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Title

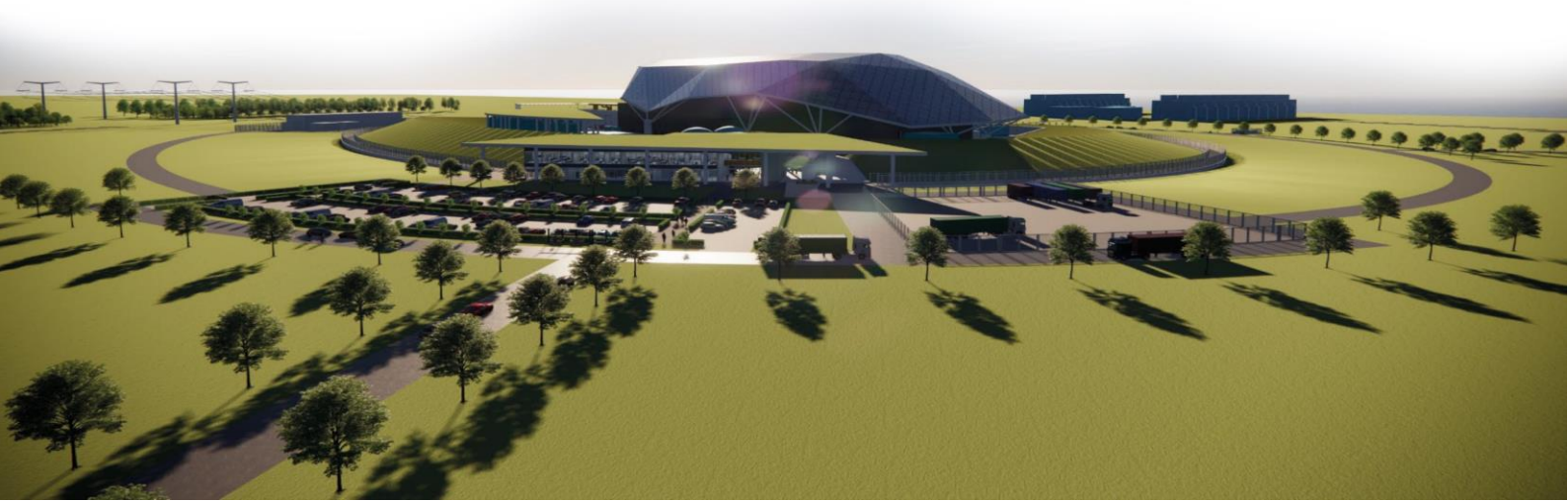
E3S Case Chapter 14: Plant Construction and Commissioning

Executive Summary

This chapter of the Environment, Safety, Security, and Safeguards (E3S) Case presents the Plant construction and commissioning aspects of the Rolls-Royce Small Modular Reactor (RR SMR).

The report outlines the arguments and preliminary evidence available at the Preliminary Concept Definition (PCD) design stage to underpin the high-level Claim that the Structures, Systems and Components (SSCs) will be manufactured, assembled, installed, and commissioned to meet their design intent and reduce risks to As Low As Reasonably Practicable (ALARP). At PCD, that is the intent for the plant construction and commissioning programme and overall philosophy and activities.

The plant construction and commissioning activities will continue to be developed in line with the strategies and philosophies outlined in this report, with continued focus on supporting the demonstration that inactive and radioactive risks introduced during construction and commissioning will be reduced to ALARP.



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14.0.1 Introduction to Chapter

Chapter 14 of the Rolls-Royce Small Modular Reactor (RR SMR) Environment, Safety, Security & Safeguards (E3S) Case forms part of the Pre-Construction Safety Report (PCSR), as defined in E3S Case Chapter 1: Introduction, Reference [1].

Chapter 14 presents a high-level overview of the proposed build and installation approach and programme for the RR SMR, and an overview of the proposed commissioning programme and associated strategies, as defined at Reference Design (RD) 5 level of design maturity.

