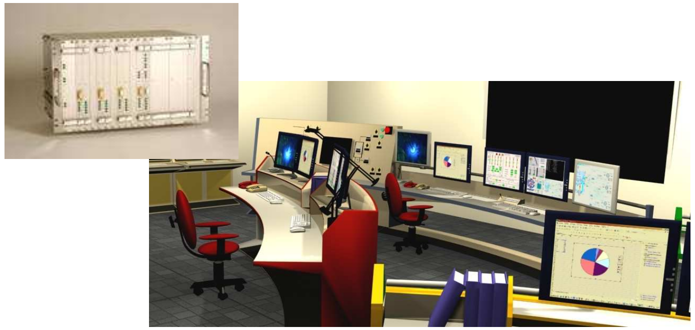
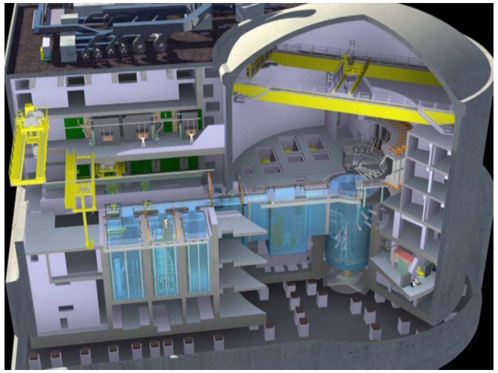


The Jules Horowitz Reactor Project
Overview of the I&C System

by Laurent RODRIGUEZ, AREVA TA I&C Project Manager

IGORR, Knoxville, Tennessee, the 19th to 23th Sept 2010

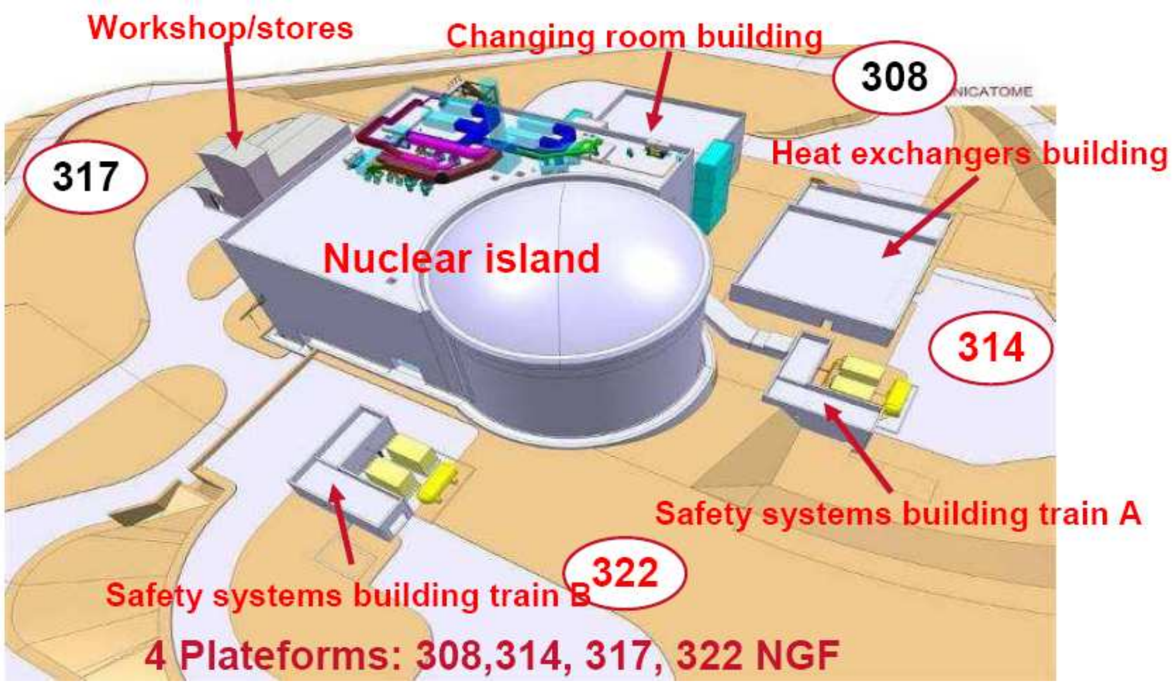


OUTLINES

- **JHR Key Features**
  - **Purposes**
  - **Key Features**
  - **Organisation and Main Milestones**
- **Overview of the Centralized I&C**
  - **Main Functions**
  - **Design Drivers**
  - **Automation & HMI Sub Systems**
- **A Few Technical Points**
  - **Defence in Depth**
  - **CQA & 2 oo 3 Architecture**
  - **Excore Flux Measures**
  - **Qualification/Durability**

