Designing the RR SMR with Ageing Management in Mind

NIC 2026 – 3rd Edition

Jason Swan – Materials Manager

Who Am I?

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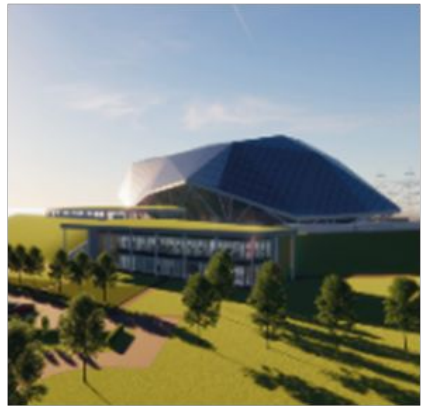
- Materials Manager: Rolls-Royce SMR: 2024 - present
- Materials Lead: Rolls-Royce SMR: 2020-2024
- Group Leader: Rolls-Royce Submarines: 2019 - 2020
- Materials Technologist: Rolls-Royce Submarines: 2013 - 2019
- PhD – University of Birmingham: School of Metallurgy and Materials: 2010 - 2013
- MEng – University of Nottingham: Mechanical Engineering: 2006 - 2010

01 Rolls-Royce SMR Overview

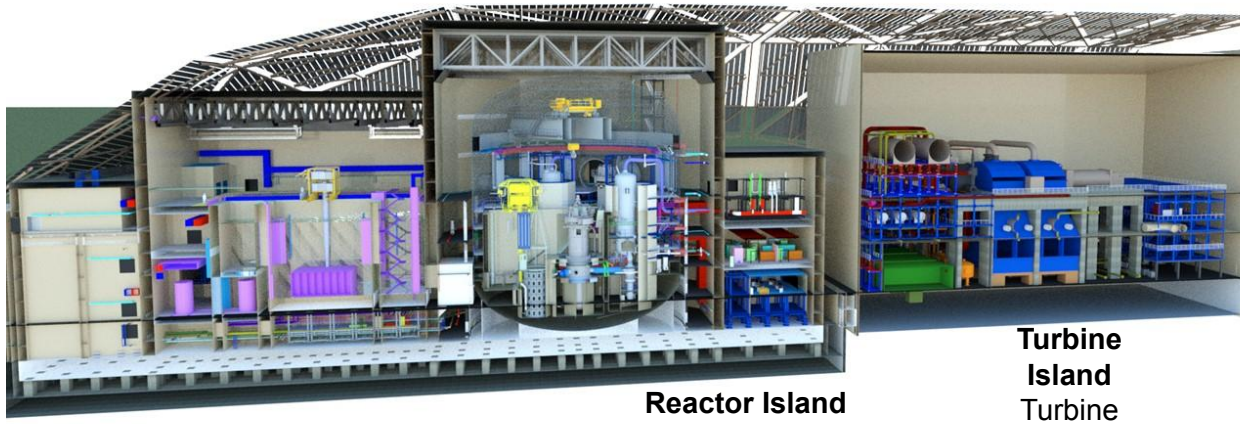
RR/RR SMR Portfolio in Nuclear

Formed in 2021

Advanced Modular Reactors (AMRs)		Submarines	Rolls-Royce SMR	Large Scale Civil
				
1 - 20 MW	15 - 150 MW	10s-100s MW	470 MW	>1 GW
Deployable power in strategic & remote locations (New Market)	Fixed Installation Heat & Power for Industry (New Market)	Naval Propulsion	Civil Power Generation (Established Power Market)	
Fuel Type: HALEU		HEU	LEU	

World Leading Whole Power Plant Solution - Standardised and Repeatable, Globally

Rolls-Royce SMR is a complete power solution, deliverable where power is needed, when it is needed, with true full-plant modularisation



Reactor Island
Containment

Turbine Island
Turbine Hall

- Pressurized Water Reactor (75% world fleet
- 470 MWe power output
- 60-year life
- Plant footprint of ~22 acres
- Most progressed through nuclear licencing
- Factory module manufacture, 4-year onsite build

