September 30, 2022

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Project Number 99902100

U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
ATTN: Document Control Desk

Subject: Submittal of Testing Programs White Paper

This letter transmits the TerraPower, LLC (TerraPower) white paper titled, "Natrium Reactor Testing Programs," which provides an overview and description of TerraPower's testing programs associated with the Natrium^{TM} design, a TerraPower and GE-Hitachi technology.

TerraPower requests that the U.S. Nuclear Regulatory Commission (NRC) staff review the subject white paper and provide documented feedback regarding topics for which additional discussion or consideration may be beneficial. TerraPower requests that a nominal review duration of 6 months be considered.

This letter and enclosure make no new or revised regulatory commitments.

If you have any questions regarding this submittal, please contact Ryan Sprengel at rsprengel@terrapower.com or (425) 324-2888.

Sincerely,

Ryan Sprengel
License Application Development Manager
TerraPower, LLC

Enclosure: NATD-EQT-RPRT-0001, Rev. 0, "Natrium Reactor Testing Programs"

cc: Mallecia Sutton, NRC

ENCLOSURE

NATD-EQT-RPRT-0001, Rev. 0, “Natrium Reactor Testing Programs”

Controlled Document - Verify Current Revision

WHITE PAPER

Document Number:	NATD-EQT-RPT-0001		Revision:	0
Document Title:	Natrium Reactor Testing Programs			
Functional Area:	Engineering	Engineering Discipline:	Safety & Licensing	
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			Page:	1 of 29

Approval

Title	Name	Signature	Date
Originator, Senior Manager	Rob Corbin	Electronically Signed in Agile	9/29/2022
Originator, Principal Engineer	Steve Unikewicz	Electronically Signed in Agile	9/29/2022
Originator, Nuclear Licensing Engineer	Leslie Holden	Electronically Signed in Agile	9/29/2022
Reviewer, Principal Engineer	Todd Lockwood	Electronically Signed in Agile	9/29/2022
Reviewer, Project Engineer	Benoit Dionne	Electronically Signed in Agile	9/29/2022
Reviewer, Manager	Ian Gifford	Electronically Signed in Agile	9/29/2022.
Approver, Senior Manager	Mike Anderson	Electronically Signed in Agile	9/29/2022

Export Controlled Content: **Yes** ☐ **No** ☒

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REVISION HISTORY

Revision No.	Effective Date	Affected Section(s)	Description of Change(s)
0	9/30/2022		Initial issuance

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EXECUTIVE SUMMARY

This document describes the testing programs that are used to verify and validate the performance characteristics, safety claims, and methods qualifications regarding the Natrium™ reactor design. The Natrium reactor is a TerraPower, LLC (TerraPower) and GE-Hitachi technology. Testing will demonstrate that the plant meets its design as stated in the Safety Analysis Report (SAR) and the requirements of 10 CFR 50.43(e)(1). Additionally, this document includes how the testing methodology addresses the 19 steps outlined in the NRC's "A Regulatory Review Roadmap for Non- Light Water Reactors," Appendix A, "Process for Determining Testing Needs" [1], which is taken from SECY-91-074, "Prototype Decisions for Advanced Reactor Designs" [2].

Necessary testing is derived from these major program areas:

- Technology Maturation Plans (TMPs)
- Equipment Qualification (EQ) Plans
- Methodology Verification and Validation (V&V) Plans
- Human Factors Engineering Program Plan (HFEPP)
- Post Construction Inspection, Testing and Analysis Program (PITAP)

The testing needs derived from these program areas are further reviewed by a broad group of stakeholders and subject matter experts to validate the necessity, requirements, and applicability, and to determine the testing priority, prior to being incorporated into the Testing Program and scheduled. Test plans, testing requirements, testing design specification, and procedures are developed and used to direct and conduct the testing. Testing is done at an appropriate level (component, sub-system, or system) for the functions being evaluated. Combined and scaled testing is used where evaluated to be appropriate. The testing needs and results are reviewed throughout the testing process to ensure that the testing requirements are being met. If additional testing needs are identified or revisions are needed to the types of testing, the testing plan is adjusted to meet any revised or new requirements. The final test results are documented and reviewed in a final test report. Open items and their proposed resolution are evaluated and tracked. The final testing and evaluation occur during the PITAP.

New, novel, or technology that lacks required pedigree or is used in a modified way, is evaluated to determine if and how that technology may be further developed (matured) to be used in the design and development of the Natrium reactor.

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

1 INTRODUCTION

1.1 Purpose:

This document describes the testing methodology that are used to verify and validate the performance characteristics, safety claims, and methods qualifications regarding the Natrium reactor design. The testing methodology provides reasonable assurance that the structures, systems, and components (SSCs) will perform their intended design and safety functions under normal operating and off-normal conditions to ensure the safety of the public. As discussed in Section 8, the test methodology addresses the guidance provided in the Nuclear Regulatory Commissions (NRC's) "A Regulatory Review Roadmap for Non-Light Water Reactors," Appendix A, "Process for Determining Testing Needs" [1], incorporates the guidance in SECY-91-074, "Prototype Decisions for Advanced Reactor Designs" [2].

1.2 Scope:

The testing program includes SSCs that are classified as safety-related (SR) or non-safety-related with special treatment (NSRST). Testing will demonstrate that the plant meets its design intent as stated in the Safety Analysis Report (SAR) and that functions operate as designed. The scope of this document includes how the testing methodology meets the 19 steps outlined in SECY-91-074 [2] summarizes the Natrium reactor testing methodology.

1.3 Objectives:

The objective of the Natrium reactor Testing Program is to verify and validate the performance characteristics, safety claims, and methods qualifications regarding the Natrium reactor design and to ensure that the requirements of 10 CFR 50.43(e)(1) are met.

10 CFR 50.43(e)(1) states:

> *"(e) Applications for a design certification, combined license, manufacturing license, operating license or standard design approval that propose nuclear reactor designs which differ significantly from light-water reactor designs that were licensed before 1997. Or use simplified, inherent, passive, or other innovative means to accomplish their safety functions will be approved only if:*
>
> > *(1)(i) The performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof;*
> >
> > *(ii) Interdependent effects among the safety features of the design are acceptable, as demonstrated by analysis, test programs, experience, or a combination thereof; and*
> >
> > *(iii) Sufficient data exists on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions;"*

Test data used to support the qualification of SSCs will meet the NRC approved TerraPower Quality Assurance Program (TP-QA-PD-0001, "TerraPower QA Program Description" [3]).

2 TESTING PROCESS

2.1 Overview

Testing the behavior of SSCs that impact safety functions and performance characteristics is critical to verifying the SSC's performance, making design decisions, and validating numerical models and methods. Along with national laboratories an integrated approach has been established for performing SSC testing necessary for the Natrium reactor design.

As needed, SSCs will have their own Technology Maturation Plan (TMP), to advance the technology and support design maturation. Section 3 describes the TMP process. This may include scale-model testing, integrated effects testing, full system testing, and component testing, as required to progress each SSC through design qualification testing, equipment qualification, factory acceptance testing, and final equipment qualification for installation and operation.