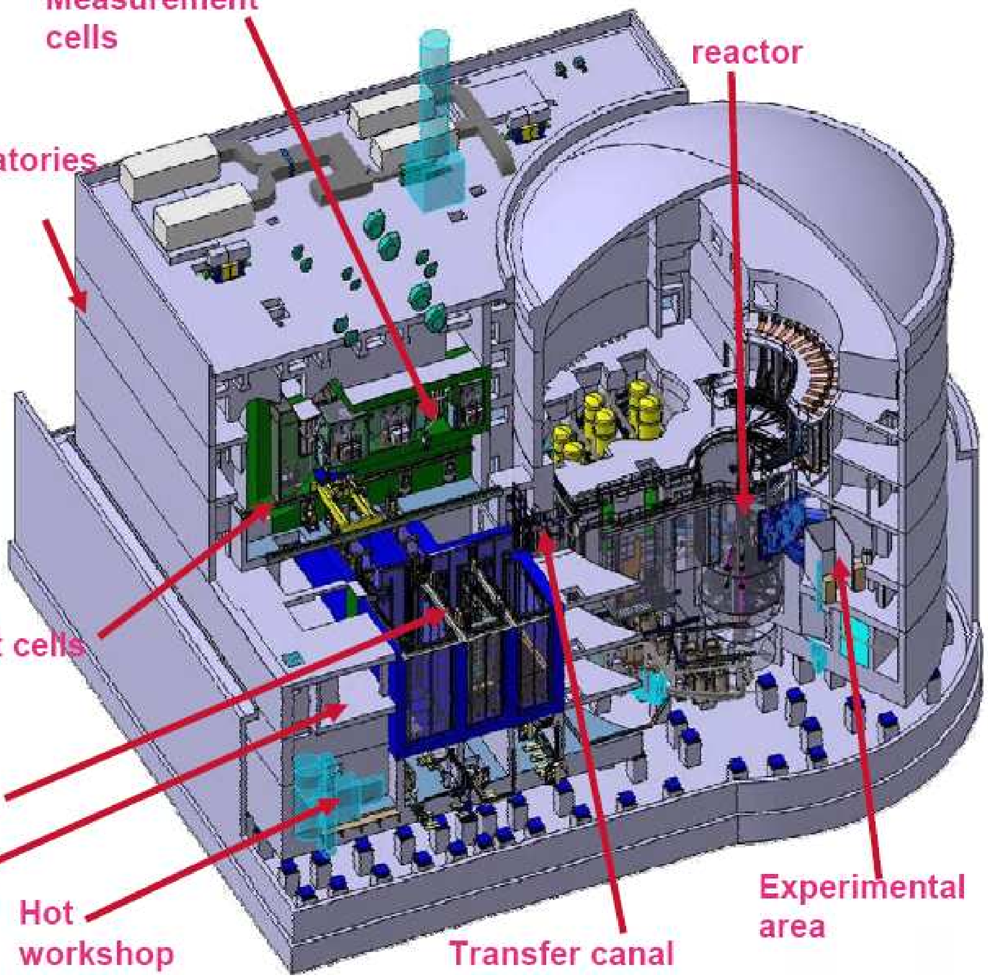
JHR Key Features - Purposes

- **A Experimental Facility dedicated to**
  - **Irradiation Experiments in support of GEN II, GEN III & GEN IV Technologies**
  - **Radioisotopes Production**



