

Small Modular Reactors

Manufacturing Philosophy

Rolls-Royce – Nigel Hart

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The Challenge

“As SMRs do not benefit from the economy of scale the designs have to rely on other factors to reach the economic targets”

***‘Current Status, Technical Feasibility and Economics of Small Nuclear Reactors’
OECD June 2011***

**Critical to this is the implementation of volume,
modular manufacture....whilst retaining the
highest standards of build quality**

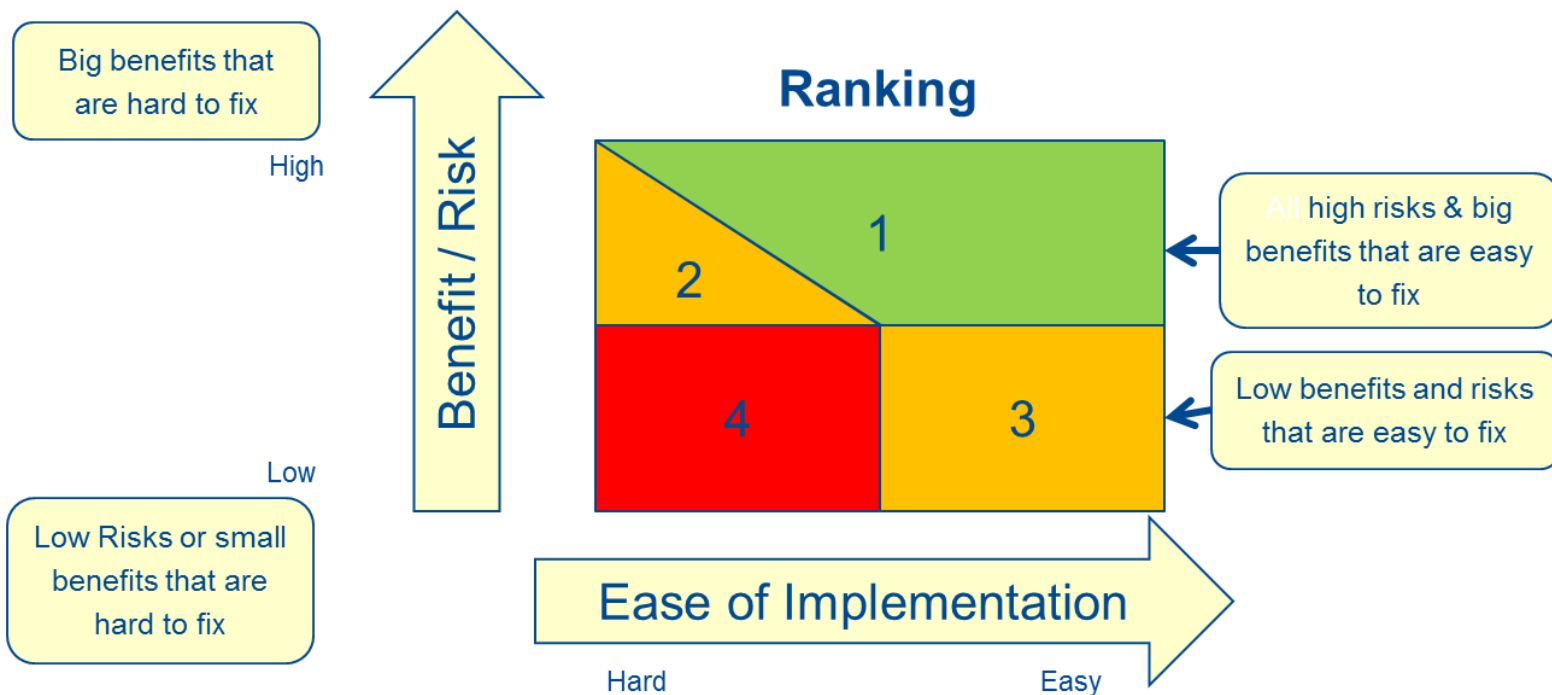
A comprehensive approach is required

- **Design for X**
- **Utilisation of Advanced Manufacturing technologies**
- **Stream-lined assembly philosophy of modular, complex assemblies – “Flowline”**
- **Integration of Supply Chain**



Design for X

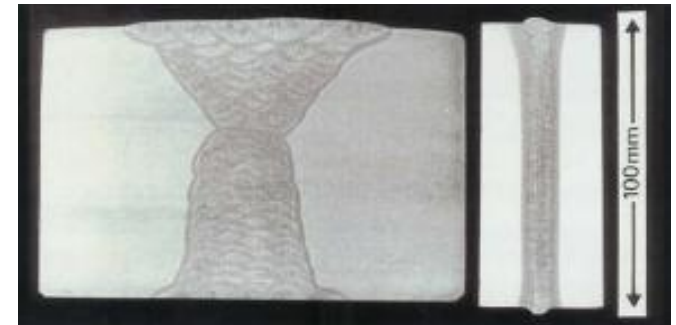
- A holistic view of the design process to ensure that all phases of the design life are optimised (for performance and cost)
- Used to identify realistic opportunities to drive down cost of ownership, through advanced manufacturing techniques and innovative approaches to maintenance and support