The test programs are directly linked to and closely integrated with the design, methods development, safety-analysis, and licensing activities, as depicted in Figure 2-1. The test programs link the supplier involvement for the procurement process through equipment qualification and proof of fabrication.

Components and materials that need Commercial Grade Dedication (CGD) are identified. Required testing facilities (e.g., sodium test facilities) to support technology development and equipment qualification of SSCs are derived through the testing determined necessary in the TMPs.

The overall testing workflow is in depicted in Figure 2-2. The test program elements are described below.

2.2 Testing Source Documentation

The necessary SSC testing is provided in testing source documents that are derived from these major program areas:

- Technology Maturation Plans (TMPs) (technology maturation, design development, and design confirmation) described in Section 3
- Equipment Qualification (EQ) Plans described in Section 4
- Methodology Verification and Validation (V&V) Plans described in Section 5
- Human Factors Engineering Program Plan (HFEPP) described in Section 6
- Post-Construction Inspection, Testing and Analysis Program (PITAP) described in Section 7

The testing source documents identify the testing needed to verify performance or safety claims, well as serve as the basis for comparison of existing data and any additional needs for justification of performance and safety claims.

2.3 Test Plans

The test plans are derived from the TMPs, EQ Plans, Methodologies V&V Plans, HFEPP, and PITAP, and provide a summary of the extensive information captured in that documentation. The test plans serve as outlines to the high-level testing needs of each program with a summary of the development history that led to the plan. This includes the purpose of the test, safety functions, objectives, legacy data, and any open items that would affect the test. The test plans also serve as the basis set of tests that will require a Test Requirements Document (TRD) and the elements to be tracked in the schedule and cost estimates. The test plans are reviewed by the Joint Test Group (JTG) (refer to Section 2.8.1).

2.4 Test Requirements Document

The TRD is the basis document that communicates the requirements of a test from the design groups to the testing group. This includes references to high-level requirement sources for the SSC being tested and the intended data use for the test (e.g., acceptance, data set generation for code validation, and test methods development). It also identifies why the test is being done (e.g., component performance, quality requirements, reliability, feasibility, or availability), what the product being produced is, and the detailed use of the test outcome. It describes the enabling assumptions for the test, how the test may be simplified to allow for the execution of the experiments, and justification for each assumption or how each assumption will be justified in future work. A brief narrative of the test articles and supporting test equipment needed to support the test including instrumentation is also provided. Similarly, brief narratives of the data requirements and codes and methods requirements are provided. Clear delineation of the type of test (e.g., separate effects testing, integrated effects testing, qualification testing) is provided. A notional test matrix is provided and the combination of variables that should be tested is described. Included in the test matrix is how variables will be implemented and how many tests of each case are required. The expected outcome of the test is provided. This information is used to justify the outcome of the test and guide the experimental design. The TRDs are reviewed by the JTG (refer to Section 2.8.2).

The TRD outlines the following areas:

- Purpose of the Test
- Test Objectives (including safety claims)
- Test Assumptions
- Test Requirements (including scaling and environmental conditions)
- Test Matrix (addresses conditions, variables, scaling, and combinations thereof to be tested)
- Pre-Test Predictions

2.5 Test Design Specification

The Test Design Specification (TDS) documents the test articles, test setup, and how the test requirements are going to be achieved. The TDS describes how the test will serve as the basis for performance of the test and is the driving document to guide the needed equipment specifications and subsequent fabrications and installations. A key interface from this document is the test facility requirements such that appropriate facility updates and /modifications can be planned, as appropriate.

The TDS outlines the following areas:

- Purpose
- Experimental Setup (including scaling and environmental conditions)
- Special equipment requirements (e.g., test apparatus, instrumentation, support equipment, test facilities, and interfaces to facilities and utilities)
- Test Criteria/Data Development Criteria (i.e., how the requirements from the TRD are being met)
- Document Product List
- Test Matrix (addresses conditions, variables, scaling, and combinations thereof to be tested)
- Process Hazard Assessment

- References

2.6 Test Procedures

Test procedures are written sets of instructions required to perform the test in addition to the methods of test control, and the technical and safety requirements. Test procedures address and include:

- Scope of the SSCs to be tested and data development goals
- General requirements including test performance, chain of direct control and supervision of the test, and assigned responsible test engineer
- Pretest briefing requirements including discussions on safety requirements, process hazards analyses, and test operation review
- Training procedures, requirements, and activities
- Tools, equipment, and supplies needed
- Safety precautions and limitations
- Interface requirements
- Prerequisite, startup, and shutdown actions
- Test procedure steps
- Appropriate signoffs
- Test log

2.7 Test Report

The test report is the final documentation of the completed test. The test report includes a description of the purpose and any safety functions of the SSCs. It also includes a description of how the system was tested, what functions were tested, and identifies the objectives of the test and a declaration that the objectives were or were not met. In addition, the test report includes a summary of any problems encountered during testing and their resolution, identification of any open items and the proposed resolutions, and a projected schedule for implementation and the tracking of open items. The test reports are reviewed by the JTG (refer to Section 2.8.3).

The test report outlines these areas:

- Scope of the test and summary of the equipment utilized
- Test results
- Description of test activities including:
  - Test methodology summary
  - Major activity chronology
  - Test procedure change summary
  - Test deficiency summary
  - Problems encountered
  - Open items
- Test conclusions including validation of test objectives
- References
- Attachments including:
  - Approved test procedure
  - Completed test procedure

- Test log
- Data sheets
- Calculations
- Supporting documentation (including Quality Assurance (QA) records)

2.8 Joint Test Group

The Joint Test Group (JTG) is the governing body that ensures that testing is focused on scope that is relevant to the design of the plant and is planned, conducted, and reported in compliance with project requirements throughout the testing process. It is composed of a broad group of stakeholders including members from design, safety, licensing, quality assurance, project management, design authority, subject matter experts, and the testing group.

2.8.1 Joint Test Group Review – High-Level Test Programs and Test Plans

The JTG reviews overall test programs that are derived from the testing source documents (e.g., TMPs, Methodologies V&V Plans, and regulatory requirements) to ensure stakeholders have reviewed and have had the opportunity to provide input to the testing programs. Upon successful review of the overall test program roadmaps, further development of the test program proceeds with development of the TRDs of the individual tests.

2.8.2 Joint Test Group Review – Test Requirement Documents for individual tests

The JTG reviews the individual test plans to ensure the tests are still required and planned accordingly (e.g., priority, need, schedule), testing alternatives are evaluated, and reviewed to determine if the tests meet technical requirements and programmatic needs. The JTG reviews higher level information such as Critical Characteristics, acceptance criteria, QA level and requirements, and data usage. The outcome of this JTG review is an authorization for the individual tests to proceed to the test design phase.