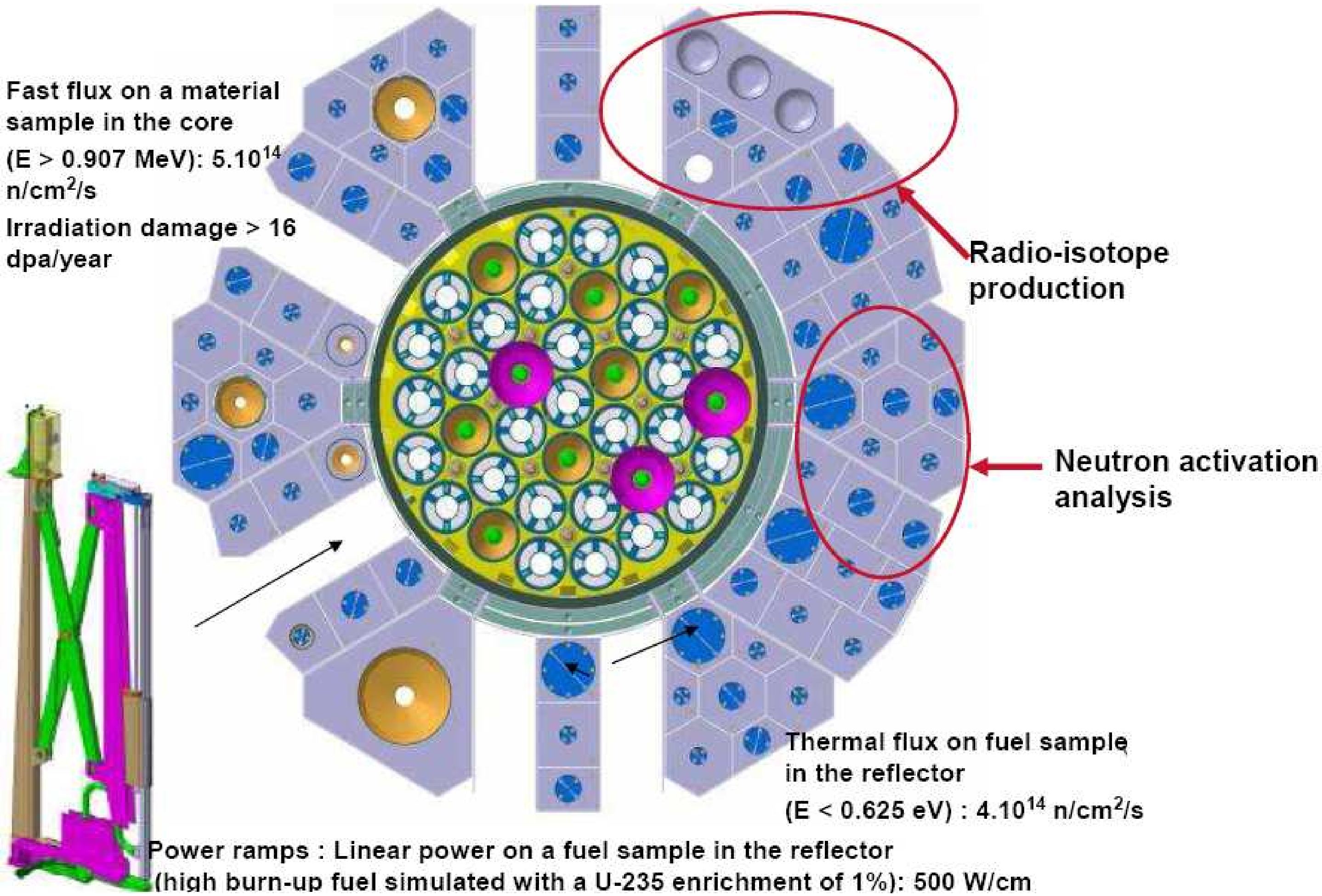
JHR Key Features

- **Reactor building:**
  - Reactor : tank in pool type 100MW
  - Large experimental area including on line fission product laboratory
  - pool for Intermediate storage and working
  - Underwater benches
- **Nuclear auxiliaries building**
  - Hot cells:
    - two beta-gamma multi-purpose hot cells for irradiation experiments,
    - a true alpha hot cell,
    - a hot cell for dry packaging of radioisotopes or irradiated fuel elements
    - measurement cells for PIE (non destructive)
  - Laboratories (radiation dosimetry,..)
  - Pools:
    - Experimental device pool
    - Fuel storage pool
    - Irradiated component pool
    - Transfer canal + hatch



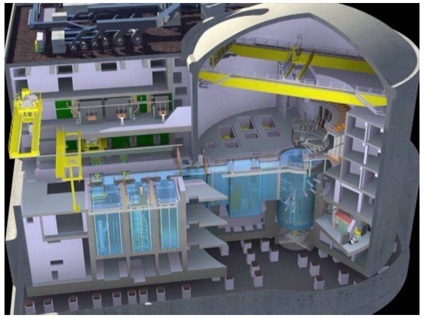
JHR Key Features

- **25 simultaneous experiments and up to 10 Incore**



JHR Key Features - Organisation

- Owner: CEA
- Prime contractor consortium AREVA TA, AREVA NP, EDF leaded by AREVA TA
- Procurement packages are defined, prepared and controlled by the prime contractor, contracts are placed by CEA
- 30 procurement packages
- Key procurement packages
  - civil work awarded by Razel
  - primary cooling pumps, supplied by Union pump
  - the reactor unit, including the control rod drive mechanisms, safety-related components, primary cooling system, and instrumentation and control system, is going to be supplied by AREVA TA in a turnkey contract
  - the fuel, fabricated by AREVA CERCA
  - In-kind contributions from some of the project's foreign partners:
    - NRI (Czech Republic): Hot cells
    - ENSA/EA (Spain): Primary Heat exchangers
    - VTT (Finland): Non Destructive Examination benches
    - SCK (Belgium): contribution for fuel qualification

