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Risk Management Plan

Risk Management Plan for the Next Generation Nuclear Plant Project

Idaho National Laboratory

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Idaho National Laboratory

RISK MANAGEMENT PLAN FOR THE NEXT GENERATION NUCLEAR PLANT PROJECT	Identifier:	PLN-3247	
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REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	09/30/09	All	New Issue

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FIGURES

TABLES

ACRONYMS

BOP	Balance of Plant
CD	Critical Decision
DDN	Design Data Need
DOE	U.S. Department of Energy
EPAct	Energy Policy Act of 2005
HTE	High Temperature Electrolysis
HTGR	High Temperature Gas Reactor
HyS	Hybrid Sulfur
IEC	International Electrotechnical Commission
INCOSE	International Council on Systems Engineering
INL	Idaho National Laboratory
ISO	International Organization for Standardization
LWP	Laboratory-wide Procedure
NGNP	Next Generation Nuclear Plant
NRC	Nuclear Regulatory Commission
PASSC	Plant, Area, System, Subsystem, Component
PCS	Power Conversion System
PIRT	Phenomena Identification and Ranking Table
PRAT	Project Risk Assessment Tool
R&D	research and development
RMP	Risk Management Plan
RMS	Risk Management System
ROT	reactor outlet temperature
S-I	Sulfur-Iodine
TDRM	Technology Development Roadmap
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
VHTR	Very High Temperature Reactor
WBS	Work Breakdown Structure

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DEFINITIONS

Critical PASSC	Physical NGNP entities against which an effective risk analysis may be performed and results evaluated.
Consequence of occurrence	A representation of the potential impact of realizing a risk (i.e., the impact of a risk event). Consequence of occurrence is expressed using a descriptor (label) and/or a numerical factor (1 to 9).
Probability of consequence	A representation of the relative likelihood that a realized risk will occur at the level of consequence assigned. Probability of consequence is expressed using a descriptor (label) and/or a numerical factor (0.1 to 0.9).
Probability of occurrence	A representation of the relative likelihood that a risk will be realized or occur. Probability of occurrence is expressed using a descriptor (label) and/or a numerical factor (0.1 to 0.9).
Realized risk	A risk that has occurred.
Residual risk	Risk remaining after the risk-handling strategy has been implemented.
Risk	A measure of the potential inability to achieve overall project objectives within defined scope, cost, schedule, and technical constraints. The term is usually reserved for situations or events that are in some way significant or that pose above-normal project risks.
Risk analysis/ assessment	Investigation (analysis) and quantification of risk.
Risk event	A potential adverse event that affects the project resulting in impacts to cost, schedule, safety, performance or other characteristics, but does not include the minor variance inherent in base costs.
Risk handling strategy	One of four methods used to reduce the likelihood or mitigate consequences of a risk, or to accept, avoid, or transfer the risk.
Risk level	Qualitative representation of a risk as Very Low, Low, Medium, High or Very High. Risk level can be associated with the risk number.
Risk number	Numerical representation of a risk. Defined as the multiplication product of the probability of occurrence and the probability that consequence occurs at level of severity noted, and multiplied by the consequence of occurrence. Expressed as a dimensionless number of that is a measure of realizing a given risk event.
Risk register	A table, spreadsheet or database used to record, organize and track risks to the project.
Risk response	The planned path forward to reduce or accept risk. Risk responses are typically comprised of Research and Development, Engineering Analysis, Licensing, and Modeling and Simulation tasks.
Weighting factor	A weight applied to the risk calculation that forces higher risk rating for risk of high consequence and recognizes the lower confidence in the users' ability to predict probability levels.

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1. INTRODUCTION

This document presents the Next Generation Nuclear Plant (NGNP) Risk Management Plan (RMP) and defines the scope and methodology for identifying, analyzing, responding, determining impact, reporting, tracking, and closing risks that could prevent the NGNP Project from achieving its objectives. The objective of risk management, as described in this plan, is to identify above-normal risks for the selective application of appropriate response actions to reduce or mitigate such risks to acceptable levels. This document also describes the NGNP Risk Management System (RMS). The RMS is a relational database developed in Microsoft® Access, which provides conventional database utility as well as a number of unique capabilities specifically designed to facilitate the development and execution of activities outlined in the RMP. These include the capability to establish the risk baseline; document and analyze the risk reduction plan; track the current risk reduction status; and organize risks by reference configuration area, system, subsystem, and component. Opportunities can also be identified, tracked, and evaluated for the potential to enhance plant efficiency, reduce cost, or accelerate schedule.

1.1 Purpose and Scope

This RMP provides a structured approach for identifying and managing above-normal risks related to the execution of the project. Above-normal risks are those risks that either (1) pose a higher risk than normally experienced for the risk or event type or (2) make normal project controls (in the absence of additional measures) inadequate to mitigate the risks to acceptable levels. There is value in developing and maintaining a structured RMP for the NGNP program. Risk identification, assessment, tracking, and reporting will inform project management and stakeholders of the risks and risk management status throughout the program life-cycle.

Risk management is a key discipline for making effective decisions and communicating the results within and across organizations. It is used to determine the feasibility of project plans, identify potential problems that may affect life-cycle activities and the quality and performance of products, and improve the active management of projects. The purpose of risk management is to identify potential programmatic and technical problems before they occur so that actions can be taken to reduce or eliminate the probability of occurrence and/or impact of these problems should they occur. Primary objectives of this RMP include:

- Ensure application of appropriate and cost-effective measures for risk mitigation, tracking, and monitoring activities
- Establish risk assessment criteria and guidelines for risk management
- Describe formats for risk reporting
- Identify risk management tools to be used (e.g., database systems for tracking risks and associated response actions)
- Describe the Risk Management System methodology and depth of functionality
- Establish the process that allows risk to inform integrated priorities and schedule
- Establish the process to identify issues, based on risk, which need additional work to determine the NGNP maturity and path forward.

The structured approach defined in this RMP includes risk management planning; risk identification; risk analysis and quantification; risk handling and response; risk impact determination; and risk reporting tracking, and closure. This approach, with the exception of the risk management planning function, is intended to be executed in a step-wise, iterative manner that is coordinated with established project phases and milestones. The risk management process will evolve throughout project execution and be captured in revisions to this plan, as appropriate.

2. PROJECT BACKGROUND AND RISK MANAGEMENT

2.1 Project Background

The *Energy Policy Act of 2005* (H.R. 6; EPAct), which was signed into law by President of the United States in August 2005, requires the Secretary of the U.S. Department of Energy (DOE) to establish the Next Generation Nuclear Plant (NGNP) Project. According to the EPAct:

> *The NGNP Project shall consist of the research, development, design, construction, and operation of a prototype plant (to be referred to herein as the NGNP) that (1) includes a nuclear reactor based on the research and development activities supported by the Generation IV Nuclear Energy Systems initiative, and (2) shall be used to generate electricity, to produce hydrogen, or to both generate electricity and produce hydrogen.*

The NGNP Project supports both the national need to develop safe, clean, economical nuclear energy and establish greenhouse-gas-free technologies for the production of hydrogen. The DOE has selected the helium-cooled High Temperature Gas-Cooled Reactor (HTGR) as the reactor concept to be used for the NGNP because it is the only near-term Generation IV concept that has the capability to provide process heat at the high temperatures necessary for highly efficient production of hydrogen.

2.2 Project Objectives and Assumptions

High-level NGNP Project objectives were formally established in the *Next Generation Nuclear Plant Project Preliminary Project Management Plan*, Revision 1, and carried forward in subsequent NGNP documents. The objectives support both the NGNP mission and the DOE vision as follows:

1. Develop and implement the technologies important to achieving the functional performance and design requirements determined through close collaboration with commercial industry end-users.
2. Demonstrate the basis for commercialization of the nuclear heat supply, heat transport, hydrogen production, and power conversion concepts. An essential part of the prototype operations will be demonstrating that the requisite capacity factor and reliability can be achieved over an extended period of operation.
3. Establish the basis for licensing the commercial version of the NGNP by the Nuclear Regulatory Commission (NRC). This will be achieved in major part through licensing the prototype by NRC and initiating the process for certification of the nuclear system design.
4. Foster development of the U.S. nuclear industrial infrastructure and contribute to making the U.S. industry self-sufficient for the country’s nuclear energy production needs.

NGNP Project assumptions associated with this RMP are as follows:

1. Initial technical risks are captured to inform decision making and task prioritization. These risks are assigned to plant, areas, systems, subsystems, and components (PASSCs) and include safety, materials performance, operating performance, and plant availability risks.

2. Programmatic risks will be captured in the future and will include licensing, funding, proliferation, availability of qualified resources, and transportation risk.

3. Opportunities (positive risks) will be captured in the future.

2.3 Structure for Risk Management

Risks are captured in the project risk register and contain attributes that allow for ranking and describing each risk. The risk register is managed as part of the RMS (see Section 4) and is available through the NGNP Project. When possible, risks are assigned to specific PASSCs. Other key attributes are detailed below.

2.3.1 Risk Types

Risk types include both technical and programmatic risks and are defined in the International Council on Systems Engineering (INCOSE) *Systems Engineering Handbook*, version 3.1, as follows:

- *Technical risk* is the possibility that a technical requirement of the system may not be achieved in the system life cycle. Technical risk exists if the system may fail to achieve performance requirements; to meet operability, producibility, testability, integration requirements; or to meet environmental protection requirements. A potential failure to meet any requirement which can be expressed in technical terms is a source of technical risk.

- *Programmatic risk* is produced by events which are beyond the control of the project manager. These events often are produced by decisions made by personnel at higher levels of authority. Programmatic risks can be produced by reductions in project priority, by delays in receiving authorization to proceed with a project, by reduced or delayed funding or by changes in licensing, enterprise, or national objectives.

These risks types may be further broken down and defined, as necessary, to encompass the current risk types of the NGNP Project.

2.3.2 Risk Scenario

Currently, the NGNP Project has embraced two different reference designs (i.e., prismatic and pebble-bed), against which all risks are evaluated. Risks are evaluated against the NGNP reactor outlet temperature (ROT) of 750-800°C. It is anticipated that a Very High Temperature Reactor (VHTR) will follow the NGNP, and since much of the research and development (R&D) is designed to envelope the VHTR, risks are also evaluated against the 950°C ROT. As the project continues to mature, more alternative designs and their related risks may be evaluated while other designs are retired. The baseline NGNP risks are contained in the risk register. These risk are evaluated based on the reference design and may be rated differently based on either the application employed or the reference design.

2.3.3 Critical Plant, Area, Systems, Subsystems, and Components

The NGNP is comprised of five areas: Nuclear Heat Supply, Heat Transport, Hydrogen Production, Power Conversion, and Balance of Plant (BOP). Each area is further broken down into systems, which are comprised of subsystems, which are further comprised of components, as shown in Figure 1.

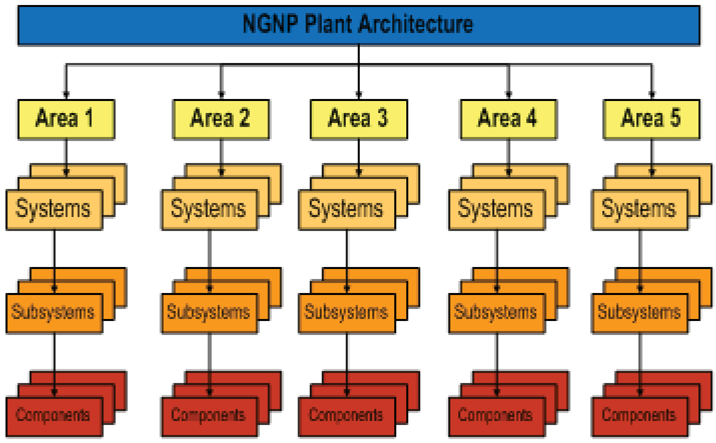

Figure 1. NGNP Architecture.

Given the five areas for the NGNP, critical PASSCs were identified for each area required to perform the desired functions and meet the needs specified by the project. Critical PASSCs, at a minimum, are defined as those physical entities that are not commercially available or do not have proven industry experience. Table 1 encompasses the critical PASSCs for each area of the 750 – 800°C ROT NGNP (as of April 2009) and for the 950°C ROT VHTR. As the NGNP and VHTR mature and uncertainty is reduced, the list of critical PASSCs may change.

Table 1. Identified Critical PASSCs for Different Reference Designs

Areas	750 – 800°C ROT INL-Consolidated Critical PASSCs	950°C ROT INL-Consolidated Critical PASSCs
Nuclear Heat Supply	Reactor Pressure Vessel Reactor Vessel Internals Reactor Core & Core Structure Fuel Elements Reserve Shutdown System Reactivity Control System Core Conditioning System (Shutdown Cooling) Reactor Cavity Cooling System	Reactor Pressure Vessel Reactor Vessel Internals Reactor Core & Core Structure Fuel Elements Reserve Shutdown System Reactivity Control System Core Conditioning System (Shutdown Cooling) Reactor Cavity Cooling System
Heat Transport	Intermediate Heat Exchangers Circulators Hot Duct – Cross Vessel High Temperature Valves (Isolation, Flapper, & Relief)	Intermediate Heat Exchangers Circulators Hot Duct – Cross Vessel High Temperature Valves (Isolation, Flapper, & Relief) Mixing Chamber
Hydrogen Production	HTE, S-I, and HyS (currently identifying all three as PASSCs until one is selected for NGNP)	HTE, S-I, and HyS (currently identifying all three as PASSCs until one is selected for NGNP)
Power Conversion	Steam Generator	Steam Generator Power Conversion System (PCS)
Balance of Plant	Fuel Handling System Instrumentation and Control	Fuel Handling System Instrumentation and Control

3. RISK MANAGEMENT PROCESS EXECUTION

Risk management provides the structured, formal, and disciplined approach, focused on the necessary steps and planning actions, to determine and control risks to an acceptable level. DOE Order 413.3A and its attendant DOE G 413.3-7, *Risk Management Guide*, establish a clear expectation that project personnel identify and analyze risks as early as possible in the life of a project and continue this analysis through succeeding project stages. This requires that (1) project risks be identified, quantified, and reduced (as appropriate); and (2) risk mitigation strategies be developed, documented, and implemented. Thus, project risk management is an iterative process where previously identified risks are monitored and new risks are identified at established review points to ensure risks have been satisfactorily managed. Implementation of the process will enhance the probability of project success by improving project performance and decreasing the likelihood of unanticipated cost overruns, schedule delays, and compromises in quality and safety. This RMP influences the integrated schedule applied to all activities, including engineering, R&D, and licensing, whether the task is performed at the Idaho National Laboratory (INL), other DOE sites, vendor locations, or university locations. The enhancement provided by improving project performance and decreasing the likelihood of risk adverse impact is highlighted in this section.

The risk management approach used in this plan follows the guidelines described in INL laboratory-wide procedure LWP-7350, *Project Risk Management*, and the DOE G 413.3-7, *Risk Management Guide*. The approach consists of the following functions:

- Risk management planning
- Risk identification
- Risk analysis and quantification
- Risk handling and response
- Risk impact determination (i.e., residual risk and risk response actions)
- Risk reporting, tracking, and closure.

These steps can generally be completed sequentially with iterations of the complete process performed at each project phase. However, in some cases, individual risk items should be addressed in a more real-time fashion. In such cases, the process can be initiated at Step 2 and proceed through Step 6, either immediately or on a scheduled basis, depending on the judgment of the system engineering lead, project manager, or the risk management team. Integration of steps in the overall risk management process is shown in Figure 2. Tailoring of the risk management steps and associated activities, including execution guidance, is provided in the following sections. ISO/IEC Guide 73:2002, *Risk Management*, and the INCOSE *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities* were used for risk management vocabulary guidelines, and the process outlined in ISO/IEEE 16085 is referenced for the management of risk in the life cycle of the project.

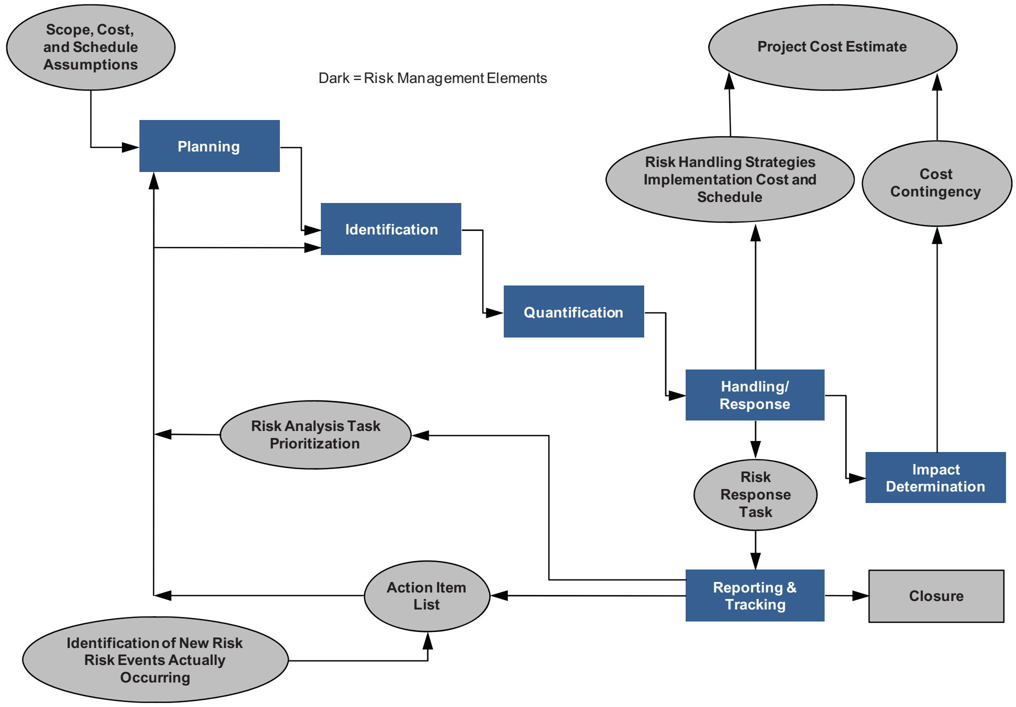

Figure 2. Risk Management Functional Flow Diagram

The NGNP Project uses a Technology Readiness Assessment (TRA) process to determine the technology maturity of critical PASSCs and then to roadmap the required maturity pathway. As a technology is studied, tested, designed, and matured, its risk is reduced as its technical maturity is increased. This process is depicted in Figure 3. For the NGNP Project, establishing and executing Technology Development Roadmaps (TDRMs) as a plan for maturing technologies is the primary method for managing and mitigating risk. The TDRMs chart the path to mature technologies from the current Technology Readiness Level (TRL) to successive readiness levels.