14.0.2 Scope

The scope of this report covers the construction and commissioning programme and overall philosophy and activities being developed by RR SMR to deliver the programme and meet the requirements of the E3S Case.

Information on the organisational structure and detailed arrangements or procedures that need to be in place to safely deliver the construction and commissioning programmes are not covered at this stage.

The constructability and commissioning risks and regulations, including Construction (Design and Management) Regulations 2015 (CDM 2015), associated with conventional health and safety are covered in E3S Case Chapter 22: Conventional & Fire safety, Reference [2].

Design/Programme Maturity

This revision of the plant construction and commissioning chapter of the E3S Case is based on design maturity at the Preliminary Concept Definition (PCD) stage. At PCD, the focus of construction and commissioning is on the development of strategies and activities required to meet the requirements of the E3S Case, and the development of requirements to embed these into the design at an early stage.

14.0.3 Claims, Arguments, Evidence Route Map

The Chapter level Claim for E3S Case Chapter 14: Plant Construction & Commissioning is:

Claim 14: Structures, Systems and Components will be manufactured, assembled, installed, and commissioned to meet their design intent and reduce risks to As Low As Reasonably Practicable

A decomposition of this Claim into Sub-Claims, Arguments, and link to the relevant Tier 2 Evidence will be presented in future revision of this report. The complete suite of evidence to underpin the Claims in the E3S Case will be generated through the RR SMR design and E3S Case programme and documented in the Claims, Arguments, Evidence (CAE) Route Map, Reference [3], described further in E3S Case Chapter 1: Introduction, Reference [1].

14.0.4 Applicable Codes & Standards

The plant construction and commissioning activities described in this report follow international and United Kingdom (UK) Relevant Good Practice (RGP) described in the E3S Design Principles, Reference [4].

International Atomic Energy Agency (IAEA) safety standards and specific safety guides (SSGs) relevant to commissioning include:

1. IAEA SSG-28: Commissioning for Nuclear Power Plants, Reference [5]
2. IAEA NP-T-2.10: Nuclear Energy Series: Commissioning Guidelines for Nuclear Power Plants, Reference [6]
3. IAEA Safety Standards, Safety of Nuclear Power Plants: Commissioning and Operation, Series Specific Safety Guide No. SSR-2/2 (Rev. 1), 2016 Reference [7]

In the UK, commissioning is a key part of the thirty-six Nuclear Site Licence Conditions (LCs), including LC1, LC6, LC19, LC20, LC21, LC24, LC28, which a dutyholder/licensee must demonstrate compliance with:

1. Commissioning definition LC1
2. Documents, records, authorities and certificates LC6
3. Construction or installation of new plant LC19
4. Modification to design of plant under construction LC20
5. Commissioning LC21
6. Operating instructions LC24 and
7. Examination, inspection, maintenance and testing LC28.

14.1 Build & Installation

14.1.1 Introduction

One of the key RR SMR objectives is ensuring build certainty, with six key objectives/requirements defined in Reference [8]:

1. Maximise off-site build and assembly
2. Simplify logistics flow for on-site Build
3. Minimise variation across all areas
4. Reduce and simplify interfaces (plug and play)
5. Increase robustness to variation, and
6. Reduce human interaction.

These requirements are informing the early concept design (see Section 14.1.3) and will be developed further prior to Final Concept Definition (FCD). One of the primary methods adopted by RR SMR to achieve build certainty is modularisation. It is intended the bulk of the RR SMR will be manufactured and assembled in offsite factories and will be transported to site and installed as a series of modules within a site factory.

Modules must be designed to allow as many complex processes as possible to be completed in the factory and for the installation to be as simple as practicable with as few interfaces as practicable, whilst ensuring the E3S requirements from the E3S Case are incorporated into the as-built plant.