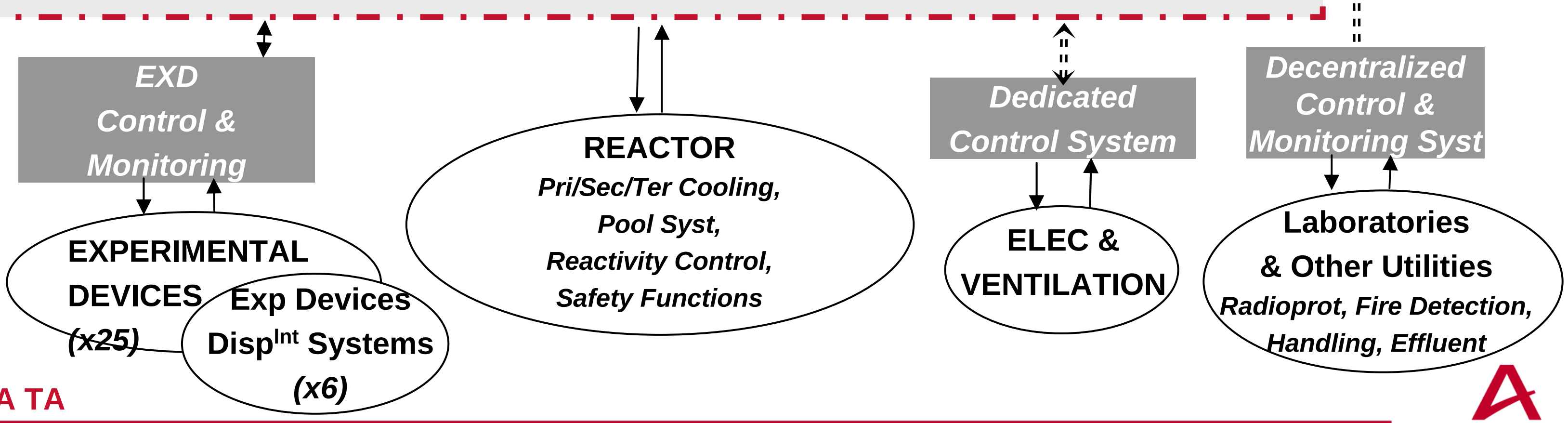


OUTLINES

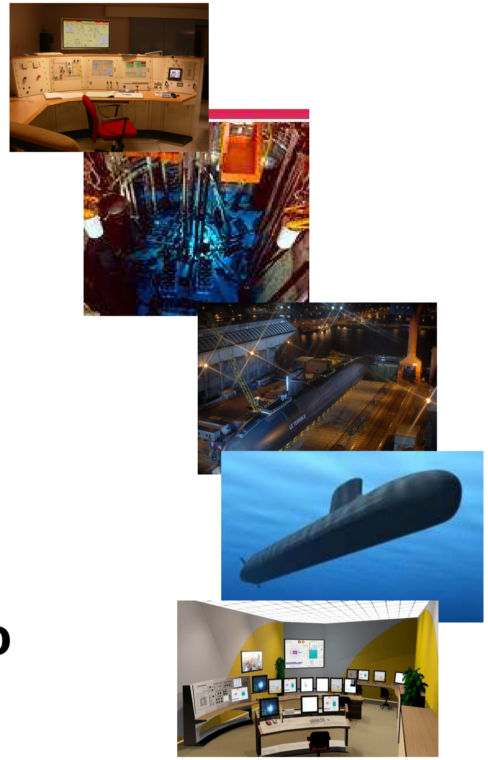
- JHR Key Features
  - Purposes
  - Key Features
  - Organisation and Main Milestones
- **Overview of the Centralized I&C**
  - **Main Functions**
  - **Main Design Drivers**
  - **Automation & HMI Sub Systems**
  - **Architecture**
- A Few Technical Points
  - Defence in Depth
  - CQA & 2 oo 3 Architecture
  - Excore Flux Measures
  - Qualification/Perianilty
  - Simulation

I&C Overview – Main Functions

- **Whole Reactor Control & Monitoring**
  - Primary, Secundary, Tertiary Cooling Systems, various Pool Systems, Reactivity System, Safety Systems
- **Complete Centralized Monitoring for processes with their own dedicated Control Systems**
  - Electricity and HVAC Utilities
- **Synthetic Monitoring in MCR & ECR for processes with their own dedicated control and monitoring systems**
  - Laboratories and Other Utilities (Radioprot, Fire Detection, Handling, Effluents)
- **Standardized Interlocks Functions between Experimental Devices and Reactor I&C**
  - Safe Shutdown Orders from Exp Devices (x25) to Reactor or from Reactor to each Exp Devices
  - Preventive Reactor Shutdown due to incident on Exp Devices or Cutoff of Exp Devices Displacement Systems (x6)
  - Transmission of Analog Parameters from Reactor to Exp Devices to give contextual informations



I&C Overview – Design Drivers(1/3)



- **Based on 25 years of experience in digital I&C Systems for nuclear reactors, we designed JHR Centralized I&C with 3 main items in mind : licensability, cost-effectiveness and durability.**

- **For a Material Testing Reactor, we also took into account the necessity of evolutivity regarding interfaces with the multiple and evolutional experiments.**

AREVA

I&C Overview – Design Drivers(2/3)

- **DD1 - Licensability : To make it easier to obtain this fundamental target we chose to**
  - **Be fully Compliant with international nuclear IEC standards (IEC 45A serie)**
  - **Re use Nuclear Proven Architecture and Technology for Category A Automation Systems**
  - **Implement a Clear Separation between Safety and Non safety systems with unidirectional links**
- **DD2 - Cost-effectiveness : We have based our approach on**
  - **a good balance between our own cost-effective safety products and the best available COTS equipment**
  - **The use of 2 safety categories rather than 3 (A & C regarding IEC 61226) to simplify and reduce the cost of qualification of the safety systems**

I&C Overview – Design Drivers(3/3)

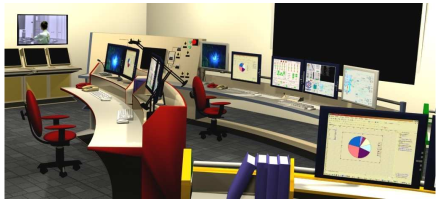
- **DD3 - Durability : 2 complementary pillars**
  - **AREVA TA is the owner of the safety calculator technology. We secure the durability of this solution reusing the same standardized products for all the reactors we design.**
    - Of course we have strong commitment from our different customers included JHR to maintain these safety calcultors for a long time.
  - **We also implement durability using well established industrial Products (Sensors, PLC & SCADA) to take advantage of proven solutions coming from other industries where there is no specific nuclear requirement.**
- **DD4 - Evolutivity essential for a MTR**
  - **with decentralized Remote Input/Output Modules and Large Margin in racks and in cabinets to improve evolutivity of Reactor I&C**
  - **Generic and Standardized Interfaces between Reactor and Experimental Devices to facilitate implementation of these various experimental devices during the life of the facility.**

I&C Overview - Sub Systems

▶ Level 1 – 5 Automation Systems

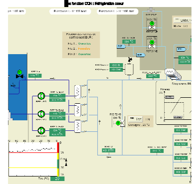
Sub system	Functions	Safety Cat	Sizing DI	AI	DO	AO	Sensors	Actuat.	Technologies
CQA Protection System	Short Term Automatic Safety Actions and Monitoring of the Emergency Shut Down	A	120x3	15x3	60	20	**80x3**	**120**	Safety Calculator from AREVA TA in a 2oo3 Architecture. Each channel is organised around a CPU card called CSG organised in a dual software architecture.
CQC Safety Related System	Complementary automatisms for MT/LT accidental situations Complementary post accidental monitoring system including safety automatic actions monitoring, Mitigation of hazards (seism) Monitoring availability of safety systems	C	1400x2	150x2	72	0	**180x2**	**130**	Industrial PLCs with RIO (Quantum from Schneider) with a strong separation from CS and unidirectional communication. 2 separate files to guarantee Single Failure Criteria
CEQ Safety Interfaces with Exp Devices	Safe Shutdown Orders from Exp Devices (x25) to Reactor or from Reactor to each Exp Devices	A							HW Relay Logic
CS Operational System	Automatisms in the normal and incidental situations	C & NC	1600	1000	500	30	**500**	**400**	Industrial PLCs with RIO (Quantum PLCs from Schneider in a HSBy architecture)
CEC Operational Interfaces with Exp Devices	Preventive Reactor Shutdown or Cutoff of Exp Devices Displacement Systems Trans of Analog Parameters from Reactor to Exp Devices	C							RIO modules with wired links between CEC and CS except for the transmission of parameters by a digital link from the reactor to the Exp Dev