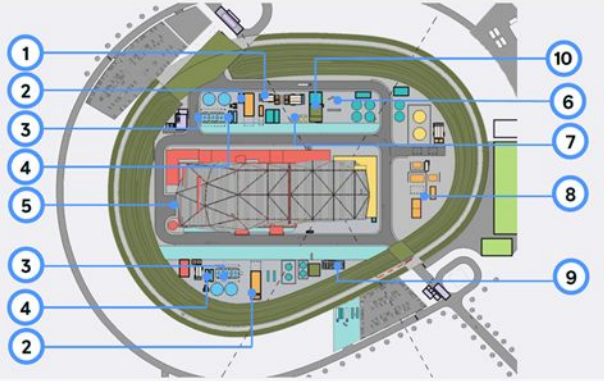
RR SMR is About Doing Nuclear Differently, Not Replicating Large Plants on a Smaller Scale

Small

- Is about maximising the power against the physical constraints applied to the design – optimising techno-economics

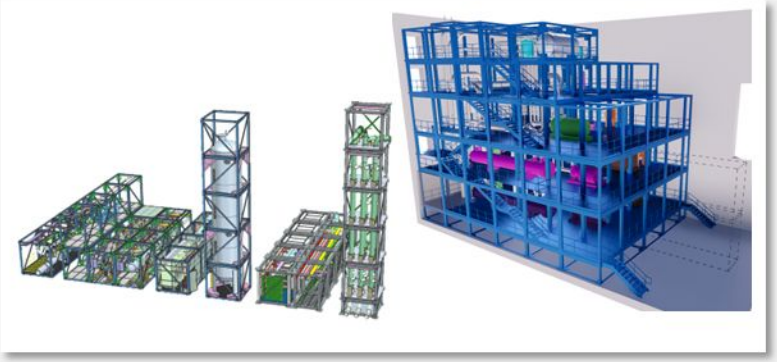
$$\text{LCOE} = \frac{\text{(Capex + Opex + Decom + Fuel + Financing)}}{\textbf{Power Generation} \times \text{Capacity Factor}}$$

- Small footprint and reduced site activity



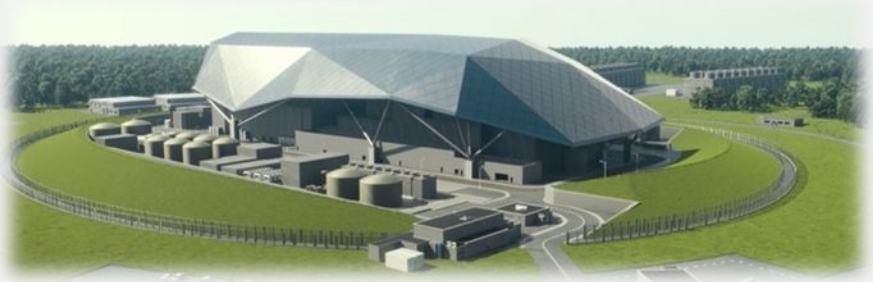
Modular

- Standardisation, factory repeatability in a production line approach.
- Whole power station modularisation, maximising off-site factory production and delivering standard transportable modules
- Modules tested in factories to reduce site activity
- Move volume of assembly activity off site and into factories



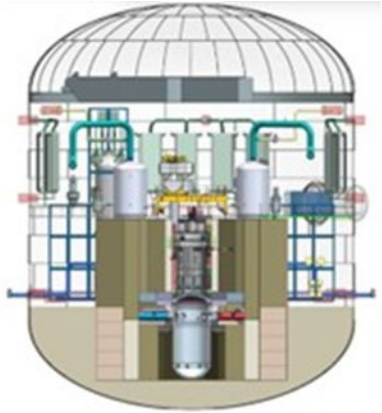
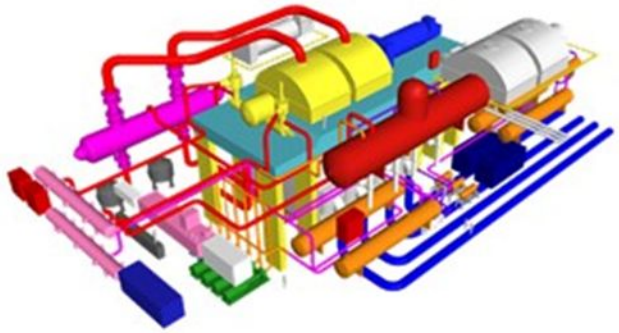
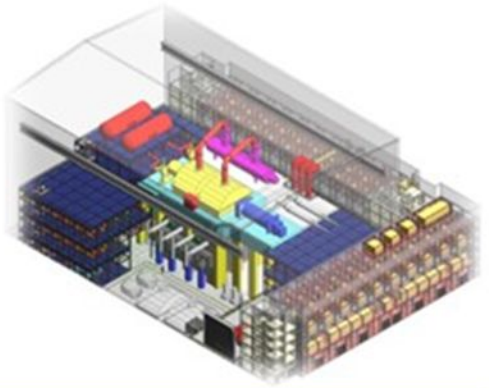
~~Reactor~~ Power Plant

