SAFETY ASSURANCE THROUGH ADVANCES IN LONG-TERM OPERATION

Presented by Kevin Mottershead, Wood, UK
With support from co-authors at CEA, CIEMAT and VTT

Presentation outline

- Introduction to the EC supported project portfolio covered by this presentation
- Overview of Nuclear Industry operational issues
- Long-term operation challenges and advances gained from project portfolio
- International engagement
- Remaining challenges
- Summary

The EC supported project portfolio

- Projects total €28.5M from EC and National funding
- INCEFA+
  - Environmental Assisted Fatigue focus
  - 16 organisations, 5 year project concluding 2020
  - Aiming to reduce assessment conservatism through creation of focused, quality data
- SOTERIA
  - Irradiation damage focus for RPV and Internals materials
  - 23 organisations, 4 year project concluding 2019
  - Emphasis on improving mechanistic understanding through combination of testing and modelling
- MEACTOS
  - Focus on mitigating SCC susceptibility through surface condition optimization
  - 16 organisations, 4 year project concluding 2021
  - Demonstrating benefit of non-nuclear novel surface finishes known to mitigate against SCC
- ATLAS+
  - Validating modelling of weld residual stresses and large ductile tearing
  - 19 organisations, 4 year project concluding 2021
- NUGENIA+
  - 13 small pilot projects
  - Projects concluded 2016
  - Materials analysis, fluid dynamics modelling, materials forming, inspection, materials degradation, soil mechanics, test optimization and test data management

Nuclear Industry operational issues

- 4 classes of issue lead to long-term operational challenges
- Economic
  - Retiring nuclear capacity exceeds new capacity building
  - European nuclear capacity forecast to reduce till at least 2030
  - Effects compounded by retiring fossil fuel stations, uncertainty of gas/oil fuel supply, and long delays bring new nuclear into service
  - Hence existing fleet is needed for as long as possible

- Engineering - Conditions not foreseen at design stage
  - Increased dose
  - Increased time of operation at temperature and pressure
    - Creep damage
    - Material embrittlement
    - Thermal degradation
    - Environmental Assisted Cracking
  - Increased thermal and mechanical cycles due to long life and/or switch from base-load to load-following

Nuclear Industry operational issues

- 4 classes of issue lead to long-term operational challenges
- Legislative
  - Safety cases usually underpinned by codes and standards
  - Codes and standards promote international consensus and general long-term stability
  - However, issues arise when:
    - Assessor needs to justify operation beyond scope of agreed standard
    - A standard is updated, and increased conservatism becomes problematic

- Safety
  - Public nuclear perception is improved since last century
  - Awareness of nuclear consequences is also increased
  - Safety legislation evolves as human experience evolves. Step changes can arise (e.g. post Fukoshima) with far-reaching implications
  - High safety reliability drives demand for confident predictions of materials degradation and structural integrity

Challenges and project portfolio advances

- Materials performance to support PLEX to at least 60 years?

INCEFA+	SOTERIA	MEACTOS	NUGENIA
Improving EAF predictability	Mechanistic focus aids extrapolation	Establishing surface finishes with maximum SCC resistance	Pilot projects helped set scene for MEACTOS, SOTERIA and INCEFA+
Carefully accelerated tests	Multi-scale approach aids mechanistic insight	Proving methods for accelerated SCC testing	Projects tackled SCC testing and machining effects
Emphasis on high statistical quality			Atom probe data protocols and database recommendations also addressed

Quality, focussed consortia (doing much more than a single organisation could) promote statistical significance and ability to shape world opinion on material ageing

Challenges and project portfolio advances

- Materials specification for long-term operation?

INCEFA+	SOTERIA	MEACTOS
Help with specifying surface finishes	Mechanistic focus aids extrapolation of ageing to new materials	Help with specifying surface finishes
Testing stabilised material to complement 304 SS tests		Testing both austenitic steel and nickel-based alloys
		Mechanistic focus aids extrapolation of ageing to new materials

INCEFA+ and MEACTOS collaborate regarding measurement and control of surface finishes

Challenges and project portfolio advances

- Design code fitness for purpose?

