Implementation of Digital I&C in NPP

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Innovations in Nuclear Technology 2012 – Brazil: Challenges and Opportunities
(INT2012) | December 10–11, 2012 | Sao Paulo, Brazil

NPPs in Ukraine

Total Gross Capacity: 13,835 MW
4 sites
15 units
2 units under construction

Rivne NPP
2×VVER-1000
2×VVER-440

Kyiv

Khmelnitsky NPP
2×VVER-1000
2×VVER-1000
under construction

Kirovograd
(Radiy)

Zaporizhzhya NPP –
The biggest NPP in Europe
6×VVER-1000

South-Ukrainian NPP
3×VVER-1000

15 out of 15 Ukrainian reactors were modernized by Radiy

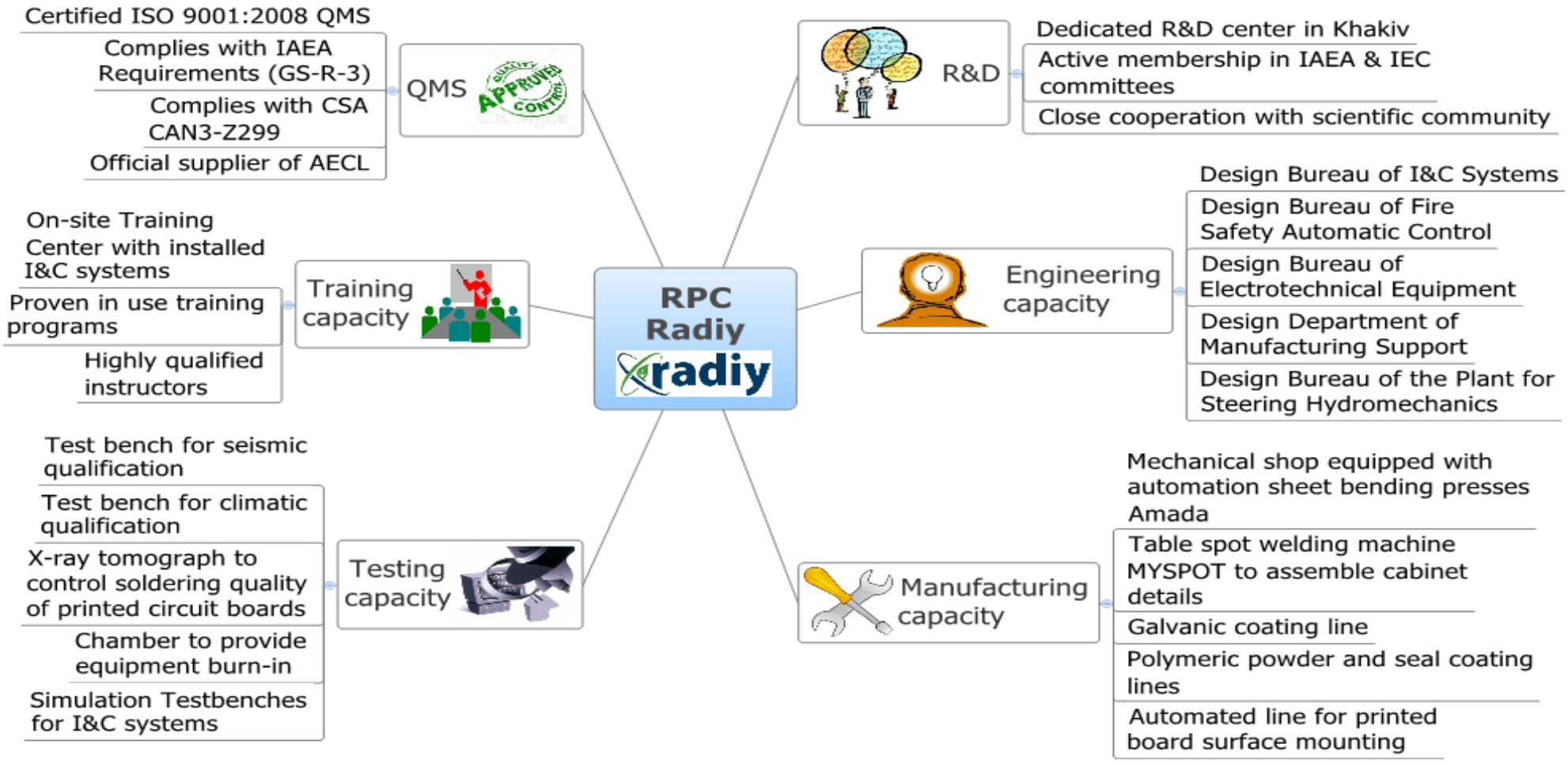
RPC Radiy Company Profile

Fast Facts

- Company is 100% private (Public Joint Stock Company)
- Company was founded in **1954** as radio-electronics factory
- Company's new business focus as I&C systems for Nuclear Power Plants was founded in **1995**
- Since 1995 Radiy is a **vendor** (**both designer and manufacture**) of advanced I&C systems for Nuclear Power Plants
- Radiy has installed **over 70** I&C Applications at NPP
- **1,300** employees work for Radiy including **300** highly-qualified designers and scientists

