NSTX-U Verification and Validation Plan

NSTX-U-PLAN-039-00

6/11/2019

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Record of Revisions

Date	Version	Brief Description of Changes
6/11/2019	Rev 0	Initial Release

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References

[1] NSTX-U-RQMT-GRD-001, *NSTX-U General Requirements Document*
[2] NSTX-U-RQMT-SRD-002, *NSTX-U SRD Magnets*
[3] NSTX-U-RQMT-SRD-003, *NSTX-U SRD Plasma Facing Components*
[4] NSTX-U-RQMT-SRD-004, *NSTX-U SRD Vacuum Vessel and Internal Hardware*
[5] NSTX-U-RQMT-SRD-005, *NSTX-U SRD Auxiliary Systems*
[6] NSTX-U-RQMT-SRD-006, *NSTX-U SRD Power Systems*
[7] NSTX-U-RQMT-SRD-007, *NSTX-U SRD Heating Systems*
[8] NSTX-U-RQMT-SRD-008, *NSTX-U SRD Real-Time Control and Protection*
[9] NSTX-U-RQMT-SRD-009, *NSTX-U SRD Central Instrumentation and Control*
[10] NSTX-U-RQMT-SRD-010, *NSTX-U SRD Test Cell*
[11] NSTX-U-RQMT-SRD-011, *NSTX-U SRD Diagnostics*
[12] NSTX-U-RQMT-SRD-011, *NSTX-U SRD Diagnostics*
[13] ENG-050 (Rev 3), *Job Requirements Documentation & Control*
[14] ENG-033, *Design Verification*
[15] ENG-062, Planning and Performing Tests
[16] QA-003, Procurement Quality Assurance
[17] QA-004, QA/QC Site Inspection and Oversight
[18] INCOSE Systems Engineering Handbook, Fourth Edition
[19] ENG-030, PPPL Technical Procedures
[20] Requirements Verification Traceability Matrix
[21] ISO / IEC / IEEE 15288 Systems and software engineering -- System life cycle processes

1. Introduction

The systems engineering process provides for a direct relationship between system verification and validation (V&V) as shown in Figure 1. The right side of the figure provides the testing and verification / validation that maps to each phase on the left side of the "V". The dotted line identifies particular plans to ensure that the system, in this case the NSTX-U, functions as expected.

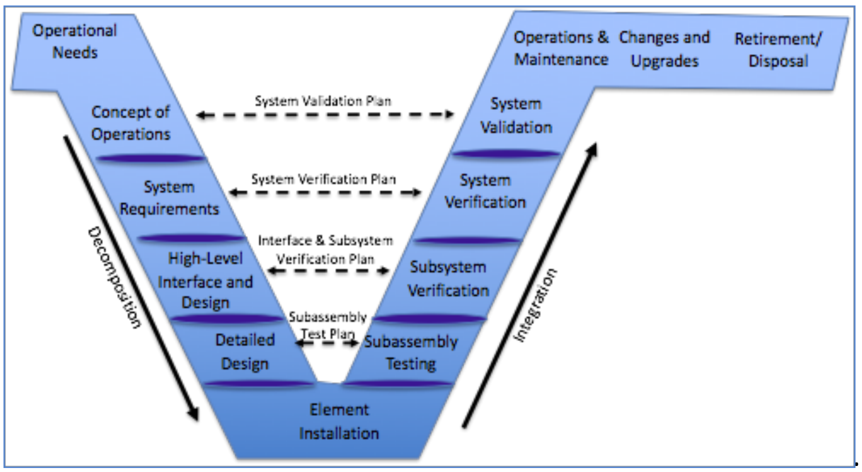

***Figure 1**: System Engineering "V" Diagram*[1]

The NSTX-U comprises systems and subsystems in different phases of the systems engineering lifecycle. Some systems / subsystems, e.g., power systems, neutral beams, diagnostics, and High Harmonic Fast Wave (HHFW), are proven and are in the Operations & Maintenance phase. Other subsystems are being modified to provide additional capability, e.g., Poloidal Field (PF1)b Bipolar circuit, NSTX-U Test Cell Shielding, and Outer PF4-5 coil alignment. Lastly, subsystems are being designed or redesigned to provide new capability, e,g., Inner PF coils, Center Stack Casing, and the Personnel Safety System.