2.8.3 Joint Test Group Review – Test Report

The JTG reviews the test results of the individual tests to evaluate successful completion of the testing evolutions as well as any retesting or follow-on testing that is necessary to satisfy the requirements of the test. Open items and their proposed resolution are evaluated. The JTG also evaluates if any changes that occurred during the testing process could have an impact on the test purpose or objectives. While not a primary purpose, this JTG review solicits any lessons learned during the testing process.

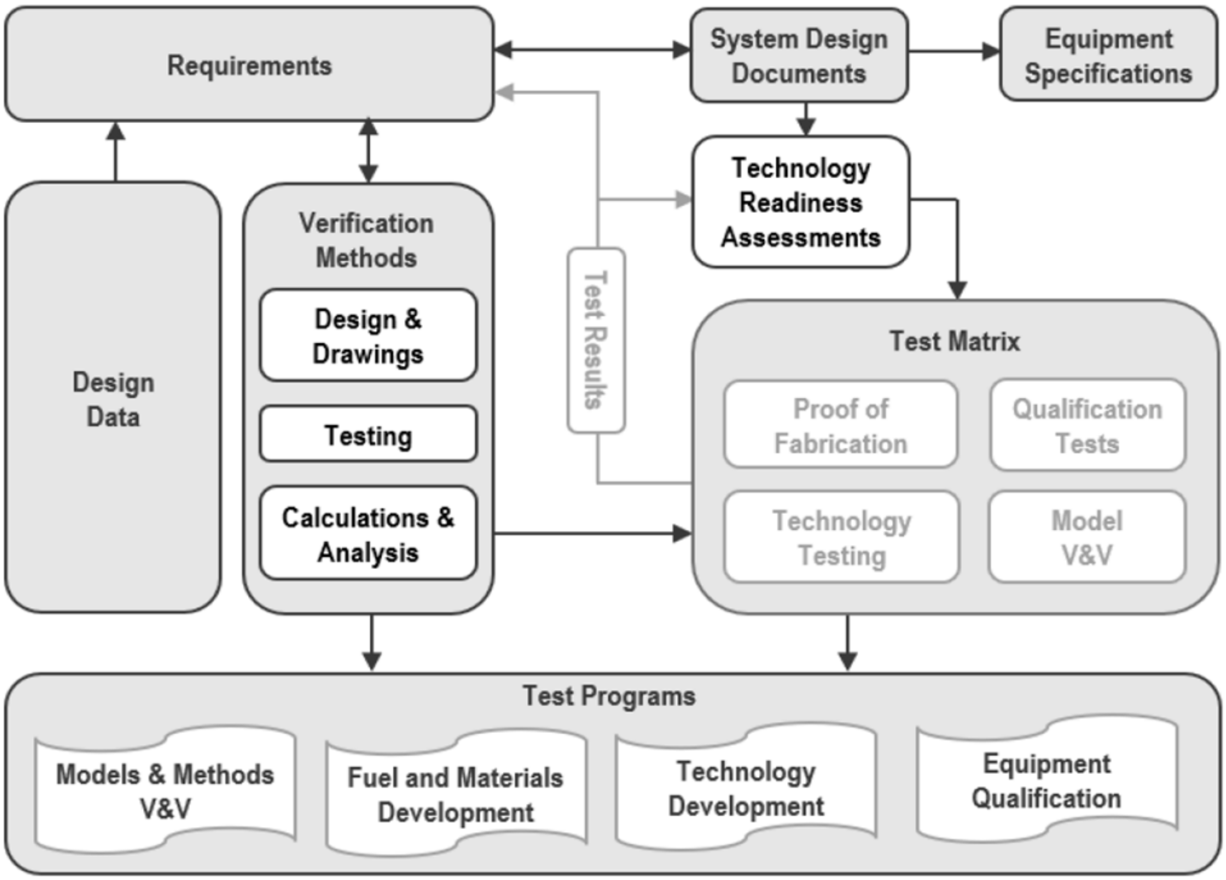

Figure 2-1: Inegration of the Testing Program into the Design Process

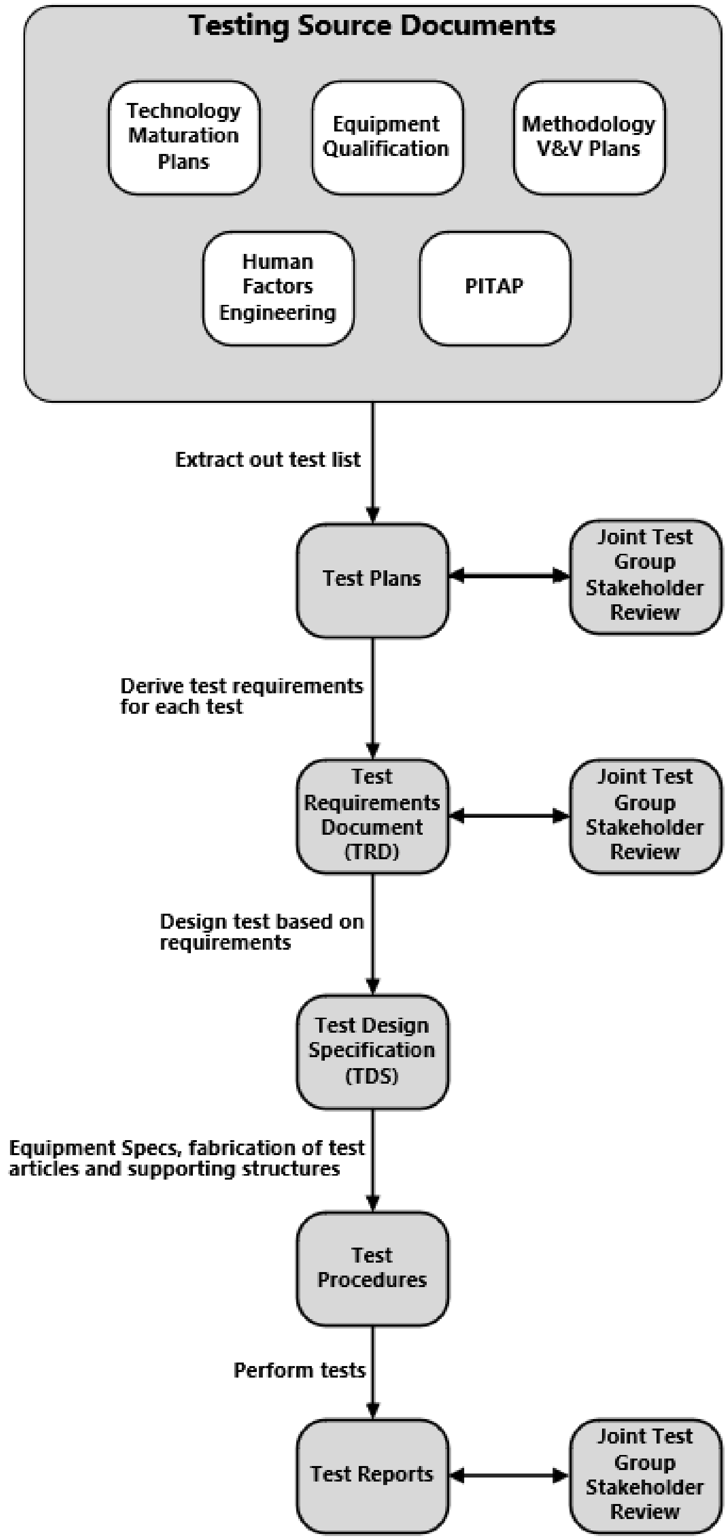

Figure 2-2: Test Program High-Level Process Flow

3 TECHNOLOGY MATURATION PLAN PROCESS

3.1 Overview

The TMP process is a planning tool for technology development. The TMPs are derived based on identified systems and a list of sub-systems and components for that system. The TMP process is primarily based on GAO-20-48G, "Technology Readiness Assessment Guide" [4], which is a U.S. Government Accountability Office (GAO) recognized technique, with modifications made to support the Natrium reactor testing goals and processes.