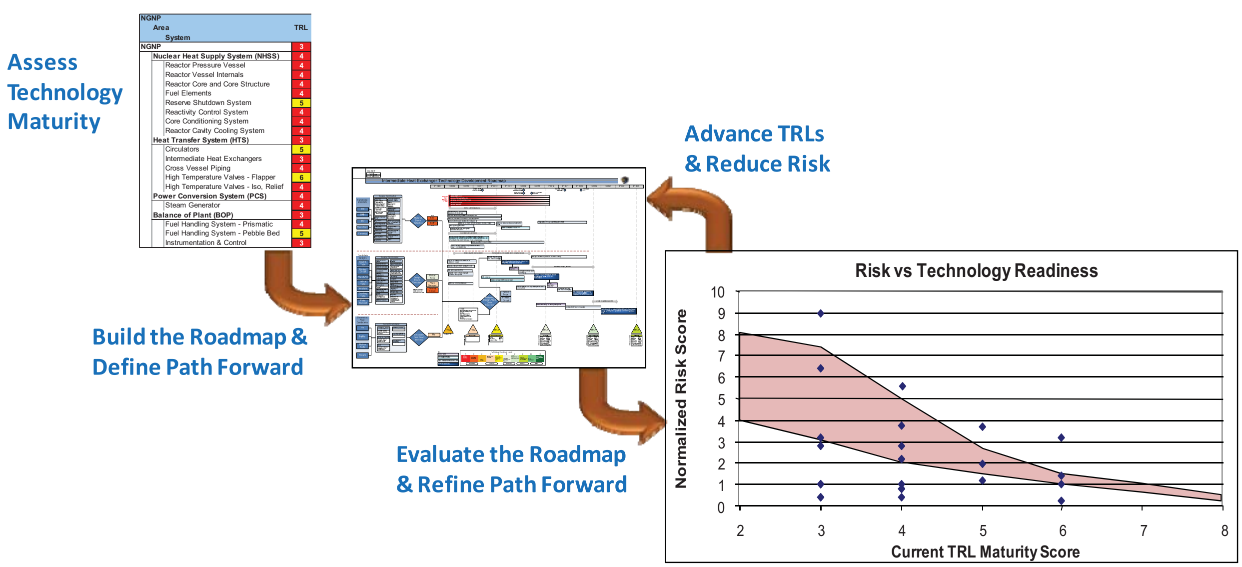

Figure 3. Roadmapping and Risk Reduction - An Iterative Process

3.1 Risk Management Planning

The RMP is the primary product of the risk management planning function. Risk management planning includes activities necessary to establish and maintain the project's process for managing risks. Maintaining the RMP is an integral part of the risk management planning, and the RMP will be updated based on informal reviews, self-assessments, and continuous improvement activities. The informal reviews should include assessment of the risk documentation, response plan effectiveness, and results of self-assessments and continuous improvement activities. If a review indicates that changes are necessary, then the plan will be revised using the INL document action request process.

During the project, management review and self-assessment actions are part of risk management planning and are performed to measure the status of plan implementation and its performance. These actions are a necessary part of the risk management planning function. Self-assessment activities are performed in accordance with applicable portions of INL procedure LWP-13750, *Performing Management Assessments*.

3.2 Risk Identification

The purpose of the risk identification function is to identify risk events likely to prevent the project from achieving its objectives and to document specific characteristics with a basis describing why these events are considered a risk. All identified above-normal risks are entered into the project RMS and tracked through closure. Risks are identified and documented, and tracking is initiated in this phase. Because risks change as the project matures with new risks developing or anticipated risks disappearing, risk identification is a continuous process.

The steps performed within this function of the project risk management process are illustrated in Figure 4. These steps include: (1) identification of preliminary above-normal risks, (2) documentation of risks to provide complete identification, including bases, and (3) initiation of risk tracking.

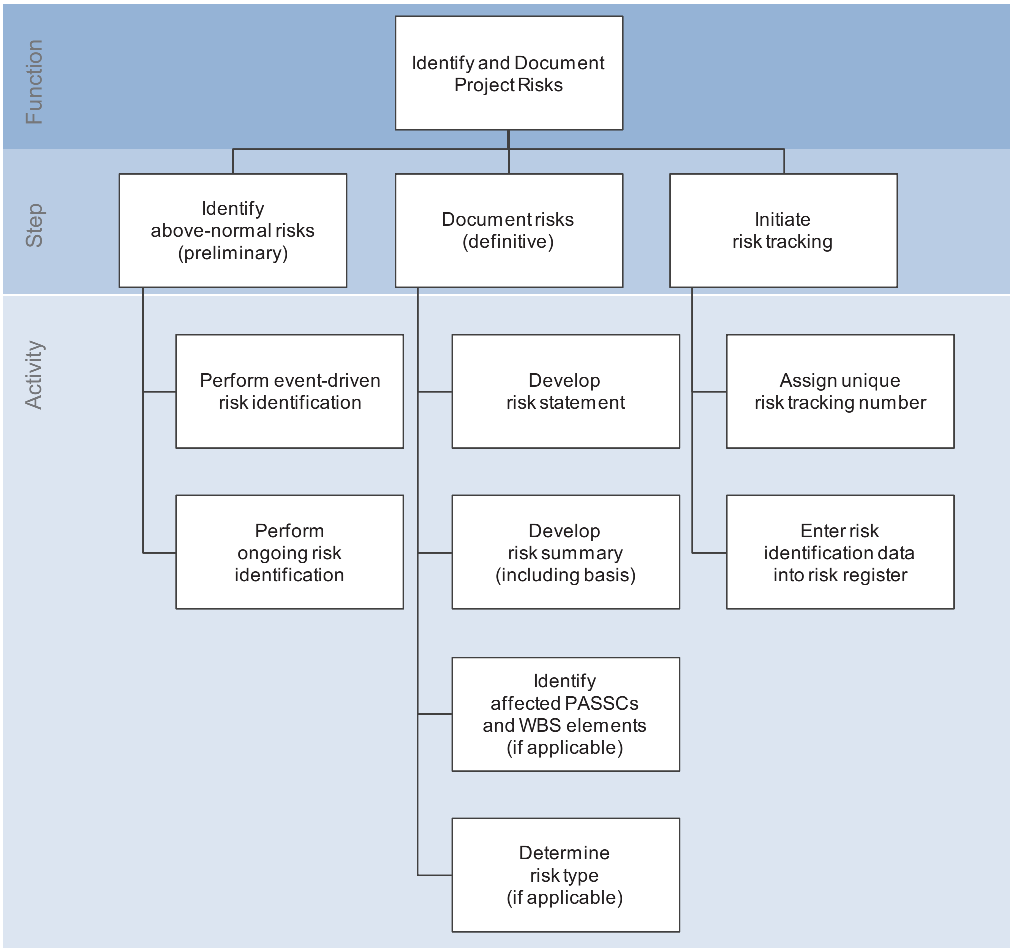

Figure 4. Risk Identification

3.2.1 Identify Risk

The first step of the risk identification function (i.e., Identify above-normal risk items) includes three main activities. The first activity, event-driven risk identification, identifies the risk and links them to specific project events (e.g., Critical Decision [CD] approvals and TRL advancement). The second activity, ongoing risk identification, is used to modify risks that result from baseline changes.

Event-driven risk identification is performed in support of the following types of project events:

- Project phases or milestones
- Project performance reviews
- TRL advancement milestones
- External independent reviews.

Risk identification is initiated using the checklist from LWP-7350, *Project Risk Management*, and includes a review of the critical PASSCs and the risk level against current project phase, critical decision, or design stage. Any newly identified risk is added to the risk register and sent through the risk management process. A Phenomena Identification and Ranking Table (PIRT) is used to identify additional risks.

Ongoing risk identification is performed during project execution. These efforts include the review of baseline change proposals, meeting minutes, and project audit and assessment results as they become available. Risk items identified as a result of a baseline change or that arise between event-driven risk identification campaigns can be either (1) tracked pending the next event-driven risk identification campaign or (2) immediately processed and integrated into the project risk analysis report.

3.2.2 Document Identified Risk

During the risk identification process, the following information is generated:

- Risk title
- Risk description
- Affected critical PASSCs
- Risk type (e.g., technical or programmatic).

The activities that comprise this step include:

- Develop risk statement
- Develop risk summary
- Identify affected PASSCs and Work Breakdown Structure (WBS) elements
- Determine risk type.

3.2.3 Initiate Risk Tracking

Once a risk has been identified, risk tracking is initiated. The systems engineering lead is responsible for maintaining the project RMS and ensuring above-normal risks are entered. The RMS is a database reflecting the current status of each risk as well as permanently retaining the information of risks that have been closed. As the risk management process proceeds, additional information associated with each step of the process is entered. The activities include assigning a unique risk tracking number and entering risk identification data into the RMS.

3.3 Risk Analysis and Quantification

The method used to analyze, score, and determine the risk level for each risk item is described below. Risk analysis is completed so that risks are prioritized and assigned an appropriate risk-handling strategy. Risks are evaluated for each applicable scenario (e.g., prismatic versus pebble-bed). The steps performed within the perform risk analysis and quantification function are illustrated in Figure 5.

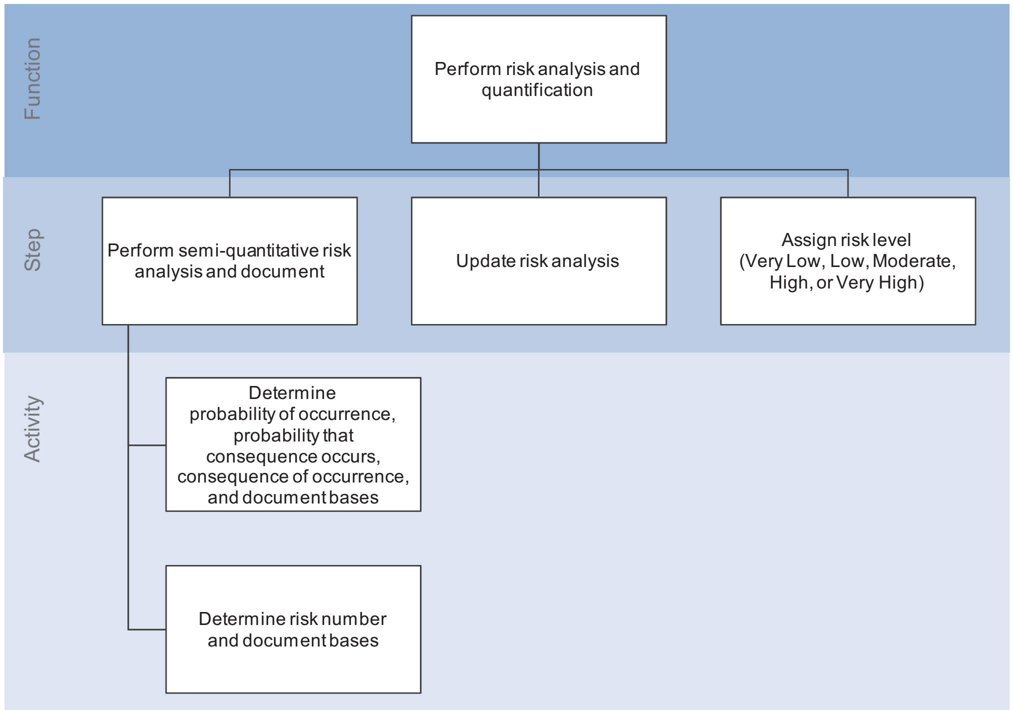

Figure 5. Risk Analysis and Quantification

3.3.1 Semi-Quantitative Analysis

Risks are analyzed using a semi-quantitative method involving calculation of a numerical risk number for each event. This risk number is based on a relative numerical value assigned to the likelihood (event probability or P_E) that a risk event will occur, the associated impacts of the risk (consequences or C), and the likelihood (P_C) that the event will result in the consequence identified. These factors are used to calculate the risk number according to the following equation:

$$Risk\ Number = (P_E \times P_C) \times C \times W \quad \text{Eq. (1)}$$

Where:

P_E = Probability of occurrence

P_C = Probability that consequence occurs at level of severity noted

C = Consequence of occurrence (loss if event occurs)

W = Weighting factor (used to emphasize consequence of occurrence).

Values are assigned to all four factors according to the criteria in Table 2 and Table 3. In general, the discrete factor values shown in the tables are used in the calculation; however, exceptions can be made to increase dispersion and discriminate between risks. In this case, an appropriate basis and annotation must be provided. For the factors P_E and C, the value assigned should reflect the risk condition before implementation of the risk-handling strategy. The value for factor P_C is set to 1.0 and will be modified in the future as designs are changed.

Risk numbers are used to prioritize risks and determine the risk level (i.e., very low, low, moderate, high, or very high) of each event. Risk levels are used to tailor appropriate risk-handling strategies, and also define tracking requirements. Levels can generally be defined by the following criteria:

- Very-Low Risk: A risk identified as *very low* has virtually no potential for impacting the project or the consequences are exceptionally minor.
- Low Risk: A risk identified as *low* has little potential for impacting cost, schedule, or performance requirements, and is probably mitigated with standard cost or schedule contingency. Minimum oversight is needed to ensure the risk remains low.
- Moderate Risk: A risk identified as *moderate* has a reasonable probability of impacting cost, schedule, or performance requirements; and in turn requires additional management actions above the normal contingency and project controls.
- High Risk: A risk identified as *high* has a strong possibility of a major impact to the project and will require additional significant action to control risk (e.g., comprehensive analysis and a formal RMP).
- Very-High Risk: A risk identified as *very high* is almost certain to occur and/or have a major impact on the project. Like a high risk, it will also require considerable action to control the risk (e.g., comprehensive analysis and formal RMP).

The semi-quantitative risk analysis involves the following steps:

1. Determine the probability of occurrence (P_E) for the risk item using criteria in Table 2.
   a. Select the appropriate qualitative descriptor in the risk register, and the associated numerical value is assigned automatically.
   b. Document the basis for the probability of occurrence (P_E) in the risk register with documented results from historical occurrence data, research, tests, comparable applications, or other objective, verifiable means.
2. Determine the probability of consequence (P_C) being realized for the risk item.
   a. As a default, set the probability of consequence to 1.0. If no information is available to discriminate the value when each risk has been or will be realized, leave probability of consequence set to 1.0.
   b. If information is available to discriminate amongst the probabilities of consequence, select the appropriate qualitative descriptor in the risk register, and the numerical value is assigned automatically.
3. Determine the consequence of occurrence (C) for the risk item using the criteria in Table 3.
   a. Select the appropriate qualitative descriptor in the risk register, and the associated numerical value is assigned automatically. If a risk has multiple consequences and meets criteria in more than one of the ratings blocks, the “worst” consequence should be selected.
   b. Document the basis for the consequence of occurrence (C) rating in the risk register with documented results from historical occurrence data, research, tests, comparable

applications, or other objective, verifiable means. At a minimum, this should include a justification or rationale for the rating and whether it applies for the duration of all project phases or for the activity being assessed.

Table 2. Probability Definition.

Probabilities	Range	Technology Criteria	Scale Criteria	Use for Calculation
Improbable	**< 10^{-4}**		Not evaluated since it is improbable	**N/A**
Very Unlikely	**10^{-4} to <0.1%**	Technology is well understood and is routinely used in similar, integrated applications and conditions	The scale of the system/ component needed is similar to existing successful applications.	**0.1**
Unlikely	**0.1% to <1%**	Technology is understood and has been used in applications and conditions close to, but not identical to, required conditions. A small amount of development is needed before deployment.	Majority of the components are similar in scale to existing applications.	**0.3**
Somewhat Likely	**1% to <10%**	Technology needs a moderate amount of research, development and design before deployment at required operating conditions.	About half of the components are similar in scale to existing applications	**0.5**
Likely	**10% to 50%**	Technology needs a major amount of research, development and design before deployment at required operating conditions.	Some of the components are scaled similar to existing applications, with the remainder needing significant design changes to achieve deployment.	**0.7**
Very Likely	**> 50%**	Low maturity, complex, unclear development path; multiple unproven technology must work together.	All needed components have never been attempted at the necessary scale.	**0.9**

Table 3. Consequence Definition.

Consequence	Technical	Schedule	Use for Calculation (risk units)
Negligible	Minimal or no impact.	Schedule delays that do not affect milestones or the critical path.	**1**
Marginal	Small change needed to design or path forward. Minor damage to equipment or facilities. Minor, temporary loss of capabilities.	Schedule delays that may affect external milestones or are threatening a slip along the critical path.	**3**
Significant	Moderate change needed to design or path forward. Moderate, but repairable damage to equipment or facilities. Moderate, temporary loss of capability	Schedule delays that will slip the critical path end date by up to 6 months.	**5**
Critical	Major change needed to design or path forward, workaround available. Significant, repairable damage to equipment or facilities.	Schedule delays that will slip the critical path end date by more than 6 months but less than 1 year.	**7**
Crisis	Major change needed to design or path forward, no workaround available now. Loss of equipment or facilities.	Schedule delays that will slip the critical path end date 1 year.	**9**

4. Assign a unique risk number

5. Document the basis and rationale for each risk determination.

3.3.2 Update Risk Analysis

Initially, the factors in the risk number calculation (P_E, P_C, and C in Equation 1) will be numerical values based on the ranges identified in steps 1 through 3 above and in the associated tables. The risk number for a particular risk event will only have meaning when compared to risk numbers for other events. Ultimately, the goal is to transition to actual calculated probabilities for occurrence (P_E) and consequence (P_C), and calculated cost impacts (in dollars) for the consequences (C) rather than the numerical factors in Table 2 and Table 3. Currently, there is insufficient information to do this. When the information to do this becomes available, the numerical factors will be replaced with the calculated values. This document will also be updated to reflect the changes.

3.3.3 Assign Risk Level

The risk level is assigned as follows:

1. A risk number is calculated using Equation 1 and assigned automatically by the risk management system. Currently, the risk number ranges in Table 4 are based on a default value of 1.0 for probability of consequence (P_C).

2. A weighting factor is applied in the calculation of the risk level, as shown in Table 5, to give emphasis to risks with high consequence. This weighting factor is used to cause risks with high consequence to rate higher than they otherwise would. Experience has shown that risks with high consequence need to be mitigated (and rated high) even though the probability of occurrence (P_E) is low [Ref: Smith and Merritt].

Table 4. Risk Level Matrix

Probability \ Consequence	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.2	Very High 5.9	Very High 7.6
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
Unlikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Table 5. Weighting Factors

Probability		Consequence: 1	3	5	7	9
0.9	> 50%	1.00	1.00	1.00	1.00	1.00
0.7	10% to 50%	1.00	1.13	1.20	1.20	1.20
0.5	1% to 10%	1.00	1.25	1.50	1.50	1.50
0.3	0.1% to 1%	1.00	1.38	1.75	2.00	2.00
0.1	10^{-4} to 0.1%	1.00	1.50	2.00	2.50	3.00

3. The calculated risk number is assigned a risk level (and color code) based on the information in Table 6.

Table 6. Risk Level Ranges

	Risk Score	< 0.4	**Very Low**
0.4 ≤	Risk Score	< 1.4	**Low**
1.4 ≤	Risk Score	< 3.3	**Moderate**
3.3 ≤	Risk Score	< 5.9	**High**
	Risk Score	> 5.9	**Very High**

3.4 Risk Handling and Response

Risk handling and response identifies the course of action or inaction selected to effectively manage each risk item. The risk handling and response function documents that either a given risk is acceptable to the project (as is) or defines actions that will be taken to make an unacceptable risk acceptable to the project. Risk handling strategies are selected after the probable impact on the project has been determined so that the strategy is appropriate for the level of risk. A risk handling strategy (i.e., accept, mitigate, avoid, or transfer) is selected for all identified above-normal project risks. The risk response is the detailed tasks that are performed to execute the risk handling strategy. The steps performed as part of the risk-response function are illustrated in Figure 6.