2. Purpose of Document

Following this V&V plan will ensure that all requirements specified in the hierarchy of requirements documents have been reviewed and have an associated verification method. This document establishes a framework for conducting both verification and validation.

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[1] *Systems Engineering Principles and Practice* / Edition 2, Alexander Kossiakoff, William N. Sweet, Samuel J. Seymour, Steven M. Biemer

3. Scope

All components of the NSTX-U machine are considered in scope. However, there is a special focus on the verification of components that are new or have been modified, e.g., Plasma Facing Components, PF1a, b, c Coils, Polar Region, Center Stack Casing, Passive Plates.

Any facilities-related requirements, e.g., lighting and HVAC, are out-of-scope for the project, as well as any off-project capabilities that the project has little control over, including tower and potable water, auxiliary commercial power, and C-Site Power.

4. Roles and Responsibilities

4.1. Responsible Engineer

The RE is responsible for determining the verification method required for meeting element / subsystem compliance. Based on the ENG-33 Design Verification procedure, there are requirements for completing and filing calculations as part of design analysis and test plans. The RE may delegate this responsibility to individuals more knowledgeable on specific systems.

4.2. Operations

Operations is responsible for conducting system level tests and performing system validation.

4.3. Systems Engineer

The Systems Engineer is responsible for completing and maintaining the Requirements Verification Traceability Matrix (RVTM) with data provided by the REs and COGs, QA and Operations.

5. Requirements Structure

Requirements Decomposition

Per ENG-050, there are three types of requirements identified:

- General Requirements Document (GRD), providing the top-level set of project goals and objectives. The GRD also contains high level requirements for subsystems.

- System Requirements Documents (SRD), providing the engineering requirements to include performance requirements, operational requirements, and interfaces required for the system to operate.
- Requirements Document (RD), providing further refinement of requirements provided in the GRD and SRDs.

6. Verification Framework

The purpose of the verification process is to provide objective evidence that a system or system element fulfils its specified requirements and characteristics. [Ref20]Specifically, this process is used to determine that the “system has been built right” and meets the overall system and subsystem requirements.

There is sometimes a misconception that verification occurs after integration and before validation. In most cases, it is more appropriate to begin verification during design and development, and continue system-level verification into Commissioning and Operations.

There are four methods for conducting requirements verification: Analysis, Demonstration, Inspection, and Test. One or more of these verification techniques can be implemented for any requirement. It is anticipated that all subsystems requirements that have not been modified will be *demonstrated,* as their requirements have previously been verified. For all requirements of subsystems that are new or modified, a combination of analysis, inspection, and/or test verification methods will be used. For system level verification, all subsystem-level requirements will be tested.

6.1. Analysis

This method is based on analytical evidence obtained without any intervention on the submitted element, using mathematical or probabilistic calculation, logical reasoning, modeling, and / or simulation under defined conditions to show theoretical compliance. Analysis is typically used when testing to realistic conditions cannot be achieved or is not cost-effective.

Analysis will be used for all methods where calculations were completed, checked, and filed. This is accomplished in accordance with ENG-33 Design Verification procedure. NSTX-U calculations provide analysis on major aspects of the systems design and are completed, signed and checked at the Final Design Review (FDR).

6.2. Demonstration

This method is used to show correct operation of the system element or subsystem against operational and observable characteristics without using physical measurements (no or minimal instrumentation or test equipment). It uses a set of actions selected to show that the element response to stimuli is suitable or to show that operators can perform their assigned tasks.

Observations are made and compared with predetermined / expected responses. Demonstration can be used for re-used subsystems that have been previously tested in a similar operational environment to verify that they continue to meet their requirements.