- Reactor plant is only ~20-30% of the power station by capital value
- Must look at modularisation and standardisation of the whole power station including civil construction
- Otherwise, we are not addressing the challenges of Repeatability, Buildability and Deliverability



Our Fundamental Technology is Proven and Low Risk With Innovation Where it Adds Value



REACTOR SYSTEMS

- A robust and licensable design:
  - 3-loop compact PWR
  - Based on proven technology
  - Designed to ASME standards
  - Compliant with all UK codes & standards
- Fuel: industry standard 17x17 assembly UO2
- Boron-free design to reduce environmental impact.
- 3 Local Ultimate Heat Sinks provide passive heat removal and long-term cooling in faulted condition
- Phased long-term emergency core cooling solution provides ultimate CAT A safety measure

COOLING WATER ISLAND

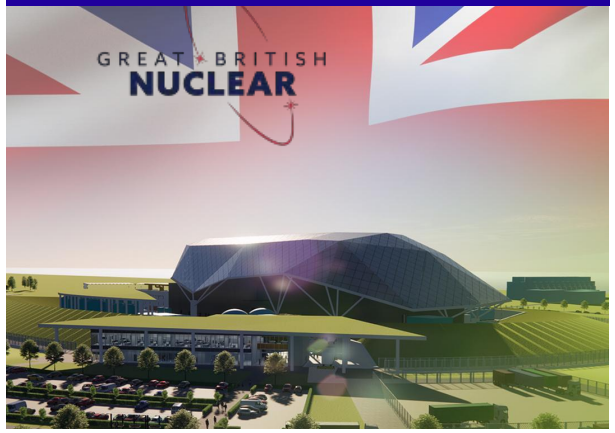
- Indirect cooling GDA baseline for maximum site flexibility
- Adaptable to site conditions and requirements
- Modular Mechanical draught cooling towers
- Direct cooling configuration also developed – both possible

TURBINE ISLAND

- Conventional turbine technology, optimised for system efficiency
- Implementing modular strategy
- Progressing with TI Partner to deliver an integrated power station design

Progress – Securing First Projects –

Contract signed for initial 3 units in Wylfa, UK



Contract signed for early works at Temelin in Czechia, CEZ becoming a RR SMR shareholder.

Selected as final two SMRs in Sweden
3 units in the first phase

ENGAGEMENT IN THE NETHERLANDS

- Our longstanding collaboration with the private developer ULC-Energy remains central to our progress in the Netherlands towards deployment
- The Dutch nuclear regulator, ANVS has been an official 'Observer' to the UK Generic Design Assessment process for several years.
- Jointly with ULC-Energy we maintain a high level of engagement with key stakeholders across the energy sector including prospective industrial customers, central and provincial government officials, energy and nuclear industry experts, financial institutions and supply chain companies, including BAM NL and Siemens Energy.
- Engagement with the supply chain continues;
  - >60 suppliers of interest identified to date
  - Dutch capability identified to supply ~36 plant commodity groups including complex mechanical equipment, heat exchangers, pressure vessels etc. and civil construction.

