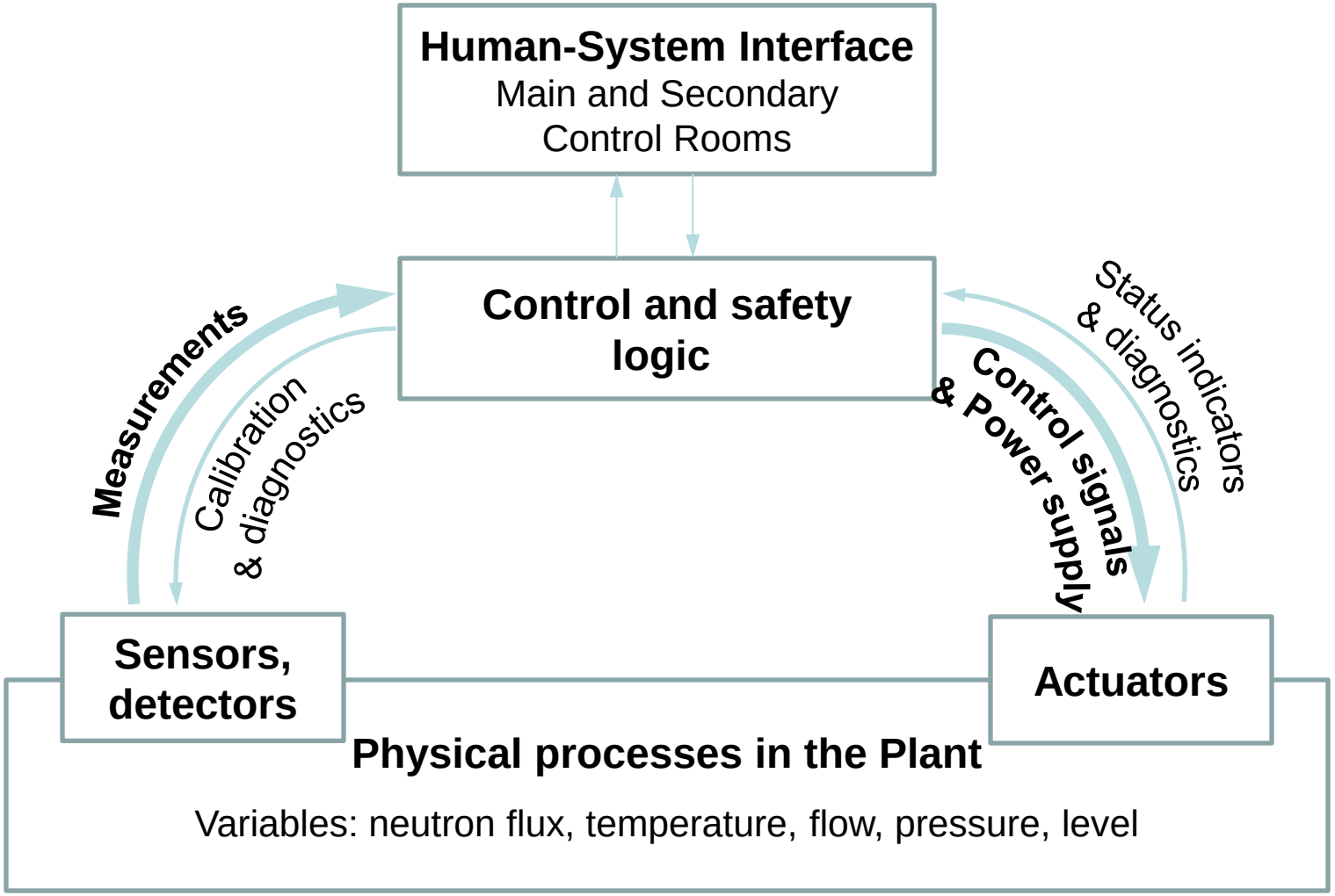
I&C functional sub-systems



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Digital I&C systems have distinctive features for NPP applications and regulatory approval:

- A digital I&C system has more connections among its many components and other systems, and it is simply more complex than its analog predecessor.
- Digital I&C systems are more dependent on system and application software, and their reliability and correctness are impacted by the quality of the software development process.
- The overall dependence on computers digital data networks raises the importance of cyber security.