14.1.2 Build & Installation Programme

At PCD, a RR SMR First of a Fleet (FOAF) build programme has been developed collating inputs from various stakeholders for each stage of the build programme, including:

1. Site enabling works, including site establishment and the set-up, testing and validation of the batching plant and on-site laboratory
2. Site factory and groundwork development, including craneage and the controlled environment to enable construction activities over Reactor Island [R01], Turbine Island [T01], Balance of Plant [BOP] and Cooling Water Island [C01]
3. Civil and structural build, based on the modular civil concept design (see Section 14.1.4)
4. Turbine Island [T01], Cooling Water Island [C01] and Balance of Plant [BoP] process and mechanical equipment installation
5. Reactor Island [R01] process and mechanical equipment installation

6. Electrical, Control & Instrumentation [E01] equipment installation and the FOAF build schedule is described further in Reference [9].

14.1.3 Build Certainty in Design

The RR SMR programme is following a design-led, E3S-informed approach, as described in E3S Case Chapter 1: Introduction, Reference [1], which includes a consistent set of design objectives that have been defined for the RR SMR project to direct the progression of the design architecture/solutions based on market and functional needs. This includes the build certainty requirements and drivers for modularisation.

As design concepts for Structures, Systems and Components (SSCs) are developed to achieve safety categorised functional requirements and non-functional system requirements, they are down selected through the design decision-making process, including evaluation against the design objectives and build certainty objectives. As such, SSCs are designed to achieve their safety requirements in a manner that supports build certainty and modularisation.

14.1.4 Modularisation Approach

The build certainty requirements alone may drive an approach towards a minimised number of mega-modules, which would create a logistical challenge and reduce flexibility. A modularisation philosophy has therefore been developed to determine the best approaches for RR SMR, presented in Reference [10].

A bespoke standardised Mechanical, Electrical and Plumbing (MEP) Module Kit of Parts (MKoP) has been developed to facilitate modularisation of SSCs, providing the primary method for their installation into the plant. The MkoP is a bespoke system of module frames and accessories that form both a seismically qualified building structure and a module system for the installation of SSCs and equipment.

RR SMR is also developing other methods for modularisation, including:

1. Novel civil kit of parts, Reference [11], providing modular solutions for civil structures utilising pre-engineered elements to solve challenges such as retaining walls, tunnels, concrete walls, aseismic bearings, hazard shield, and other large scale civil assemblies

2. Original Equipment Manufacturer (OEM) supplied modules or skids, for systems small enough to be fully self-contained or where a system does not need to be integrated into a cluster of RR SMR modules and

3. Custom modularised structures or assemblies, where other modularisation approaches are not possible.

14.1.5 Offsite Factory Testing

The RR SMR approach to build certainty includes the manufacture of MEP and Heavy Vessel modules in a factory that is remote from the power station site. This approach includes maximising offsite testing and other activities, where possible, that would traditionally be completed onsite during power station construction.

The potential MEP testing activities that could be undertaken in an offsite factory are described in Reference [12], including:

1. Factory Acceptance Testing (FAT) of functional requirements, which may include hydrotesting of fluid systems

2. Manufacturing Quality Assurance (MQA) tests intended to verify the as-built design meets its design definition, such as visual inspections or non-destructive testing (NDT).

14.1.6 Site Factory

RR SMR is adopting a 'Site as a Factory' approach to onsite construction and assembly to achieve build certainty. This innovative approach assumes modularisation has been maximised to minimise on site complexity, reducing on-site activities to largely placement, jointing and final commissioning.

The Site Factory provides an environmental shelter to the SMR assembly area, providing a significant change in the construction methodology from traditional nuclear construction, enabling installation of mechanical, electrical, control & instrumentation, and process equipment in a controlled environment for up to 24 hours a day, 365 days a year.

The strategy for planning, controlling, and operation of a generic 'Site as a Factory' is presented in Reference [13].

14.2 Commissioning

14.2.1 Introduction

Commissioning is the process during which plant components and systems, having been constructed, are made operational and verified to be in accordance with design assumptions and to have met the appropriate safety criteria, Reference [14] Licence Condition 1, The ONR Licence Condition Handbook.

Whilst commissioning will ultimately be the responsibility of the site dutyholder/licensee, RR SMR is working to ensure that the plant design, along with the approach to manufacture, build and installation, facilitates a safe, structured, and efficient commissioning programme.

