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Reactor performance, system reliability, instrumentation and control

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Maintenance

“Effective maintenance is essential for safe operation of a nuclear power plant.”

„Maintenance of Nuclear Power Plants“, IAEA Safety Series No. 50-OG-07, 1990

Maintenance scope

"Effective maintenance is essential for safe operation of a nuclear power plant. It […] ensures that the level of reliability and effectiveness of all plant structures, systems and components having a bearing on safety remains in accordance with design assumptions and intent."

„Maintenance of Nuclear Power Plants", IAEA Safety Series No. 50-OG-07, 1990

Maintenance

"Effective maintenance is essential for safe operation of a nuclear power plant. It not only ensures that the level of reliability and effectiveness of all plant structures, systems and components having a bearing on safety remains in accordance with design assumptions and intent, but also that the safety status of the plant is not adversely affected after commencement of operation."

„Maintenance of Nuclear Power Plants", IAEA Safety Series No. 50-OG-07, 1990

Outline

1. Safety Systems covered
2. A quick project portrait
3. Scientific challenges
4. Industrial Impact, End user implication and academic involvement
5. Lessons learnt and follow-up issues

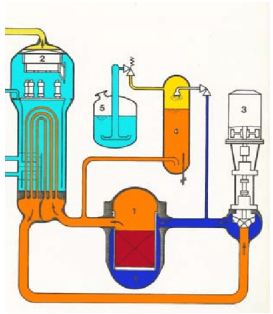
Safety systems covered

NOMAD

ADVISE
Advanced Inspection of Complex Structures

TeaM CABLES
European Tools and Methodologies for an efficient ageing management of nuclear power plant Cables

HARMONICS

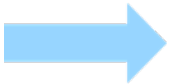


NOMAD

Euratom Horizon2020

LTO of RPVs

- The reactor pressure vessel (RPV) is the only part of the primary loop which cannot be replaced
- Irradiation induced embrittlement limits the lifetime of the reactor pressure vessel
- => A systematic study of correlation of
  - microstructure
  - Mechanical properties
  - Neutron irradiation conditions (accumulated dose)
  - NDE properties (Ultrasound, micromagnetic and eddy current)



- Extending the existing database on irradiation impact
- Evaluate reliability of NDE techniques
- Assess impact of material heterogeneity

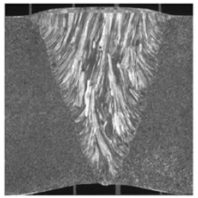
Massively experimental approach

ADVISE
Advanced Inspection of Complex Structures

Euratom Horizon2020

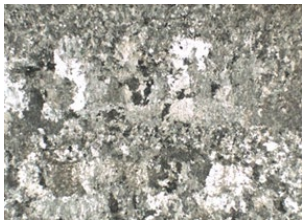
LTO of NPPs

- Complex structured materials are common in NPPs: claddings, transition welds, repairs, CASS
- The microstructure of corrosion resistant alloys limits the performance of ultrasonic inspection
- Welds: beam skewing, beam splitting and scattering
- Cast stainless steel: high structural noise



No silver bullet!

- In-situ material characterization techniques
- Fast on-line simulation of ultrasound propagation
- Inspection method optimisation
- Defect evaluation and assisted diagnostics using characterization data
- Optimised transducers
- Signal processing for noise reduction



Increased inspection depth

Team CABLES

TeaM CABLES — European Tools and Methodologies for an efficient ageing management of nuclear power plant Cables

LTO of cables/polymers

Euratom Horizon2020

- ~1,500 km of electrical cables in a plant: **Complete cable replacement is not economically feasible**
- Polymer ingredients impact dramatically polymer properties and ageing

Need for

- Generic accurate predictive models of lifetime
- Generic methods and tools for on-site monitoring of cables

→ Cable ageing ~ polymer layers ageing

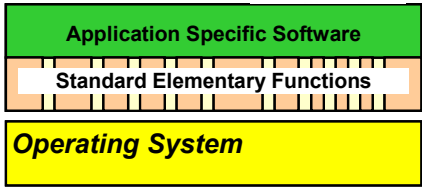
- Carry out accelerated ageing inside a reactor building to identify polymer ageing mechanisms
- Identify the impact of ageing on the behaviour of cables subject to accidental conditions
- Develop a kinetic model for polymer ageing and multiscale models (mechanical, physical, electrical)
- Contribution to standards on cable ageing characterisation and NDT techniques
- Define criteria and deployment protocols for non-destructive tests or micro-sampling techniques used for on-site monitoring
- Provide and promote a numerical tool for cable ageing management and lifetime prediction

HARMONICS

HARMONICS

- A fact of life: Software cannot be proven to be completely defect-free!
- Focus: I&C systems performing high order safety functions (category A IEC 61226)
- => Systematic and consistent, yet realistic and practical approaches for software assessment
  - Software verification & validation (V&V)
  - Software safety justification
  - Quantitative evaluation of software (related aspects of system) reliability
  - Address software and system lifecycle (40years, 60y with LTO)
  - Demonstrate feasibility of proposed approaches in the field
  - Get regulators involved

SEVENTH FRAMEWORK PROGRAMME



Scientific Challenges

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„Continually improving safety and realiability of Gen II and III reactores“ (Euratom 2016): Obtain a deeper understanding of operation-induced degradation mechanisms			How to formally justify very high reliability figures for a given piece of software?
Multi-scale polymer aging model (up to 80 years) for a high diversity of polymers	Quantify neutron irradiation induced embrittlement independent of the cladding	State of the art report to establish challenges in terms of a „snap shot“ at the start of the project	Lack of universally accepted approach for the quantitative evaluation of software reliability.
Produce realistic (irradiated and thermally aged cladded blocks/) samples through highly accelerated ageing within reactors/reactor buildings		In-situ characterization, predictive weld models, UT models	
	Highly sensitive and robust ultrasound NDE needed (unaffected by cladding/microstructure)		
		Ultimately gain acceptance of regulator (qualification)	

Industrial Impact and end user implication

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Joint symposium/seminar		Training workshop for NPP operators and researchers of developed tool, summer school, symposium	IAEA report „Dependability assessment of Software for Safety I&C Systems at NPPs“
Access to Western and russian (VVER) type reactors			Link with chinese project
Integration into acquisition system	Database	End user workshops to establish and maintain link with stakeholders	
Integration into CIVA software	Delivery of tools for LTO assessment (ageing)		
Ensure industrial applicability of developments through end-user groups with external advisors			
Provide background for robust national and EU strategies for nuclear reactor safety			
Collaboration with EPRI		NUGENIA	

Academic involvement

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1 PhD student		3 PhD students	2 PhD students
Imperial College London, University of Bristol	Coventry University	University of Bologna ENSAM Paris	Harbin Engineering University (via RAVONSICS co-project)

Academic involvement

Follow-up issues

- Lifetime extension of current Gen II plants to 60 years has become economically viable (increased capital cost, licensing, …)
- LTO of these plants raises issues (some of which being the motivation for the projects in this presentation)
- For Gen II, NDE has often been designed as an afterthought, instead of being an integral part of the design

Follow-up issues

- Continuous monitoring has demonstrated its added value in other industries as a complement to in-service inspections at programmed intervals.
- Ageing models allow for predictive maintenance (as opposed to scheduled maintenance).
- Inspection-oriented design has to be considered at manufacture and for replacement components.

Reactor Performance, System Reliability, Instrumentation and Control