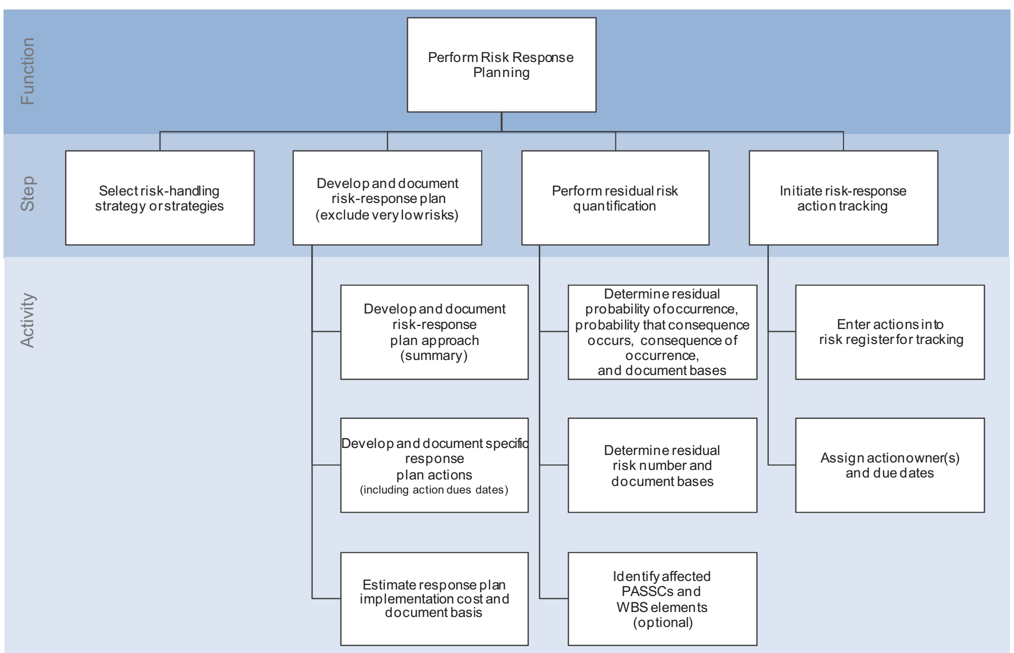

Figure 6. Risk-response planning.

Risk owners are responsible for selecting the risk-handling strategy and, when required, developing the associated risk-response approach (including specific actions) for assigned risk items. The handling strategy, response approach (optional), and actions are documented and presented to the risk management team. The assembled risk management team reviews all risk responses and makes any necessary adjustments to reach team consensus. The agreed-on risk responses are then entered into the risk register and tracked. The following sections provide additional information to be used in performing the risk-response planning function.

3.4.1 Select Risk-Handling Strategy

The risk-handling strategies employed by the NGNP Project and consistent with DOE G 413.3-7, *Risk Management Guide*, are as follows:

- Accept
- Mitigate
- Avoid
- Transfer.

Many R&D, licensing, and engineering tasks, which are shown on the TDRMs and designed to advance the TRL will simultaneously reduce the risk. Figure 7 shows a hypothetical risk reduction that occurs as the TDRM plan is executed and as technologies are matured through the advancing readiness levels.

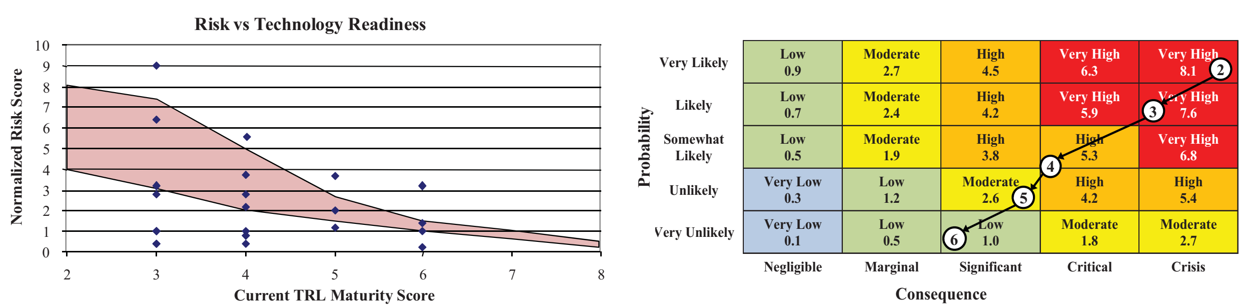

Figure 7. Hypothetical risk reduction.

The majority of risk should be reduced early in the project at lower technology maturity. To reduce cost and schedule overruns, the TDRMs are designed to reduce risk at the lowest possible technical maturity. When the risks for a given critical PASSC are mapped to the tasks needed to mature the technology, risk reduction is quantified. The technique for quantification of risk reduction is shown in Appendix A for each of the critical PASSCs. The four risk handling strategies are discussed in the following sections.

Risk Acceptance

Acceptance is a deliberate strategic decision by the project based on the understanding that it is more cost-effective to continue the project as planned, with no additional resources (e.g., time and money) being allocated to control the risk. Low risks are typically accepted. When the strategy to accept a risk is employed, the risk level remains the same (i.e., residual risk equals initial risk), but no costs or schedule impacts are incurred for risk-response implementation.

Risk Mitigation

Risk mitigation involves identifying specific steps or actions that will reduce the probability of the event or lessen the consequence of a risk if the event occurs. Since risk is defined as probability times consequence, reducing the probability or lessening the consequence of occurrence will reduce the project's exposure to a particular risk by reducing the expected value of the outcome. Mitigation can often be accomplished by taking action before the event occurs (i.e., prevention) or by identifying actions to be performed after the event occurs (i.e., contingency or recovery planning). As discussed above, the primary example of risk mitigation for NGNP is developing a roadmap to study, test, design, and mature technologies that will reduce the probability of occurrence as the plans defined in the roadmap are executed. Other examples of mitigation include:

1. Incorporating barriers or engineering controls into a design
2. Planning for and then executing work-arounds
3. Ensuring physical separation of primary and backup systems
4. Prepositioning resources to be used in case of event occurrence (e.g., to reduce the response or recovery time). This strategy results in some residual risk and also has the potential for incurring implementation costs and schedule impacts.

Risk Avoidance

Risk avoidance focuses on total elimination of the potential threat, usually by eliminating the potential that the risk event can occur. This strategy requires a clear understanding of the root cause of the event. Examples of risk avoidance include totally redesigning a PASSC or selecting an alternate technology that is not subject to the same risk. When this strategy is selected, there is a potential for implementation costs and schedule impacts. However, the risk is removed from the reference design and, therefore, the residual risk is reduced to zero. Other strategies include changing or lowering requirements while still meeting the needs of the project.

Risk Transfer

The risk transfer strategy involves shifting the entire risk to a third party, typically after the risk is converted to a monetary amount. Private industry examples of this strategy include requiring performance bonds from subcontractors and purchasing insurance policies. For these two examples, the implementation cost is the incremental cost to the subcontract (if measurable) and the cost of insurance policy premiums, respectively. Typically, no residual risk remains after transfer.

In DOE, the risk is transferred between federal and contractor entities via contract. Transferred risks are monitored to ensure new risks are not created and do not impact project mission and objectives.

Guidance for Risk-Handling Strategy Selection

Selecting good risk-handling strategies for project risks is critical, and in some cases, it may be prudent to employ something other than a conventional risk-handling strategy. In that case, alternative strategies may be used for the NGNP Project. While several strategies can usually be used to control a risk, the simplest and most cost-effective strategy should always be sought. This requires a thorough understanding of the risk and its causes and consequences. Table 7 shows the typical application of risk-handling strategies for controlling project risks.

Table 7. Typical application of risk-handling strategies for controlling project risks.

Risk Level	Risk-Handling Strategies			
	Accept	**Mitigate**	**Avoid**	**Transfer**
Very High		✓	✓	✓
High		✓	✓	✓
Moderate		✓	✓	
Low	✓	✓		
Very Low	✓			

3.4.2 Develop Risk Response Plans

Risk response plans are required for all but *very low* level risks. As previously stated, the risk response reflects the application of a graded approach (i.e., establishing a justifiable level of effort relative to the risk level). For this reason, risk items assessed as *very low* should normally be handled using the accept-risk handling strategy and would not require a documented response plan. However, strategies other than *accept* can be used for *very low* risks where a compelling argument can be made for doing so (e.g., if the risk can be handled without implementation cost or schedule impact). In all cases, the number of actions created (and requiring subsequent tracking) should be kept to the minimum necessary to implement the planned risk response to minimize administrative action-tracking costs.

The cost associated with implementing the risk response plan is evaluated against the cost and schedule impact should the risk be realized. This evaluation is a consideration used in determining which risks to accept without mitigation. For instance, if the risk response implementing costs are high in comparison to the risk cost and schedule impact, then the risk is a candidate for acceptance without mitigation. For the NGNP, the risk response plan is documented in the TDRMs, the R&D Program Plans, and other planning documents. The TDRMs are the high-level representation of the risk response plan.

3.4.3 Perform Residual Risk Quantification

As part of the risk-response planning function, the risks are tracked to verify reduction per the plan. Quantification of the residual risk is calculated using the same method as the initial risk quantification (see Section 3.3) and documented in the risk register. If the risk level is not sufficiently reduced, project personnel may need to reevaluate the risk-response plan.

3.4.4 Initiate Risk-Response Action Tracking

After agreement is reached by the risk management team on the risk-handling strategy, the response plan, and the residual-risk quantification; the risk-response actions are entered into the RMS. The RMS provides a means for assigning action owners and action due dates.

3.5 Risk Impact Determination

Risk impact to the project is measured by quantifying the cost of risk management and evaluating the efficiency of risk response strategies. Risk can impact the project in two ways:

- Implementation of the risk-handling strategy, which has the potential to impact the project baseline
- Residual risk, which has the potential to impact project contingency.

The risk impact determination function of the risk management process ensures that the cost and schedule impacts from both of these sources are factored into the project cost and schedule baselines as well as associated contingency values. The steps for performing the risk impact determination function are illustrated in Figure 8.

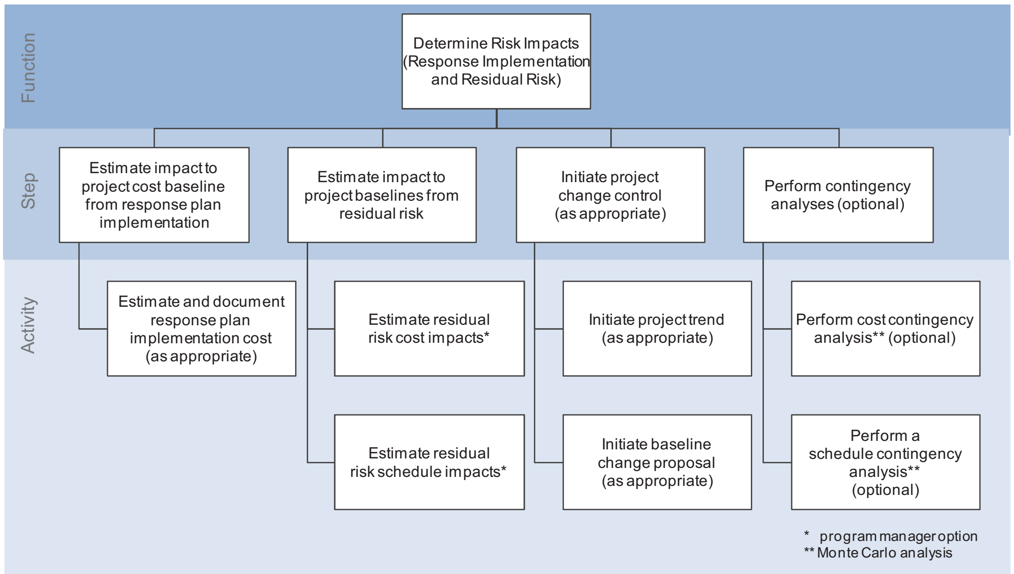

Figure 8. Risk Impact Determination Functions.

The system engineering lead will work with others to perform an initial risk impact determination for all risks for which a response plan has been developed. The risk management team reviews the results from the risk response actions to verify that the risks have been reduced as planned. Impacts resulting from this analysis are noted and used for data entry into the project RMS. The following sections provide additional guidance for performing risk impact determinations.

3.5.1 Estimate Impacts from Risk Response Implementation

After the risk-handling strategy and response actions have been determined, they should be reviewed to identify areas of additional cost (e.g., material, equipment, subcontract, or labor costs). If a cost increase is identified, the estimated amount of the increase and the basis for the cost estimate is documented as part of baseline change control (see LWP-7400, *Baseline Change Control*).

3.5.2 Estimate Impacts from Residual Risk

Estimation of impacts resulting from residual risk identifies the cost and schedule impacts if the risk event were to occur following implementation of the response plan. These values provide the basis for calculating technical and programmatic risk and cost and schedule contingencies.

3.5.3 Initiate Change Control

When risk response plans are executed and risk reduction does not occur as planned or when a risk event occurs, appropriate change control actions are initiated if the project baselines are affected. Otherwise, the risks are managed appropriately and the project proceeds according to documented baselines.

3.5.4 Perform Technical and Programmatic Risk Analysis Contingencies Analyses

Technical and programmatic risk analysis for contingency is optional. Supporting data may be collected and entered into the project RMS for potential future use. If deemed necessary by the project manager, then Technical and Programmatic Risk Analysis can be performed, as described in DOE Practice 8.

3.6 Risk Reporting, Tracking, and Closure

The risk reporting, tracking, and closure function of the risk management process includes the steps shown in Figure 9 and described in the following sections. The RMS provides the capability to support risk reporting, tracking, and closure by providing the ability to issue update notices, status progress on actions, and close actions when completed.

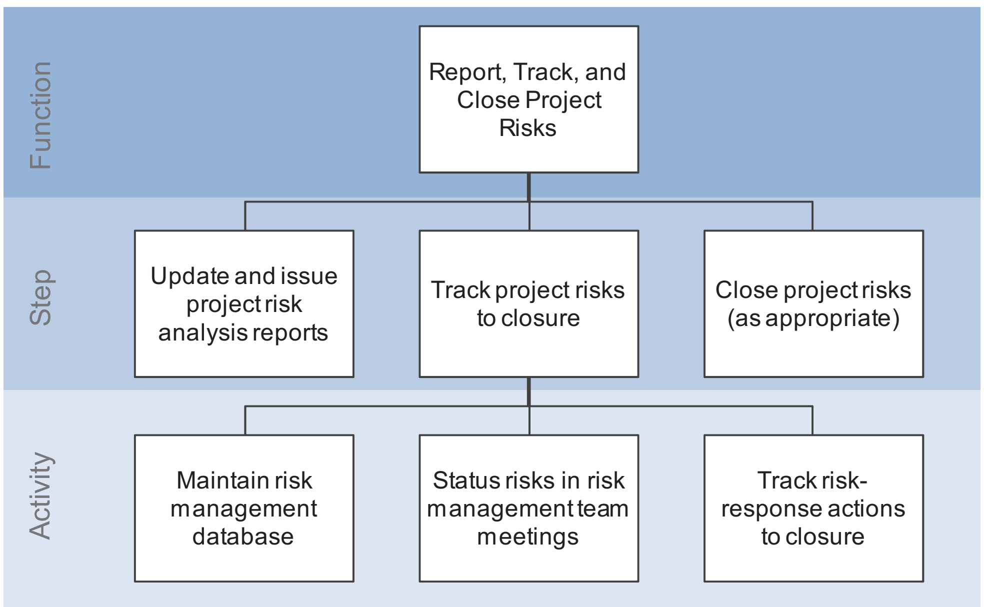

Figure 9. Risk Reporting, Tracking and Closure Functions.

3.6.1 Risk Reporting

Risk reporting is the documentation of the risk identification, quantification, response, and impact determination activities for the project in a risk analysis report. This report is produced annually by NGNP systems engineering and is used in future risk-analysis activities.

Risk information is maintained in the project RMS. The information contained in this system provides the basis for the risk analysis report.

3.6.2 Risk Tracking

Risk tracking is the active monitoring of identified risks and the action items developed from the risk-handling strategies, and the evaluation of new risks or changes in previously identified risks. Risk tracking is performed by establishing performance, schedule, and/or cost indicator thresholds to evaluate the status of the risk. When tracked risks exceed defined thresholds, new risk handling options may be invoked. Risk tracking is performed for the life of the project because risks change as the project matures.

Tracking individual risk items is accomplished using the following mechanisms:

- Project RMS, where all above-normal project risks are entered and maintained until closure. Records of past risk items remain in the system after closure.
- Risk management team meetings, where risks are reviewed, assigned, and coordinated.
- Tracking of risk response action items by the risk management team until they have been closed.
- Monitoring for risk-event occurrence by the risk owners. Through monitoring, the owner determines whether the risk event has occurred or determines that the response plan may no longer be effective in controlling the risk.

3.6.3 Closure of Project Risk Items

Closure of risk items can occur when the following conditions have been met:

- All response plan actions have been completed and closed
- Monitoring of risk event occurrence or trouble triggers is no longer necessary
- Re-evaluation of the risk no longer provides any benefit (i.e., the window of opportunity for event occurrence has passed)
- Project manager concurrence is obtained for closure (*moderate* to *very-high* level risks only).

3.7 Supporting Risk Analysis Methods

As stated above, alternate analysis and quantification methods are allowed. Typical alternate methods include expert judgment, simulation (e.g., Monte Carlo), and risk or decision trees. These methods are used in project phases when specific analytical or statistical results are desired. This section describes additional risk analysis methods that will be used to support the risk analysis process and provides summaries of some assessments that were employed at the pre-conceptual development stage.

3.7.1 Technology Readiness Level Assessment

The risk analysis method described in Section 3.3.1 is a conventional risk management methodology used to assess known risks. However, many of the NGNP technologies are less mature, leading to higher uncertainty in design parameters and risks that may not be known. To estimate the level of unknown risk associated with the performance of these technologies, a measure of technical maturity, called the TRL, will be used. An assessment of TRLs for the critical NGNP PASSCs complements the conventional risk assessment for technical risks and is an integral part of the risk management strategy.

Definitions for the TRLs were established, as show in Table 6, and initial TRL estimates were made for critical PASSCs by the reactor supplier teams from AREVA, General Atomics, and Westinghouse. TDRMs were established to define the steps necessary to advance the TRLs in selected areas [Ref: Reports INL/EXT-08-15148 and INL/EXT-09-16598]. These roadmaps outline the engineering, licensing, and R&D efforts; the known risks that they address; and the anticipated effect on the TRLs. Each task focuses on reducing known risk, increasing TRLs, or both.