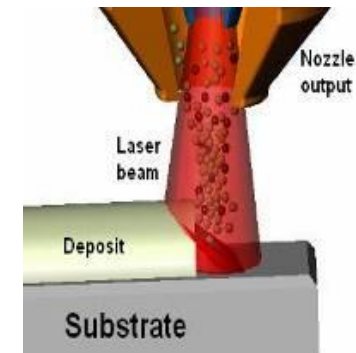
Advanced Manufacturing Techniques to be integrated

Invest to address most time-consuming, labour intensive, defect incurring techniques

Local Vacuum Electron Beam Welding



Diode Laser Powder Deposition cladding



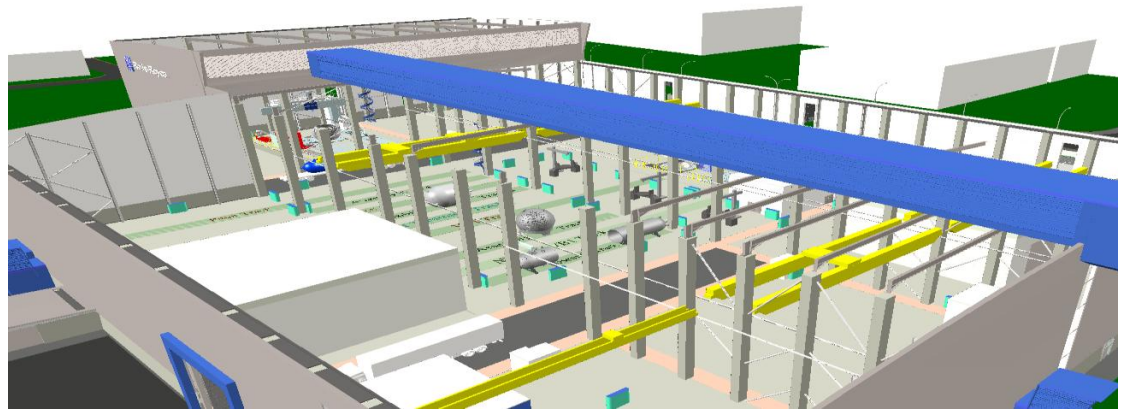
Hot Isostatic Pressing (HIP)

Assembly, Combination and Build

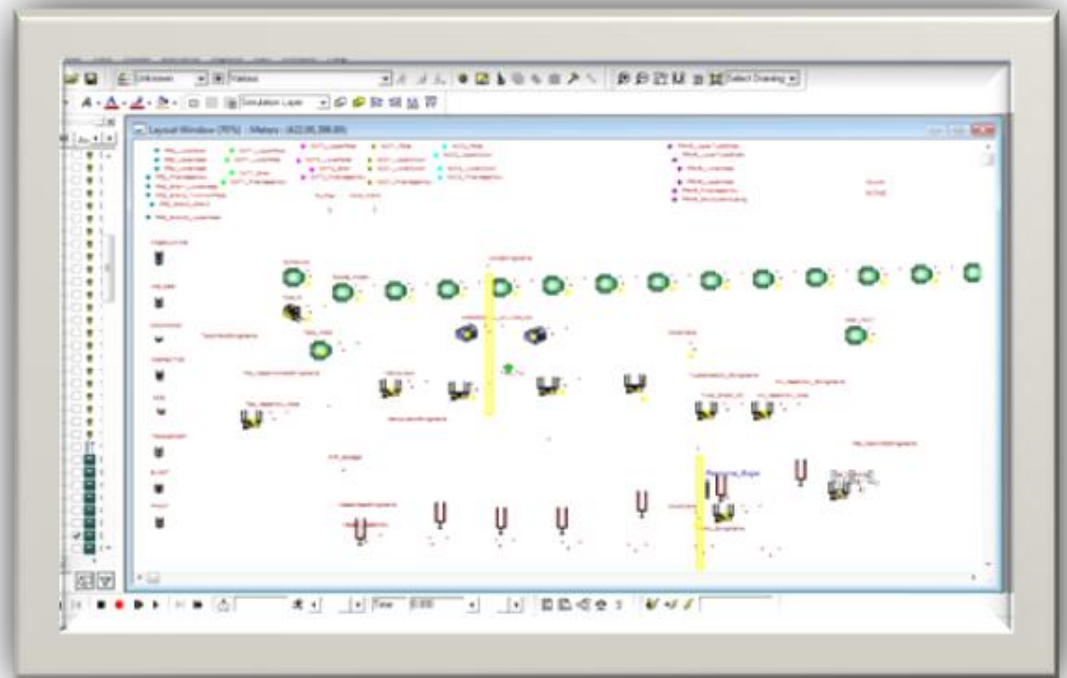
- **Flowline methodology, currently used for Civil Aerospace Engine Manufacture and Assembly, would benefit small modular reactors**
- **Key Features:**
 - Facility and processes developed and tested virtually prior to construction
 - Quality built into process
 - Standardisation and Validation
 - Extensive use of:
 - automation techniques
 - visual management techniques
 - tooling techniques