safety category refers to IEC 61226 classification

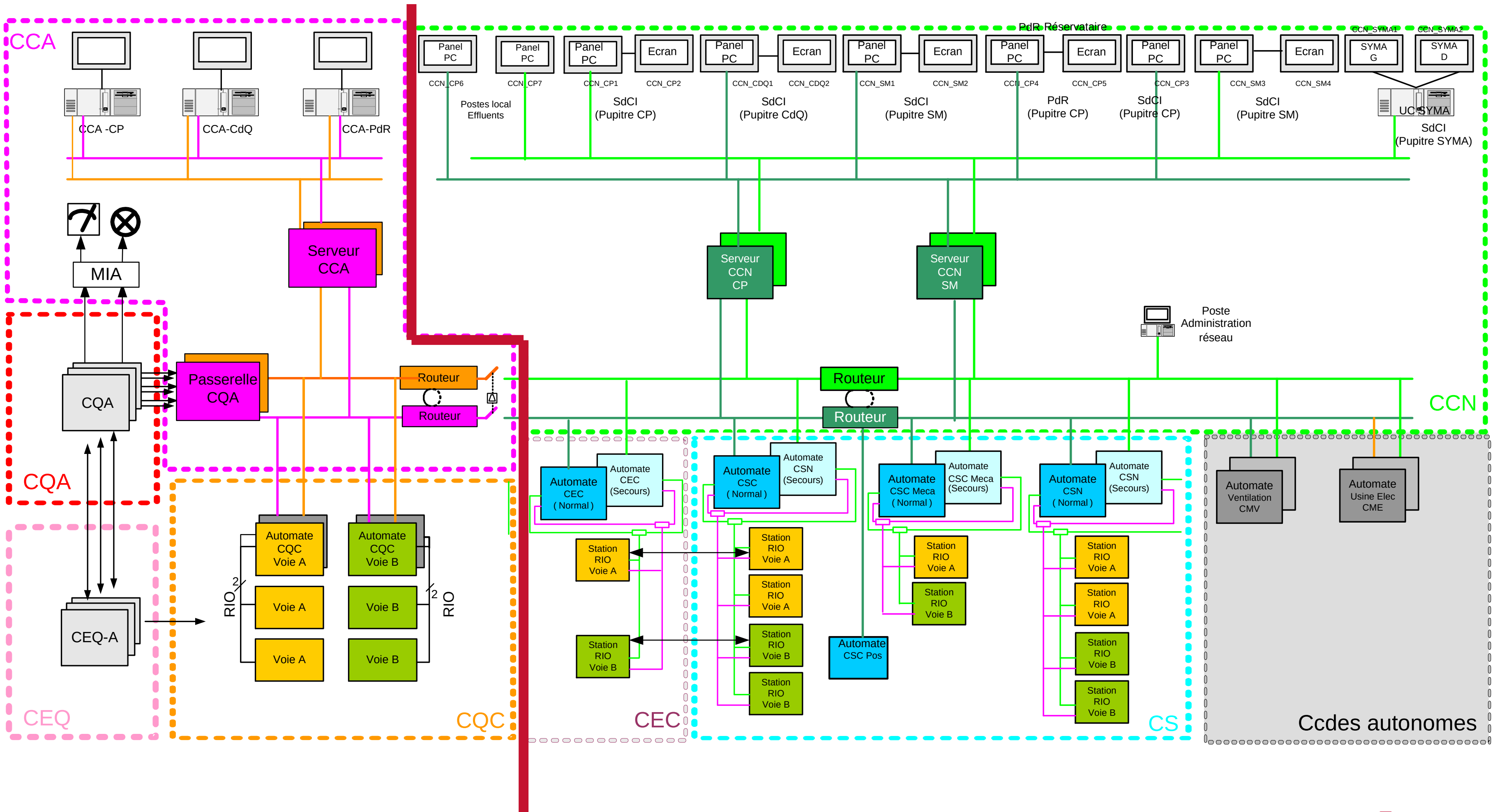


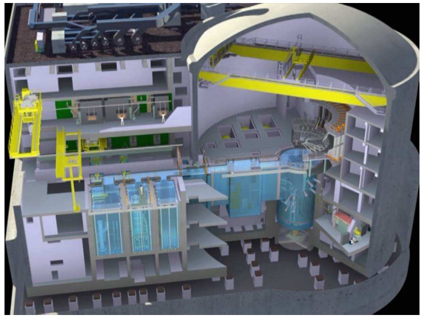
I&C Overview - Sub Systems

▶ Level 2 – 3 Supervision & HMI Systems

Sub system	Functions	Safety Cat	Sizing	Technologies
CCA_A **Accidental HMI**	HW HMI for Monitoring the Safety Limits Thresholds and the Main Safety Parameters	A	20 to 30 Galvanometers 30 to 40 indicators lights 80 operator commands for CCA_A & CCAc	 HW approach with Indicators, Galvanometers and a mediator module MIA to connect digital output of the triplex redundant CQA to these HW Galvanometers and Indicators
CCAc **Post Accidental HMI**	Digital Monitoring HMI & HW Commands Complementary to CCA_A for monitoring post accidental situations	C	2 VDU in MCR + 1 in ECR 60 accidental views	 Digital Monitoring HMI and HW Operator Commands Developed by TA to improve digital HMI capabilities regarding safety requirements Based on VME HW for calculator and QNX OS with a set of graphical level C objects for SW application
CCN **Operational HMI**	Digital HMI in the normal and incidental situations	NC	11 VDU in MCR + 2 VDU in ECR + 1 Large Wall Screen 120 operational views	 Industrial SCADA Panorama E^2 from CODRA with HSBy OPC Servers