02 Designing the RR SMR with Ageing Management in Mind

Materials in RR SMR is "Boring"……Intentionally

- What we do:
  - Innovate only where it is beneficial.
  - Rely extensively on established technology and qualified materials, applying them within design envelopes comparable to other PWRs, including temperature and pressure conditions.
  - Apply lessons learned from prior experience.
- Our approach to ageing: Ageing Management Plan:
  - Eliminate ageing effects through design wherever feasible.
  - Develop technical justifications for relevant degradation mechanisms.
    - Assess any gaps between available Operational Experience and the RR SMR design
    - Address those gaps where required to support design justification.
      - For example, KOH – B-free (RR SMR novelty): IASCC, SCC, General Corrosion, EAF
    - Establish design requirements that reduce susceptibility to degradation.
  - Examination, Maintenance, Inspection and Testing (EMIT) are managed through life in accordance with code requirements, supplemented where needed.

RR SMR Primary Water Chemistry Regime: KOH – Boron-free

- A substantial body of test data and OPEX exists concerning degradation of primary circuit materials in a conventional PWR Lithium Hydroxide with Soluble Boron (LiOH+B) chemistry regime, together with relevant evidence from BWR and VVER chemistry regimes.
- Reproducing the current evidence base within RR SMR's Potassium Hydroxide (KOH) Boron-free chemistry regime would not be reasonably practicable.
- Accordingly, we (RR SMR) have applied a combination of analysis and comparative testing to confirm that the existing test data and OPEX remain applicable to our design.
- Further support is provided by RR SMR's selection of proven materials, operating within design envelopes: temperature, pressure and related conditions consistent with those of other plants.

Materials Reliability Program: Stress Corrosion Crack Growth Rates in Stainless Steels in PWR Environments (MRP–458)

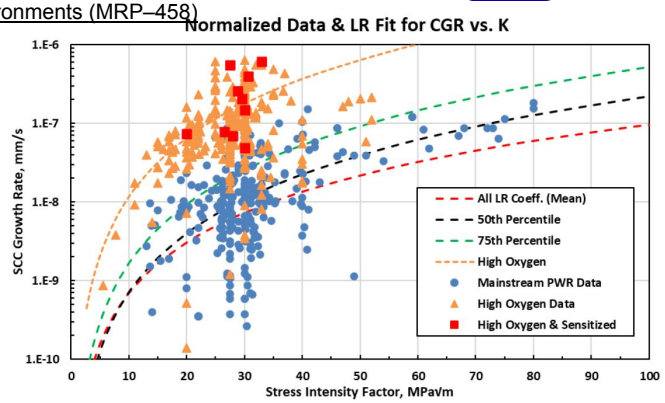
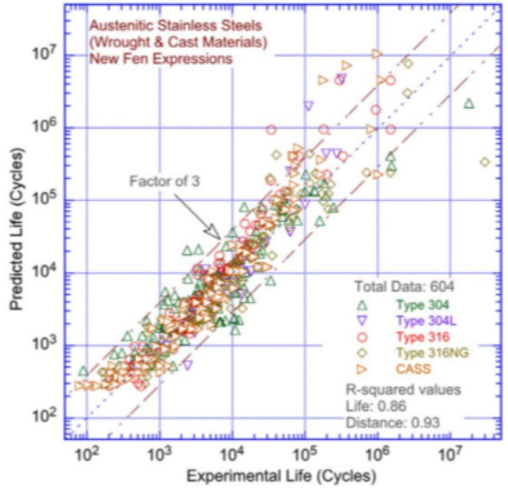


Figure 3-23
SCC growth rate data (mm/s) vs. K with the 50th percentile and 75th percentile curves. The individual data points are normalized to, and the curves are drawn for H_V = 220 and 290°C. The effect of dissolved oxygen is shown in the 75th percentile orange curve. Sensitized (GB Cr depleted) data are shown in red.



NUREG/CR-6909, Rev. 1, "Effect of LWR Water Environments on the Fatigue Life of Reactor Materials" - Final Report.