The technology roadmaps, and the associated tasks depicted, have been adopted into the risk-response plans for the risks that they address. As part of a response plan, the extent to which a technology is matured and the risk reduced by each task is quantified. Assuming a task is successful, the expected completion date for the task becomes the date upon which the risk is reduced. This can be displayed in a risk waterfall chart, like the one shown in Figure 11. The RMS described in Section 4 is the system used to analyze the risk data and generate the NGNP risk waterfall charts.

Figure 11 shows the risk is reduced each time a relevant piece of information is gathered from a task that reduces known uncertainty or increases technology maturity.

Table 8. NGNP TRL Scale and Definitions.

Rating Level	Technology Readiness Level Definition	TRL Abbreviated Definition
1	**Basic principles observed** and reported in white papers, industry literature, lab reports, etc. Scientific research without well defined application.	Basic principles observed
2	**Technology concept and application formulated**. Issues related to performance identified. Issues related to technology concept have been identified. Paper studies indicate potentially viable system operation.	Application formulated
3	**Proof-of concept**: Analytical and experimental critical function and/or characteristic proven in laboratory. Technology or component tested at laboratory-scale to identify/screen potential viability in anticipated service.	Proof of Concept
4	**Technology or Component is tested at bench-scale** to demonstrate technical feasibility and functionality. For analytical modeling, use generally recognized benchmarked computational methods and traceable material properties.	Bench-scale testing
5	**Component demonstrated at experimental scale in relevant environment**. Components have been defined, acceptable technologies identified and technology issues quantified for the relevant environment. Demonstration methods include analyses, verification, tests, and inspection.	Component Verified at Experimental Scale
6	**Components have been integrated into a subsystem** and demonstrated at a pilot-scale in a relevant environment.	Subsystem Verified at Pilot-scale in a relevant environment
7	**Subsystem integrated into a system** for integrated engineering-scale demonstration in a relevant environment.	System demonstration at Engineering-scale
8	**Integrated prototype of the system is demonstrated** in its operational environment with the appropriate number and duration of tests and at the required levels of test rigor and quality assurance. Analyses, if used support extension of demonstration to all design conditions. Analysis methods verified. Technology issues resolved pending qualification (for nuclear application, if required). Demonstrated readiness for hot startup	Integrated Prototype Tested and Qualified in a non-radiological operating environment
9	**The project is in final configuration** tested and demonstrated in operational environment.	Plant Operational.
10	**Commercial-scale demonstration** is achieved. Technological risks minimized by multiple units built and running through several years of service cycles.	Commercial Scale – Multiple Units

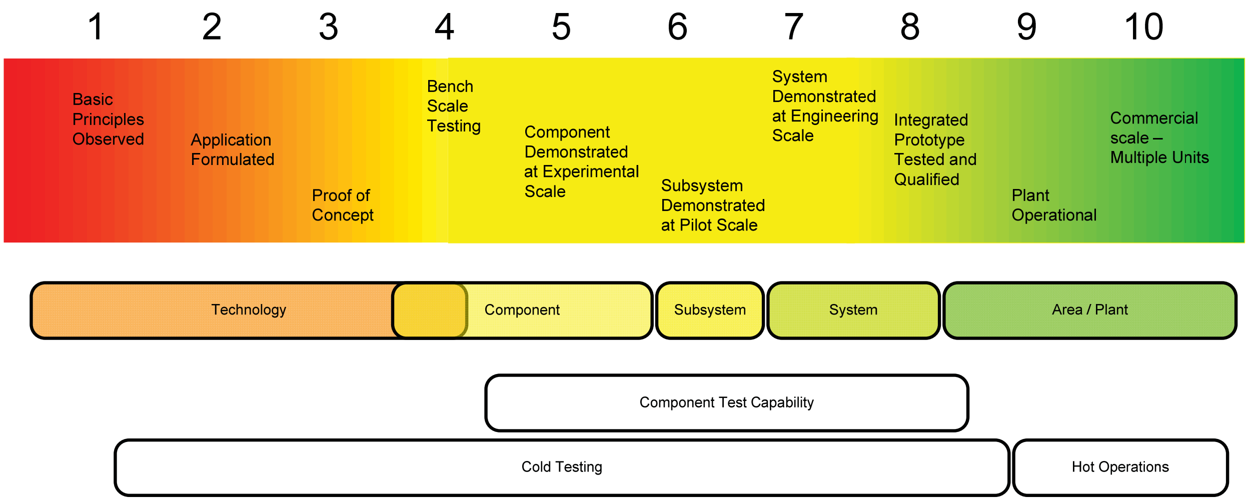

Figure 10. Technology Readiness Levels.

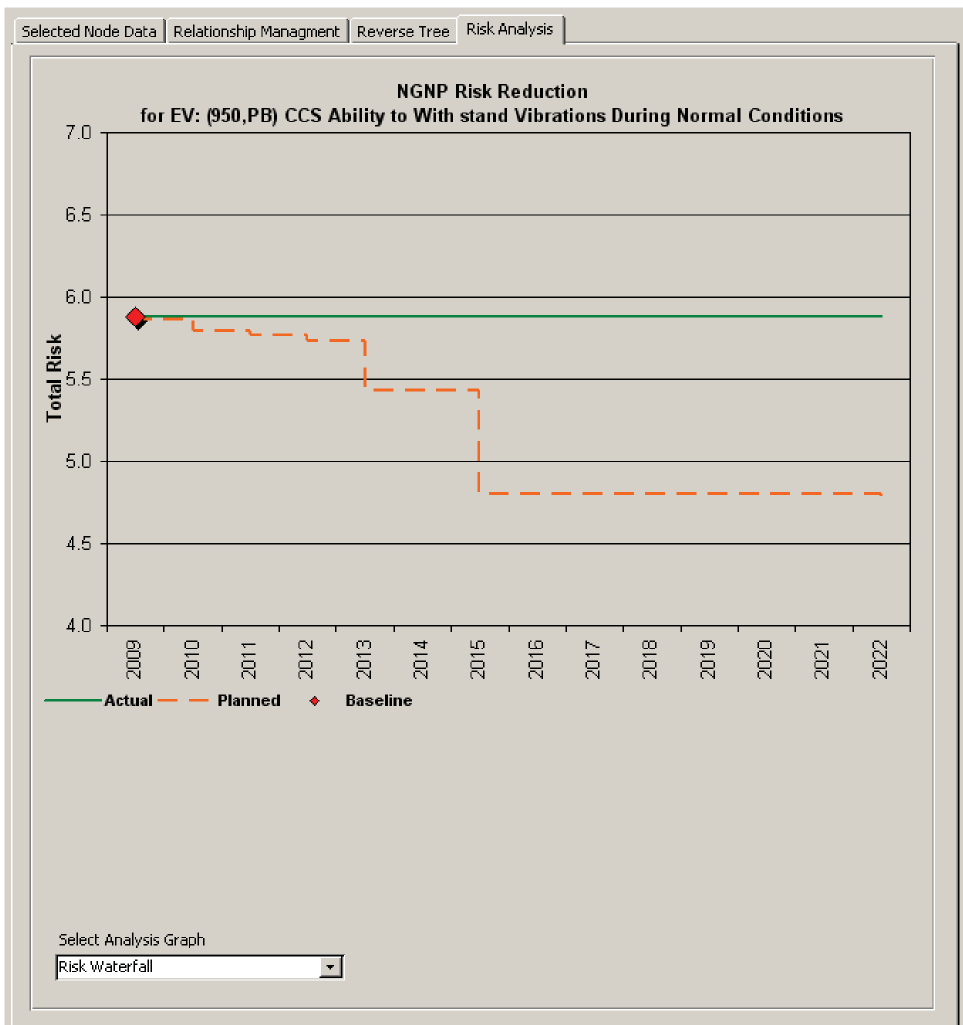

Figure 11. Risk Waterfall Chart from the RMS.

4. RISK MANAGEMENT SYSTEM

To facilitate the implementation of the RMP, the NGNP has developed and employed an analytical software tool called the NGNP Risk Management System (RMS). A relational database developed in Microsoft® Access, the RMS provides conventional database utility, including data maintenance, archiving, configuration control, and query ability. Additionally, the tool's design provides a number of unique capabilities specifically designed to facilitate the development and execution of activities outlined in the RMP. Specifically, the RMS provides the capability to establish the risk baseline, document and analyze the risk reduction plan, track the current risk reduction status, organize risks by reference design PASSC, and inform NGNP decision making.

The RMS Hierarchy Viewer provides a rollup/drilldown analysis capability that summarizes quantitative risk scores at various levels of granularity, as shown in Figure 12. The risk scores can be displayed for either the baseline, current status, or the final projected risk. Risks can be rolled up by average or worst case for a selected design configuration. The tool's Hierarchy Viewer also allows the visualization and analyses of the complex relationships between various NGNP Project entities (e.g., Critical PASSCs, Risks, Risk Mitigation Tasks, Design Data Needs [DDNs], and PIRTs).

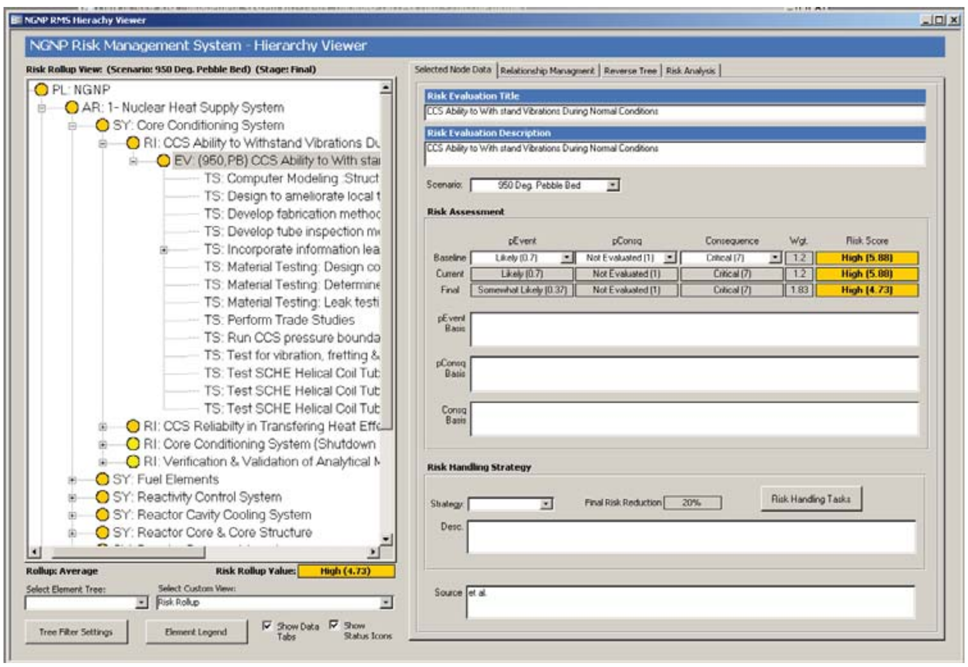

Figure 12. RMS Hierarchy Viewer

The RMS provides the capability to outline and status a risk handling strategy for each identified risk. Risk reduction tasks, which are primarily the tasks needed to advance the TRLs, are assigned to each risk item and the magnitude of risk reduction estimated for each associated task can be specified as shown in Figure 13. The status of the risk handling strategy is primarily based on the percent completion of risk reduction tasks. The status of the strategy can also be seen graphically in a Risk Waterfall chart that displays the actual/current risk reduction versus the planned risk reduction over time, as shown in Figure 14.

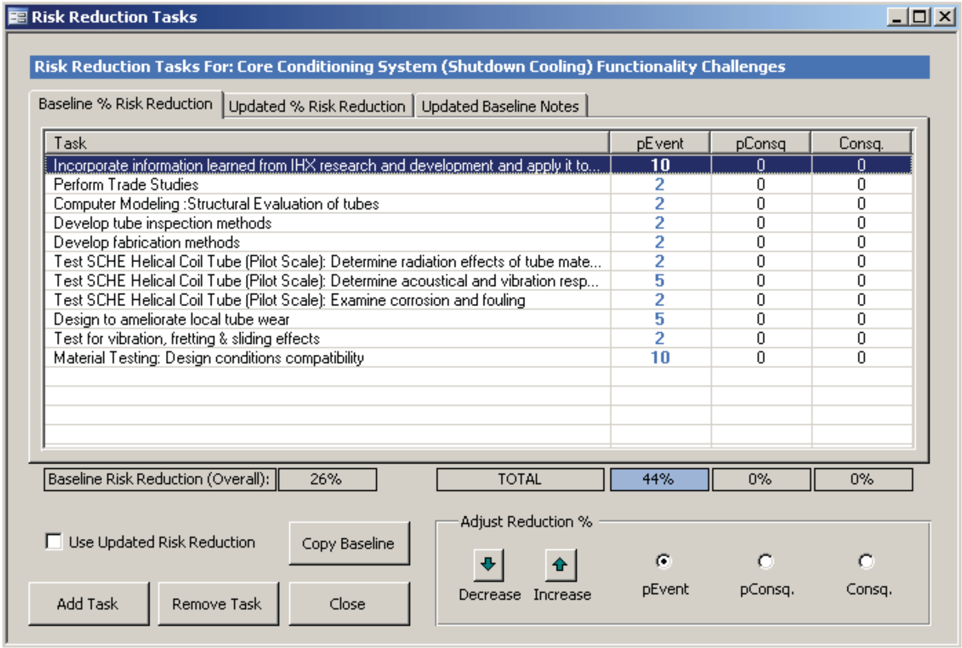

Figure 13. RMP Risk Reduction Tasks

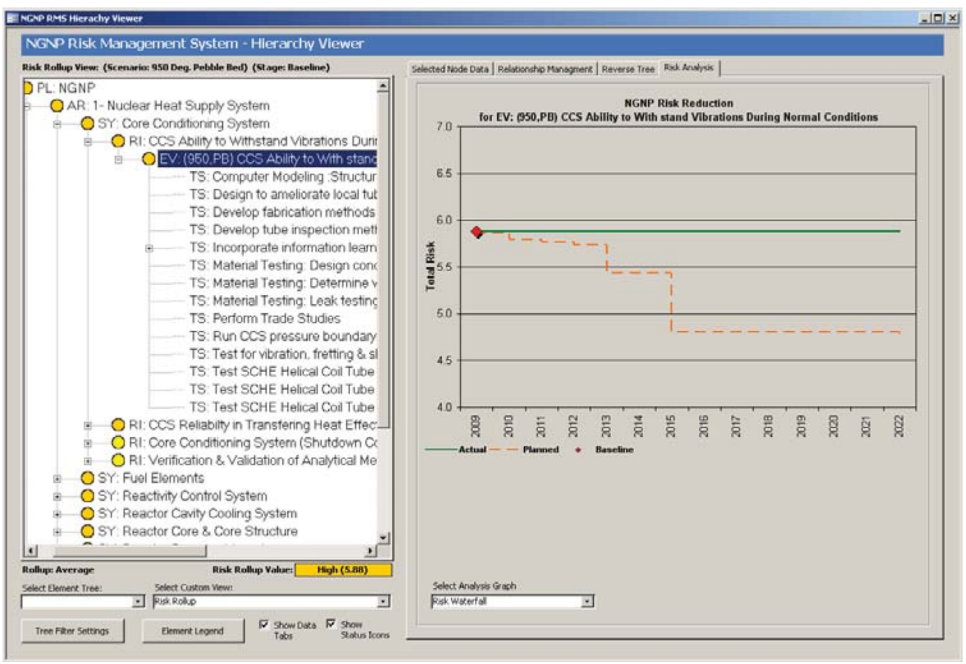

Figure 14. Risk Waterfall Chart displayed in the RMS Hierarchy Viewer

For tasks that provide a reduction in risk for more than one risk item, the tool provides the ability to summarize its contribution across the entire NGNP risk plan. This capability makes it possible to rank order tasks by the magnitude of risk reduction provided for the entire project. This rank ordering of task then provides valuable input into NGNP Project planning and prioritization.

Additional RMS functionality includes the ability to analyze and track relational mapping between project risks and PIRTs, risk reduction tasks, and DDNs, thus facilitating gap identification in planning R&D activities.

5. REFERENCES

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Appendix A

NGNP Project Risk Analysis Tool

Appendix A
NGNP Project Risk Analysis Tool

The Project Risk Analysis Tool (PRAT) Matrix was used by NGNP Engineering personnel to evaluate the technical risk associated with deploying each critical PASSC and determine the risk reduced by performing each task which advances the technical maturity. This tool captures the risk reduction anticipated by each of the R&D, Licensing, and Engineering tasks forecasted in the TDRMs. The risk and risk reduction data captured using this tool was then placed in the Risk Management System (Section 4 of the RMP) for tracking, analysis, and configuration control.

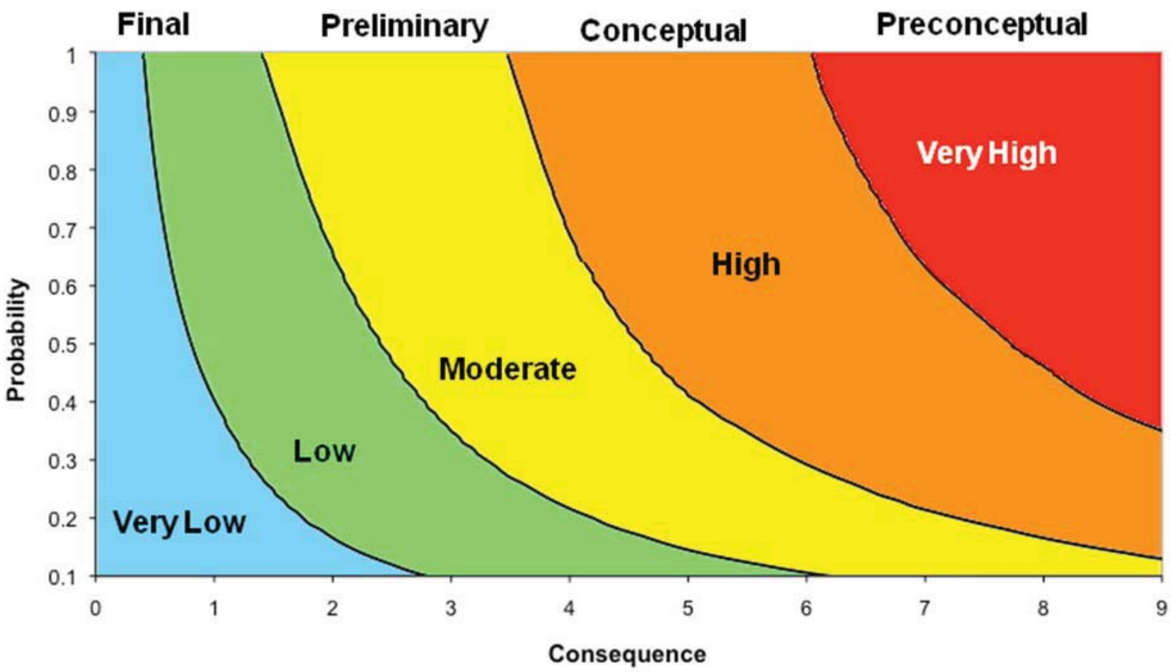

Figure A-1. Acceptable project risk present at each of the design phases.