TMPs are used for technologies that are new, novel, used in a modified way. They can also be used for existing technologies with outdated, minimal, or not properly documented supporting data.

TMPs provide high-level guidance to generate an initial roadmap for the maturation of technology components and processes through their corresponding Technology Readiness Levels (TRLs) (refer to Section 3.3).

The TMP process is used to:

1) Define the specific aspects of technology development,
2) Calculate the progress toward achieving a technical performance goal for a specific technology or group of technologies,
3) Identify potential concerns, gaps, and risks,
4) Gather evidence to continue development efforts or initiate steps toward using an alternative or backup technology,
5) Demonstrate and mature fieldable technologies or prototypes through the TRLs to achieve the desired performance objectives, and
6) Determine whether technologies are ready to transition to new or existing programs.

Technologies are validated through physical testing, analytical testing, or through a combination of component, separate effects, integral effects, initial start-up, and pre-operational tests, as called out in the TMP.

Figure 3-1 shows the overall technology readiness level development of the TMP. The progression of TRL levels, as part of the TMP development, provides a roadmap for the Testing Program. The following sections describe the steps in the TMP development process.

3.2 Critical Technology Element Identification

The TMP process begins with technology elements identification and the preliminary determination of the Critical Technology Elements (CTEs). From the GAO documentation [4] *"… technology elements are generally considered critical if they are new or novel, or used in a new or novel way, and are needed for a system to meet its operational performance requirements..."*.

The Technology Readiness Assessment (TRA) defines what functional technology elements are required (e.g., if a rotating shaft is required for the plant to function, the bearings allowing rotation are a technology element). The TRA then determines the TRL for the CTEs based on questions from GAO-20-48G and engineering judgement. CTEs are identified based on some basic elements (e.g., status of technology, risks, novel portions). The knowns and unknowns of the technology are identified. Each CTE is evaluated and processed individually.

For each CTE, the TRA identifies a list of Critical Characteristics. A Critical Characteristic is a functionality that is required for a technology element to perform as intended (e.g., for a pump it may include such things as flow/head, power consumption, vibration, endurance, coast down, thermal profile, seal integrity, and shielding). The TRA compiles a complete list of Critical Characteristics.

3.3 Technology Readiness Assessment

The TRA is conducted by a team of subject matter experts from fields relevant to the technologies to be assessed. The TRA evaluates program concepts, technology requirements, and demonstrated technology capabilities.

The TRA plan includes a comprehensive assessment approach. Past technical assessments and any previous assessments that have contributed to the need for the TMP are reviewed, including previous technology development activities that brought the technology to its current state of readiness.

Historical testing and data are used when possible. TerraPower has a process for qualifying and using historical data, including testing performed at other sodium sites, and from other designs in the United States and abroad. TerraPower is using the guidance developed by Idaho National Laboratory (INL), “Guidance on Evaluating Historic Technology Information for Use in Advanced Reactor Licensing” [5]. This process will review applicability of previous NRC questions, comments, and evaluations, and evaluate how the information can be used in the Natrium reactor design.

CTEs are evaluated through the TRA process to determine the current TRL and gaps in future TRL progressions. The TRL is a metric used for describing and assessing the maturity of evolving technologies (e.g., materials, components, devices) on a scale of 1 to 9, prior to incorporating that technology into a system or subsystem. Table 3-1 gives the range of technology readiness that is used for the Natrium reactor program. Table 3-1 is from GAO-20-48G [4].

Testing, tasks, and risks are identified for each TRL phase. Testing considerations include identification of operational testing, the test environment, and the scale of testing for each TRL phase. Relative order of magnitude costs and scheduling are also determined for each TRL phase. Technology alternatives are assessed throughout the process.

3.4 Technology Maturation Roadmap

The Technology Maturation Roadmap (TMR) for each CTE is developed from the TRA.

The purpose of the TMR is to identify the tasks required to increase maturity to TRL 8. The TMR identifies items to be completed for moving to each of the next TRL levels. The TMR identifies the tasks to be undertaken including design, analysis, and success criteria required to support the separate effects testing, integrated effects testing, and prototype testing required for advancement to the next TRL as well as the equipment qualification requirements (including environmental) and any test scaling. A TMR is developed for each CTE, for outlining the approach to progress it through TRL 7.

Table 3-1: Natrium Reactor Technology Readiness Level

Technology readiness level (TRL)	Description
1 Basic principles observed and reported	Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2 Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3 Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4 Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5 Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components.
6 System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7 System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).
8 Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9 Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Source: GAO analysis of agency documents. | GAO-20-48G