RPC Radiy Company Profile

RPC Radiy at glance

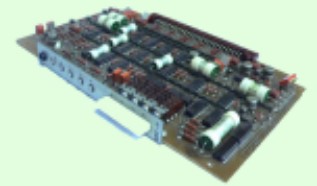


RPC Radiy Company Profile

Products evolution

1995

Started development and supply of the equipment for NPP I&C systems



Replacement of obsolete NPP I&C modules

1998

First generation of equipment for NPP I&C systems

FPGA-based NPP I&C

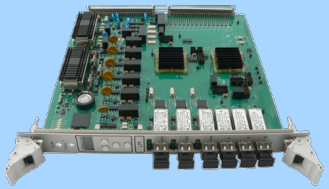
2002

Second generation of equipment for NPP I&C systems

FPGA-based platform RADIY

2011

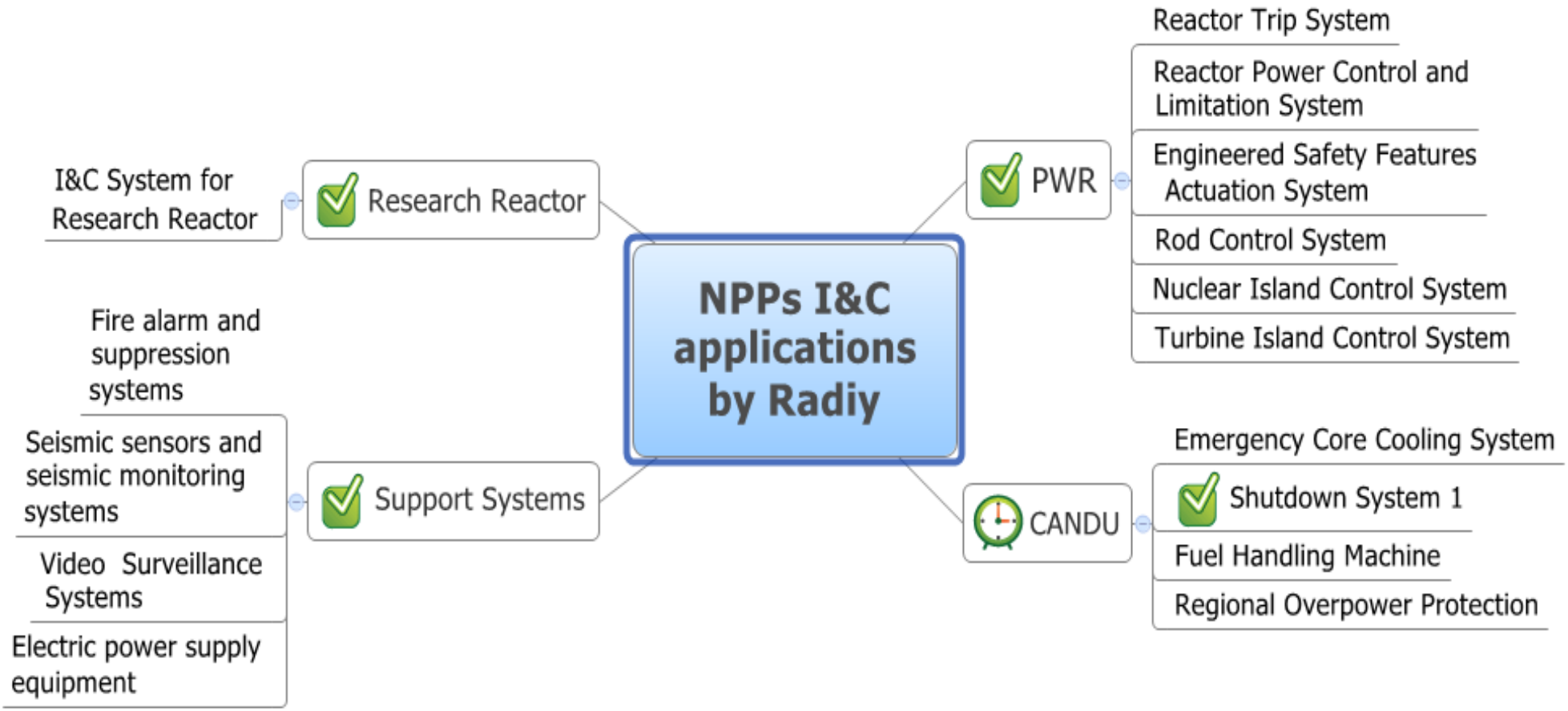
Third generation of equipment for NPP I&C systems



FPGA-based platform RadICS

RPC Radiy Company Profile

NPP I&C applications



RPC Radiy's achievements: What is new since 2011?

Continued

- Start of modernization project on Rod Control System for South-Ukrainian NPP, Unit 1

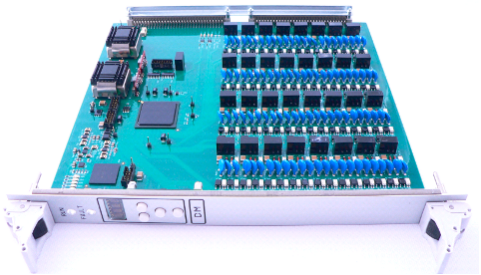
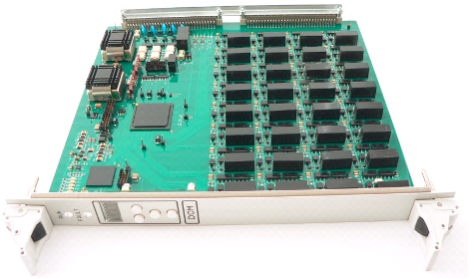
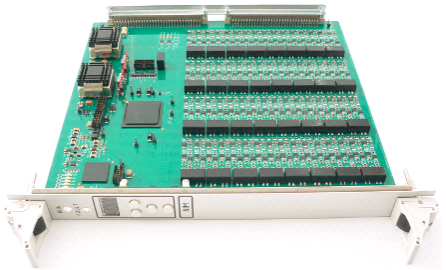
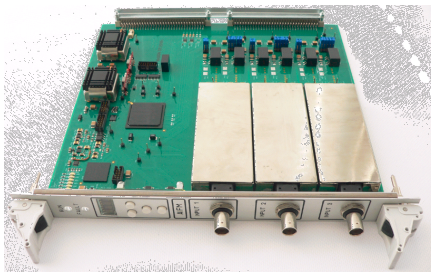
RPC Radiy's achievements: What is new since 2011?

Continued

- Modernization of 4 Nuclear and Turbine Island Control System at Rivne NPP and South-Ukrainian NPP

RPC Radiy's achievements: What is new since 2011?

Continued

exida FMEDA

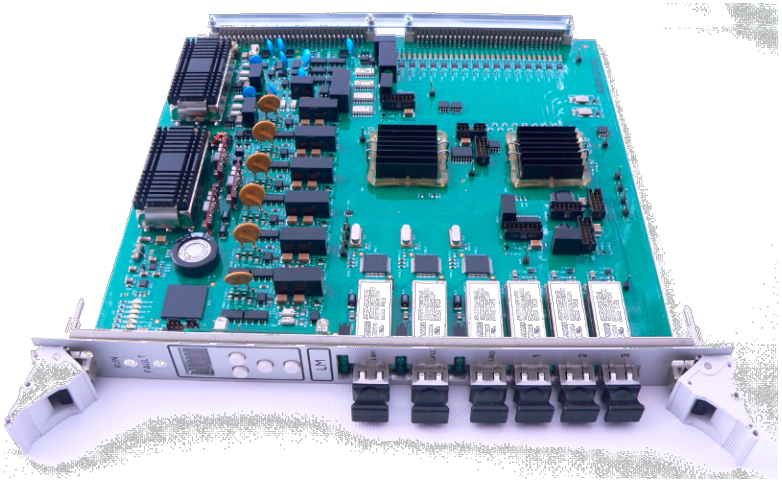
D7.24

Failure Modes, Effects and Diagnostic Analysis

Project:
Radiy FPGA-based Safety Controller (FSC)

Company:
RPC Radiy
Kirovograd
Ukraine

Contract Number: Q12/04-109
Report No.: RPC 12/04-109 R001
Version V2, Revision R0, September, 2012
John C. Grebe / R. David Fournier



exida Certification Services

D13.2

IEC 61508 Preliminary Functional Safety Assessment

Project:
Radiy FPGA-based Safety Controller (FSC)