Plant design for commissioning will be driven through various means, including by specifying 'design for commissioning' requirements that are applied to all relevant SSCs (in development at PCD, will be in place for final concept definition), and by conducting early commissioning reviews of key systems during the concept design phase, to identify the commissioning activities and ensure the design enables those to be conducted in a safe and efficient way.

As part of this, RR SMR is developing a programme for the commissioning activities, where those activities will be derived and recorded in a structured form based on the plant requirements and design.

14.2.2 Commissioning Programme

Non-Nuclear and Nuclear Commissioning Activities

Commissioning will be performed in a systematic sequence, with tests arranged to be progressive so that the plant is exposed to less onerous conditions before more onerous tests as the plant moves through commissioning to the start of normal operation.

The different aspects and stages of on-site commissioning are illustrated in Figure 14.2-1. The premise is that before moving on to the next level of the pyramid it is important to ensure the previous level is secured, robust and reliable. The pre-operational tests begin with component testing, followed by system and then the various stages of integrated testing. Operational tests commence with fuel load leading onto initial criticality, low power physics tests and Power Ascension Testing (PAT).

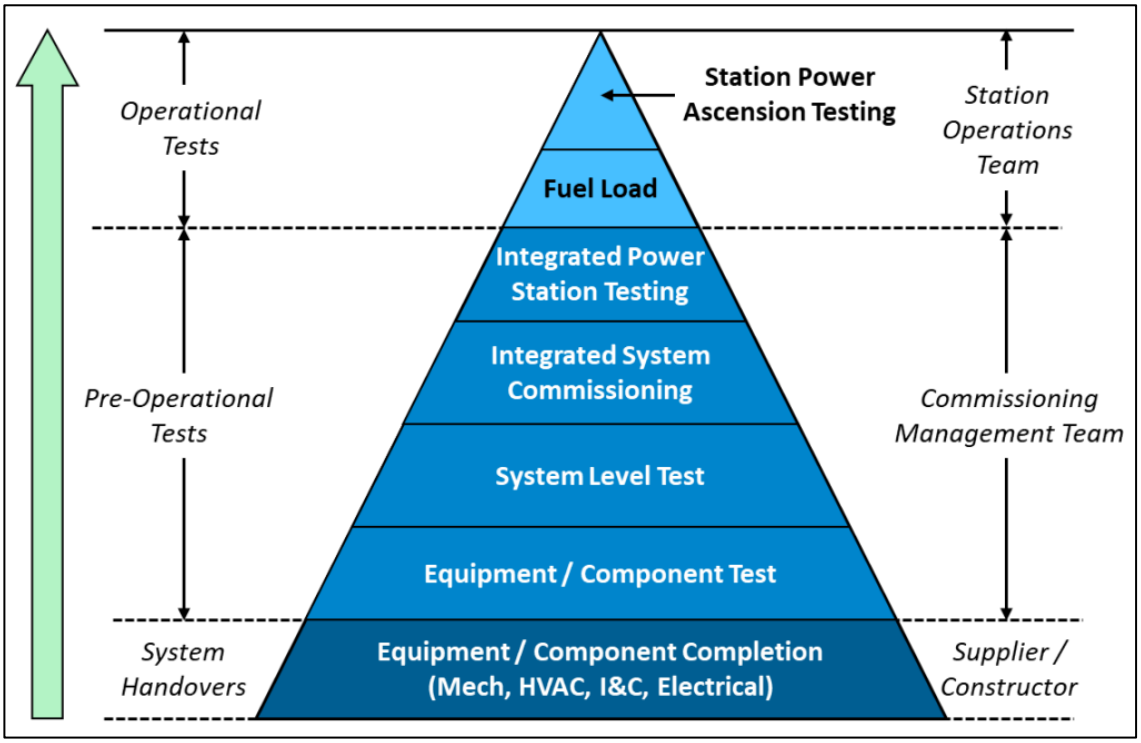

Figure 14.2-1: Overview of Commissioning Phases

The full RR SMR commissioning programme is in development and will be refined in an iterative manner through the design programme and beyond. It is anticipated to follow the structure of activities in Figure 14.2-1, and to be in line with the sequencing outlined in the IAEA Commissioning Guidelines, Reference [6] as summarised below:

1. Pre-operational or non-nuclear tests (also called inactive commissioning): comprising system completions and handovers (Mechanical, Heating, Ventilation & Air Conditioning (HVAC), Control and Instrumentation (C&I), Electrical, etc.),

2. Pre-operational tests or non-nuclear tests (also called inactive commissioning): these are performed before fuel loading, after turnover from construction and installation to commissioning. They typically include:

a. Individual structure, system, and component tests, including primary containment tests,

b. Integrated functional system level tests in cold conditions, including primary circuit cold hydrostatic test and secondary hydrostatic test,

c. Integrated functional system tests in hot conditions,

3. Operational tests or nuclear tests (also called active commissioning), which start with fuel loading. They typically include:

a. Fuel load and core loading tests,

b. Pre-critical tests,

c. First criticality and low power tests,

d. PAT, ending with full power and performance tests.

Hold Points

RR SMR recognises the need for clear hold points through the commissioning programme, which can be used as part of permissioning. These are being defined as part of the work to develop the commissioning programme. An initial proposal was created as part of the programme at PCD, Reference [15].

Potential FOAF tests, First-Plant-Only-Tests and First-Three Plant-Only-Tests

At PCD, the commissioning programme does not yet consider potential First-Plant-Only-Tests (FPOT) or First-Three Plant-Only-Tests (F3POT). The criteria for identifying these tests will be developed as the design progresses. It is recognised that this will require early engagement with both the dutyholder/licensee and regulators to determine the acceptability for allowing FPOT or F3POT to be credited, where demonstrated to be valid, for subsequent RR SMR units of similar design.

Relevant international and UK guidance will be followed in the identification of these tests (FPOT, F3POTs), such as the Multinational Design Evaluation Programme (MDEP) common position paper addressing FPOT, Reference [16] and MDEP Working Group Design-Specific Technical Report on Lessons Learnt from Implementation of the Common Position on FPOT for AP1000, Reference [17].

Nuclear Site Dutyholder/Licensee

RR SMR will ensure that the overall objectives of commissioning are aligned with the dutyholder/licensee's, who is responsible for making and implementing adequate arrangements for the commissioning of any plant or process which may affect safety. It is anticipated that the dutyholder/licensee's commissioning arrangements will include activities to:

1. Verify, where reasonably practicable, through commissioning that the as-built installed SSCs operate in accordance with the design intent stated in the E3S case, through all relevant operating modes and operating range

2. Demonstrate, where reasonably practicable, for which the commissioning tests provide representative activities and/or conditions, that emergency operating procedures, operating rules, operating instructions, and examination, inspection, maintenance, and testing requirements are validated as claimed in the E3S case

3. Ensure suitably qualified and experienced station and operations staff are directly involved at all levels and in all areas in the commissioning activities to allow them to gain physical plant experience ahead of SMR operation

4. Facilitate the collection of baseline data for SSCs for retention by RR SMR and the dutyholder/licensee for future reference

5. Implement programme hold points, which will be required to ensure ordered and sequential progress between defined steps within the commissioning programme and

6. Verify main design parameters, including compliance with applicable codes, standards, and the quality assurance requirements.

14.2.3 Commissioning Strategy

The pre-PCD RR SMR Commissioning Strategy, Reference [18] captures areas of RGP and innovation from across industry, which RR SMR will look to adopt where they deliver a benefit in terms of the safety, environmental impact or schedule of the commissioning programme.

One of the key topics identified in this report is the opportunity to utilise enhanced FAT on SSCs constructed within RR SMR modules in the offsite factory, in order to reduce the activities (e.g., completions, handovers) that need to be carried out in the on-site factory. This builds on, and is enabled by, the project's modularisation philosophy (see section 14.1.4).