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Common cause failure (CCF)

- I&C systems interact with every system in the NPP, therefore they can be a source of CCF that affect multiple layers of defence-in-depth or multiple barriers.

- Protective measures against CCF: Diversity, Defence-in-Depth, Independence

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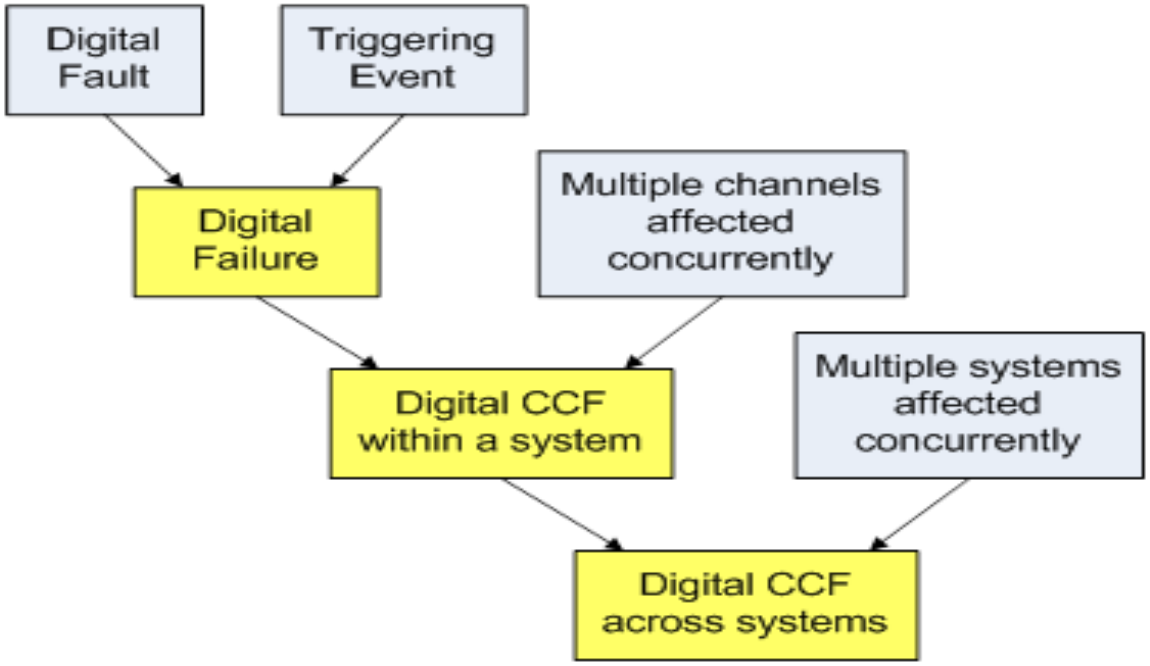
Conditions for a potentially unsafe CCF to occur:

- Existence of latent faults that can cause functional failure;
- A triggering event, usually an unanticipated or untested operational condition is present to activate the fault;
- Multiple channels are affected concurrently;
- The affected function is needed to respond to an unsafe plant condition.



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Diversity to prevent common cause failures

- Human diversity:
  - Different teams for specification, design, development, integration, installation, maintenance
  - Different management teams in the same organization
  - Different evaluation personnel for V&V testing and certifying

- Functional diversity:
  - Same process parameter sensed by different physical phenomena
  - Different underlying physical mechanism for actuation
  - Different response time scale

- Design diversity:
  - Different technologies, manufacturers, approaches, platforms, architecture, algorithms, data and execution, and timing structure

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New applications and technologies

- New sensing technologies: advanced sensors, detectors, transmitters, and data transmission lines;
- Communication and digital control;
- Wireless sensor networks and communication;
- On-line condition monitoring and diagnostic systems;
- Integrated remote operation in SMRs;
- Field Programmable Gate Arrays (FPGAs).