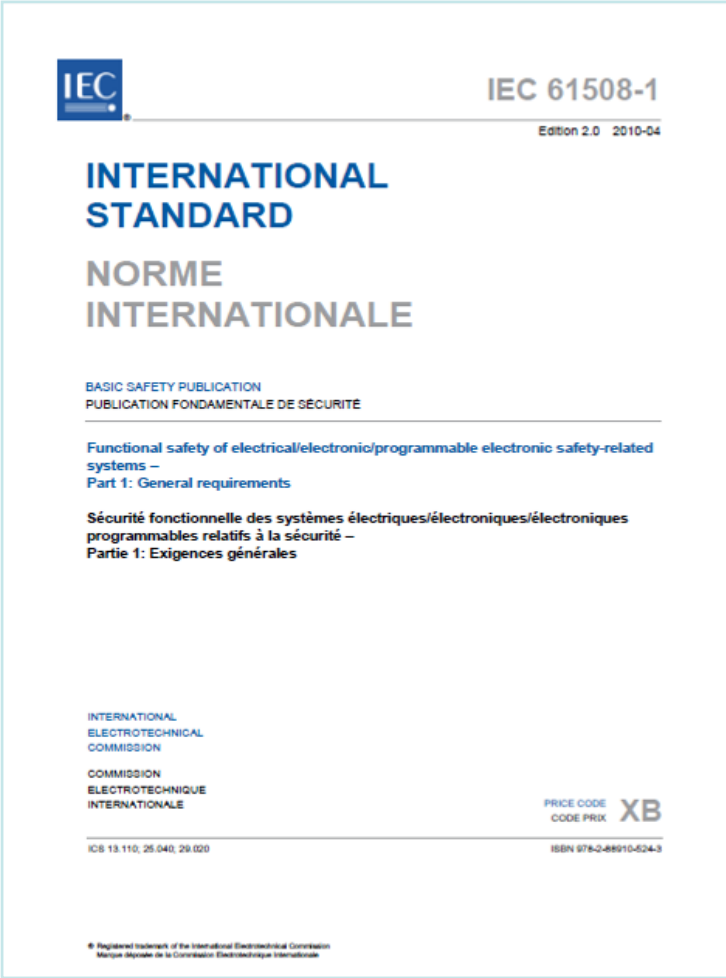
Customer:
RPC Radiy
Kirovograd
Ukraine

Contract No.: Q12/02-074
Report No.: RAD 12-02-074 R001
Version V1, Revision R3, July 30, 2012
Michael Medoff

RPC Radiy's achievements: What is new since 2011?

Continued

➞ FPGA-based safety I&C platform certification in accordance with Safety Integrity Level 3 (SIL3) requirements



IEC 61508-1

Edition 2.0 2010-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

BASIC SAFETY PUBLICATION
PUBLICATION FONDAMENTALE DE SÉCURITÉ

Functional safety of electrical/electronic/programmable electronic safety-related systems –
Part 1: General requirements

Sécurité fonctionnelle des systèmes électriques/électroniques/électroniques programmables relatifs à la sécurité –
Partie 1: Exigences générales

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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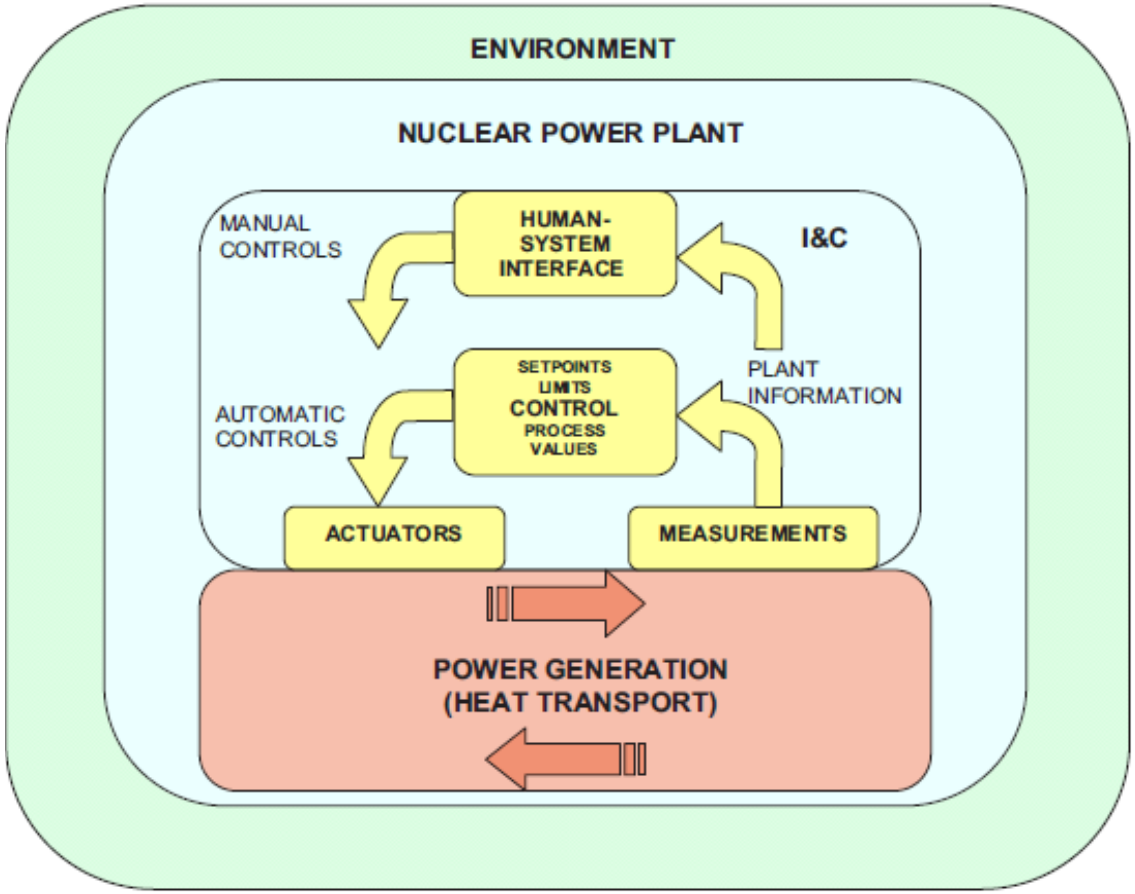
Agenda

- General concept of I&C for NPP
- FPGA technology for NPPs I&C Systems
- Approach to implementation of I&C projects using FPGA-based I&C platform
- Conclusions