Summary of Materials Test Programmes

- Testing has been targeted at degradation mechanisms that could potentially be influenced by the adoption of a KOH, boron-free primary water chemistry, thereby addressing residual evidence gaps and strengthening confidence:
  - SCC
    - Nominal chemistries
    - Concentrated chemistries
  - IASCC
    - Proton-irradiated 4-point bend specimens (low dpa)
    - Neutron-irradiated flux thimble tube specimens (higher dpa)
  - EAF
    - Endurance (strain-controlled tension-compression)
    - Crack growth rates (at different K_{max}, R and rise times)
  - General corrosion
    - Oxide characterisation
    - Metal release rates
    - Cobalt deposition
  - Fuel clad corrosion

Conventional PWR / VVER

pH(300°C) ≈ 7.0 – 7.4

LiOH / KOH + H_3BO_3

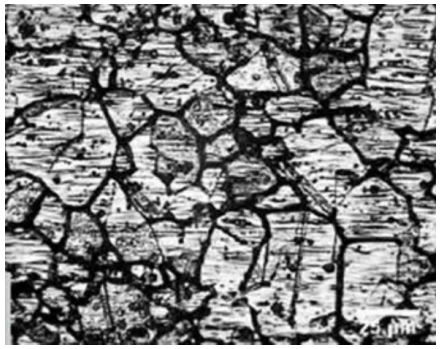
Rolls-Royce SMR

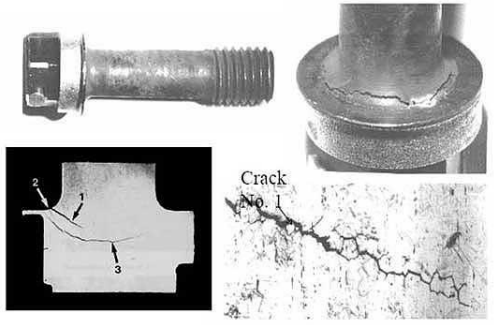
- pH(300°C) = 7.4
- KOH (no boron)

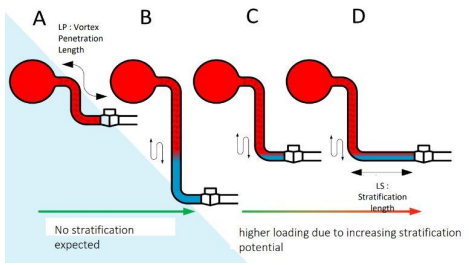
What We Are **NOT** Doing (Ex

- **Connecting Nuclear Generations:** How can newbuild profit from Long Term Operation experience and vice versa. We will connect different generations of nuclear power to each other.

- Using Alloy 600.
- Using standard AuSS where sensitisation is a risk.
- Using low Cr materials where FAC is a risk.
- Having Baffle former plates and bolts.
- Using X-750 in non-suitable heat treatment conditions.
- Designing the layout of pipework such that thermal fatigue can become an issue.
- RPV with welds within the fuelled region.
- Pressuriser heaters with high residual stress and crevices in heated regions.
- ……..



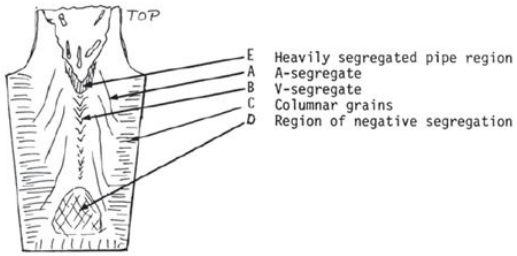




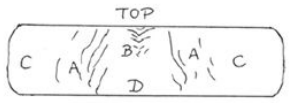
It’s Not Just About Through-life Lessons Learnt

- RR SMR is designed using principles of DfX (“Design for X)
  - Where X can mean: Manufacturability, fabricability, Inspectability…
  - And learning from challenges of the past:
- Large low alloy steel forgings:
  - Mitigations against carbon macro segregation
  - Controls to minimise hydrogen flaking
  - Non-metallics controls, ensuring good quality clean steel
- Large austenitic stainless steel forgings
  - Limits of grain size for inspectability
- Exploring the use of A52 variants for weldability

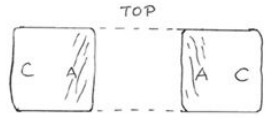
- **Connecting Nuclear Generations:** How can newbuild profit from Long Term Operation experience and vice versa. We will connect different generations of nuclear power to each other.