Testing in a clean factory environment where specialist equipment is close at hand and systems are easily accessible can provide safety benefits and reduce onsite risks, as well as reducing the schedule of on-site activity.

RR SMR is further developing the strategy for this opportunity. This activity involves considering the scope of inspection and test activities that can be more safely and efficiently conducted within the off-site factory. It also considers the measures which will be necessary to preserve the validity of module FAT results from off-site factory into on-site factory.

RR SMR is continuing to review and develop the wider Commissioning Strategy post-PCD as the plant design is matured, as the manufacturing and build & installation plans develop, and as further industry Operating Experience (OPEX)/RGP is assimilated.

14.3 Conclusions

14.3.1 ALARP

At PCD, plant construction and commissioning strategies and activities are being developed in accordance with international and UK RGP, to ensure that the design intent of the RR SMR can be verified through appropriate methods and testing, in a manner that reduces associated risks to As Low As Reasonably Practicable (ALARP).

As part of the systems engineering approach for RR SMR, plant construction and commissioning requirements are being developed and embedded into the design requirements at an early stage, such that design solutions can achieve these requirements and reduce associated risks at a later stage in the programme.

The plant construction and commissioning activities will continue to be developed in line with the strategies and philosophies described throughout this report, with continued focus on supporting the demonstration that inactive and radioactive risks introduced during construction and commissioning will be reduced to ALARP.

14.3.2 Conclusions

Preliminary evidence is presented to support the overall claim that 'Structures, Systems and Components will be manufactured, assembled, installed, and commissioned safely to meet their design intent and reduce risks to As Low As Reasonably Practicable', which contributes to the overall E3S objective to protect people and the environment from harm, and the demonstration that risks are reduced ALARP.

The intent for the plant construction and commissioning programme and overall philosophy and activities described in this chapter, are expected to meet the requirements of the E3S Case. The complete suite of evidence to underpin the claim will be developed in line with the CAE Route Map and reported in future revisions of the E3S Case.

14.3.3 Assumptions & Commitments on Future Dutyholder/ Licensee

None identified at this revision.

14.4 References

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[14] The ONR Licence Condition Handbook February 2017.
[15] RR SMR Report, SMR0001021/001, PCD Commissioning Primary and Secondary Commissioning Hold Points, June 2022.
[16] Multinational Design Evaluation Programme, CP-STC-01, “Common Position addressing First-Plant-Only-Test (FPOT),” April 2018.
[17] Multinational Design Evaluation Programme Working Group Design-Specific Technical Report on Lessons Learnt from Implementation of the Common Position on FPOT for AP1000, TR-AP1000WG-05.
[18] RR SMR Report, EDNS01000919142/001, “Commissioning Strategy in the Concept Phase,” December 2020.

14.5 Acronyms and Abbreviations

ALARP	As Low As Reasonably Practicable
C&I	Control and Instrumentation
CAE	Claims, Arguments, Evidence
CDM	Construction (Design and Management) Regulations 2015
E3S	Environment, Safety, Security & Safeguards
FAT	Factory Acceptance Testing
FCD	Final Concept Definition
FOAF	First of a Fleet
FPOT	First-Plant-Only-Tests
F3POT	First-Three Plant-Only-Tests
HVAC	Heating, Ventilation & Air Conditioning
IAEA	International Atomic Energy Agency
LC	Licence Condition
MDEP	Multinational Design Evaluation Programme
MEP	Mechanical, Electrical and Plumbing
MKoP	Module Kit of Parts
MQA	Manufacturing Quality Assurance
NDT	Non-Destructive Testing
OEM	Original Equipment Manufacturer
OPEX	Operating Experience
PAT	Power Ascension Testing
PCD	Preliminary Concept Definition

PCSR	Pre-Construction Safety Report
RD	Reference Design
RGP	Relevant Good Practice
RR SMR	Rolls-Royce Small Modular Reactor
SSC	Structures, Systems and Component
SSG	Specific Safety Guide
UK	United Kingdom