General concept of I&C for NPP

High Level Overview of NPP I&C

- About 10 000 sensors and detectors
- About 5000 km of I&C cables
- Total mass of I&C related components is about 1000 tonnes



IAEA Nuclear Energy Series, No. NP-T-3.12

Typical I&C Function

HMI

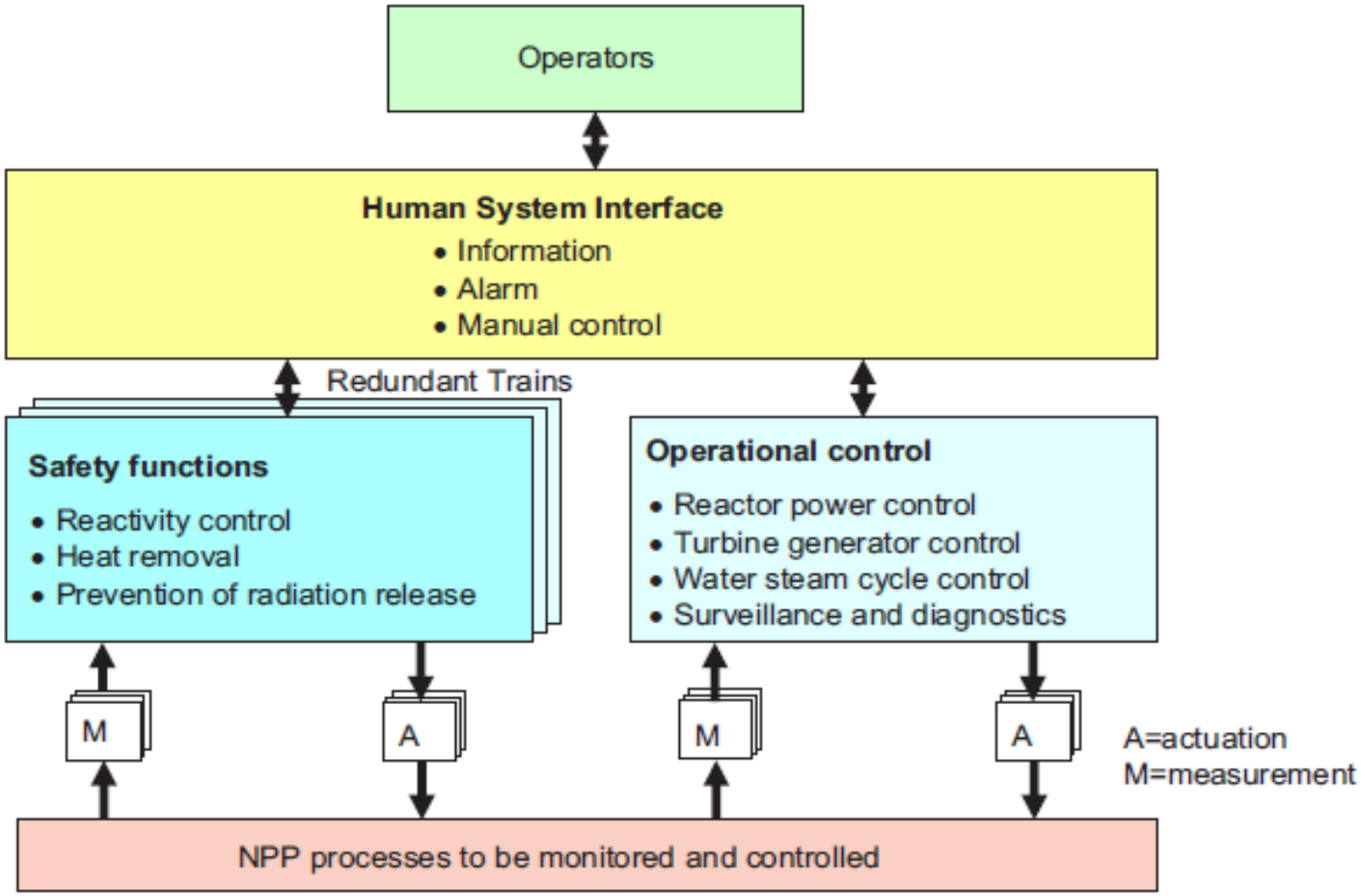
Sensor

Logic solver

Switchgears

Actuator

Functional overview of NPP I&C



IAEA Nuclear Energy Series, No. NP-T-3.12

Analog I&C example

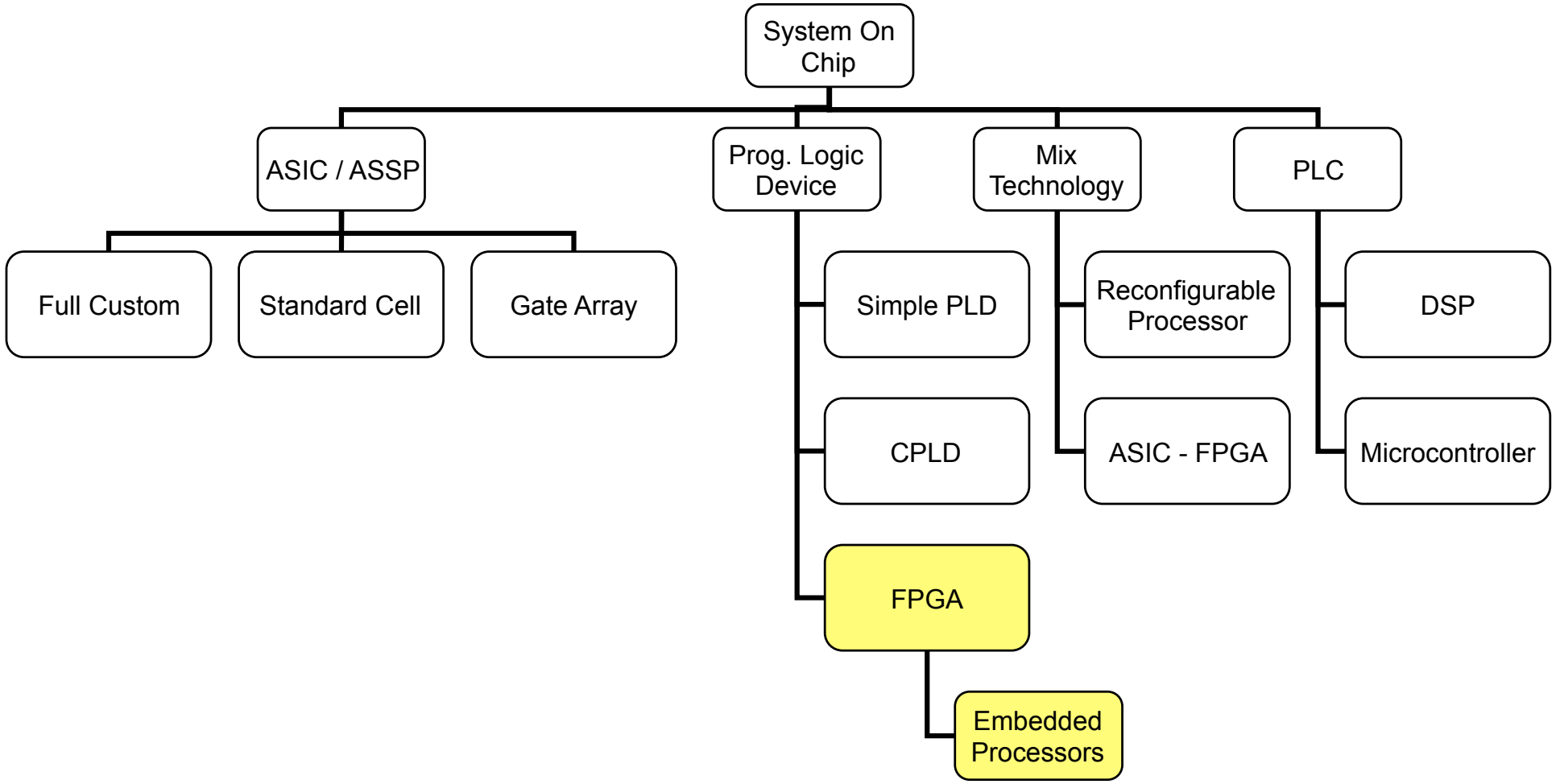
Logic solver (relay-based I&C of VVER type reactor)