Risks are analyzed to verify that the amount of project risk present at each of the design phases is acceptable, as shown in Figure A-1. During the pre-conceptual design phase many of the risks will be *Very High*. As the project advances to the conceptual design phase, risk should be reduced such that no risk is higher than *High*. At preliminary design, the risks should be reduced to *Moderate*, and for final design, risks need to be reduced to *Low* and *Very Low*.

The PRAT matrix will need to be evaluated as tasks are completed. Often, the amount of risk reduced by tasks differs from that forecasted. The PRAT matrix will be re-analyzed to verify that the new risk level is commensurate with the current design phase.

Figures A-2 through A-19 show the PRAT matrix for each of the critical NGNP PASSCs for a reference configuration of 950°C Pebble Bed Reactor outlet temperature. The matrix overlays the risks against the tasks designed to advance technology maturity and reduce risk, and the anticipated amount of risk reduction is forecasted for each task. Some tasks reduce several different risks. Using the matrix for risk-informed prioritization, these tasks will rate higher than others. The risk management system contains the data for each scenario (750°C or 950°C reactor outlet temperatures and pebble bed or prismatic reactors).

How to Read A PRAT Matrix

The left hand column of the PRAT matrix contains the current technical risks for the critical PASSCs. Columns to the right of the risk column contain the baseline risk score (based on Consequence [C], Probability of Occurance [P_E], and Probability of Consequence [P_C]) and the risk score at the completion of each risk reducing task, which are listed horizontally across the top of the matrix. Each task was evaluated, and the task's impact on risk reduction is recorded in the body of the matrix.

The bar charts on the bottom of the matrix depict the impact each task has on the overall risk reduction. The sum of the green bar values is 100%, which refers to the total risk reduced from the current baseline risk to the projected risk after all tasks have been completed. The baseline risk and risk score after task completion is summarized in the bars on the right-hand columns of the matrix. The overall length of the bar is consistent with the baseline risk, and the length of the green bar represents the amount of risk reduced. The length of the red bar is reflective of the amount of residual risk remaining.

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Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology — Component — Subsystem — System — Plant

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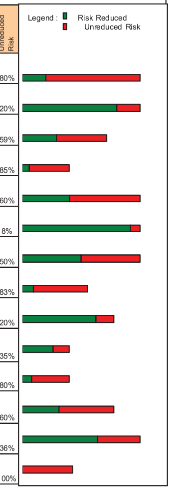
RPV Risk Reduction Tasks

- A – Develop updated/simplified design analysis methods - PLN-2803 Rev 0 NGNP RPV Materials R&D Plan April 2008 (TRL 4 - 5)
- B – Collect heavy section material data data Grade 91 (TRL 4 - 5)
- C – Analyze data to identify gaps for NGNP application (TRL 4 - 5)
- D – Collect data to fill gaps in data for : creep, creep fatigue,aging,irradiation,emissivity (TRL 4 - 5)
- E – Find material supplier (TRL 4 - 5)
- F – Evaluate Grade 91 against large scale fossil industry experience (TRL 4 - 5)
- G – Develop NDE inspection for thick (>200mm) Grade 91microstructure (TRL 4 - 5)
- H – Analyze aging & environmental effects for SA 508/533 (TRL 4 - 5)
- I – Determine allowable operating stress values - PLN-2803 Rev 0 NGNP RPV Materials R&D Plan April 2008 (TRL 4 - 5)
- J – Evaluate creep-fatigue crack growth at discontinuities & weldments -PLN-2803 Rev 0 NGNP RPV Materials R&D Plan April 2008& (TRL 4 - 5)
- K – Test RPV sealing Device - Pilot Scale Test (TRL 5 - 6)
- L – Develop stress analysis model (TRL 5 - 6)
- M – Develop computer model of RPV system to perform analysis & VCS (TRL 5 - 6)
- N – Develop manufacturing process for selected design (TRL 6-7)
- O – Validate analytical model predictions (TRL 6-7)
- P – Qualify welding for RPV material at full scale (TRL 6-7)
- Q – Fabricate and weld large sections with representative geometries (TRL 6-7)
- R – Develop post weld heat treatment (TRL 6-7)
- S – Third party inspection of welds (TRL 6-7)
- T – Fabricate NGNP reactor pressure vessel (TRL 7 - 8)
- U – Test and Qualify full scale NGNP prototype reactor pressure vessel in integrated operational environment-non-rad ops (TRL 7 - 8)

Each task column has ΔC / ΔPc / ΔPe sub-columns followed by the risk score after the task. Values in brackets are the printed changes.

ID	RPV TECHNICAL RISKS	BASELINE C	Pc	Pe	Baseline Score	Risk Score After Task Completion	A	B	C	D	E	F	G	H	I	J
35	RPV Emissivity vs. Power Level - INL/EXT-05 - 00952(PLN-2489) Revision 3	9.00	1.00	0.70	6.30	5.04	6.30	6.30	6.30	5.67 (ΔPe 0.10)	5.67	5.67	5.67	5.67	5.67	5.67
78	Weldments and postweld heat treatment of Modified 9Cr-1Mo- INL PLN-2674	9.00	1.00	0.70	6.30	1.26	6.30	1.26 (ΔPe 0.80)	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
48	RPV Loss-of-Coolant Strength and Creep Resistance - INL/EXT-07-12967 Revision 1	9.00	1.00	0.50	4.50	2.66	4.50	4.50	4.46 (ΔPe 0.01)	4.01 (ΔPe 0.10)	4.01	4.01	4.01	4.01	4.01	4.01
79	Effects of Sulfur on RPV Wall - INL PLN-2674	5.00	1.00	0.50	2.50	2.13	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.38 (ΔPe 0.05)	2.38	2.25 (ΔPe 0.05)
102	Micro Structural Stability-INEEL/EXT-04-01816	9.00	1.00	0.70	6.30	3.78	6.30	6.30	6.30	5.67 (ΔPe 0.10)	5.67	5.67	5.36 (ΔPe 0.05)	5.04 (ΔPe 0.05)	5.04	4.41 (ΔPe 0.10)
105	RPV: Vessel Size/Fabrication- INEEL/EXT-04-01816	9.00	1.00	0.70	6.30	0.50	6.30	6.30	6.30	6.30	6.30	6.17 (ΔPe 0.02)	6.17	6.17	6.17	6.17
9	Inspection of Thick Sections and Weldments - INL/EXT - 08-15148	9.00	1.00	0.70	6.30	3.15	6.30	6.30	6.30	6.30	6.30	6.30	5.36 (ΔPe 0.15)	5.36	5.36	5.36
76	Thermal Aging Effects - PLN-2803 NGNP RPV Materials R&D Plan	7.00	1.00	0.50	3.50	2.91	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.26 (ΔPe 0.07)	3.26	2.91 (ΔPe 0.10)
132	Irradiation Effects On Fracture Performance - PLN-2803 NGNP RPV Materials R&D Plan	7.00	1.00	0.70	4.90	0.98	4.90	4.90	4.90	0.98 (ΔPe 0.80)	0.98	0.98	0.98	0.98	0.98	0.98
133	Temperature Effects On Mechanical Properties of Grade 91 - PLN-2803 NGNP RPV Materials R&D Plan	5.00	1.00	0.50	2.50	0.88	2.50	2.50	2.50	1.25 (ΔPe 0.50)	1.25	0.88 (ΔPe 0.15)	0.88	0.88	0.88	0.88
225	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT-07-12967	5.00	1.00	0.50	2.50	2.00	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
226	Uncertainty in Extrapolated Data to Higher Temperatures - INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	2.94	4.90	4.41 (ΔPe 0.10)	4.17 (ΔPe 0.05)	3.43 (ΔPe 0.15)	3.43	3.19 (ΔPe 0.05)	3.19	3.04 (ΔPe 0.03)	3.04	3.04
227	Temperature of Pressure Boundary-INEEL/EXT-04-01816	9.00	1.00	0.70	6.30	2.27	6.30	6.30	5.99 (ΔPe 0.05)	5.04 (ΔPe 0.15)	5.04	4.73 (ΔPe 0.05)	4.73	4.41 (ΔPe 0.05)	4.10 (ΔPe 0.05)	3.15 (ΔPe 0.15)
228	NRC Issues Identified In PIRT and Not Addressed by Vendors - Phil Mills, et. al	9.00	1.00	0.30	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70

ID	K	L	M	N	O	P	Q	R	S	T	U	Risk % Reduction	Unreduced Risk
35	5.67	5.04 (ΔPe 0.10)	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	20%	80%
78	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	80%	20%
48	4.01	4.01	3.56 (ΔPe 0.10)	3.56	2.66 (ΔPe 0.20)	2.66	2.66	2.66	2.66	2.66	2.66	41%	59%
79	2.25	2.25	2.25	2.25	2.13 (ΔPe 0.05)	2.13	2.13	2.13	2.13	2.13	2.13	15%	85%
102	4.41	4.41	4.41	4.41	3.78 (ΔPe 0.10)	3.78	3.78	3.78	3.78	3.78	3.78	40%	60%
105	6.17	6.17	6.17	5.54 (ΔPe 0.10)	5.54	5.54	5.54	5.54	5.54	0.50 (ΔPe 0.80)	0.50	92%	8%
9	5.36	5.36	5.36	5.36	5.36	4.41 (ΔPe 0.15)	4.41	4.41	3.15 (ΔPe 0.20)	3.15	3.15	50%	50%
76	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	17%	83%
132	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	80%	20%
133	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	65%	35%
225	2.50	2.50	2.50	2.50	2.13 (ΔPe 0.15)	2.13	2.13	2.13	2.13	2.13	2.00 (ΔPe 0.05)	20%	80%
226	3.04	3.04	3.04	3.04	3.04	3.04	3.04	3.04	3.04	3.04	2.94 (ΔPe 0.02)	40%	60%
227	3.15	3.15	3.15	3.15	2.84 (ΔPe 0.05)	2.39 (ΔPe 0.07)	2.39	2.39	2.39	2.39	2.27 (ΔPe 0.02)	64%	36%
228	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	0%	100%



Baseline-Average RVI Risk Score: 4.70

Average RVI Risk Score after Task Completion: 2.37

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Task % Impact on Risk Reduction	0.00%	16.95%	1.85%	26.24%	0.00%	3.25%	3.86%	3.52%	0.97%	6.28%	0.00%	1.93%	1.38%	1.93%	7.19%	4.25%	0.00%	0.00%	3.86%	15.45%	1.07%
Risk score reduction	0.00	5.53	0.61	8.56	0.00	1.06	1.26	1.15	0.32	2.05	0.00	0.63	0.45	0.63	2.35	1.39	0.00	0.00	1.26	5.04	0.35

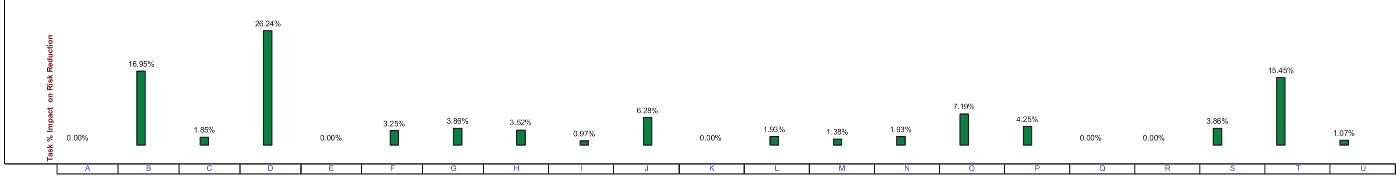


Figure A-2. PRAT matrix for the Reactor Pressure Vessel

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology — Component — Subsystem — System — Plant

REACTOR VESSEL INTERNALS RISK REDUCTION TASKS

Task	Description	TRL
A	Qualification of Nuclear GRADE Graphite	TRL 4 - 5
B	Development and initial composite material properties testing	TRL 4 - 5
C	Metallic material properties testing	TRL 4 - 5
D	Down selection tasks: Determine expected material,mechanical & thermal properties through limited testing	TRL 4 - 5
E	Down selection tasks: Estimate mean time to failure	TRL 4 - 5
F	Down selection tasks: Calculate availability factors	TRL 4 - 5
G	Down selection tasks: Determine max. design temperatures & stresses	TRL 4 - 5
H	Produce final, or near-to-final designs of reactor vessel internal components - PL-2498-REV1	TRL 5 - 6
I	Design and buid MIR (Match Index of Refraction) methods experiments - PLN-2498 REV1	TRL 6 - 7
J	Design and build Plenum-to-Plenum methods experiments - PLN-2498 REV1	TRL 6 - 7
K	Design and build Lower Plenum methods experiment (full scale pressure and temperature - PLN-2498 REV1	TRL 6 - 7
L	Design and build Core Heat Transfer methods experiments (full pressure and temperature) - PLN-2498 REV1	TRL 6 - 7
M	Determine key thermal hydraulic parameters for conduction cooldown modeling	TRL 6 - 7
N	Qualify composite materials	TRL 6 - 7
O	Test upper core restraint blocks: Statistically significant number of samples to qualify	TRL 6 - 7
P	Test lower floor blocks: Statistically significant number of samples to qualify - PLN-2498 REV1	TRL 6 - 7
Q	Perform MIR (Match Index of Refraction) methods experiments and V&V computer codes (12 experiments) - PLN-2498 REV1	TRL 7-8
R	Perform plenum-to-plenum methods experiments and V&V computer codes (12 experiments) - PLN-2498 REV1	TRL 7-8
S	Perform Lower plenum methods experiments and V&V computer codes (12 experiments) - PLN-2498 REV1	TRL 7-8
T	Perform core Heat Transfer methods and V&V computer codes (12 experiments) - PLN-2498 REV1	TRL 7-8
U	Fabricate NGNP reactor vessel internals	TRL 7-8

Each task cell has ΔC, ΔPc, ΔPe entries; the non-empty deltas are shown in parentheses after the resulting risk score.

ID	REACTOR VESSEL INTERNALS TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	Baseline score	Risk Score After Task Completion	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Risk % Reduction	Unreduced Risk
74	Qualification of Structural Graphite Source - INL PLN-2674 & INL/EXT-05-00952(PLN-2489) Revision 3/TDRM doc.	9.00	1.00	0.90	8.10	0.00	0.00 (ΔC 1.00, ΔPc 1.00, ΔPe 1.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100%	0%
229	Failure Mechanisms for Design Criteria - Creep - Fatigue - INL PLN-2674	9.00	1.00	0.90	8.10	5.18	8.10	8.10	8.10	7.29 (ΔPe 0.10)	6.89 (ΔPe 0.05)	6.89	6.32 (ΔPe 0.07)	6.32	6.32	6.32	6.32	6.32	6.32	6.32	5.75 (ΔPe 0.07)	5.18 (ΔPe 0.07)	5.18	5.18	5.18	5.18	5.18	36%	64%
230	Fouling Effects on Vessel Internals - INL/EXT-05 - 00952(PLN-2489) Revision 3	3.00	1.00	0.30	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0%	100%
231	NRC Issues Identified In PIRT and Not Addressed by Vendors - Phil Mills, et al.	9.00	1.00	0.90	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	0%	100%
232	Consistency in Graphite Properties - TDRM_01_09	9.00	1.00	0.90	8.10	1.62	4.05 (ΔPe 0.50)	4.05	4.05	3.24 (ΔPe 0.10)	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	2.43 (ΔPe 0.10)	1.62 (ΔPe 0.10)	1.62	1.62	1.62	1.62	1.62	80%	20%
233	Uncertainty in Extrapolated Material Data to Higher Temperatures - INEEL/EXT-04-01816	9.00	1.00	0.90	8.10	5.67	8.10	8.10	8.10	6.89 (ΔPe 0.15)	6.89	6.89	6.48 (ΔPe 0.05)	6.48	6.48	6.48	6.48	6.48	6.48	6.48	6.08 (ΔPe 0.05)	5.67 (ΔPe 0.05)	5.67	5.67	5.67	5.67	5.67	30%	70%
234	Contaminant Effects on Material Properties - INL PLN-2674	7.00	1.00	0.70	4.90	0.49	4.90	4.90	4.41 (ΔPe 0.10)	3.92 (ΔPe 0.10)	3.09 (ΔPc 0.10, ΔPe 0.10)	3.09	2.06 (ΔPc 0.20, ΔPe 0.10)	0.49 (ΔC 0.50, ΔPc 0.30, ΔPe 0.10)	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	90%	10%
106	Reactor Vessel Internals: Temperature at the core outlet- INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	0%	100%
174	Qualification of Alloys - INL/EXT-05-00952 (PLN -2489) Revision 3, INL/EXT- 07-12967 Revision 1	7.00	1.00	0.70	4.90	1.96	4.90	4.90	4.66 (ΔPe 0.05)	4.17 (ΔPe 0.10)	3.92 (ΔPe 0.05)	2.94 (ΔPe 0.20)	2.45 (ΔPe 0.10)	1.96 (ΔPe 0.10)	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	60%	40%
100	Temperature of Carbon Based Materials (Graphite)- INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	1.96	4.90	4.90	4.66 (ΔPe 0.05)	4.17 (ΔPe 0.10)	3.92 (ΔPe 0.05)	2.94 (ΔPe 0.20)	2.45 (ΔPe 0.10)	1.96 (ΔPe 0.10)	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	60%	40%
235	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07-12967	3.00	1.00	0.90	2.70	2.03	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.57 (ΔPe 0.05)	2.57	2.57	2.57	2.57	2.43 (ΔPe 0.05)	2.30 (ΔPe 0.05)	2.16 (ΔPe 0.05)	2.03 (ΔPe 0.05)	2.03	25%	75%
236	Pursue Alloys 617 and 230 in Thin Product Form (small grain sizes)- INL PLN-2674	3.00	1.00	0.90	2.70	2.16	2.70	2.70	2.57 (ΔPe 0.05)	2.16 (ΔPe 0.15)	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	20%	80%
237	Working Fluid Imapct on Vessel Internals (Coolant Flow Viscosity/Friction)	3.00	1.00	0.90	2.70	2.19	2.70	2.70	2.70	2.65 (ΔPe 0.02)	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.46 (ΔPe 0.07)	2.40 (ΔPe 0.02)	2.40	2.40	2.35 (ΔPe 0.02)	2.30 (ΔPe 0.02)	2.24 (ΔPe 0.02)	2.19 (ΔPe 0.02)	2.19	19%	81%
	Baseline-Average RVI Risk Score				5.32		38.04%	0.00%	3.49%	14.91%	5.41%	6.14%	9.33%	7.98%	0.00%	0.00%	0.00%	0.42%	0.59%	0.17%	5.58%	5.58%	0.59%	0.59%	0.59%	0.59%	0.00%		
	Average RVI Risk Score after Task Completion				2.86		12.15	0.00	1.12	4.76	1.73	1.96	2.98	2.55	0.00	0.00	0.00	0.14	0.19	0.05	1.78	1.78	0.19	0.19	0.19	0.19	0.00		