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Field Programmable Gate Arrays (FPGAs)

- Semiconductor-based programmable devices which can be configured to perform custom-designed functions.
- FPGA hardware components (tested against hardware qualification requirements).
- Electronic design, represented by a set of instructions in hardware description language (HDL) to be configured into the FPGA hardware (verified against functional requirements).

FPGA chips

- EPROM / EEPROM / Flash based chips are re-writable types and non-volatile (no data or logic is lost in case of power losses);
- SRAM based chips are re-writable, but volatile;
- Anti-fuse based chips are non re-writable and non-volatile.

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General characteristics of FPGA-based design

- FPGA technology presents a suitable (in some cases desirable) alternative to CPU based technology
- FPGAs can implement a wide variety of logic and processing functions, including microprocessor emulation
- Programmed by using well established languages (HDL)
- Depending on chip selection, applications could be reprogrammed
- Once programmed, FPGA chips are as close to a hardware device as could be achieved with a programmable device

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Types of applications of FPGA in NPPs

- ‘pin-to-pin’ and ‘like-for-like’ replacement of obsolete electronic components
- Form, Fit and Function (FFF) replacement of obsolete electronic components
- reverse engineering of existing components
- computer emulation of obsolete CPUs
- straight replacement of components and/or systems
- providing diverse systems to reduce the possibility of CCF in safety systems
- large-scale I&C system modernization projects
- complete I&C systems design for new NPPs

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Advantages of FPGAs

- Simpler and, therefore, more reliable technology, partly because it doesn’t include an operating system and any kind of embedded software;
- Simplicity and transparency of processes for design, development, implementation, and operation;
- Easy portability of algorithms and possibility of re-programming, if algorithms or technology may change in the future, but the hardware stays the same;
- Reduction of vulnerability of the digital I&C system to cyber attacks or malicious acts due to absence of any system software or operating systems;

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Advantages of FPGAs (continued)

- Parallel processing inside the FPGA chip and its integrated;
- Faster and more deterministic performance due to capability of executing logic functions and control algorithms in a parallel mode;
- More reliable, testable and error-free end-product due to reduction in the complexity of the verification and validation (V&V) and implementation processes.

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Potentials of FPGA technology

- The FPGA technology provides a diverse alternative to the widely used microprocessor-based digital I&C systems;
- It is already a mature technology on its own for safety and control system applications, proven in use for operating NPPs;
- FPGAs can be used to implement any of the typical safety and control functions presently found in any NPP designs, PWR, PHWR, VVER, or BWR reactors.

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Challenges that affect the application of FPGA technology

- FPGAs are still considered as a relatively new technology and not widely known in the nuclear power industry;
- Lack of normative documents for the utilization of FPGAs in nuclear I&C applications (with the exception of IEC 62566:2012, which provides requirements for “HDL-Programmed Devices” for use in Category A I&C systems);
- Lack of regulatory experience in licensing FPGA-based I&C safety systems.

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International Experience with FPGA Applications in NPPs

- Countries that have installed FPGA components or systems in their operating NPPs are: Bulgaria, Canada, Czech Republic, France, Japan, Korea, Sweden, Ukraine, United States;
- Several countries have started R&D activities in safety system applications of new NPP designs: Argentina, Canada, China, Japan, Ukraine, United Kingdom, United States.

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6th FPGA Workshop – 2013 Kirovograd, Ukraine, hosted by RPC Radiy

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Technical areas covered:

- Benefits and challenges in FPGA applications;
- Methods and tools for application development;
- Methods and tools for verification and validation;
- Lifecycle of FPGA-based platforms, systems, and applications;
- Regulatory perspectives on FPGA technology, licensing and standards;
- Specific standards for FPGAs;

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Technical areas covered (continued):

- Qualification and certification;
- Diversity provided by FPGA-based systems;
- FPGAs as prototyping tools;
- Cyber security;
- Operating experience with FPGA-based I&C systems installed;
- FPGA-based modernization of I&C systems and components;
- FPGA-based systems installed in operating NPPs;
- Potential future applications in operating NPPs and in new NPP I&C designs.