HMI (The world's first nuclear control room I&C, 1943)

FPGA technology for NPPs I&C Systems

FPGA technology for NPP I&C systems

Context Diagram



FPGA technology for NPP I&C systems

Basic concept

Radiy uses FPGA (Field Programmable Gates Array) as programmable components in Instrumentation and Control (I&C) platform

- FPGA is an alternative to PLC
- FPGA can embed microprocessors and all kind of logic and mathematical processing capabilities
- FPGA integrated circuit is a hardware
- Functions of this hardware are configured by use of hardware description languages (HDL)
- This configuration can be updated even after the product has been installed

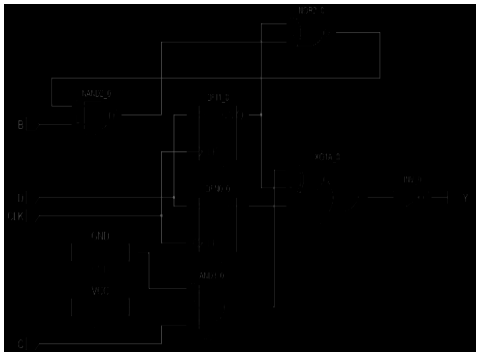
FPGA technology for NPP I&C systems

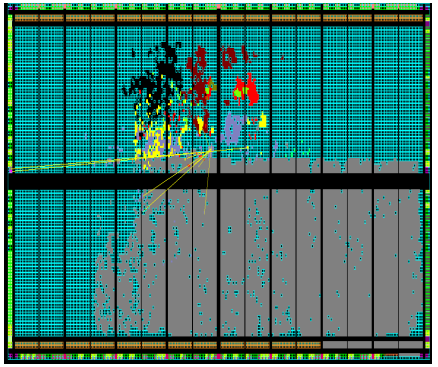
Design flow

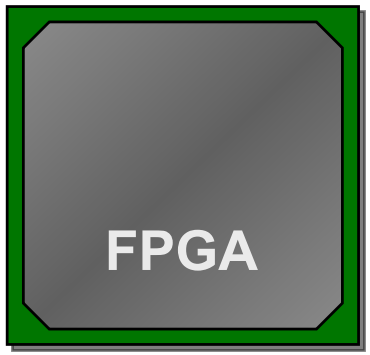
- Electronic design: a highly active and extremely successful engineering and scientific domain since many years
- Standardised and widely supported hardware description languages (HDL)

  VHDL, Verilog, Shematic entity
- Availability of integrated design environments (IDE) covering the complete development cycle

```
library IEEE;
use IEEE.std_logic_1164.all;
use IEEE.std_logic_arith.all;
use IEEE.std_logic_unsigned.all;

entity count8_behave is
  port(Clock : in std_logic;
       Q : out std_logic_vector(7 downto 0);
       Aclr : in std_logic);
end count8_behave;

architecture behavioral of count8_behave is

  signal Qaux : UNSIGNED(7 downto 0);

begin

  process(Clock, Aclr)
  begin

    if (Aclr = '1') then
      Qaux <= (others => '0');
    elsif (Clock'event and Clock = '1') then
      Qaux <= Qaux + 1;
    end if;

  end process;

  Q <= std_logic_vector(Qaux);

end behavioral;
```







HDL **Synthesis** **Place & Route** **Prog.**

Regulatory basis of FPGA technology for NPPs

- Functional safety standards IEC 61508:2010 ed. 2.0 **(Functional safety of E/E/EP safety-related systems**) include requirements for ASIC (FPGA) designs
- IEC 62566 NPP – I&C important to safety – Development of HDL-programmed integrated circuits for systems performing category A functions
- **Oak Ridge NL** has developed NUREG-CR-7006 (Review Guidelines for FPGA in NPP Safety Systems, 2009) **for US NRC**
- **EPRI** has developed TR 1019181, (Guidelines on the Use of FPGAs in NPP I&C Systems, 2009) and TR 1022983 (Recommended Approaches and Design Criteria for Application of FPGAs in NPP I&C Systems, 2011)
- **IAEA** is developing a Tech Doc on application of FPGA in I&C systems

International Workshops on Applications of Field Programmable Gate Arrays in Nuclear Power Plants

- The 1st Workshop – 2008, Chatou, France, EdF R&D
- The 2nd Workshop – 2009, Kirovograd, Ukraine, Radiy
- The 3rd Workshop – 2010, Hamilton, Ontario, Canada, McMaster University & AECL
- The 4th Workshop – 2011, Chatou, France, EdF R&D
- The 5th IAEA Workshop – 2012, Beijing, China, CNCS

IAEA
International Atomic Energy Agency

FPGA-based I&C drivers and advantages

- Proven in use technology with extensive experience of operation at NPPs in certain countries and other applications in safety-critical industries
- Implementation of safety functions without the use of any software and operating system
- Parallel performance of all control algorithms and communication functions ensures fast response time with deterministic value
- Providing transparent and relatively simple design what allows to reduce the efforts necessary for development and V&V