Legend: Risk Reduced; Unreduced Risk

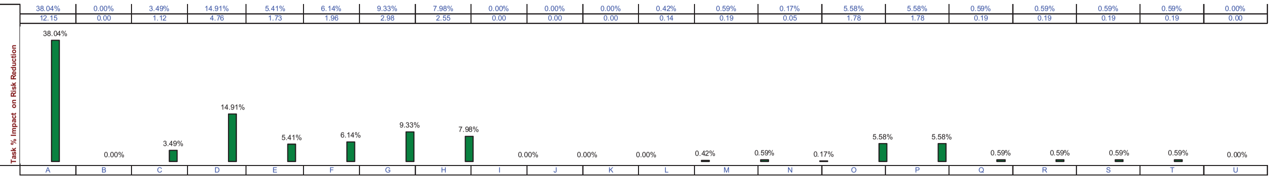


Figure A-3. PRAT matrix for the Reactor Vessel Internals

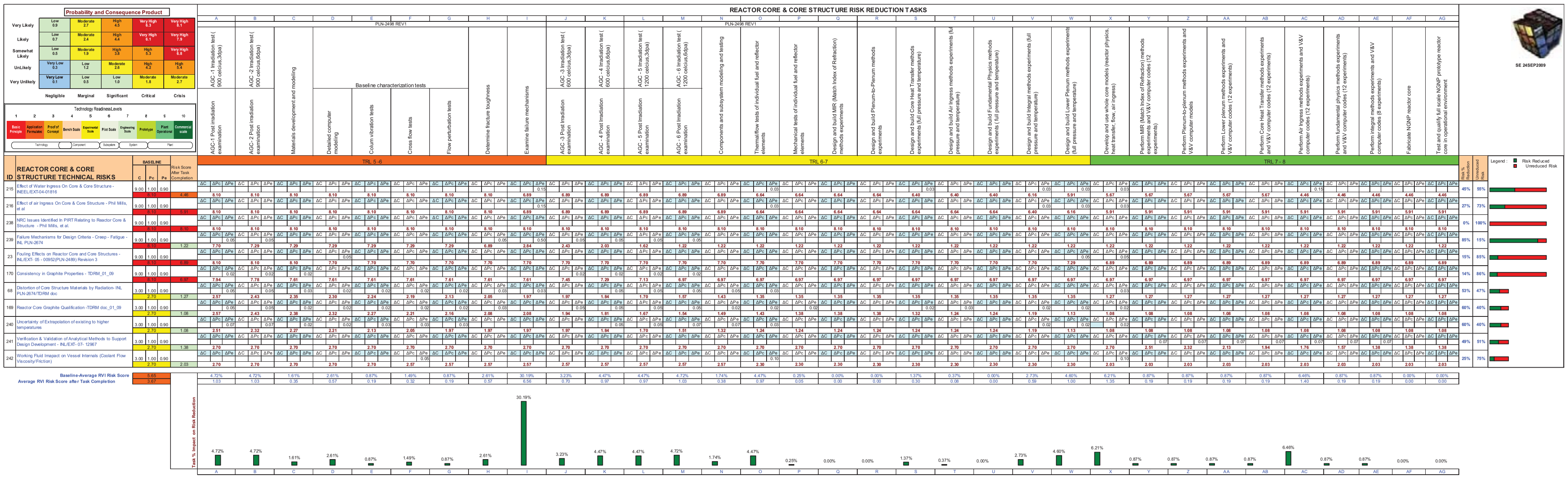


Figure A-4. PRAT matrix for the Reactor Core and Core Structure

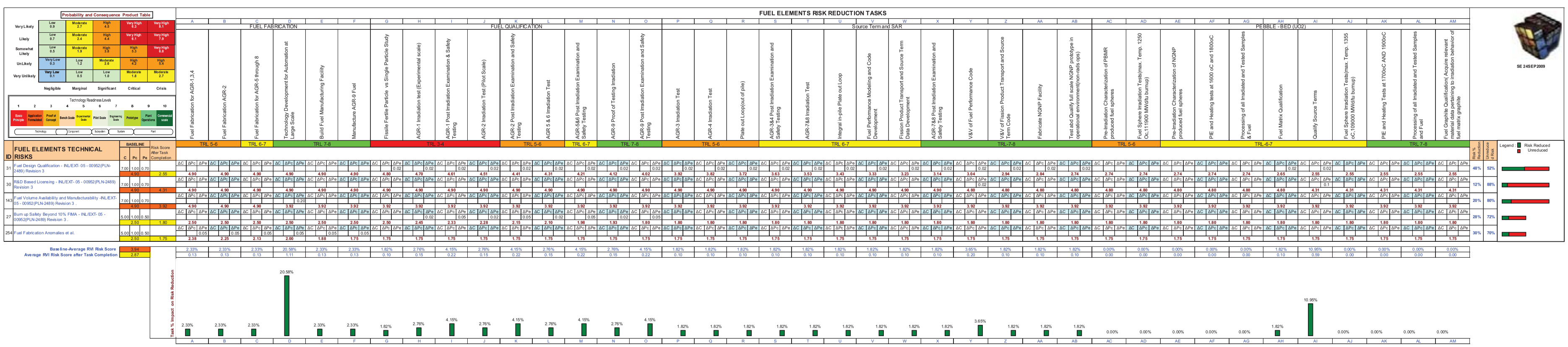
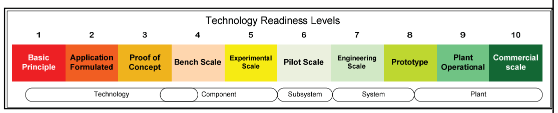


Figure A-5. PRAT matrix for the Fuel Elements

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7



SE 24SEP2009

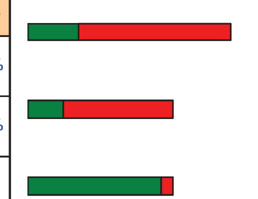
RESERVE SHUTDOWN SYSTEM RISK REDUCTION TASKS

Task	Description	TRL
A	Performance / functional testing of F	TRL 5 - 6
B	Perform analyses to determine NGNP delta and subsequent Small Absorber Spheres (SAS) material requirements	TRL 5 - 6
C	Trade Studies	TRL 5 - 6
D	Selection and Qualification of Small Absorber Spheres material for NGNP conditions	TRL 5 - 6
E	Performance Testing of RSS in Demonstration Power Plant (DPP)	TRL 6-7
F	Performance / functional testing of NGNP validated SAS in modified Helium Test Facility	TRL 6-7
G	Fabricate NGNP full scale RSS	TRL 7 - 8
H	Test and qualify full scale NGNP prototype RSS in integrated operational environment (non-rad ops)	TRL 7 - 8

ID	RESERVE SHUTDOWN SYSTEM TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	Baseline Score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk
247	Instrumentation and Control Systems - ITRG INEEL/EXT-04-01816	7.00	1.00	0.50	3.50	2.63	25%	75%
248	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07-12967	5.00	1.00	0.50	2.50	1.88	25%	75%
177	RSS: Selection and Qualification of SAS - INL/EXT - 08 - 15148	5.00	1.00	0.50	2.50	0.20	92%	8%

ID	A ΔC	A ΔPc	A ΔPe	A Score	B ΔC	B ΔPc	B ΔPe	B Score	C ΔC	C ΔPc	C ΔPe	C Score	D ΔC	D ΔPc	D ΔPe	D Score
247				3.50				3.50				3.50				3.50
248			0.05	2.38			0.05	2.25				2.25				2.25
177			0.10	2.25			0.10	2.00			0.02	1.95			0.10	1.70

ID	E ΔC	E ΔPc	E ΔPe	E Score	F ΔC	F ΔPc	F ΔPe	F Score	G ΔC	G ΔPc	G ΔPe	G Score	H ΔC	H ΔPc	H ΔPe	H Score
247			0.20	2.80				2.80				2.80			0.05	2.63
248			0.05	2.13			0.05	2.00				2.00			0.05	1.88
177			0.40	0.70			0.10	0.45				0.45			0.10	0.20



		A	B	C	D	E	F	G	H
Baseline-Average RVI Risk Score	2.83	9.87%	9.87%	1.32%	6.58%	48.03%	9.87%	0.00%	14.47%
Average RVI Risk Score after Task Completion	1.57	0.38	0.38	0.05	0.25	1.83	0.38	0.00	0.55

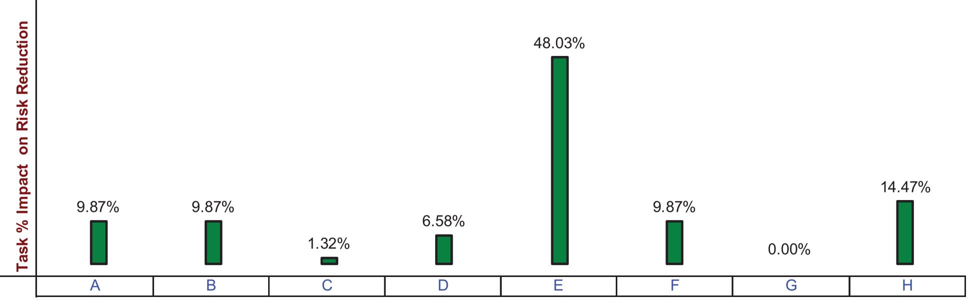


Figure A-6. PRAT matrix for the Reserve Shutdown System

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology | Component | Subsystem | System | Plant

SE 24SEP2009

REACTIVITY CONTROL SYSTEM RISK REDUCTION TASKS

ID	REACTIVITY CONTROL SYSTEM TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	Baseline score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk %
178	Thermal Bending in Control Rods Under Extremely High Temperatures - INL/EXT- 08-15148	9.00	1.00	0.70	6.30	3.34	47%	53%
85	Limited Availability of Silicon Carbide Fibers for Control Rods Fabrication - INL PLN-2674	7.00	1.00	0.70	4.90	4.66	5%	95%
253	Instrumentation and Control Systems - ITRG INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	4.31	12%	88%
254	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07-12967	5.00	1.00	0.50	2.50	1.88	25%	75%
	Baseline-Average RVI Risk Score				4.65			
	Average RVI Risk Score after Task Completion				3.55			

Legend: Risk Reduced / Unreduced Risk

Each task column has sub-columns ΔC, ΔPc, ΔPe for each risk; all printed changes are in ΔPe. Values per task (ΔPe / resulting score):

Task	Description	TRL	178 ΔPe	178 score	85 ΔPe	85 score	253 ΔPe	253 score	254 ΔPe	254 score	Task % impact	RVI reduction
A	Modeling to define maximum normal and off-normal rod temps	TRL 4 - 5	0.02	6.17		4.90		4.90		2.50	2.85%	0.13
B	Design analysis to determine Alloy 800H control rod performance envelope	TRL 4 - 5	0.05	5.86		4.90		4.90		2.50	7.13%	0.32
C	Limited testing for C/C and SiC/SiC composites to obtain data	TRL 4 - 5	0.02	5.73		4.90		4.90		2.50	2.85%	0.13
D	Design analysis for C/C and SiC/SiC composite control rods	TRL 4 - 5	0.05	5.42		4.90		4.90		2.50	7.13%	0.32
E	Modeling to define maximum normal and off-normal temps for guide tubes	TRL 4 - 5	0.02	5.29		4.90		4.90		2.50	2.85%	0.13
F	Assess Alloy 800H guide tube performance and high-temperature exposure impact	TRL 4 - 5	0.02	5.17		4.90		4.90		2.50	2.85%	0.13
G	Development and limited testing for C/C composites to define cost and performance of guide tubes	TRL 4 - 5	0.02	5.04	0.05	4.66		4.90		2.50	8.40%	0.37
H	Establish design criteria and select candidate materials	TRL 4 - 5		5.04		4.66		4.90		2.50	0.00%	0.00
I	Perform tests for candidate materials at reactor operating conditions	TRL 4 - 5		5.04		4.66		4.90		2.50	0.00%	0.00
J	Perform Trade Studies: Develop a composite architecture for the control rod consistent with the control rod	TRL 4 - 5	0.02	4.91		4.66		4.90		2.50	2.85%	0.13
K	Perform Trade Studies: Perform the following screening tests: • Neutron irradiation • Basic	TRL 4 - 5		4.91		4.66		4.90		2.50	0.00%	0.00
L	Perform Trade Studies: Obtain hi-temp material properties data	TRL 4 - 5	0.02	4.79		4.66		4.90		2.50	2.85%	0.13
M	Test Reactivity Control System (Pilot Scale): Systems Integration Testing	TRL 5 - 6	0.05	4.47		4.66	0.05	4.66		2.50	12.67%	0.56
N	Test Reactivity Control System (Pilot Scale): Detector assembly subsystems testing	TRL 5 - 6		4.47		4.66		4.66		2.50	0.00%	0.00
O	Test Reactivity Control System (Pilot Scale): Drive mechanism subsystems testing	TRL 5 - 6	0.02	4.35		4.66		4.66		2.50	2.85%	0.13
P	Test Reactivity Control System (Pilot Scale): Support structures, movement guidance structures, pressure seals,	TRL 5 - 6	0.02	4.22		4.66		4.66		2.50	2.85%	0.13
Q	Demonstrate control rod insertion in guide tubes without interference for normal and off-normal conditions	TRL 5 - 6	0.05	3.91		4.66	0.05	4.41		2.50	12.67%	0.56
R	Demonstrate fluid flow through guide tubes and around control rods is adequate for cooling	TRL 5 - 6		3.91		4.66		4.41		2.50	0.00%	0.00
S	Verification and Validation of Analytical Models to support design	TRL 6 - 7		3.91		4.66		4.41	0.25	1.88	14.14%	0.63
T	Test Reactivity Control System (Engineering Scale)	TRL 6 - 7	0.05	3.59		4.66		4.41		1.88	7.13%	0.32
U	System Interconnection and alignment testing	TRL 6 - 7	0.02	3.47		4.66		4.41		1.88	2.85%	0.13
V	Seismic testing	TRL 6 - 7		3.47		4.66		4.41		1.88	0.00%	0.00
W	Rod rubout limitation features, speed and positioning accuracy, control rod tip features, and RSCE backup features	TRL 6 - 7		3.47		4.66		4.41		1.88	0.00%	0.00
X	Integrated system operability testing: Conduct vibration testing	TRL 6 - 7		3.47		4.66		4.41		1.88	0.00%	0.00
Y	Integrated system operability testing: Conduct structural integrity test	TRL 6 - 7		3.47		4.66		4.41		1.88	0.00%	0.00
Z	Fabricate NGNP Reactivity Control System	TRL 7 - 8		3.47		4.66		4.41		1.88	0.00%	0.00
AA	Test and qualify full scale NGNP prototype RCS in operational environment (non-rad ops)	TRL 7 - 8	0.02	3.34		4.66	0.02	4.31		1.88	5.07%	0.22

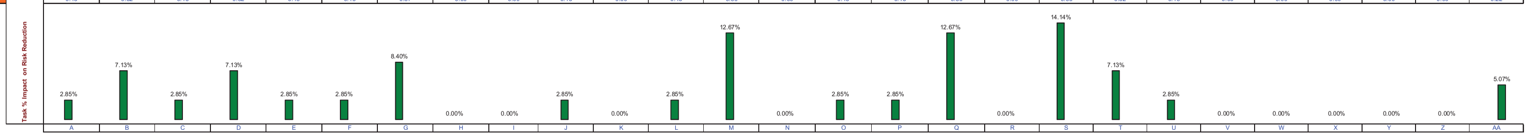


Figure A-7. PRAT matrix for the Reactivity Control System

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

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CORE CONDITIONING SYSTEM RISK REDUCTION TASKS

ID	CORE CONDITIONING SYSTEM TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	BASELINE Score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk %
250	CCS Ability to Withstand Vibrations During Normal Conditions - et al.	7.00	1.00	0.70	4.90	2.21	55%	45%
205	CCS Reliabilty in Transfering Heat Effectively- et al.	7.00	1.00	0.70	4.90	2.16	56%	44%
251	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07-12967	3.00	1.00	0.90	2.70	2.16	20%	80%
179	Core Conditioning System (Shutdown Cooling) Functionality Challenges - INL/EXT - 08 - 15148	3.00	1.00	0.90	2.70	1.51	44%	56%
	Baseline-Average RVI Risk Score				3.80			
	Average RVI Risk Score after Task Completion				2.01			

Legend: Risk Reduced / Unreduced

Task	Task group	Task description	TRL	250 ΔC	250 ΔPc	250 ΔPe	250 Score	205 ΔC	205 ΔPc	205 ΔPe	205 Score	251 ΔC	251 ΔPc	251 ΔPe	251 Score	179 ΔC	179 ΔPc	179 ΔPe	179 Score	Task % Impact on Risk Reduction	RVI
A		Incorporate information learned from IHX research and development and apply it to the CCS	TRL 4 - 5			0.02	4.80			0.02	4.80				2.70			0.10	2.43	6.50%	0.47
B		Perform Trade Studies	TRL 4 - 5			0.02	4.70			0.02	4.70				2.70			0.02	2.38	3.49%	0.25
C	Computer Modeling	Thermal Sizing	TRL 4 - 5				4.70			0.1	4.21				2.70				2.38	6.84%	0.49
D	Computer Modeling	Gas Size Pressure Drop	TRL 4 - 5				4.70			0.1	3.72				2.70				2.38	6.84%	0.49
E	Computer Modeling	Structural Evaluation of tubes	TRL 4 - 5			0.05	4.46				3.72				2.70			0.02	2.32	4.17%	0.30
F		Develop tube inspection methods	TRL 5 - 6			0.02	4.36				3.72				2.70			0.02	2.27	2.12%	0.15
G		Develop fabrication methods	TRL 5 - 6			0.02	4.26				3.72				2.70			0.02	2.21	2.12%	0.15
H		Develop mockup or computer simulation flow and temperature	TRL 5 - 6				4.26			0.05	3.48				2.70				2.21	3.42%	0.25
I	Test SCHE Helical Coil Tube (Pilot Scale)	Determine radiation effects of tube materials	TRL 5 - 6			0.02	4.17				3.48				2.70			0.02	2.16	2.12%	0.15
J	Test SCHE Helical Coil Tube (Pilot Scale)	Determine acoustical and vibration response	TRL 5 - 6			0.1	3.68				3.48				2.70			0.05	2.03	8.72%	0.63
K	Test SCHE Helical Coil Tube (Pilot Scale)	Examine corrosion and fouling	TRL 5 - 6			0.02	3.58			0.02	3.38				2.70			0.02	1.97	3.49%	0.25
L	Test SCHE Helical Coil Tube (Pilot Scale)	Heat Transfer Performance Testing - et al	TRL 5 - 6				3.58			0.1	2.89				2.70				1.97	6.84%	0.49
M		Design to ameliorate local tube wear	TRL 6 - 7			0.02	3.48				2.89				2.70			0.05	1.84	3.25%	0.23
N		Test for vibration, fretting & sliding effects	TRL 6 - 7			0.1	2.99				2.89				2.70			0.02	1.78	7.59%	0.54
O	Material Testing	Determine vibration and radiation effects	TRL 6 - 7			0.1	2.50				2.89				2.70				1.78	6.84%	0.49
P	Material Testing	Leak testing	TRL 6 - 7			0.02	2.40				2.89				2.70				1.78	1.37%	0.10
Q	Material Testing	Design conditions compatibility	TRL 6 - 7			0.02	2.30				2.89				2.70			0.10	1.51	5.13%	0.37
R		Fabricate NGNP CCS	TRL 7 - 8				2.30				2.89				2.70				1.51	0.00%	0.00
S	Test and qualify full scale NGNP prototype CCS in operational environment (non-rad ops)	Heat Transfer performance Testing- et al	TRL 7 - 8				2.30			0.1	2.40			0.2	2.16				1.51	14.37%	1.03
T	Test and qualify full scale NGNP prototype CCS in operational environment (non-rad ops)	Determine blower performance	TRL 7 - 8				2.30			0.05	2.16				2.16				1.51	3.42%	0.25
U	Test and qualify full scale NGNP prototype CCS in operational environment (non-rad ops)	Run pressure boundary leak tests	TRL 7 - 8			0.02	2.21				2.16				2.16				1.51	1.37%	0.10