The existing subsystems and system elements that have been previously tested and not been modified, e.g., Neutral Beam Injection (NBI), High Harmonic Fast Waves (HHFW), Electron Cyclotron Pre-ionization Heating (ECH), AC auxiliary power and Centralized Instrumentation and Control (CI&C), will be demonstrated. Demonstration consists of systems operation and verifying that performance and interfaces continue to function as originally defined.

6.3. Inspection

This method is based on visual or dimensional examination of an element; the verification relies on the human senses or uses simple methods of measurement and handling. Inspection is generally nondestructive and typically includes the use of sight, hearing, smell, touch, and taste, simple physical manipulation, mechanical and electrical gauging, and measurement. The technique is used to check properties best determined by observation (e.g., paint color, weight, documentation, listing of code).

In some cases, QA inspections per QA-003 and QA-004 will satisfy the requirement for verification by inspection, pending the nature of the requirement.

6.4. Test

Testing is performed on the system element or subsystem in this way: functional, measurable characteristics, operability, supportability, or performance capability of the system element or subsystem is quantitatively verified when subjected to controlled conditions that are real or simulated. Testing often uses special test equipment or instrumentation to obtain accurate quantitative data to be analyzed. Test plans will be documented per ENG-62 and required for design reviews as part of ENG-033.

The different types of tests that can be considered are shown in Table 1. A test may address multiple test types, e.g., functional & risk reduction. Typically, a test procedure will address each test event to the goal to each specific test type.

Table 1. *Potential Test Types*

Test type	Description
Functional	Testing which ignores the internal parts and focuses only on the output to check if it is as per the requirement
Integration	Testing of all integrated modules to verify the combined functionality after integration
Performance	Testing whether the system meets the performance requirements
Risk-Based	Testing of highly critical functionality, which has the highest impact on the program and in which the probability of failure is very high
Stress	Testing when a system is stressed beyond its specifications to check how and when it fails
System	Testing the entire system based on overall requirements and covering all the combined parts of a system, including system interfaces
Acceptance	Testing performed to evaluate the system’s compliance to business requirements and acceptability for delivery (used for system validation)

At PPPL PTPs (Preoperational Test Procedures) are written instructions that define the equipment, methods and steps required to test equipment and systems in order to qualify them as fully operational at predetermined performance levels. These tests are normally conducted to ensure systems are fully operational prior to the initial operation of a system, after a long shutdown period, or after some critical maintenance or repair tasks. The PTPs are typically the final step to verify that subsystems meet their requirements.

7. Validation Framework

The purpose of the validation process is to provide objective evidence that the system, when in use, fulfills its business or mission objectives and stakeholder requirements, achieving its intended use in its intended operational environment. The validation process is conducted prior to system operations, and provides evidence that the system, subsystem, and system elements achieve their intended use in the operational environment.

The validation process can be applied to any subsystem or system element to help ensure that the system or subsystem meets the needs of its stakeholder in the life cycle (i.e., the engineering processes and the transformation of inputs produced what was intended—the “right” result).

For NSTX-U, there are two validation test methods: The Integrated Systems Test Procedure (ISTP) as defined in ENG-30 PPPL technical procedures, and The Initial Phase of Plasma Operations. Together, these constitute commissioning of the device.

Integrated Systems Test Procedures (ISTP) are written instructions that define the equipment, methods, and steps required to test the integrated operation or interactions of multiple systems. The NSTX-U ISTP functions as an acceptance test and is used to validate that the NSTX-U machine functions correctly; magnet, rectifier, control, and vacuum systems are operated in a synchronized fashion during this test procedure. This is accomplished by orchestrating and recording each step required to operate the system and validating that it operates properly. If there are performance values, e.g., voltage ranges, temperature, and time, the values are recorded. In other cases, the function may be a boolean: did the subsystem operate correctly or not? The ISTP ensures that all subsystems are ready and plasma operations can begin. Each component contributes to the operation of the NSTX-U machine.

Once the ISTP is successfully completed, NSTX-U is ready to begin plasma operations, including the achievement of first plasma that results in completion of the final KPP. The resulting commissioning operations provides additional validation of system behaviors under the full demands of plasma operations.