FPGA-based I&C drivers and advantages
Continued

- Resilience to obsolescence due to the portability of the Hardware Description Language (HDL) code between various FPGA-chips produced by different manufacturers
- Fit for reverse engineering via emulation of obsolete CPU without modification of existing software code
- Specific beneficial properties regarding cyber security that are different from those of Programmable Logic Controller (PLC) based technologies (no viruses for FPGA)

FPGA vs. Microcontrollers (1)

Criterion	FPGAs	Microcontlollers
Architecture	Flexible	Fixed
Parallel data processing	Yes	No
Response time of I&C systems based on corresponding technology	~10 ms	~100 ms
Deterministic timing characteristics	Yes	No
Design complexity	Lower	Higher
Verification complexity	Lower	Higher
Emulation capabilities (for example, different microcontrollers)	Yes	No

FPGA vs. Microcontrollers (2)

Criterion	FPGAs	Microcontlollers
Application experience in safety critical domains	Yes	Yes
Licensing efforts and risks	Acceptable	Acceptable
Average time for I&C system design	6-12 month	14-24 month
Automated design and verification tools	Yes	Yes
Remote on-line modification of control logic of I&C systems based on corresponding technology	Not possible	Possible
Cyber security vulnerabilities	At the present time there are no known viruses and malware for FPGAs	Vulnerable (for example, Stuxnet worm)

Recommended Approaches and Design Criteria for Application of Field Programmable Gate Arrays in Nuclear Power Plant I&C Systems (EPRI – 1022983, June 2011)

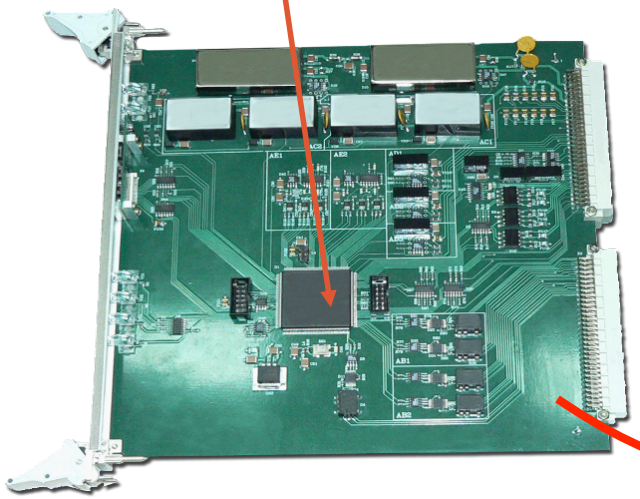
- Existing system examples
  - → Bulgaria (Kozlodyi NPP – ESFAS)
  - → Canada
  - → Czech Republic (Temelin NPP – Diesel sequencer)
  - → France (Rod Control System)
  - → Japan
  - → South Korea
  - → Sweden
  - → Ukraine
  - → United States

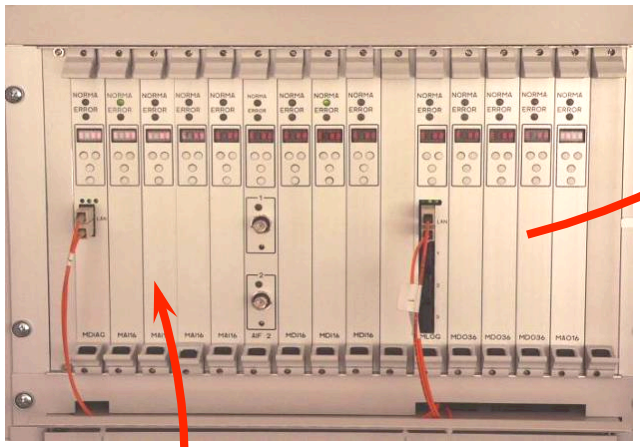
FPGA-based RadICS Platform

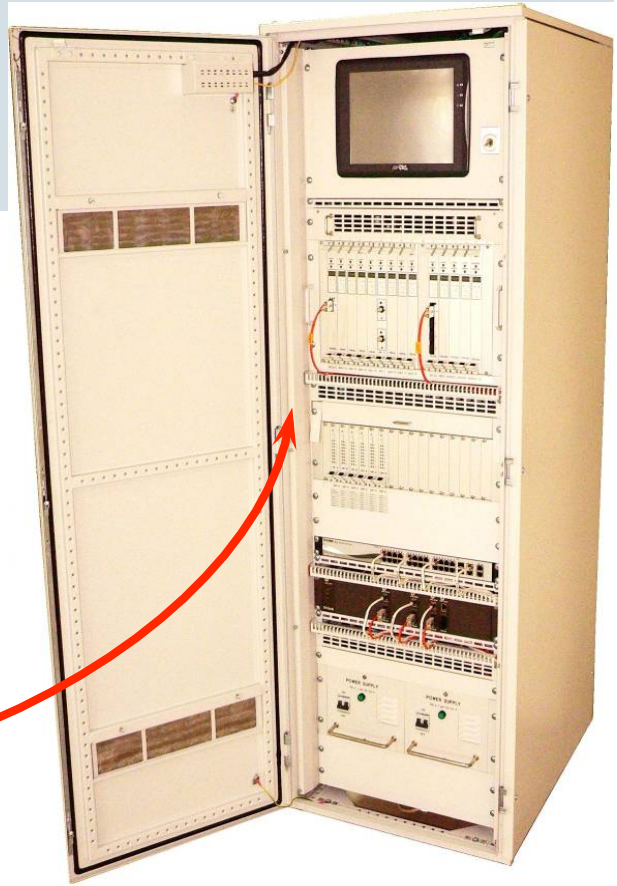
Modules and chassis

Platform is a set of generic hardware modules, chassis, cabinets, communications, and software Functional Library Blocks which is a base for implementation of applications

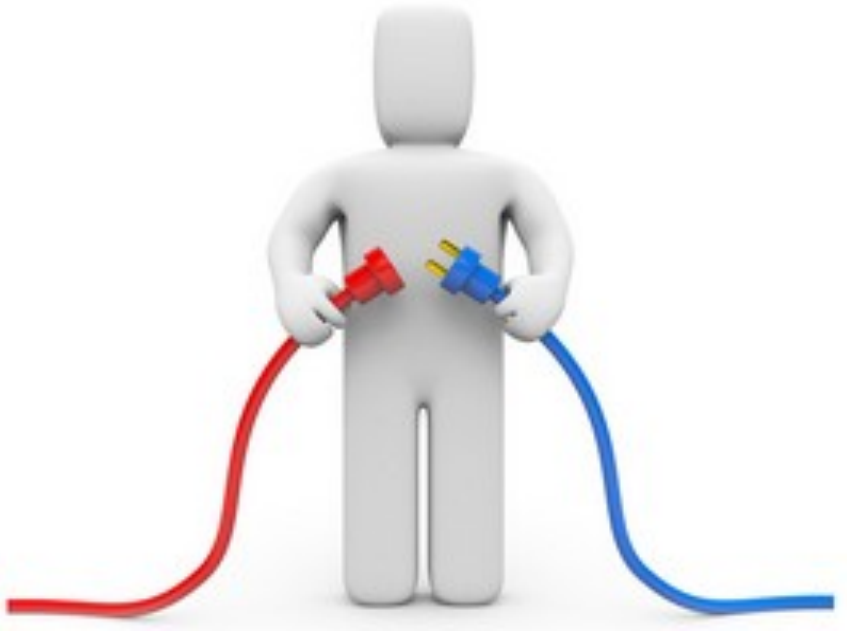
FPGA







Approach to implementation of I&C projects using FPGA-based I&C Platform



NPP I&C Implementation Stages

Project implementation (1)