INCEFA+	MENCIOS	ATLAS+	NUGENIA
Responding to emergent USNRC/ASME guidance	Tackles reliance on surface roughness as surface control measure	Improving piping ductile tearing prediction and LBB assessments	Examined benefits of probabilistic RPV integrity assessment
Aiming to demonstrate that environmental penalties can justifiably be reduced under specific circumstances	Considers machining developed for non-nuclear applications (aeronautics and automotive)	Probabilistic focus helps quantify uncertainties for methods that fall beyond traditional codes	
Statistical significance is vital for robust response	Will produce guidelines for designers specifying surface finish	Multi-scale validation of methods (including very large scale testing)	

Quality, focussed consortia (doing much more than a single organisation could) promote statistical significance and ability to challenge world opinion on codes and standards

Challenges and project portfolio advances

- Justification for operation of structures.
- Would failure be benign or catastrophic?

ATLAS+	NUGENIA
Improving ductile tearing and LBB methods for piping	Probabilistic RPV integrity assessment benefits

Challenges and project portfolio advances

- Threat mitigation through inspection?
  - All projects deliver advances in degradation rates which aids inspection scheduling
  - Inspection reliability is addressed by projects outside the scope of this presentation, these projects build on NUGENIA+ pilot projects
  - NOMAD addresses the development, demonstration and validation of a NDE tool for the local and volumetric characterisation of the embrittlement in operational RPVs
  - ADVISE aims to advance ultrasonic inspection of complex microstructure materials, for which conventional ultrasonic techniques suffer from severe performance limitations

Challenges and project portfolio advances

- Expertise availability?
  - Skewed demographics, experts retiring and next generation limited in experience
  - Difficulties attracting new researchers into Nuclear, possibly because of perceived low nuclear technical innovation due to conservatism?
  - Assurance of LTO depends on securing the next generation of experts
  - All EC funded projects major on dissemination and sponsoring of students, and also encouraging good project demographics
  - Dissemination events include:
    - Conference presentations
      - INCEFA+ presented at 9 international conferences, and joined at one by ATLAS+
      - Annual ASME PVP events are important for both projects (special project sessions already held for both projects)
    - Workshops
      - Each current project has held (or is about to hold) mid-term workshops targeted at new researchers needs.
      - INCEFA+ and SOTERIA have already committed to final project workshops aimed at established researchers.
      - NUGENIA+ pilot projects were presented to an open audience at a major end of project event.
    - Websites
    - Training missions
      - An INCEFA+ researcher from Spain worked on secondment to JRC in the Netherlands for ~3 months
      - ATLAS+ has 9 training missions planned for researchers to visit other partners
    - Feedback, when available, is always very positive
  - The membership of all the projects covered by this presentation include a good mix of new and established researchers which also aids succession

International engagement

- The credibility and usefulness of results from EC supported R&D projects is increased significantly with support from outside projects and outside Europe
  - INCEFA+
    - Setting up data sharing agreements with USNRC (USA), EPRI (USA) and JNRA (Japan) whereby data from these organisations will be uploaded to MatDB thereby setting up the first international database for this subject area
    - Confirmed interest in collaboration after INCEFA+ from KAERI (South Korea), EPRI (USA) and ThESIS (Germany)
  - SOTERIA
    - Regular interfacing with End-User Group comprising CRIEPI (Japan), EPRI (USA) and NRG (Netherlands)
  - MEACTOS
    - Regular interfacing with End-User Group comprising Jakub Ertl Elektrama (Czech Republic), Rolls-Royce (UK), Tractabel (Belgium), Ringhals AB (Sweden) and ANAV (Spain)
  - ATLAS+
    - In-kind collaboration agreements with Oak Ridge Consulting International (USA) and MHI (Japan) whereby experience is shared at technical meetings, and they participate in benchmark calculations, data sharing, and in preparation of key deliverables

Remaining challenges

- INCEFA+
  - Other sensitivities to explore, especially scale effects
- SOTERIA
  - Statistical significance will need more data
  - Data accessibility will necessitate work on databases
- MEACTOS
  - Optimum machining method is likely to require focused testing to improve parameterization for SCC control
- ATLAS+
  - Knowledge gaps likely to remain
  - Data accessibility also likely to remain a challenge

Benefits assured despite above challenges.

Interest from outside Europe in the projects demonstrates perceived benefit

Summary

- LTO safety assurance demands work on:
  - Materials performance over extended periods
  - Selection of materials for new plant
  - Design and assessment codes
  - Structural performance
  - Inspection scheduling and techniques
  - Expertise availability
- Required complexity of work and/or volume of data constrains potential unless organisations collaborate
- EC R&D support facilitates the collaboration, as demonstrated through the project examples in this presentation

Thank you for your attention!