Virtual Development and Test of Facility and Processes

- **Virtual reality modelling**
- **Modelling and process simulation**



Screen-shot from a VR simulation of the internals of the Rolls-Royce nuclear components facility



Screen-shot of modelling capability (Rolls-Royce)

Quality built into the Process

Advanced Product Quality Planning (APQP)

- R-R has developed rigorous quality methods
- APQP has been developed alongside Flowline to achieve significant improvement in safety, cost, quality and delivery performance.
- For deployment in the nuclear, APQP will be used to augment existing quality controls, especially for Flowline when applied to volume manufacture of SMRs

Standardisation and Validation

- **Factory based assembly of standardised modules, assemblies and sub-assemblies has the potential to enhance productivity, reliability and learning**
- **This is manifest through:**
 - Application of 'Poka-yoke' type principles in design of sub-assemblies improves reliability and reduces risk during final assembly
 - Potential to make mistakes is reduced and validation process is simplified reducing cost and improving productivity
 - Factory based processes that enhance productivity can be applied, learned and improved iteratively at a much higher rate than is currently possible within nuclear build programs
 - A factory based workforce with standard products to assemble requires lower individual skills and enhances the ability of an organisation to learn quickly and apply changes effectively

Automation, Visual Management and Tooling

Automation

- Part tracking systems
- Online assembly software



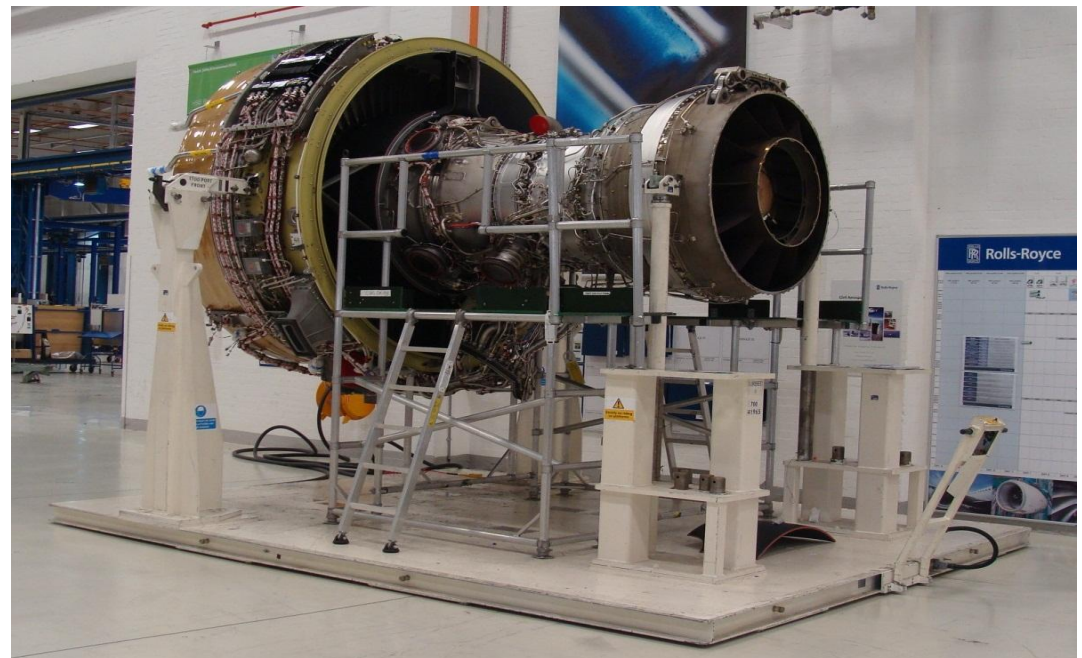
Index time Countdown Clock

Visual Management

- Flowline Index Times
- Traffic Light Control of Assembly Lines

Tooling

- Flexible workstations
- Air float heavy-lifting systems



Trent engine on a Rolls-Royce, UK Flowline

Integration of Supply Chain

- **Standardised modules, assemblies and sub-assemblies have the potential to simplify supply chain management and integration**
- **Potential Benefits:**
 - Improved product quality and cost management through application of make/buy strategies to divide production between appropriately skilled sub-assembly supply chain partners
 - Enhanced lead-time management driven by volume production of sub-assemblies on batch/continuous Just-in-Time basis
 - Centralised final assembly facility with skilled workforce facilitates continuous feedback and enhanced learning processes

Summary

- Realisation of true benefits of modular build is a philosophy and methodology that will require cultural change from existing nuclear practices
- The SMR needs to be designed to suit the needs of modular build process
- Investment is required to minimise time consuming and costly manufacturing techniques
- Quality must be built into the assembly process
- Infrastructure to support flowline must be in place prior to assembly facility build
- The reward is an optimised SMR assembly methodology, delivering right-first-time product to the demand drum-beat.