8. Requirements Verification Traceability Matrix

Per ENG-62, a Requirements Verification Traceability Matrix (RVTM) [see Ref 18, above] is managed as a Google Sheet to track requirements compliance. The format of each row of the RVTM is shown in Table 2. It provides the title, a brief definition of each column and an example from the table of the Plasma Facing Component (PFC) Horizontal Target requirement.

Table 2. *RVTM Format*

Title	Definition	Example
Sequence Number	Unique count of each requirement	221
Requirement ID	Unique requirements identifier mapped to GRD, SRD, or RD paragraph numbers	PFC-4-4.2.a
Subsystem Name	Name of the system identified in the SRD / system breakdown structure (SBS)	Horizontal Target
Sub-Count	Unique requirement count for a given subsystem.	33
SBS Number	Mapping to the systems breakdown structure	1.1.1.1.4
Requirement	Requirement definition	Heat flux requirements on this surface are given in Table 4.2-1.
Functional Description	A functional description is provided in the comment field in first instance of a subsystem requirement	c. The IBDH tiles protect the horizontal casing flange and any cooling features mounted to that flange, while protecting the plasma from impurities generated from those objects. They also protect the PF-1c coil re-entrant flanges, in concert with the outboard divertor PFCs. ...
Link	This provides a link to any figures or tables that cannot be displayed in a cell of the Google sheet	See Figure 2 below, shows the IBDH Heat Flux parameters referenced the requirement
Analysis Checkbox	Checkbox to determine if analysis will be used for verification	X
Demonstration Checkbox	Checkbox to determine if demonstration will be used for verification	None Selected

Inspection Checkbox	Checkbox to determine if inspection will be used for verification	None Selected
Test Checkbox	Checkbox to determine if testing will be used for verification	X
Analysis Reference	Provides a reference to the analysis, i.e., calculation document	IBDH: NSTX-U-CALC-11-18-00
Demonstration Reference	Provides a reference to any demonstration events	N/A
Inspection Reference	Provides a reference to the inspection, i.e., QA inspection document	N/A
Test Reference	Provides a reference to the test plans and procedures	PFC Preliminary Material Testing Completed NSTX-U-REC-083-00

IBDH	**Case # ->**	**1**	**2**	**3**	**4**
Range of Application	m	0.47 < R < 0.6		R < 0.6	R < 0.47
Extent	cm	15	full	full	full
Max Angle	degrees	1.0	5.0	-1	4.0
Min Angle	degrees	1.0	5.0	-5	1.0
Heat Flux	MW/m^2	6.5	5.4	1	3.5
Duration	sec	1.5	5	1	5
Reference Scenario	---	Stationary High Ip/Bt w/ large poloidal flux expansion	High Ip/Bt Long Pulse Swept Case	Reversed Helicity Requirement	Spill Over From HHF Regions

Table 4.2-1: Required heat flux parameters for the IBDH. Cases 1, 2, and 4 have the "normal" helicity.

Figure 2. Example of a Figure/Table (Table 4.2-1 defined in requirements PFC-4.2-a) in the RVTM that cannot be displayed in the sheet

The current RVTM has recorded over 1,500 requirements and is updated with verification methods as design reviews are completed. This is an iterative process as analyses and subsequent calculations have principally been conducted as part of design reviews. Additional verification will be added over time as the system matures and testing and inspections of sub-assemblies becomes more prevalent.

9. Summary

This V&V plan provides a framework for conducting verification and validation of NSTX-U. As part of the verification process, a Requirements Validation and Traceability Matrix (RVTM) is actively updated as design reviews occur, and the NSTX-U progresses through the system lifecycle from design to subsystems integration to system test. Each requirement will be traced to at least one verification method.

In addition, Pre-operational Test Procedures (PTP) and Integrated Systems Test Procedures (ISTP) will be used for conducting system validation prior to NSTX-U acceptance, Commissioning, and Operations.