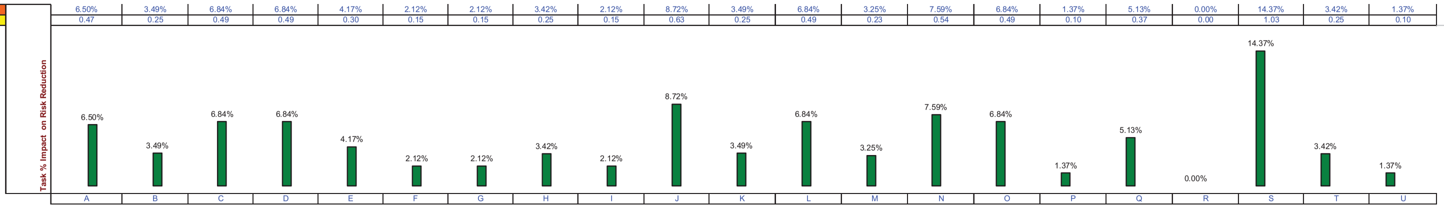

Figure A-8. PRAT matrix for the Core Conditioning System

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

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REACTOR CAVITY COOLING SYSTEM RISK REDUCTION TASKS

Task	TRL	Task description	Sub-task
A	TRL 4 - 5	Test and evaluate cooling panels (experimental scale)	Determine emissivity data
B	TRL 4 - 5	Test and evaluate inlet/outlet structures (experimental scale)	Determine pressure profiles
C	TRL 4 - 5	Perform analysis to demonstrate the RCCS removes the necessary heat from the reactor cavity under normal and off-normal conditions	
D	TRL 4 - 5	PIRT To DDN Reconciliation	
E	TRL 4 - 5	Fabricate Pilot Scale Cooling Panels	
F	TRL 5 - 6	Design and build RCCS methods experiments - PLN-2498 REV1	
G	TRL 5 - 6	Test and evaluate Cooling Panels (Pilot Scale - ~ ¼ scale) in relevant environment covering normal and accident conditions	Determine effects of particulates and plate-out
H	TRL 5 - 6		Determine effects of temperature and heat flux on heat transfer and friction factor data
I	TRL 5 - 6		Determine effect of Reynolds number on heat transfer and friction factor data
J	TRL 5 - 6		Determine effect of riser internal surface conditions on heat transfer and friction factor data
K	TRL 5 - 6		Determine effect of entry region conditions on heat transfer and friction factor data
L	TRL 5 - 6		Examine integral effects of heat transfer and fluid flow
M	TRL 5 - 6		Evaluate effects of non-uniform heat fluxes
N	TRL 6 - 7	Perform RCCS methods experiments and V&V computer codes (8 experiments) - PLN-2498 REV1	
O	TRL 6 - 7	Perform sensitivity analysis studies	
P	TRL 6 - 7	Determine flow and circulation behavior	
Q	TRL 6 - 7	Determine stresses in cooling panels	
R	TRL 6 - 7	Determine design margin	
S	TRL 6 - 7	Determine effects of particulates and plate-out	
T	TRL 6 - 7	Validate analytical model predictions	
U	TRL 6 - 7	Develop manufacturing processes for selected design	
V	TRL 6 - 7	Evaluate effects of asymmetry in integrated design	
W	TRL 6 - 7	Fabricate Engineering Scale RCCS	
X	TRL 6 - 7	Test and evaluate Engineering Scale (near full scale) of RCCS in integrated relevant environment (and accident scenarios)	
Y	TRL 7 - 8	Fabricate NGNP RCCS	
Z	TRL 7 - 8	Test and qualify full scale NGNP prototype RCCS in integrated and operational environment (non-nad ops)	

Each task cell has sub-columns ΔC, ΔPc, ΔPe; entries below give the printed Δ value (where present) and the resulting risk score.

ID	REACTOR CAVITY COOLING SYSTEM TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	Baseline score	Risk Score After Task Completion	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Risk % Reduction	Unreduced Risk %	R	Nr
248	NRC Issues Identified In PIRT and Not Addressed by Vendors (Annealing,Spatial - Phil Mills, et al.	7.00	1.00	0.70	4.90	0.49	4.90	4.90	4.90	ΔPe 0.90; 0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	90%	10%	2.16	0.54
163	RCCS - Ability To Remove Heat Degrading Over Time - TDRM doc_01_09	7.00	1.00	0.70	4.90	3.28	4.90	4.90	4.90	4.90	4.90	4.90	ΔPe 0.10; 4.41	4.41	4.41	4.41	4.41	4.41	4.41	ΔPe 0.02; 4.31	ΔPe 0.02; 4.21	4.21	4.21	ΔPe 0.07; 3.87	ΔPe 0.10; 3.38	ΔPe 0.02; 3.28	3.28	3.28	3.28	3.28	3.28	3.28	33%	67%	0.84	1.86
162	RCCS - Maintaining Vessel Concrete Temperatures Below Destructive Temperatures -TDRM Doc_01_09	3.00	1.00	0.90	2.70	0.81	2.70	ΔPe 0.02; 2.65	ΔPe 0.20; 2.11	2.11	ΔPe 0.02; 2.05	2.05	2.05	ΔPe 0.02; 2.00	ΔPe 0.02; 1.94	ΔPe 0.02; 1.89	ΔPe 0.02; 1.84	ΔPe 0.02; 1.78	ΔPe 0.02; 1.73	ΔPe 0.04; 1.62	1.62	ΔPe 0.07; 1.43	ΔPe 0.07; 1.24	ΔPe 0.02; 1.19	1.19	ΔPe 0.02; 1.13	ΔPe 0.02; 1.08	ΔPe 0.02; 1.03	ΔPe 0.02; 0.97	ΔPe 0.02; 0.92	ΔPe 0.02; 0.86	ΔPe 0.02; 0.81	70%	30%	1.89	0.81
161	Degradation of Emissivity in RCCS Over Time - TDRM doc_01_09	3.00	1.00	0.90	2.70	1.86	ΔPe 0.15; 2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	ΔPe 0.02; 2.24	ΔPe 0.02; 2.19	2.19	2.19	ΔPe 0.10; 1.92	1.92	ΔPe 0.02; 1.86	1.86	1.86	1.86	1.86	1.86	1.86	31%	69%	1.62	3.28
249	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07-12967	3.00	1.00	0.90	2.70	0.54	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	ΔPe 0.5; 1.35	1.35	1.35	1.35	1.35	1.35	ΔPe 0.3; 0.54	0.54	0.54	0.54	0.54	0.54	0.54	80%	20%	4.41	0.49
	Baseline-Average RVI Risk Score				3.58		3.71%	0.49%	4.95%	40.41%	0.49%	0.00%	4.49%	0.49%	0.49%	0.49%	0.49%	0.49%	0.49%	14.75%	1.39%	1.73%	1.73%	6.11%	4.49%	9.31%	0.49%	0.49%	0.49%	0.49%	0.49%	0.49%				
	Average RVI Risk Score after Task Completion				1.40		0.41	0.05	0.54	4.41	0.05	0.00	0.49	0.05	0.05	0.05	0.05	0.05	0.05	1.61	0.15	0.19	0.19	0.67	0.49	1.02	0.05	0.05	0.05	0.05	0.05	0.05				

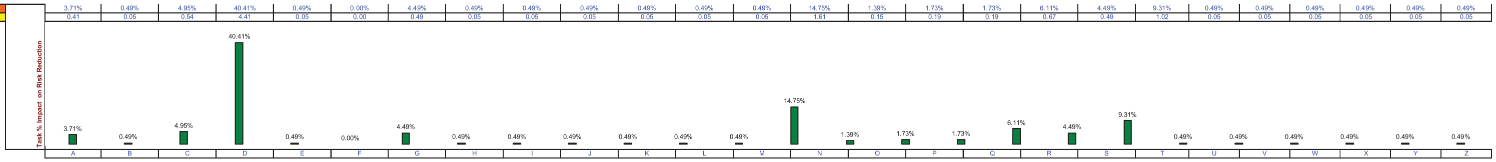

Figure A-9. PRAT matrix for the Reactor Cavity Cooling System

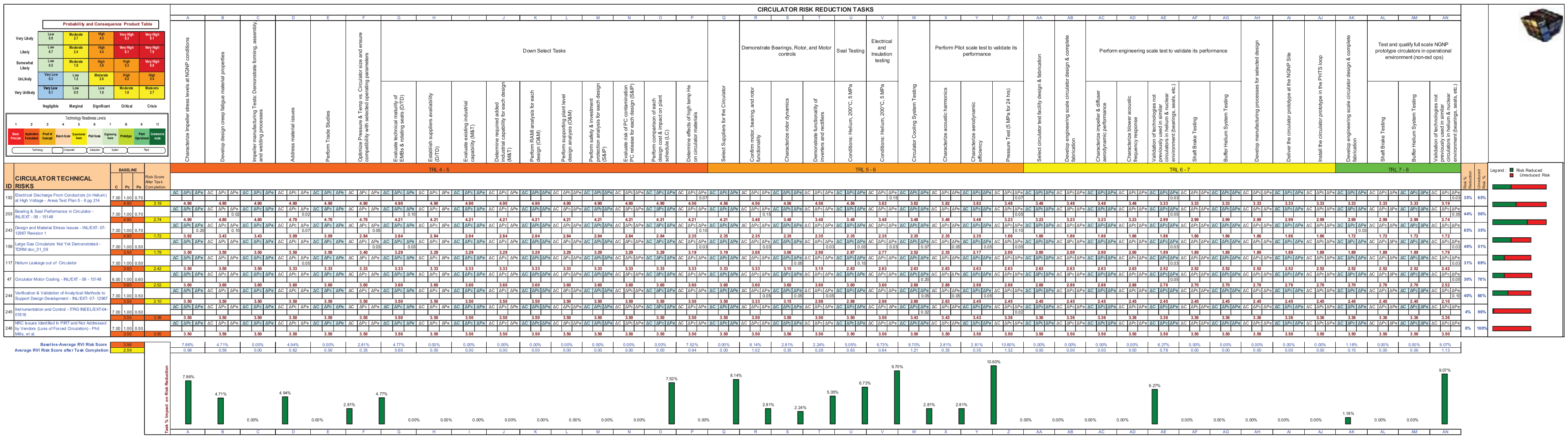

Figure A-10. PRAT matrix for the Circulators

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.5	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

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IHX RISK REDUCTION TASKS

Task	Description	TRL
A	Establish reference specifications & procure mat'ls for testing	TRL 3 - 4
B	Establish criteria for structural integrity of IHX	TRL 3 - 4
C	Develop joining procedures	TRL 3 - 4
D	Evalate effects of thermal aging & environmental exposure	TRL 3 - 4
E	Experimentally based constitutive models (excluding I&C)	TRL 3 - 4
F	Develop thermal/fluid, stress/strain and performance models	TRL 3 - 4
G	Determine corrosion allowances	TRL 3 - 4
H	Determine inspection needs of IHX - PLN2804 Rev 0 NGNP IHX R&D Plan April 2008	TRL 3 - 4
I	Product form definition with thin sheet and thick section materials -PLN-2804 Rev 0 NGNP IHX R&D Plan April 2008	TRL 3 - 4
J	Charactization of thin product forms-PLN-2804 Rev 0 NGNP IHX R&D Plan April 2008	TRL 3 - 4
K	Explore creep mechanisms - PLN-2804 Rev 0 NGNP IHX R&D Plan April 2008	TRL 4 - 5
L	)Determine thermal, physical & mechanical properties (including tritium migration	TRL 4 - 5
M	Determine performance of weldments discontinuities at elevated temperatures	TRL 4 - 5
N	Determine effects of cyclic loadings on creep& fatigue	TRL 4 - 5
O	Assist in the development of a guideline for inelastic analysis and life prediction	TRL 4 - 5
P	Assess effects of grain size & section thickness	TRL 4 - 5
Q	Test experimental scale heat exchanger in relevant environment	TRL 4 - 5
R	Determine flaw assessment and leak before break	TRL 5-6
S	Validate analytical model	TRL 5-6
T	Fabricate pilot scale heat exchanger	TRL 5-6
U	Demonstrate in-service inspectability for inelastic design method	TRL 5-6
V	Extrapolation of creep data to 60 years for 800H	TRL 6 - 7
W	Develop manufacturing process for selected design	TRL 6 - 7
X	Test engineering scale heat exchanger in relevant environment	TRL 6 - 7
Y	Fabricate NGNP heat exchanger	TRL 6 - 7
Z	Test and evaluate NGNP Prototype full scale IHX in integrated operational environment	TRL 7 - 8
AA	Compare results against performance criteria	TRL 7 - 8

Each task column has sub-columns ΔC, ΔPc, ΔPe; the ΔPe entered is shown in parentheses, followed by the resulting score.

ID	IHX TECHNICAL RISKS	C	Pc	Pe	Baseline score	Score After Task Completion	A	B	C	D	E	F	G	H	I	J	K	L	M
122	Graphite Dust - Phil Mills, et al.	7.00	1.00	0.70	4.90	2.45	4.90	4.90	4.90	(0.20) 3.92	3.92	3.92	(0.20) 2.94	2.94	2.94	2.94	2.94	2.94	2.94
92	IHX: Creep and Fatigue Analysis- INL PLN-2674	7.00	1.00	0.70	4.90	3.19	4.90	4.90	4.90	4.90	(0.05) 4.66	(0.05) 4.41	4.41	4.41	4.41	4.41	(0.05) 4.17	4.17	4.17
95	Alloy Thickness For IHX Materials Unknown- INL PLN-2674	7.00	1.00	0.70	4.90	4.66	(0.05) 4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66
126	Kinetic Model Development - PLN-2804 NGNP IHX Materials R&D Plan rev1	7.00	1.00	0.70	4.90	2.94	4.90	4.90	4.90	4.90	4.90	(0.20) 3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92
128	Immature Compact Heat Exchanger Technology - PLN-2804 NGNP IHX Materials R&D Plan rev1	7.00	1.00	0.70	4.90	2.55	4.90	4.90	(0.03) 4.75	(0.03) 4.61	(0.03) 4.46	(0.03) 4.31	4.31	(0.03) 4.17	(0.03) 4.02	(0.03) 3.87	(0.03) 3.72	(0.03) 3.58	(0.03) 3.43
137	ASTM Standards Unavailable For IHX - PLN 2803 NGNP RPV Materials R&D plan	7.00	1.00	0.70	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
224	Inspection of Thick Sections and Weldments - INL/EXT - 08-15148	7.00	1.00	0.70	4.90	2.79	4.90	4.90	(0.05) 4.66	4.66	4.66	4.66	4.66	(0.05) 4.41	4.41	4.41	4.41	4.41	(0.08) 4.02
12	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07- 12967	5.00	1.00	0.50	2.50	1.70	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
56	Instrumentation and Control Systems - ITRG INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	4.07	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
103	Uncertainty in Extrapolated Data to Higher Temperatures - INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	2.30	4.90	4.90	4.90	(0.02) 4.80	4.80	(0.10) 4.31	4.31	4.31	4.31	4.31	(0.02) 4.21	(0.02) 4.12	(0.05) 3.87
91	Failure Mechanisms for Design Criteria - Creep - Fatigue - INL PLN-2674	7.00	1.00	0.70	4.90	2.21	4.90	4.90	4.90	4.90	(0.05) 4.66	(0.05) 4.41	4.41	4.41	4.41	4.41	(0.02) 4.31	(0.02) 4.21	(0.02) 4.12
104	Temperature of Pressure Boundary- INEEL/EXT-04-01816	7.00	1.00	0.50	3.50	2.14	3.50	3.50	3.50	(0.02) 3.43	3.43	(0.02) 3.36	3.36	3.36	3.36	3.36	(0.05) 3.19	(0.05) 3.01	(0.02) 2.94
121	Tritium Migration - Phil Mills, et al.	7.00	1.00	0.70	4.90	4.07	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	(0.10) 4.41	4.41
142	NRC Issues Identified In PIRT and Not Addressed by Vendors - Phil Mills, et. al	7.00	1.00	0.70	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
217	Effects of Helium Contaminants On Material Micro Structure and Performance - Bill Landman, et al.	7.00	1.00	0.70	4.90	3.82	4.90	4.90	4.90	(0.10) 4.41	4.41	4.41	(0.02) 4.31	4.31	4.31	(0.05) 4.07	4.07	(0.05) 3.82	3.82
206	Potential PHTS Leakage - Bill Landman, et al.	7.00	1.00	0.70	4.90	2.76	4.90	(0.03) 4.75	(0.03) 4.61	4.61	4.61	(0.03) 4.46	4.46	4.46	(0.03) 4.31	4.31	(0.03) 4.17	(0.03) 4.02	(0.03) 3.87