Figures from “Macroscopic Segregation in Ingots and Its Implications in Modelling of Structures Made From Heavy Sections” by S.F. Pugh, U.K. Atomic Energy Authority, 1982



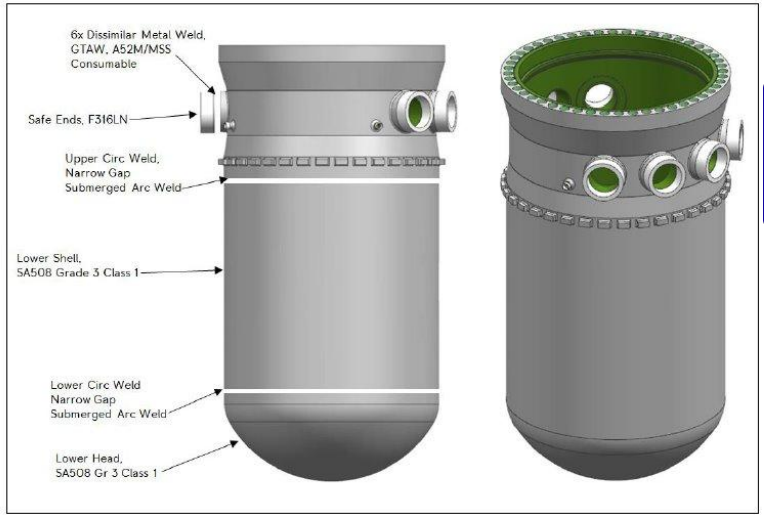
Upset disk, such as might be used for fabrication of a head



Forged ring; the center is removed (trepanned), significantly reducing the volume of macrosegregation

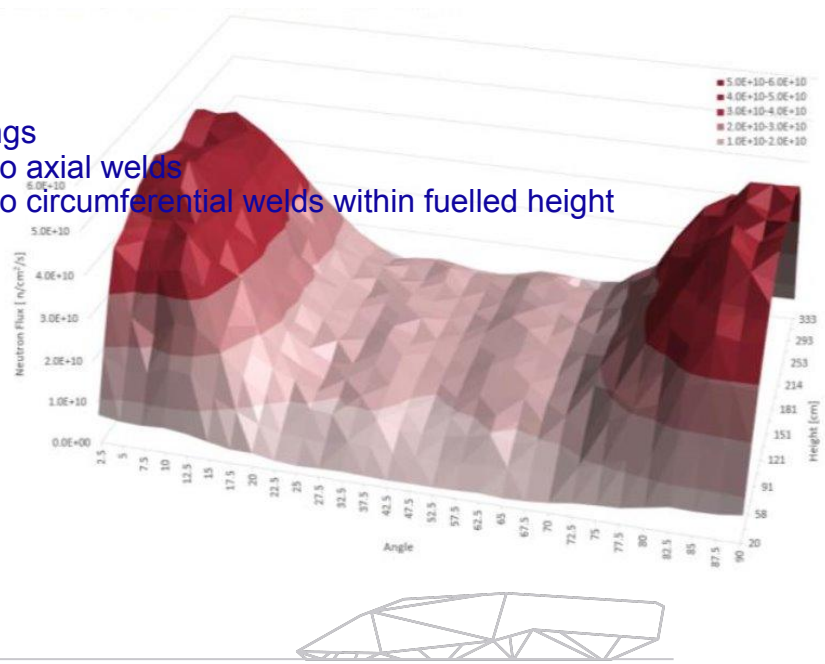
RR SMR Being “Small”

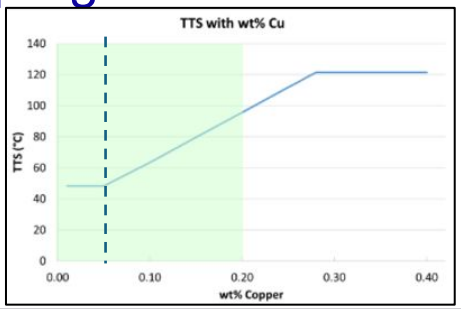
- Designed within the constraints of road transportability: compact but high-power.
- Irradiation embrittlement of the RR SMR RPV remains bounded by industry OE and reflects t latest understanding:
  - No welds are located within high-flux regions: (no mid-beltline weld, or axial welds)
  - Low copper content (parent and weld consumables)
  - Controlled levels of: Cu, Ni, P
  - Heavy reflector
  - Transition toughness is included within the surveillance programme