I&C Architecture





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- JHR Key Features
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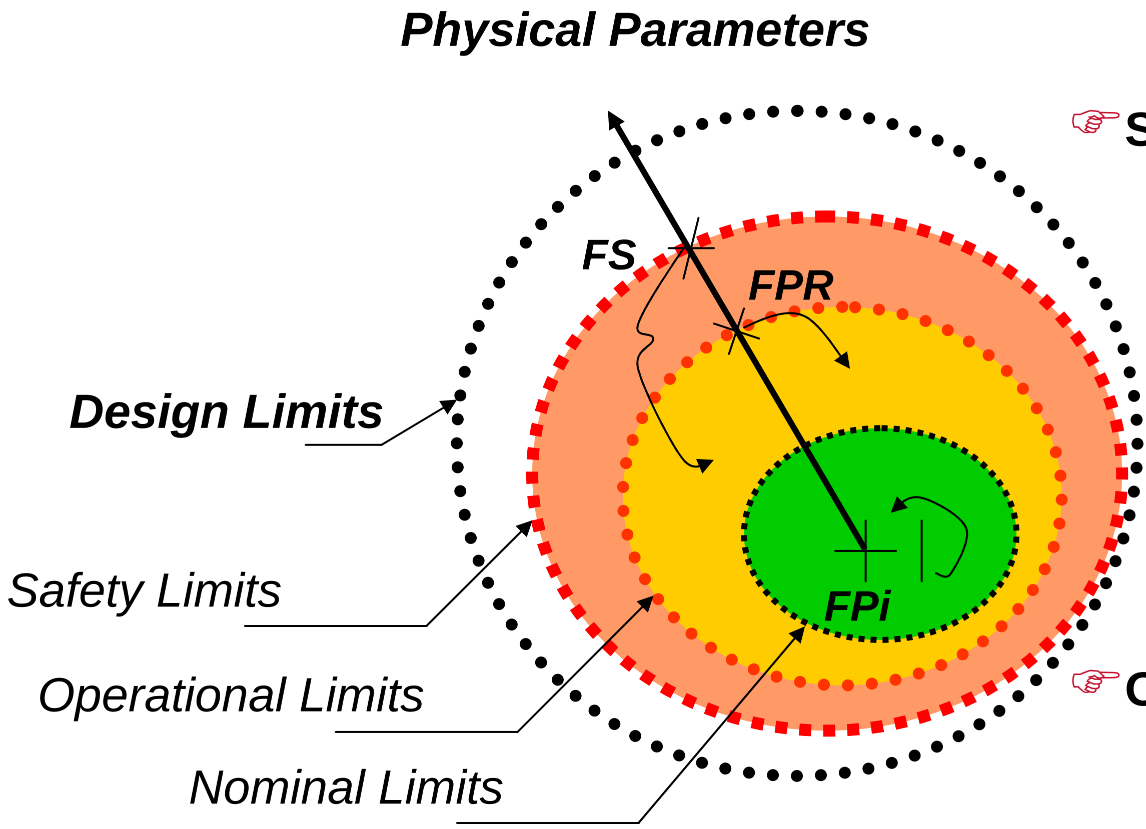
- Overview of the Centralized I&C
  - Main Functions
  - Design Drivers
  - I&C Sub Systems : 5 Automation & 3 HMI Systems
- **A Few Technical Points**
  - **Defence in Depth**
  - **CQA & 2oo3 Architecture**
  - **Excore Flux Measures**
  - **Qualification/Durability**

DEFENCE IN DEPTH FOCUS



☞ **Safety System**

For Safety Function (FS)

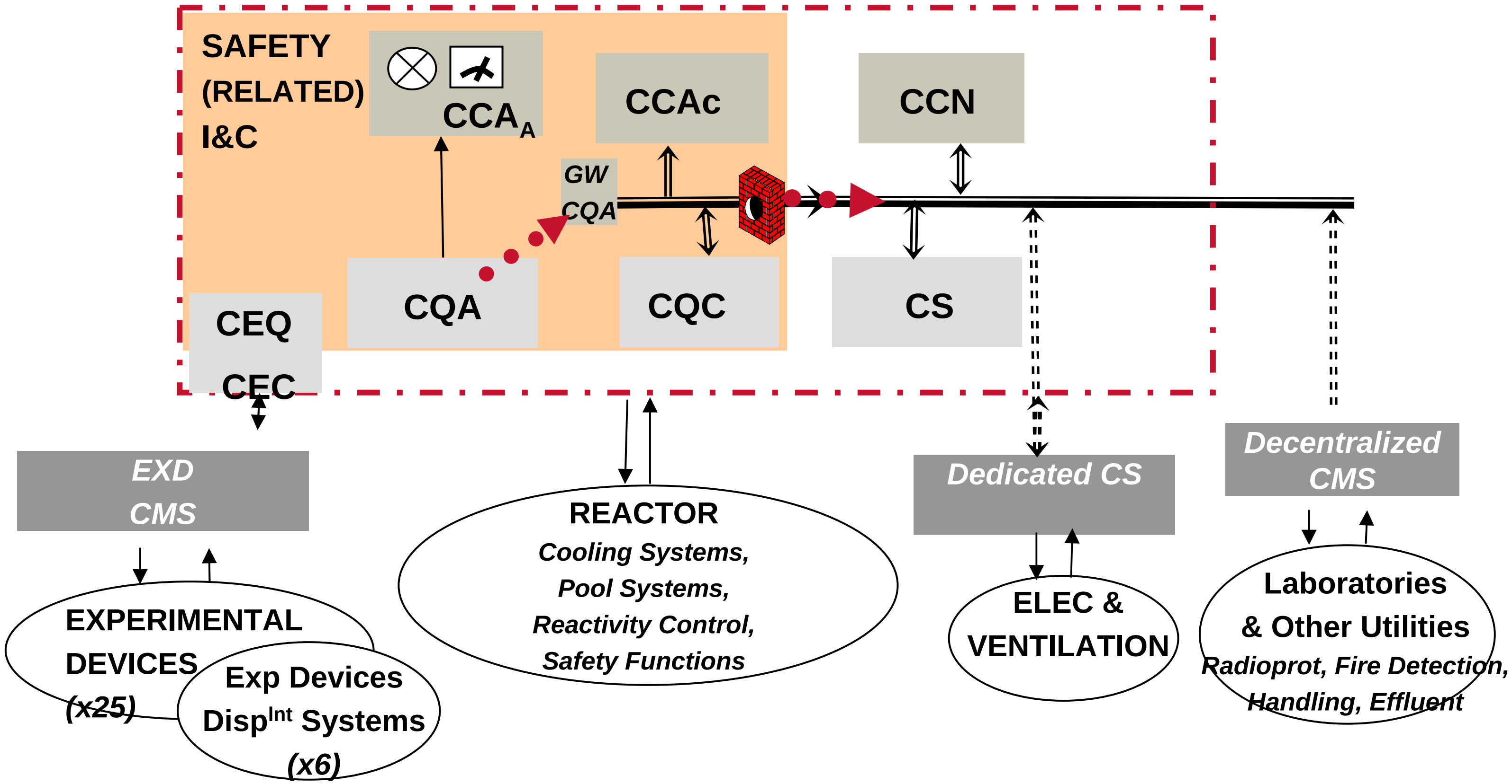
- **Short Term (Controlled State by $CQA+CCA_A$)**
- **MT/LT (Safe State by $CQA + CCA_A + CQC + CCA_C$)**