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The Workshop in numbers

- **110** participants
- **24** presentations
- **20** countries
- **4** IAEA break-out groups
- **2** panel discussions
- **1** technology demonstration

- **18** vendors/suppliers
- **14** utilities/NPPs
- **14** service/research/TSOs
- **5** nuclear regulators
- **4** universities
- **2** government organizations
- **1** international organization

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5th FPGA Workshop - 2012 Beijing, China, hosted by CNNC/CNCS

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Previous FPGA Workshops:

2008 Chatou, France, hosted by EdF;
2009 Kirovograd, Ukraine, hosted by Radiy;
2010 Hamilton, Ontario, Canada, hosted by AECL/McMaster University;
2011 Chatou, France, hosted by EdF;
2012 Beijing, China, hosted by CNNC/CNCS
2013 Kirovograd, Ukraine, hosted by Radiy;

Next FPGA Workshop:

To be hosted by Electric Power Research Institute (EPRI) at EPRI's offices in Charlotte, North Carolina, USA, October 2014

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Kozloduy NPP Units 5 & 6, Bulgaria - Replacing ESFAS

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Kozloduy NPP Units 5 & 6, Bulgaria - Replacing ESFAS

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I&C related activities of

the International Atomic Energy Agency

(IAEA)

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IAEA assistance to global nuclear power

- Review missions
- Meetings and workshops
  - Consultants' Meetings
  - Technical Meetings
  - Technical Cooperation Workshops / Training Courses
  - International Conferences and Symposia
  - International Expert's Meetings (new)
- Technical Cooperation (TC) projects
- Coordinated research projects
- Publications (standards, guidance, and other documents)

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IAEA Publications:

On-Line Monitoring For Improving Performance of Nuclear Power Plants; Part 1: Instrument Channel Monitoring

Nuclear Energy Series Report, NP-T-1.1 (2008)

On-Line Monitoring For Improving Performance of Nuclear Power Plants; Part 2: Process and Component Condition Monitoring and Diagnostics

Nuclear Energy Series Report, NP-T-1.2 (2008)

The Role of I&C Systems in Power Uprating Projects in Nuclear Power Plants

Nuclear Energy Series Report, NP-T-1.3 (2008)

Implementing Digital Instrumentation and Control Systems in the Modernization of Nuclear Power Plants

Nuclear Energy Series Report, NP-T-1.4 (2009)

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IAEA Publications (continued):

Protecting Against Common-Cause Failures in Digital I&C Systems

Nuclear Energy Series Report, NP-T-1.5 (2009)

Integration of Analog and Digital Instrumentation and Control Systems in Hybrid Control Rooms

Nuclear Energy Series Report, NP-T-3.10 (2010)

Core Knowledge on Instrumentation and Control Systems in NPPs

Nuclear Energy Series Report, P-T-3.12 (2011)

Assessing and Managing Cable Ageing in NPPs

Nuclear Energy Series Report, D-NP-T-3.6 (2012)

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IAEA Publications (continued):

Electric Grid Reliability and Interface with NPPs

Nuclear Energy Series Report, NG-T-3.8 (2012)

Advanced Surveillance, Diagnostics, and Prognostics Techniques in Monitoring Structures, Systems, and Components in NPPs

Nuclear Energy Series Report, NP-T-3.14 (2013)

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IAEA Publications (continued):

Technical Challenges and Solutions in Application of Digital I&C Systems in NPP

Nuclear Energy Series Report, Draft, to be published in 2014

Accident Monitoring Systems for Nuclear Power Plants

Nuclear Energy Series Report, Draft, to be published in 2014

Application of Field Programmable Gate Arrays in Instrumentation and Control Systems of NPPs

Nuclear Energy Series Report, Draft, to be published in 2014

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IAEA Publications (continued):

Instrumentation and Control (I&C) Systems in Nuclear Power Plants: A Time of Transition

Annex 5 of the Nuclear Technology Review issued for the 2008 IAEA General Conference