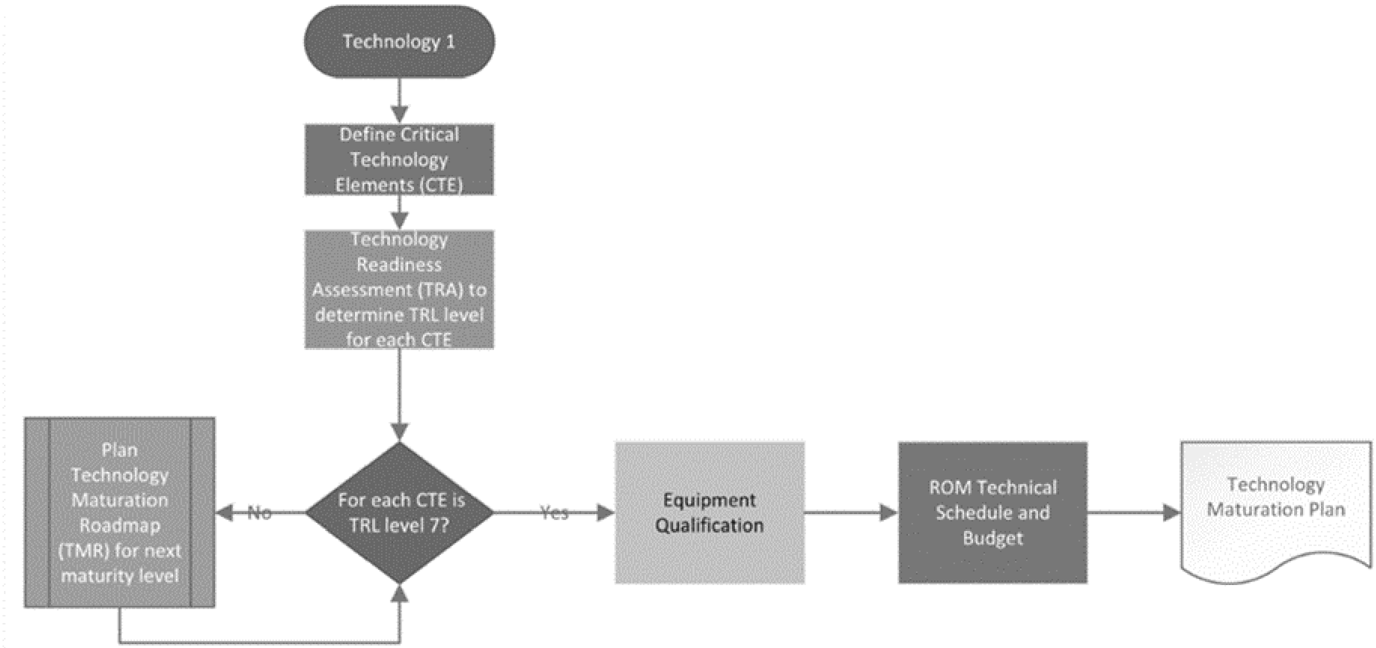

Figure 3-1: Technology Maturation Plan Development

4 EQUIPMENT QUALIFICATION PROGRAM

4.1 Overview

Once the TMP has been developed, the EQ Program is used to evaluate the testing identified in the TMP and develop the Equipment Qualification Testing Specification (EQTS). If the EQ Program identifies revised or additional testing needs, the TMP is revised to incorporate those testing requirements.

The EQ Program provides direction on how equipment qualification is established and performed. The EQ Program defines how components are in compliance with Codes, Standards, and regulatory requirements. The EQ Program identifies content to be included and how testing requirements are to be translated into test specifications. Equipment qualification and acceptance testing requirements are included in the component design and purchase specifications, and the content of these documents will meet the requirement for qualification of equipment as defined in the TerraPower QA Program Description, TP-QA-PD-0001 [3].

The EQ Program will follow Regulatory Guide 1.100, “Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants” [6].

Equipment qualification is performed for SR and NSRST components. Environmental qualification considerations, which is included under the EQ Program, applies to all important to safety equipment. EQ may be used for non-safety-related with no special treatment (NST) SSCs and also to provide “proof of concept.”

4.2 Equipment Qualification Test Specification

The EQTS describes the requirements used to ensure that industry standards and federal regulations are met. The specification ensures that SSCs are validated through analytical and physical testing with a combination of component, separate effects, integral effects, scale testing, start-up, and preoperational tests, as appropriate.

The following types of tests may be included based on the testing needs identified in the TMR:

- Proof of concept
- Reliability
- Seismic
- Environmental
- Dynamic
- Functional qualification
- Electromagnetic compatibility

Testing is performed using test equipment calibrated and traceable in accordance with TerraPower QA Program [3].

5 METHODOLOGIES VERIFICATION AND VALIDATION TEST PLAN

Design and licensing require analysis and evaluation of the performance of SSCs under normal operating and off-normal conditions. To perform this analysis and evaluation, methodologies as discussed in this section are used to evaluate the design against its requirements and regulatory limits. Methodologies include a sequence of one or more engineering computer programs, combined with special models and design information. V&V testing is an integral part of the development process to ensure that the methodologies and associated codes are adequate for the analysis and evaluation being performed.

Most of the methodologies used for design and licensing of the Natrium reactor are based on approaches developed and used by TerraPower for the Traveling Wave Reactor® (TWR) and draw from prior and ongoing work by the Department of Energy (DOE) National Laboratories to analyze sodium fact reactors (SFRs). These methodologies are divided into the following five key disciplines: Safety Analysis, Absorber and Fuel Performance, Core Mechanical, Neutronics and Shielding, and Thermal-Hydraulics.

Figure 5-1 depicts the V&V framework which is a time tiered approach from early in the project to develop and mature codes and methodologies to ensure their adequacy for design and licensing. It also illustrates its relationship to the Testing Program through methodologies specific activities.

These methodologies require the use of internally developed software and commercial software. Code maturity level is evaluated in a range between early stages of development to highly mature (Figure 5-1, Step 1). Many of the acquired codes are highly mature and have previously undergone a V&V process for other applications, but not for SFRs. Close collaboration with national laboratories ensures that key codes are appropriately modified to address the reactor design and V&V is conducted early in the design process.

Methodology specific activities performed during development such as creation of important phenomena ranking table, scaling methodology and analysis, verification test suites, benchmark analyses, comparison with other codes (including higher fidelity numerical results), comparisons to qualified historical data, commercial grade dedication, and acceptance testing help inform the testing needs.

Assessment matrices identify needs for component performance testing, separate effect and integral testing, and other type of testing needs (criticality, fuel performance, etc.). These assessments are created as part of the maturation work for this methodology which, in turn, support the quantification of uncertainties and formal updates to the testing program (Figure 5-1, Step 2). These can be represented as testing roadmap for the various methodology areas.

More specifically, the available experimental data will be examined to see if the experiments can represent some part(s) or the whole of the transient scenarios of the Natrium reactor plant that simulate the important phenomena. If some phenomena are not covered by the available experimental data, test objectives and requirements for experiments need to be developed for the appropriate validation of the safety analysis evaluation model. From this information, initial testing matrices are established within the Natrium reactor testing programs, as needed, and individual V&V Test Plans for the documented methodologies are developed.

Methodology reports are developed and used to support the analyses (shown in Figure 5-1, as Step 3). This includes an assessment of the data and documentation of ranges of use for the software as defined by the V&V test suites. The methodology reports communicate uncertainties in the methods and support the design analyses of corresponding SSCs. Methodology reports are developed and may be revised due to changes to design and analysis requirements, results of validation testing, and feedback from the NRC.

Specific methodologies will be addressed in more detail in future NRC regulatory engagements.