☞ **Operational System (CS+CCN)**

For PIlot functions (FPI) and PRevention ones (FPR)

☺ **Unidirectional Links between CQA->CQC, CQC->CS, CCA->CCN to avoid domino effect between defence lines**

- **Unidirectional Communication from higher to lower safety level Syst to improve Defence in Depth and Avoid Domino Effect**



CQA FOCUS

CQA = Safety I&C, Category A

- Single Failure Criteria with Redundant 2oo3 architecture to allow high level of safety and availability
- Safety Oriented Failure Calculators to have a very high reliability level per channel
- Requirement of Common Cause Failure Evaluation according to IEC 61226
  - System PFD $=10^{-4}$ to 10^{-5}

Redundancy	Spurious Trip	Failure Per Demand (PFD)
1	X	Y
1oo2	2X	Y^2
2oo2	X^2	2Y
2oo3	$3X^2$	$3Y^2$

$$PFD = 3\,\lambda_{unsafe}^{2} \times T^{2} + \beta \times \lambda_{unsafe} \times T$$

CQA TECHNOLOGY

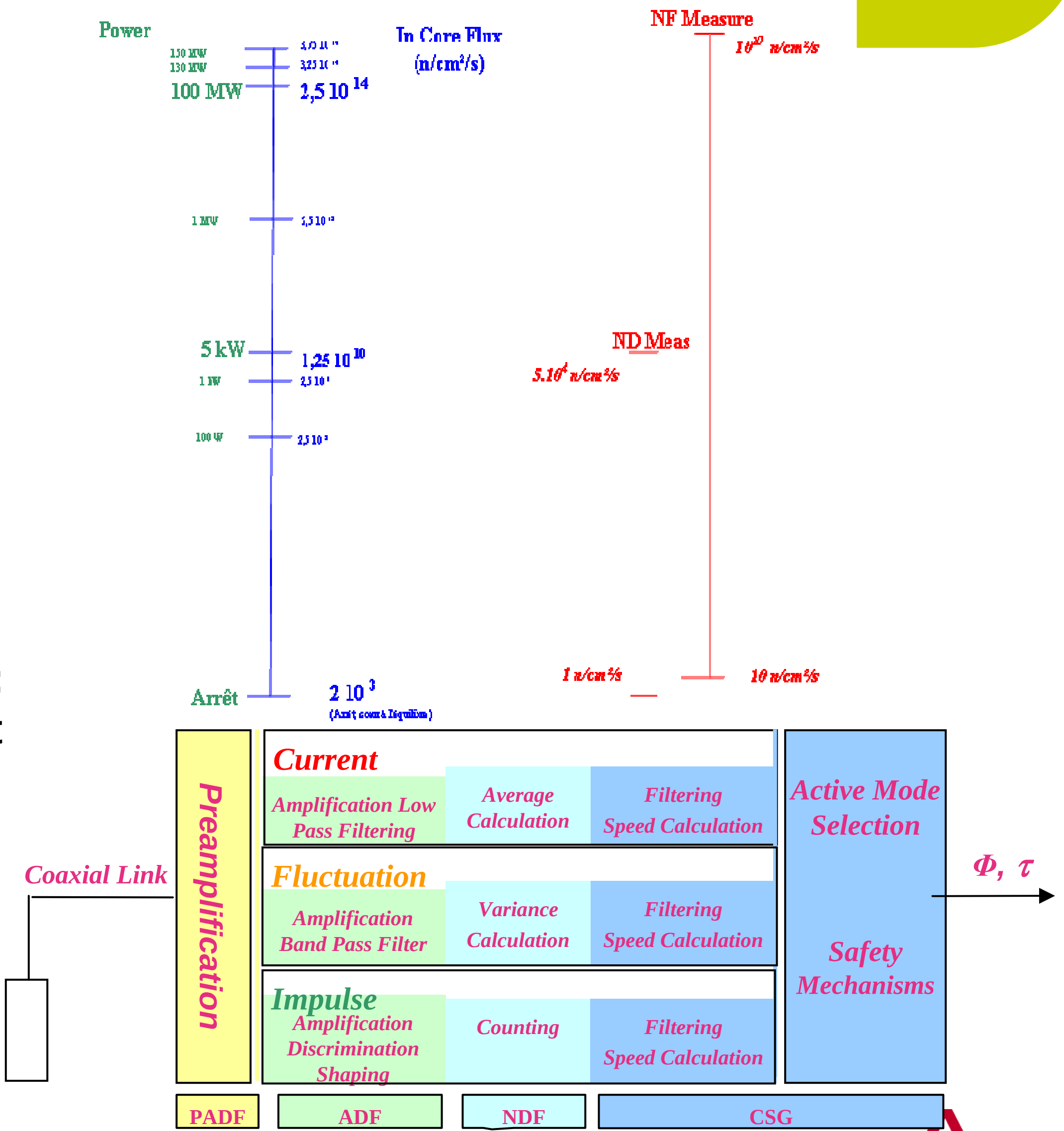
- Based upon our experience in digital safety systems, we've developed *PEGASUS™ NR-S*, System/HW/SW mastered by TA
- Using commercial components (FreeScale *–ex Motorola* processor, VME 6U format, rack EUROFER, FPGA ACTEL)
- Each channel is organised around a CPU card called CSG organised in a dual software architecture