- QA program development
  - *Necessary step to ensure that work would be done properly in terms of safety and quality*
- Scope definition
  - *Collecting initial data on quantity of I/O signals and their types, wiring as well as on quantity of actuators of existing system, capturing HMI features*
  - *Design concept definition*
- I&C system definition
  - *Development and approval of I&C requirements specification*
  - *Global design*
- I&C system design
  - *Detailed design*

NPP I&C Implementation Stages

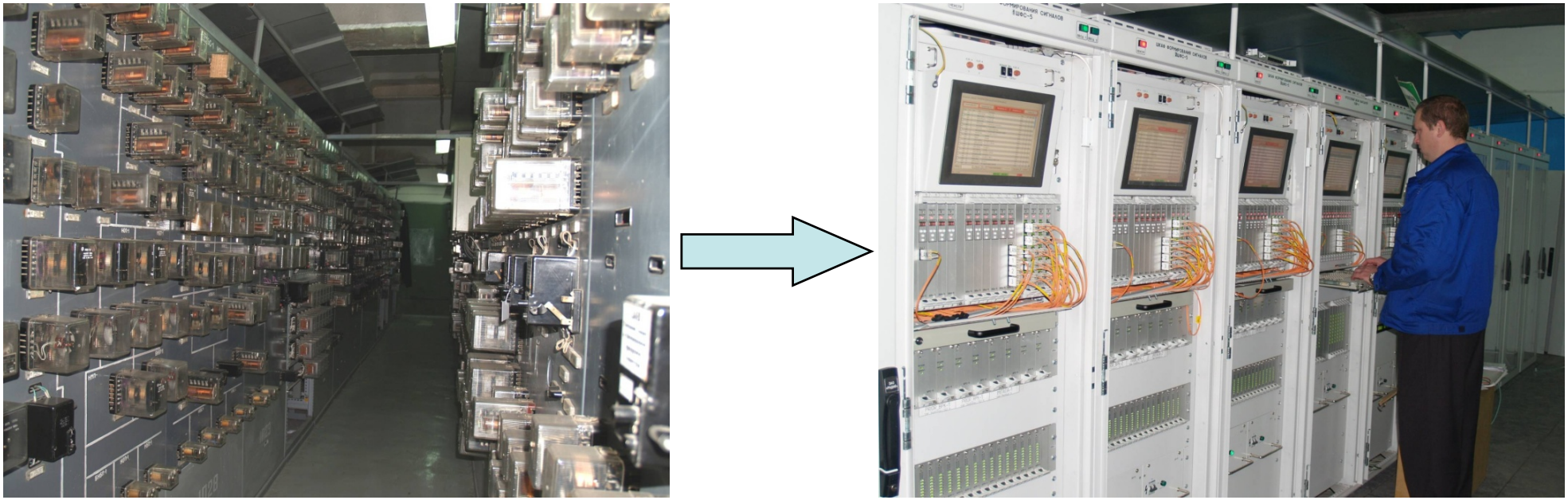
Project implementation (2)

- Hardware/Software development
- Qualification
  - *Equipment qualification and FAT are performed in-house*
  - *Test lab provides possibilities for implementing seismic tests, electrical and environmental testing, etc.*
- I&C installation
  - *Transportation to the site*
  - *Assembly*
- I&C system commissioning
  - *Site acceptance test (SAT) and operational acceptance test (OAT)*
  - *Updating of design documentation*
  - *Training of operating and maintenance staff*

NPP I&C Implementation Stages

Results

ESFAS modernization for Rivne NPP Unit 1 using RadICS FPGA-based Platform



18 FPGA-based ESFAS have been installed at Ukrainian NPPs during 2005-2010

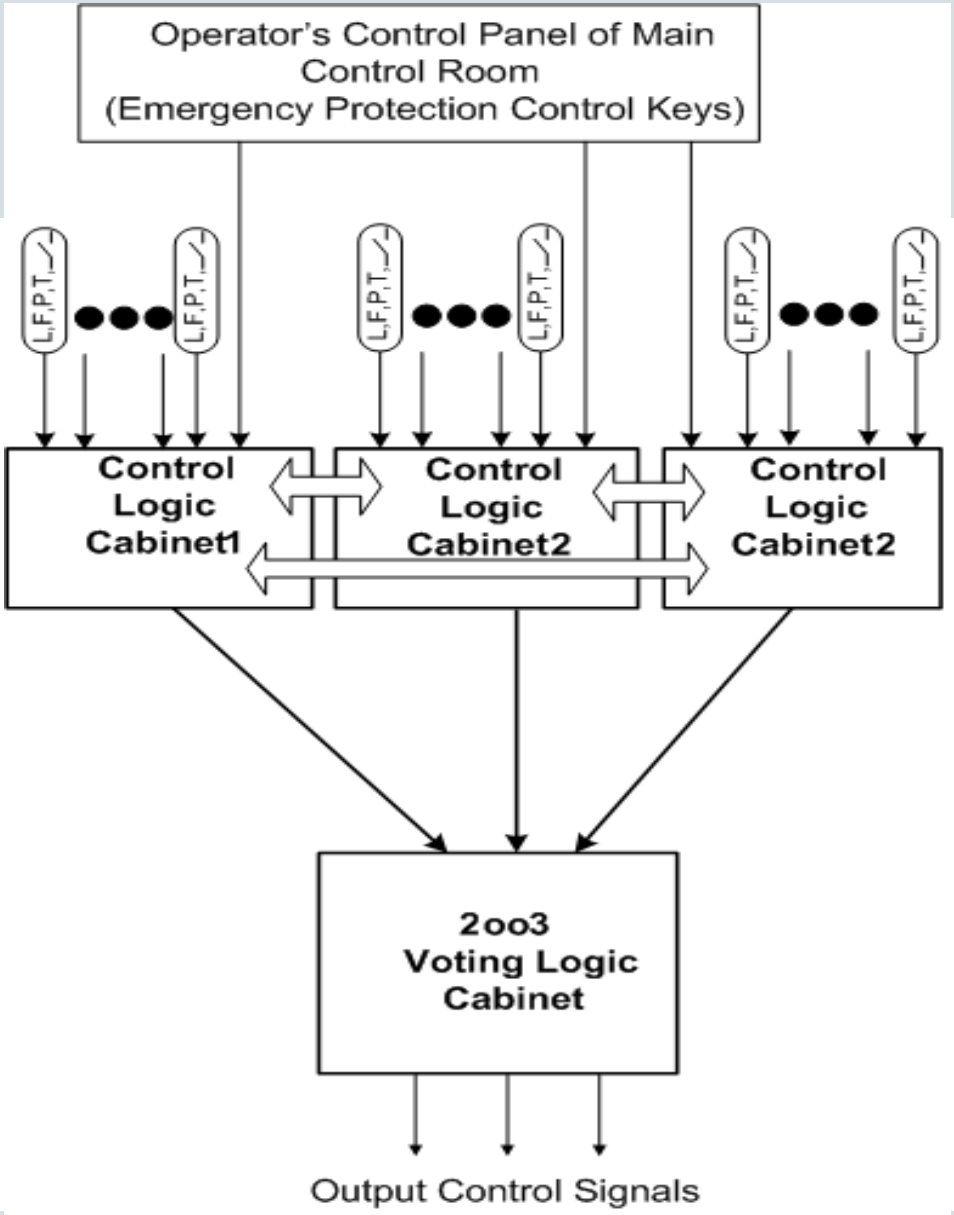
Examples of FPGA-based NPP I&C Applications (1)