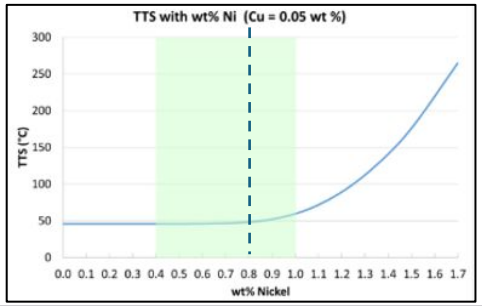


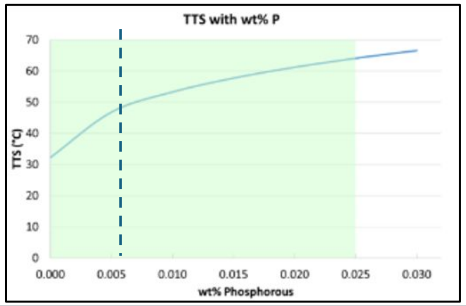
ROLLS ROYCE SMR

- RPV
  - 150 tonnes (dry)
  - 8 m tall, 4 m Ø
- 3 forgings
  - No axial welds
  - No circumferential welds within fuelled height









And of Course We Are Doing Lots More……

To Deliver Clean, Affordable Energy For All | Rolls-Royce SMR
RR SMR homepage with high-level information of the technology, Tier 1 reports of the E3S case, vacancies….. + more

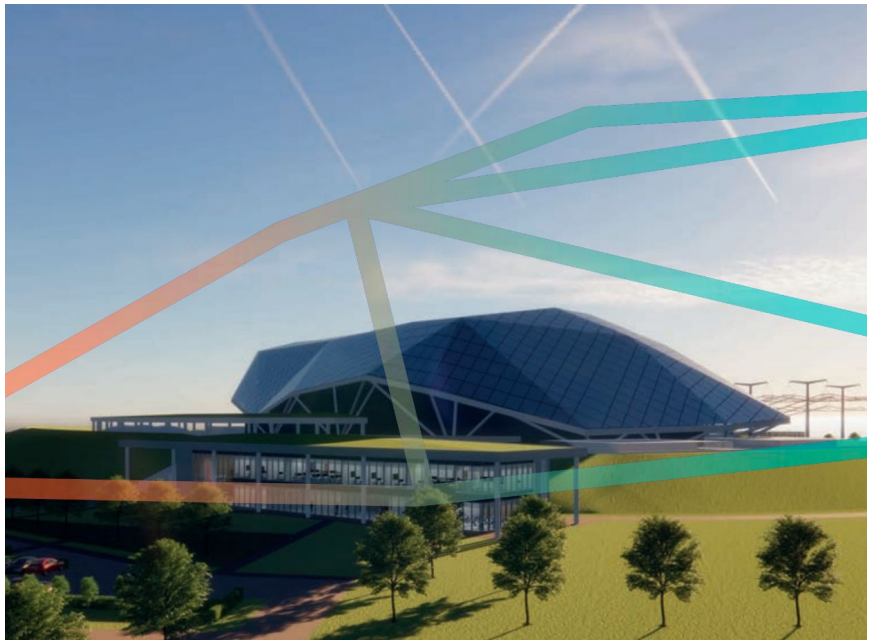
Rolls-Royce Small Modular Reactors Intl | Videos & Movies on Vimeo

Rolls-Royce SMR Ltd - YouTube

www.linkedin.com/company/rolls-royce-smr

Rolls-Royce SMR | Office for Nuclear Regulation

SMR_booklet_2022.pdf
IAEA publication - Small Modular Reactors: Advances in SMR Technology Developments 2022 – provides high level overview of SMR designs



03 Q&A

ROLLS ROYCE SMR

Q&

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SITE FOOTPRINT AREA: 100,000 m²*

ELECTRICAL CAPABILITY UP TO 470 MWe

THERMAL CAPACITY 1358 MWth

FUEL CYCLE 18 MONTHS

DESIGN LIFE 60 YEARS

MULTIPLE ACTIVE AND PASSIVE SAFETY SYSTEMS

121 INDUSTRY STANDARD FUEL MODULES

*inclusive of berm, exclusive of cooling water island

SMR

BE SAFE. **BE** BOLD. **BE** INCLUSIVE. **BE** IMPACTFUL. **BE** CREATIVE. **BE** ENGAGED