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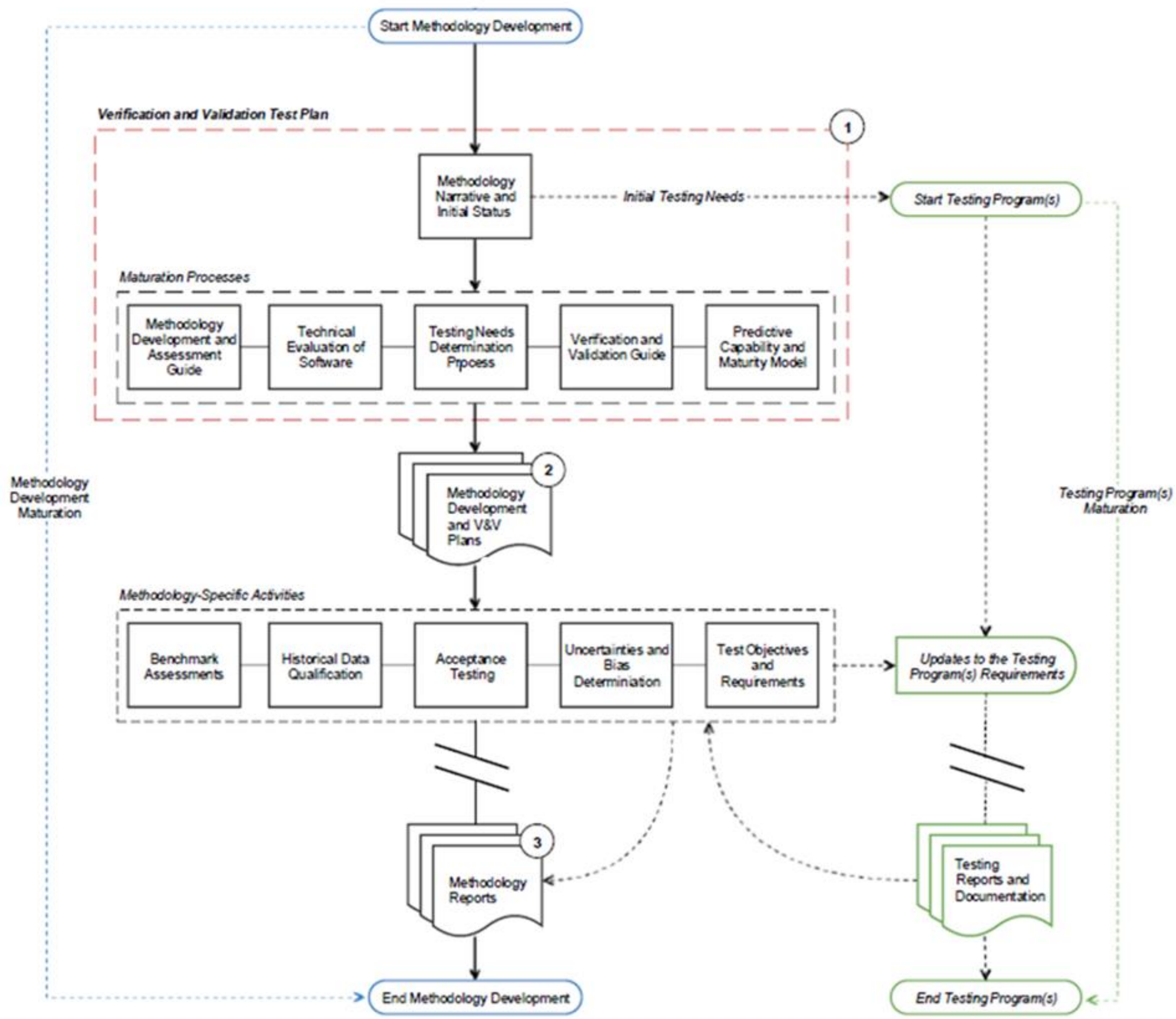

Figure 5-1: V&V Framework for the Methods Development and Testing Program Interface

6 HUMAN FACTORS ENGINEERING PROGRAM PLAN

A detailed human factors test program has been developed that evaluates man-machine interfaces as well as other human factors considerations. The HFEPP provides a comprehensive, iterative design approach for the development of human-centered control and information infrastructure. The general objectives of the HFEPP are stated in human-centered terms, which are developed, coordinated, and refined throughout the design process, including HFE related testing. A part-task simulator and a full scope simulator are being developed.

The HFEPP will be addressed in more detail in future NRC regulatory engagements.

7 POST-CONSTRUCTION INSPECTION, TESTING AND ANALYSIS PROGRAM

The PITAP includes construction testing requirements, construction turnover process, and the initial test programs. The initial test programs are comprised of pre-operational tests (including component, system, and pre-core hot functional testing), initial fuel loading, post-core hot functional testing, initial criticality, low-power physics tests, and power-ascension tests. The PITAP represents integrated testing that ensures that the SSCs meet performance requirements, test objectives, and design criteria as established in the SAR and project design and performance requirements.

The PITAP allows for the verification of the assumptions made in the SAR and ensures that adequate margin exists between the design and the safety requirements and the actual performance of the plant. The PITAP will contain a detailed list of PITAP activities and tests that must be performed.

The PITAP will:

- Demonstrate that the safety-significant SSCs were constructed and installed properly and will operate in accordance with the design and as described in the SAR.
- Address the major phases of the test program including construction testing, preoperational tests, initial fuel loading, initial criticality, low-power tests, and power-ascension tests.
- Demonstrate the adequacy of administrative controls.
- Familiarize the plant's operating and technical staff with operation of the facility, along with the use of the simulator as appropriate.
- Verify the adequacy of the plant operating and emergency procedures.
- Provide reasonable assurance that the plant will operate in accordance with the safety analysis and the applicable NRC regulations.

The PITAP will also address Nuclear Island testing needed to ensure all SSCs functions operate per design. Integrated plant and system test procedures should be demonstrated on the simulator, when possible, to further validate test results and the adequacy of the testing.

The PITAP will be addressed in more detail with the Operating License Application (OLA) submittal.

8 ALIGNMENT TO REGULATORY ROADMAP - TESTING

The Natrium reactor overall testing process incorporates guidance addressed in the NRC's "A Regulatory Review Roadmap for Non-Light Water Reactors," Appendix A, "Process for Determining Testing Needs" [1], which is taken from SECY-91-074, "Prototype Decisions for Advanced Reactor Designs" [2]. Figure 8-1 provides the simplified process diagram from SECY-91-074 (Figure 1). The following paragraphs, as identified, correspond to the numbered item on the SECY-91-074 testing needs process flow chart.

8.1 Identify and Define Test Objectives

(Figure 8-1, Item 1, Identify and define testing objectives)

Tests are performed to justify the performance characteristics and safety claims regarding the design. The types of tests to be performed include tests of components, systems, simulators, non-nuclear and nuclear test loops, and comprehensive testing to validate proof of principle.

Test objectives are identified for each performance or safety claim. The selected objectives and subordinate objectives define the results needed from the testing process. The objectives will determine the type of testing to be conducted.

Each of the testing source documents inherently identify the performance or safety claims as the basis for comparison of existing data and any additional needs for justification of performance and safety claims. Refer to Section 2.2.

The CTEs and Critical Characteristics are used to identify and define testing objectives. During the TRA, testing, tasks, and risks are identified for each CTE at each TRL phase. Refer to Sections 3.2 and 3.33.3.

The TRD provides detailed requirements of each test (e.g., test objectives, prerequisites, initial conditions, testing method, data collection requirements, and acceptance criteria). Refer to Section 2.4.

The EQTS incorporates the TRD by including the testing objectives and defining the testing procedure to validate the objectives. Refer to Section 4.2.