Reactor Trip System (RTS)

28 systems (main and diverse) were commissioned at:

- Zaporizhzhia NPP
- Rivne NPP
- South-Ukrainian NPP
- Khmelnitskiy NPP

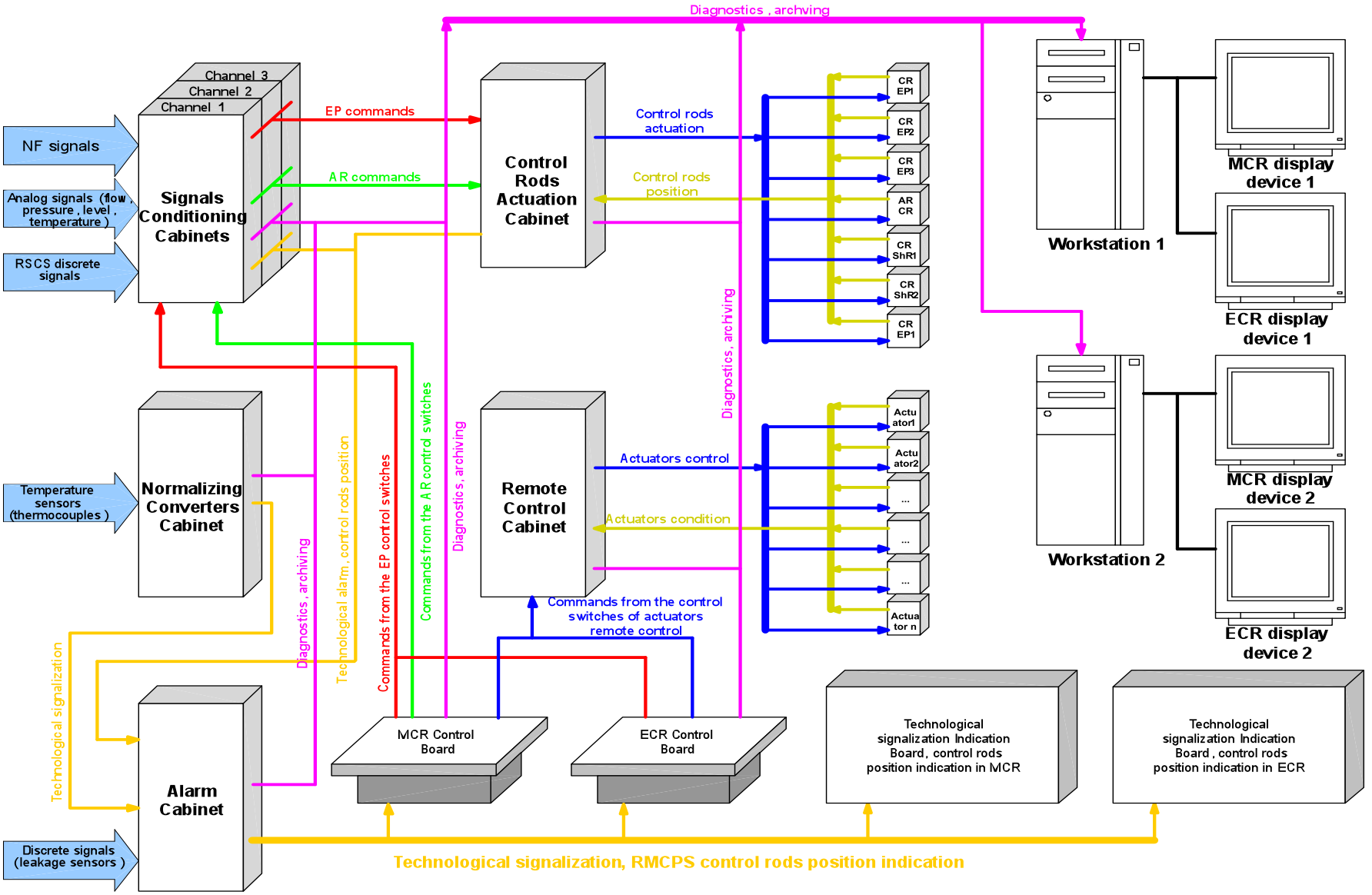
Structure diagram of FPGA-based Reactor Trip System



Examples of FPGA-based I&C Application for Research Reactor VVR-M

- Reactor's power – 10 MW;
- Start of operation – February, 1960
- Location – Kiev, Ukraine
- Operator – Kiev Institute for Nuclear Research of National Academy of Science of Ukraine
- I&C system modernization project was implemented by Radiy during 2006-2008

Structure diagram of FPGA-based I&C system for Research Reactor



Conclusions

Conclusions

- Digital I&C systems is a **hot topic** in the context of NPPs **life extension and new builds**
- **Positive expirience** in Ukraine shows that **FPGA technology** suites for **of NPPs I&C systems**
- **Radiy** is a vendor of **FPGA-based safety I&C platform** as well as turnkey applications for NPPs
- Since 2003 Radiy has designed, produced and commissioned **over 70 FPGA-based turnkey application at NPPs**

Thank you for your attention!

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