Interfacing Nuclear Power Plants with Electric Grid: Need for Reliability amid Complexity

Annex 5 of the Nuclear Technology Review issued for the 2009 IAEA General Conference

Preparing and Conducting Independent Engineering Review of I&C Systems (IERICS) Missions in NPPs

IAEA Technical Document, TECDOC 1662 (2011)

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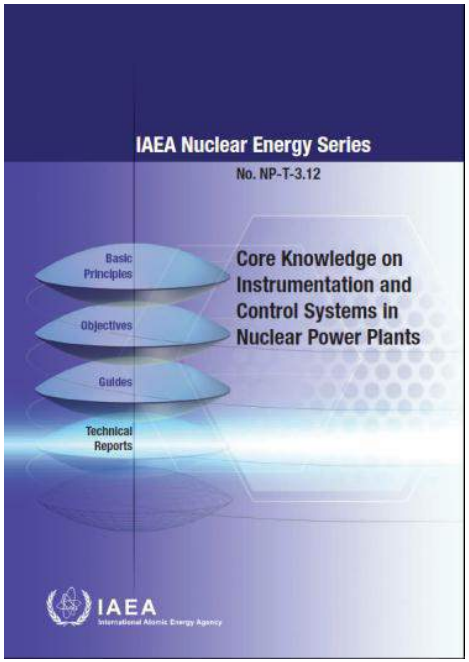
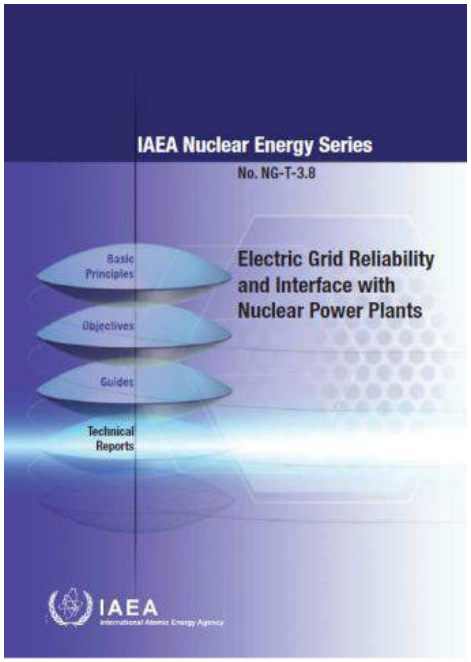

IAEA Nuclear Energy Series
No. NP-T-3.12
Basic Principles
Objectives
Guides
Technical Reports
Core Knowledge on Instrumentation and Control Systems in Nuclear Power Plants
IAEA
International Atomic Energy Agency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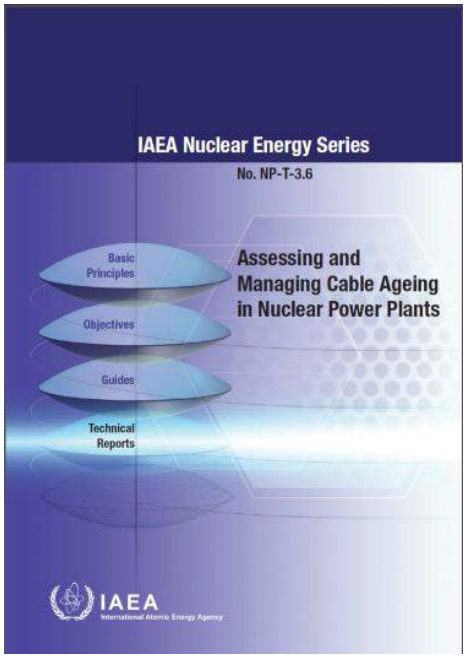
IAEA
International Atomic Energy Agency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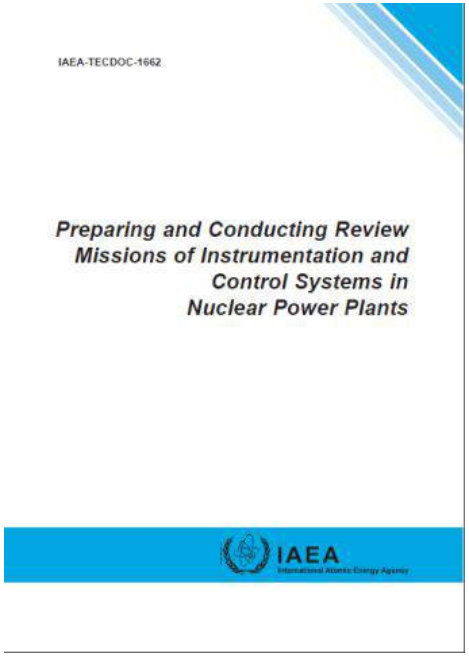
IAEA
International Atomic Energy Agency