Individual V&V Test Plans for the documented methodologies are developed. These individual plans will leverage the maturation processes described to guide the development of more detailed V&V testing, including the development of testing objectives and requirements. Refer to Section 5.

PITAP includes testing objectives for construction, construction turnover, and initial testing requirements. Refer to Section 7.

8.2 Component Testing

(Figure 8-1, Item 2, Is testing required for component performance, reliability, feasibility, or availability? Item 3, Component test(s) or separate effects test(s) are required.)

The intent of component testing is to validate component performance, reliability, feasibility, or availability and to identify if additional testing is needed. Evaluations of the component design with respect to plant performance and the ability to mitigate events are also conducted. The need for component tests or separate effects tests is assessed during this evaluation.

Test objectives are identified for each performance or safety claim. The testing program for each component demonstrates that its performance fulfills test objectives. Refer to Section 8.1. As identified as part of the TRD and the EQTS, testing includes environmental and seismic qualification as appropriate.

For components with existing reliability and performance data based on light-water reactor nuclear plants (e.g., motor-operated valves, check valves, breakers, and relays), additional testing is performed only if the performance or reliability data is not sufficient to meet the Natrium reactor reliability requirements.

Testing, tasks, and risks are identified for each CTE at each TRL phase. Testing considerations include identification of operational testing, the test environment, and the scale of testing for each TRL phase. Refer to Sections 2.5 and 3.3.

The TMR identifies the potential testing, design, and/or analysis required for advancement to the next TRL as well as the equipment qualification requirements. The testing environment and scale of the test are identified in the TMR. Refer to Sections 3.4 and 4.2.

The EQ Program provides direction on how SR and NSRST EQ testing is established and performed. The EQ Plan defines the Codes, Standards, and regulatory requirements needed to qualify equipment. Refer to Section 4.2.

8.3 Human Interface Testing

(Figure 8-1, Item 4, Is testing required for man-machine interface, instrumentation information transfer, plant automation, or operator actions? Item 5, Simulator, or mock-up test(s) are required.)

The HFEPP evaluates testing requirements for human-machine interface, instrumentation information transfer, plant automation, and operator actions. HFE is part of the development of Critical Characteristics as identified in the TMP process and as such are included in the development of the TRD and TDS. Refer to Sections 2.4, 2.5, and 3.2, respectively.

The plant simulator and mock-up tests are used to confirm routine operator actions and sequences. HFEPP tests will include simulator or mockup tests and are reflected in the PITAP. Refer to Sections 6 and 7.

8.4 System Reliability Testing

(Figure 8-1, Item 6, Is testing required to determine the performance, reliability, availability, or feasibility of systems? Item 7, Systems test(s), or non-nuclear integral loop test(s) are required.)

Evaluations of the testing is performed to ensure system performance, reliability, feasibility, and availability of the safety systems based on the identified test objectives. Test objectives are discussed in Section 8.1. Evaluations of the system design with respect to plant performance and ability to mitigate events is conducted. These evaluations determine the associated system test or integral loop test requirements.

The Testing Program ensures the reliable operation at the system level of SSCs to meet their overall performance, reliability, availability, or feasibility objectives. The process for testing systems parallels the overall process described in Section 8.2 for component testing at the system level.

8.5 Nuclear Performance Testing

(Figure 8-1, Item 8, Is testing required for determining nuclear performance, physics coefficients, reactivity control, or stability? Item 9, Critical testing facility is required.)

This evaluation includes consideration of the basic characteristics of the core design, including its stability and control margins for reactivity, and the stability of any neutronic and thermal-hydraulic interactions, as they may affect the stability and control margins of the reactor.

Extensive data and information exist for SFR core physics and performance characteristics that are relevant to the Natrium reactor design and are identified where appropriate in the individual test documents.

Evaluation of the testing required to demonstrate nuclear performance, physics coefficients, reactivity control, and stability will primarily be done through Methodologies V&V Process as well as the Start-Up Program core testing under the PITAP. Refer to Sections 5 and 7, respectively.

8.6 System Interaction Testing

(Figure 8-1, Item 10, Is testing required for systems interactions, interdependencies, overall feasibility, integrated system performance, or reliability?)

Testing required for systems interactions, interdependencies, overall feasibility, integrated system performance, and reliability is conducted. Determining the need for partial or full-scale tests is part of this evaluation. Multiple system tests may be performed based on the degree of interdependency of systems in the design.

Tests will account for:

- redundancy and diversity of the systems that may reduce the consequences of individual system failures,
- possibility of synergistic effects from the interactions of various phenomena or systems, and
- susceptibility of the design to failures that propagate through one or more systems.

Integrated system tests, as determined to be appropriate, are conducted as part of the PITAP. The integrated system tests, typically referred to as hot functional tests, are performed to verify proper systems operation. Refer to Section 7.

8.7 Other Required Objective Test

(Figure 8-1, Item 11, Is testing required for other objectives?)

The test programs are directly linked to and closely integrated with the design, methods development, and licensing activities. If new characteristics are identified as the design progresses, additional testing is identified. Refer to Section 2.

Throughout the design and testing process, if additional characteristics, requirements, or testing objectives are identified that have not already been covered by previous testing evaluations, they are formally documented and evaluated to determine if additional testing is required. Refer to Sections 2 and 3.

8.8 Combined Testing

(Figure 8-1, Item 12, Is combined testing possible?)

Testing objectives and proposed tests are evaluated throughout the testing process to determine if combinations of tests can improve the overall confidence of testing results and achieve economic savings in the Testing Program. Where tests involve phenomena related to each other, combined testing generally gives higher confidence to the results and may identify synergistic effects. For example, it may be possible to combine equipment qualification tests for similar equipment. Separate effects tests may be applicable to more than one SSC. These evaluations are part of ongoing assessments of test needs and facilities. Refer to Sections 2, 3, 4, and 7 for integrated testing evolutions.

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8.9 Scale Testing

(Figure 8-1, Item 13, Can test(s) objective(s) be demonstrated with scale test(s)?)

Evaluations are made to determine whether the test objectives can be satisfied by tests of scale models or partial systems. Testing requirements are identified on the TRD, including a description of the testing, the testing environment, and any test scaling. Refer to Section 2.4.

8.10 Component or Separate Effects Tests

(Figure 8-1 Item 14, Conduct separate test(s).)

Evaluations may determine that separate tests are necessary if a test(s) cannot be combined with other tests and scale testing is not necessary or possible. The flow-down of these requirements for types of testing is inherent in the TMPs and Methodologies V&V testing; and are described in the TRD. Refer to Sections 3, 5, and 2.4, respectively.

8.11 Partial Scale Test

(Figure 8-1, Item 15, Conduct partial scale test(s).)

Evaluations are made to determine if partial scale tests are necessary to test limited interactions of SSCs to establish performance parameters or basic design proof-of-principle. The Equipment Qualification Program and the Methodologies V&V process are the source of the scaling methodology. Refer to Sections 4 and 5, respectively. The impacts and requirements are described in the TRD. Refer to Section 2.4.