Ex Core Flux Measures FOCUS

- **To control Reactivity we will use 3 groups of excore sensors**
  - **Starting Neutron Flux Chains – ND (x3)**
    - To Monitor Reactivity and Protect Reactor from refuelling to LT Post Accidental Situations
    - To Start Reactor and Monitor Criticalty (up to 1 kw)
  - **Power Neutron Flux Chains – NF(x3)**
    - To Monitor Reactivity and Protect Reactor in power operations
  - **Gamma Chains (x2) for Reactor Power Regulation**
    - To control Power Reactor with a set point from 10 % to full Power and a diversifiate technology regarding safety functions

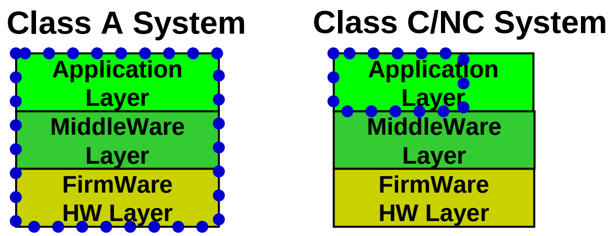
Ex Core Flux Measures

- **Wide Range Neutron Channels with**
  - **ND : 4,5 decades with a Boron Deposit Chamber in impulsion mode (CPNB64) *or 10 decades with the Wide Range Fission Chamber (CFUG08).***
  - **NF : 10 decades with a fission Chamber (CFUL08) in 3 modes : impulsion, fluctuation & current**
  - **Triplex Architecture and High Dynamic Electronic with 12 decades range and 3 automatic switching modes**



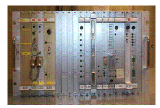
Qualification/Durability

- **We look for a good balance between safety proven equipment to answer the nuclear requirements for safety functions and well established COTS solutions to use the best of the market.**



- **Based upon IEC 61226 Clasification, for JHR, we have decided to implement only 2 classes to limit the number of technologies to qualify and to maintain**

  - **Classes A : with integrated packages for harsh environment requirements**
    - *PEGASUS™ NR-S,* System/HW/SW mastered by TA using commercial components (Motorola processor, VME 6U format, rack EUROFER, FPGA ACTEL, etc.)
    - To make easier to maintain for long term a critical technology and associated certification with a reasonable level of dependency from providers of components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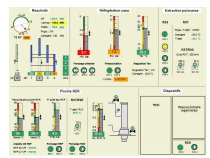

  - **Classes C & NC : using good COTS solutions**
    - Using the best of the market
    - Keeping under control the strategic reactor application software
    - Nota : It's a real Challenge to certified Windows SCADA for class C HMI. We propose 2 alternative ways : A simplified HW HMI without SCADA Classified System or a Digital solution with a QNX Platform.

Additional Point - Simulators

- **2 complementary uses of simulators for Research Reactors**
  - **To improve the Design of the Process**
    - ***To adapt the design with an appropriate compromise between safety and availability requirements but also with a better prediction of transient situations***
    - ***To Reduce risks & costs in commissioning phases***
    - ***To start the Human factor studies and the validation of accidental procedures***
  - **To support End Users**
    - ***To Learn and Train operators***
    - ***To maintain installation in operational conditions***
    - ***To maintain know-how***
- **For JHR, CEA asked AREVA TA for an optional training reactor simulator. So we propose a solution based on :**
  - **The ALICES Workshop software from Corys Tess**
  - **An adaptation of reactor design models**
  - **An emulation of Reactor I&C software**
  - **And a partnership with Corys Tess, a world reference company in training and engineering simulators with over 600 simulators provided over the world**

http://www.corys.com

Conclusion

- **Based on 25 years of experience in digital I&C Systems for nuclear reactors, AREVA TA designed JHR Centralized I&C with 3 main items in mind : licensability, cost-effectiveness and durability.**

- **Regarding the specific purposes of a Material Testing Reactor, we took also into account the necessity of the evolutivity of this class of reactor.**

- **Finally, the solution we offer to our CEA customer is an efficient alliance between our own proven safety calculators and good COST equipment.**

We have to keep in mind that for a nuclear I&C system, safety certification is still a main issue. But it will also be a challenge for an adaptable MTR to maintain the safety level during the whole life of the facility.