IAEA-TECDOC-1662
Preparing and Conducting Review Missions of Instrumentation and Control Systems in Nuclear Power Plants
IAEA
International Atomic Energy Agency

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IAEA Independent Engineering Review of I&C Systems (IERICS) in NPPs

Established in 2009 as a peer review of I&C 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:
http://www.iaea.org/NuclearPower/IandC/IERICS/index.html

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1st IERICS at Doosan Heavy Industries & Construction Co.
Yongin-si, Republic of Korea, February 1-6, 2010

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2nd IERICS at Research and Production Corporation Radiy, Kirovograd, Ukraine, December 5-10, 2010

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3rd IERICS at Joint Stock Company VNIIAES, Moscow / Novovoronezh, Russia, December 6-15, 2012

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4th IERICS at Private Joint Stock Company SRPA “Impulse” Severodonetsk / Kiev, Ukraine, April 21-27, 2013

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24th Biennial Meeting of the Technical Working Group of Nuclear Power Plant Instrumentation and Control (TWG-NPPIC)
22-24 May 2013, IAEA, Vienna, Austria

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Recommendations by IAEA Member States:

- Accident monitoring systems for nuclear power plants;
- Application of Field Programmable Gate Arrays in instrumentation and control systems of NPPs;
- Wireless technologies;
- Instrumentation and control in advanced small modular reactors (SMRs);
- Software evaluation and dependability assessment;
- Aging management of electrical equipment and components;
- Support for new plants and newcomer countries;
- Human factors engineering;
- Engineering and design aspects of computer security in NPP I&C systems.

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Links to access and download IAEA publications

- For Nuclear Energy I&C publications
  http://www.iaea.org/NuclearPower/IandC/

- For all Nuclear Power Engineering Publications
  http://www.iaea.org/NuclearPower/Engineering/Publications/

- For all Nuclear Energy Series publications
  http://www.iaea.org/OurWork/ST/NE/NESeries/ClickableMap/

- IAEA Publications in general
  http://www.iaea.org/Publications/index.html

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SunPort SA is a consulting company

Business activity: providing engineering, safety analysis, licensing support, training and project management services to suppliers, designers, operators and regulators of the nuclear industry

- Headquartered in Lausanne, Switzerland
- Personnel in Toronto, Vienna, and Kirovograd
- Project-based involvement of a large pool of external experts and reviewers from NPP countries

  USA, Canada, France, UK, Germany, Switzerland, Sweden, Netherlands, Hungary, Ukraine, Russia, China, South Korea, Romania, Argentina