8.12 Full Scale or Prototype Test

(Figure 8-1, Item 16, Conduct full-scale integrated test(s) or prototype test.)

Overall integrated test(s) are conducted to verify that the objectives of each of the contributing test(s) have been satisfied. Integrated tests are performed to justify claims where the testing objectives cannot be satisfied by other testing methods. Full scale integrated test or prototype testing will be evaluated and conducted if deemed necessary. The TRD addresses integrated testing. Refer to Section 2.4

8.13 Claims Justified

(Figure 8-1, Item 17, Did the testing successfully justify the safety claims? Item 18, The safety claims are justified.)

Construction, Pre-Operational, and Start-up testing is planned to verify that the identified safety and performance claims have been met. These are driven from requirements identified in the TMPs, EQ Programs, and Methodologies V&V. Refer to Sections 3, 4, and 5. These types of tests are documented in the TRDs and Test Reports. Refer to Sections 2.4 and 2.7, respectively.

8.14 Redefine Tests

(Figure 8-1, Step 19, Redefine the testing objective(s) or redesign the plant.)

Throughout the testing process, if weaknesses are identified in the testing objectives or methods, they are re-evaluated and modified to correctly assess and support performance and safety claims. If at any time during the testing process, testing results fail to substantiate performance and safety claims, the designs are re-evaluated and re-designed as appropriate. If the proposed final design cannot meet the performance and safety claims, then the final design is revised, and necessary testing is performed the to support certification of the revised final design. Refer to Sections 2, 3, 4, and 5.

Figure 1 – Process Diagram

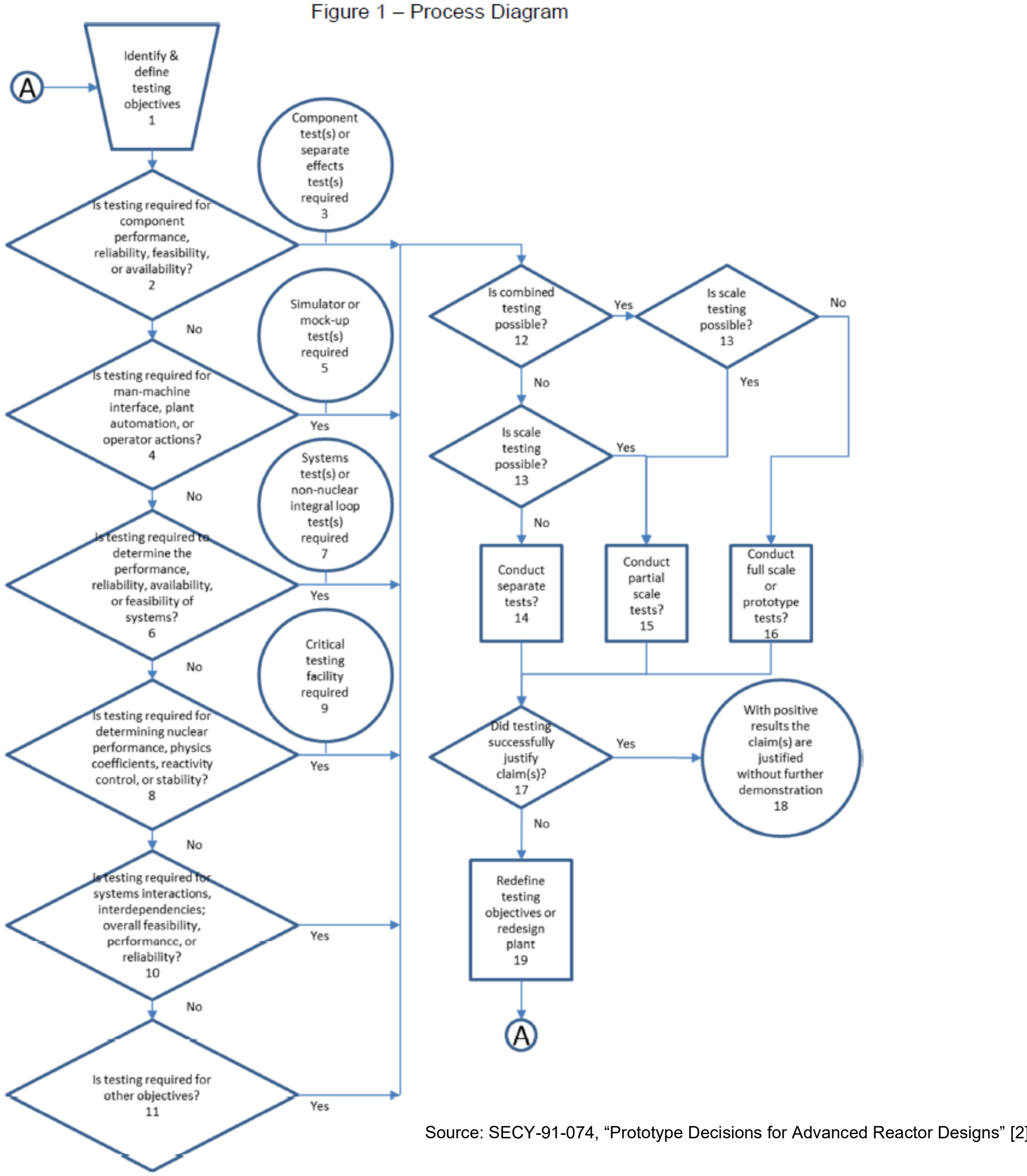

Figure 8-1: Process for Determining Testing Needs

9 ACRONYMS AND ABBREVIATIONS

BCR	Benchmark Comparison Reports
CFR	Code of Federal Regulations
CGD	Commercial Grade Dedication
CTE	Critical Technology Element
DOE	Department of Energy
EQ	Equipment Qualification
EQTS	Equipment Qualification Test Specification
HFE	Human Factors Engineering
HFEPP	Human Factors Engineering Program Plan
INL	Idaho National Laboratory
JTG	Joint Test Group
NRC	Nuclear Regulatory Commission
NSRST	Non-Safety-Related with Special Treatment
NST	[Non-Safety-Related with] No Special Treatment
NUREG	Nuclear Regulatory Report [NRC]
PITAP	Post-Construction Inspection, Testing and Analysis Program
QA	Quality Assurance
ROM	Rough Order of Magnitude
SAR	Safety Analysis Report
SECY	Commission Papers [Papers submitted by the NRC to the NRC Commission]
SFR	Sodium-Cooled Fast Reactor
SR	Safety-Related
SSCs	Structures, Systems, and Components
TDR	Technology Development Roadmap
TDS	Test Design Specification
TMP	Technology Maturation Plan
TMR	Technology Maturation Roadmap
TP	TerraPower

TRA	Technology Readiness Assessment
TRD	Test Requirements Document
TRL	Technology Readiness Level
TWR	Traveling Wave Reactor
V&V	Verification and Validation

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