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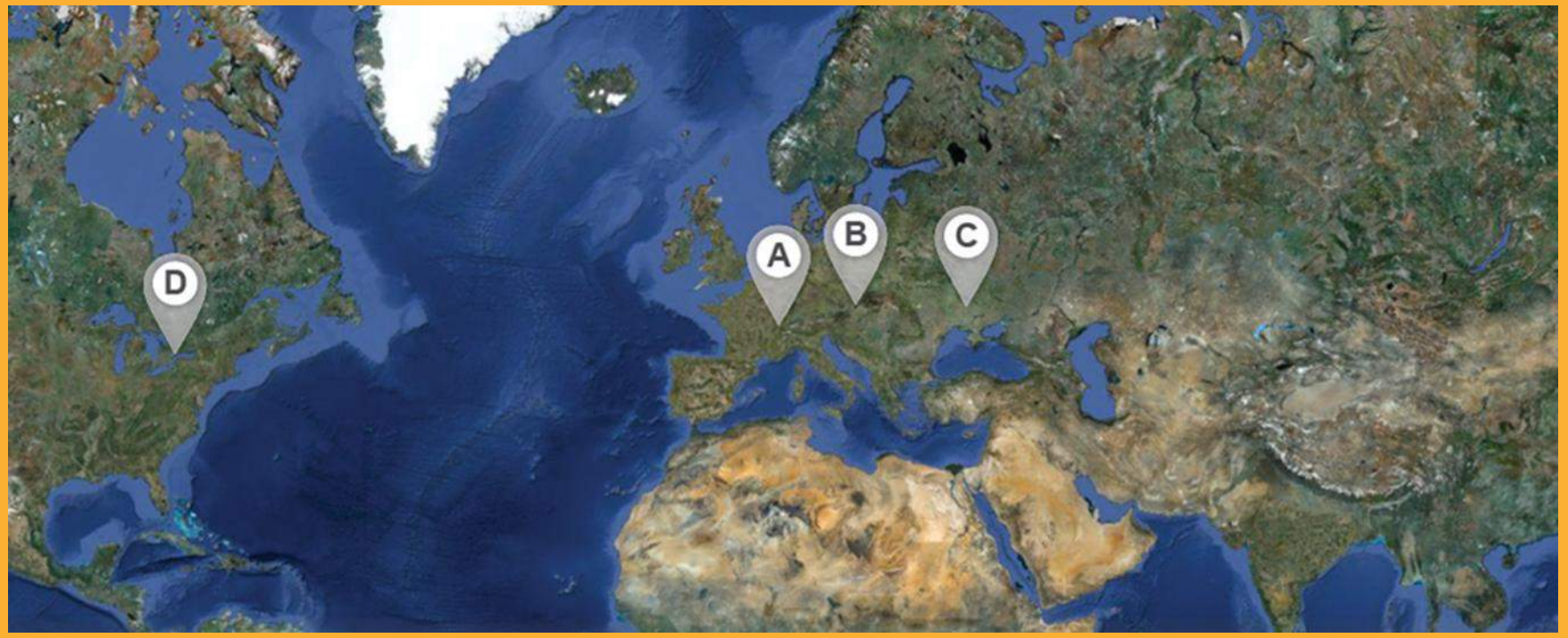
SunPort SA Locations



A **Lausanne, Switzerland**
Avenue de l'Université 24
CH-1005 Lausanne
Switzerland

B **Vienna, Austria**
Wagramerstrasse 4/1202
A-1220 Vienna
Austria

C **Kirovograd, Ukraine**
29 Geroyev Stalingrada
25009, Kirovograd,
Ukraine

D **Toronto, Canada**
403-278 Bloor St. E.
Toronto, Ontario
M4W 3M4 Canada

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SunPort SA provides services during all phases of projects. These include:

- Design reviews of I&C safety and process control systems,
- Design engineering,
- Project management and contract management,
- Preparation, coordination, and delivery of training and technical information exchange meetings for the nuclear industry,
- Market research and studies to assist equipment suppliers and services providers in marketing their products,
- Preparation of technical reports,
- Technical support to patent applications,
- The distribution of third-party products, systems and components to customers.

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Promoting information exchange, education, and research:

- SunPort is actively taking part in the organization and implementation of the FPGA Workshop series

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Promoting information exchange, education, and research:

- October 1, 2013: SunPort delivered an FPGA-based testbed to McMaster University in Ontario, Canada, to support their research and education programs and the project on "Certification of Safety-Critical Software-Intensive Systems"

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Promoting information exchange, education, and research:

- SunPort experts contribute to IAEA workshops, review missions, and development of technical documents (TC Workshops, IERICS missions, FPGA Report)

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Thank you

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