ID	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	Risk % Reduction	Unreduced Risk %
122	2.94	2.94	2.94	(0.05) 2.70	2.70	2.70	(0.05) 2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	50%	50%
92	(0.05) 3.92	3.92	(0.05) 3.68	3.68	3.68	(0.05) 3.43	3.43	3.43	(0.05) 3.19	3.19	3.19	3.19	3.19	3.19	35%	65%
95	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66	5%	95%
126	3.92	3.92	3.92	3.92	3.92	(0.20) 2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	40%	60%
128	(0.03) 3.28	3.28	(0.03) 3.14	(0.03) 2.99	2.99	(0.03) 2.84	(0.03) 2.70	2.70	2.70	2.70	(0.03) 2.55	2.55	2.55	2.55	48%	52%
137	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	0%	100%
224	4.02	4.02	(0.05) 3.77	3.77	(0.10) 3.28	3.28	3.28	(0.10) 2.79	2.79	2.79	2.79	2.79	2.79	2.79	43%	57%
12	2.50	2.50	2.50	(0.05) 2.38	2.38	(0.20) 1.88	1.88	1.88	1.88	1.88	(0.05) 1.75	1.75	1.75	(0.02) 1.70	32%	68%
56	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	(0.15) 4.17	4.17	(0.02) 4.07	4.07	17%	83%
103	(0.02) 3.77	(0.02) 3.68	3.68	(0.07) 3.33	3.33	(0.02) 3.23	3.23	3.23	(0.15) 2.50	2.50	(0.02) 2.40	2.40	(0.02) 2.30	2.30	53%	47%
91	(0.05) 3.87	(0.01) 3.82	(0.01) 3.77	(0.05) 3.53	(0.05) 3.28	(0.05) 3.04	3.04	3.04	(0.10) 2.55	2.55	(0.05) 2.30	2.30	(0.02) 2.21	2.21	55%	45%
104	(0.07) 2.70	2.70	2.70	(0.02) 2.63	2.63	(0.02) 2.56	2.56	2.56	(0.05) 2.38	2.38	(0.05) 2.21	2.21	(0.02) 2.14	2.14	39%	61%
121	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	(0.05) 4.17	4.17	(0.02) 4.07	4.07	17%	83%
142	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	0%	100%
217	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	22%	78%
206	(0.03) 3.72	3.72	(0.03) 3.58	(0.03) 3.43	(0.03) 3.28	3.28	(0.03) 3.14	(0.03) 2.99	2.99	2.99	(0.03) 2.84	2.84	2.84	(0.03) 2.76	44%	56%

Legend: Risk Reduced / Un reduced

Baseline-Average RVI Risk Score: 4.66
Average RVI Risk Score after Task Completion: 3.21

Task	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Task % Impact on Risk Reduction	1.06%	0.63%	2.33%	7.70%	2.75%	10.03%	4.65%	1.69%	1.27%	1.69%	3.93%	6.04%	4.74%	4.86%
	0.25	0.15	0.54	1.79	0.64	2.32	1.08	0.39	0.29	0.39	0.91	1.40	1.10	1.13

Task	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
Task % Impact on Risk Reduction	0.63%	3.59%	5.70%	3.81%	9.86%	2.33%	2.75%	7.10%	0.00%	8.27%	0.00%	1.99%	0.58%
	0.15	0.83	1.32	0.88	2.29	0.54	0.64	1.65	0.00	1.92	0.00	0.46	0.14

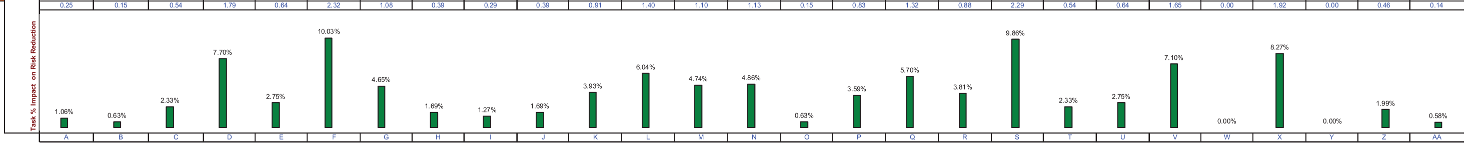

Figure A-11. PRAT matrix for the Intermediate Heat Exchangers

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology — Component — Subsystem — System — Plant

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CROSS VESSEL RISK REDUCTION TASKS

Column	Task	TRL
A	Study He Effects	TRL 4 - 5
B	Duct and Insulation Material Property (Coupon) Tests	TRL 4 - 5
C	Component testing: Environmental Qualification of ducts and insulation	TRL 4 - 5
D	Perform Trade Studies: Thermal Expansion Analysis	TRL 4 - 5
E	Perform Trade Studies: CFD Analysis	TRL 4 - 5
F	Perform Trade Studies: FEA Analysis	TRL 4 - 5
G	Perform Trade Studies: Leak Detection	TRL 4 - 5
H	Define assembly processes for the coaxial cross vessel piping system	TRL 5 - 6
I	Define inspection and maintenance techniques for the coaxial cross vessel piping system	TRL 5 - 6
J	Determine thermal-hydraulic performance of the coaxial cross vessel piping system using analytical calculations	TRL 5 - 6
K	Determine structural performance of the coaxial cross vessel piping system using analytical calculations	TRL 5 - 6
L	Test Insulation and hangers (Pilot Scale)	TRL 5 - 6
M	Develop manufacturing processes for selected design	TRL 5 - 6
N	Develop computer model of piping system to perform analysis	TRL 5 - 6
O	Validate analytical model predictions	TRL 6-7
P	Fabricate NGNP Engineering Scale Cross Vessel Piping	TRL 6-7
Q	Test Engineering scale cross vessel piping in integrated relevant operational environment to determine performance	TRL 6-7
R	Fabricate NGNP cross vessel piping	TRL 7 - 8
S	Test and qualify full scale NGNP prototype cross vessel piping in operational environment (non-rad ops)	TRL 7 - 8

Each task column has sub-columns ΔC, ΔPc, ΔPe; only ΔPe entries are filled. For each risk, the first line gives the ΔPe values and the second line the resulting risk score.

ID	CROSS VESSEL TECHNICAL RISKS	Baseline C	Baseline Pc	Baseline Pe	Baseline score	Risk Score After Task Completion		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	Risk % Reduction	Unreduced Risk %
218	Design and Material Stress Issues - INL/EXT-07-12967 Revision 1	8.00	1.00	0.70	5.60	3.98	ΔPe		0.07		0.02	0.02	0.02				0.02	0.05	0.02			0.05				0.02	29%	71%
							Score	5.60	5.21	5.21	5.10	4.98	4.87	4.87	4.87	4.87	4.76	4.48	4.37	4.37	4.37	4.09	4.09	4.09	4.09	3.98		
219	NRC Issues Identified In PIRT (Fission Product Transport,Cracking,etc) Pertaining to CV - Phil Mills, et al.	8.00	1.00	0.70	5.60	5.60	ΔPe																				0%	100%
							Score	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60		
66	Insulated Systems / Mechanical Integrity-INEEL/EXT-04-01816	7.00	1.00	0.50	3.50	2.17	ΔPe		0.10		0.02	0.02	0.02	0.02					0.10					0.05		0.05	38%	62%
							Score	3.50	3.15	3.15	3.08	3.01	2.94	2.87	2.87	2.87	2.87	2.87	2.52	2.52	2.52	2.52	2.52	2.35	2.35	2.17		
107	Reactor Inlet/Outlet Temperature Seals of Concentric Pipe(s)- INEEL/EXT- 04 - 01816	7.00	1.00	0.50	3.50	2.21	ΔPe			0.10	0.02	0.02	0.02	0.02					0.05	0.02	0.02			0.05		0.05	37%	63%
							Score	3.50	3.50	3.15	3.08	3.01	2.94	2.87	2.87	2.87	2.87	2.87	2.70	2.63	2.56	2.56	2.56	2.38	2.38	2.21		
183	High Temperature Creep and Fatigue - INL/EXT - 08 - 15148	7.00	1.00	0.50	3.50	2.80	ΔPe		0.10									0.10									20%	80%
							Score	3.50	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80		
220	Uncertainty in Extrapolated Data to Higher Temperatures - INEEL/EXT-04-01816	7.00	1.00	0.50	3.50	2.77	ΔPe		0.10	0.05								0.03				0.03					21%	79%
							Score	3.50	3.15	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.87	2.87	2.87	2.87	2.77	2.77	2.77	2.77	2.77		
221	Effects of Sulfur on CV Wall - INL PLN-2674	7.00	1.00	0.50	3.50	2.28	ΔPe		0.05	0.10		0.01						0.07				0.03		0.07		0.02	35%	65%
							Score	3.50	3.33	2.98	2.98	2.94	2.94	2.94	2.94	2.94	2.94	2.70	2.70	2.70	2.70	2.59	2.59	2.35	2.35	2.28		
222	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07-12967	7.00	1.00	0.50	3.50	2.98	ΔPe															0.15					15%	85%
							Score	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	2.98	2.98	2.98	2.98	2.98		
223	Mechanisms of Degradation in CV - INL PLN - 2674	5.00	1.00	0.70	3.50	2.00	ΔPe		0.10	0.07			0.07				0.05					0.05		0.07		0.02	43%	57%
							Score	3.50	3.15	2.91	2.91	2.91	2.66	2.66	2.66	2.66	2.49	2.49	2.49	2.49	2.49	2.31	2.31	2.07	2.07	2.00		
	Baseline-Average RVI Risk Score				3.97			0.00%	22.00%	12.53%	2.82%	3.21%	5.56%	1.57%	0.00%	0.00%	3.21%	10.96%	7.13%	0.78%	0.78%	13.31%	0.00%	9.40%	0.00%	6.73%		
	Average RVI Risk Score after Task Completion				2.97			0.00	1.97	1.12	0.25	0.29	0.50	0.14	0.00	0.00	0.29	0.98	0.64	0.07	0.07	1.19	0.00	0.84	0.00	0.60		

Legend: Risk Reduced; Unreduced Risk

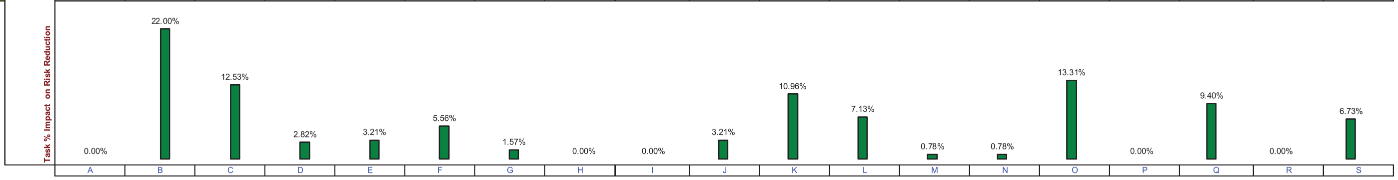
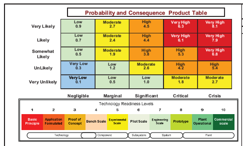


Figure A-12. PRAT matrix for the Cross Vessel Piping



HT VALVES RISK REDUCTION TASKS

SE 24SEP2009

Task groups: Perform Trade Studies (A–D); Isolation Valves & Relief Valves (E–P); Isolation Valves & Relief Valves (R–T); Isolation V (U–V); Flapper Valves (W–X); All 3 Valves (Y); Integrated System (Z–AD).

TRL bands: TRL 3-4 (A–D); TRL 3 - 4 (E–J); TRL 4-5 (K–P); TRL 5-6 (Q–Y); TRL 6-7 (Z–AD); TRL 7-8 (AE–AF).

Each task column has ΔC, ΔPc and ΔPe sub-columns. In the task tables below, each printed reduction (all of them sit in the ΔPe sub-column) comes first, followed by the resulting risk score.

ID	HT VALVES TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	BASELINE Score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk %
153	Frictional Increase in Actuator over long term - TDRM doc_01_09	7.00	1.00	0.70	4.90	2.50	49%	51%
256	Effects of Sulfur on HT Valves - INL PLN-2674	7.00	1.00	0.70	4.90	4.36	11%	89%
184	Relief Valve - Differential Thermal Expansion- INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	2.74	44%	56%
187	Differential Thermal Expansion in Isolation Valve - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	2.74	44%	56%
152	High Temperature Corrosion - TDRM doc_01_09	5.00	1.00	0.50	2.50	1.98	21%	79%
154	Relief Valve - Spring Property Changes at High Temperatures - Closing - TDRM Doc_01_09	5.00	1.00	0.50	2.50	1.43	43%	57%
151	Cobalt - 60 Activation in HT valves- TDRM doc_01_09	5.00	1.00	0.50	2.50	2.50	0%	100%
186	Differential Thermal Expansion in Flapper Valve - INL/EXT - 08 - 15148	5.00	1.00	0.50	2.50	1.40	44%	56%
155	Potential Failure in Valve Caused by Packing Material - TDRM doc_01_09	5.00	1.00	0.50	2.50	1.43	43%	57%
255	I & C for Valves - ITRG INEEL/EXT-04-01816	5.00	1.00	0.50	2.50	2.13	15%	85%
	Baseline-Average RVI Risk Score				3.30			
	Average RVI Risk Score after Task Completion				2.30			

ID	A Establish conditions of service	B Transient Analysis	C Stress Analysis	D RAMI analysis	E Establish relevant standards & codes applicability	F Determine thermal & mechanical properties	G Establish conditions of service	H Valve material stress testing
153	4.90	4.90	4.90	4.90	4.90	4.90	ΔPe 0.01; 4.85	4.85
256	4.90	4.90	4.90	4.90	4.90	ΔPe 0.02; 4.80	ΔPe 0.02; 4.70	ΔPe 0.02; 4.61
184	ΔPe 0.02; 4.80	4.80	4.80	4.80	4.80	ΔPe 0.02; 4.70	4.70	ΔPe 0.02; 4.61
187	ΔPe 0.02; 4.80	4.80	4.80	4.80	4.80	ΔPe 0.02; 4.70	4.70	ΔPe 0.02; 4.61
152	ΔPe 0.05; 2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38
154	ΔPe 0.01; 2.48	2.48	2.48	2.48	2.48	ΔPe 0.15; 2.10	2.10	ΔPe 0.10; 1.85
151	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
186	ΔPe 0.02; 2.45	2.45	2.45	2.45	2.45	ΔPe 0.02; 2.40	2.40	ΔPe 0.02; 2.35
155	2.50	2.50	2.50	2.50	2.50	ΔPe 0.07; 2.33	2.33	ΔPe 0.02; 2.28
255	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
%	3.47%	0.00%	0.00%	0.00%	0.00%	7.84%	1.29%	5.65%
Total	0.40	0.00	0.00	0.00	0.00	0.89	0.15	0.64

ID	I Material durability tests	J Determine performance of gaskets, packing and seals	K Determine RAMI and Testability	L 3D modeling and FEA stress analysis	M Endurance and creep analysis	N Identify maintenance requirements	O Erosion and corrosion testing	P He leak tightness, welding methods
153	ΔPe 0.05; 4.61	4.61	4.61	ΔPe 0.01; 4.56	ΔPe 0.05; 4.31	4.31	ΔPe 0.10; 3.82	3.82
256	4.61	ΔPe 0.02; 4.51	ΔPe 0.02; 4.41	4.41	4.41	ΔPe 0.01; 4.36	4.36	4.36
184	4.61	4.61	4.61	ΔPe 0.02; 4.51	ΔPe 0.02; 4.41	4.41	4.41	ΔPe 0.02; 4.31
187	4.61	4.61	4.61	ΔPe 0.02; 4.51	ΔPe 0.02; 4.41	4.41	4.41	ΔPe 0.02; 4.31
152	2.38	2.38	2.38	2.38	2.38	2.38	ΔPe 0.10; 2.13	2.13
154	1.85	1.85	1.85	ΔPe 0.02; 1.80	ΔPe 0.02; 1.75	1.75	1.75	1.75
151	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
186	2.35	2.35	2.35	ΔPe 0.02; 2.30	ΔPe 0.02; 2.25	2.25	2.25	ΔPe 0.02; 2.20
155	ΔPe 0.07; 2.10	ΔPe 0.15; 1.73	1.73	1.73	ΔPe 0.03; 1.65	1.65	1.65	1.65
255	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
%	3.68%	4.15%	0.86%	3.03%	5.40%	0.43%	6.49%	2.16%
Total	0.42	0.47	0.10	0.35	0.62	0.05	0.74	0.25

ID	Q Physical test preparation for pilot scale test	R Determine NDE methods	S Verify 3D models	T Determine Leak Rate Detection Method Validation	U Select Actuator	V Sliding surface friction & wear characterization at design temperatures	W Characterize materials, surface finish and dimensional tolerances	X Demonstrate open-close functionality
153	3.82	ΔPe 0.01; 3.77	3.77	3.77	ΔPe 0.05; 3.53	ΔPe 0.15; 2.79	2.79	ΔPe 0.02; 2.70
256	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36
184	4.31	4.31	ΔPe 0.05; 4.07	ΔPe 0.05; 3.82	3.82	3.82	3.82	ΔPe 0.05; 3.58
187	4.31	4.31	ΔPe 0.05; 4.07	ΔPe 0.05; 3.82	3.82	3.82	3.82	ΔPe 0.05; 3.58
152	2.13	2.13	2.13	2.13	2.13	2.13	2.13	ΔPe 0.02; 2.08
154	1.75	1.75	ΔPe 0.03; 1.68	ΔPe 0.03; 1.60	1.60	1.60	1.60	ΔPe 0.03; 1.53
151	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
186	2.20	2.20	ΔPe 0.05; 2.08	ΔPe 0.05; 1.95	1.95	1.95	1.95	ΔPe 0.05; 1.83
155	1.65	1.65	1.65	ΔPe 0.02; 1.60	1.60	ΔPe 0.02; 1.55	1.55	1.55
255	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
%	0.00%	0.43%	6.05%	6.49%	2.15%	6.88%	0.00%	7.35%
Total	0.00	0.05	0.69	0.74	0.25	0.79	0.00	0.84

ID	Y Fabricate NGNP Engineering Scale Valves	Z Test engineering scale valve in integrated relevant operational environment to determine performance	AA Integrated test connected to hot ducts and circulator	AB QME Pipe end load testing	AC Seismic analysis	AD Operability tests	AE Fabricate NGNP High Temperature Valves	AF Test and qualify full scale NGNP prototype high temperatures valves in operational environment (non-rad ops)
153	2.70	ΔPe 0.02; 2.60	2.60	2.60	2.60	2.60	2.60	ΔPe 0.02; 2.50
256	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36
184	3.58	ΔPe 0.10; 3.09	3.09	3.09	3.09	3.09	3.09	ΔPe 0.07; 2.74
187	3.58	ΔPe 0.10; 3.09	3.09	3.09	3.09	3.09	3.09	ΔPe 0.07; 2.74
152	2.08	ΔPe 0.02; 2.03	2.03	2.03	2.03	2.03	2.03	ΔPe 0.02; 1.98
154	1.53	ΔPe 0.02; 1.48	1.48	1.48	1.48	1.48	1.48	ΔPe 0.02; 1.43
151	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
186	1.83	ΔPe 0.10; 1.58	1.58	1.58	1.58	1.58	1.58	ΔPe 0.07; 1.40
155	1.55	ΔPe 0.02; 1.50	1.50	1.50	ΔPe 0.01; 1.48	1.48	1.48	ΔPe 0.02; 1.43
255	2.50	2.50	ΔPe 0.15; 2.13	2.13	2.13	2.13	2.13	2.13
%	0.00%	12.96%	3.29%	0.00%	0.22%	0.00%	0.00%	9.73%
Total	0.00	1.48	0.38	0.00	0.02	0.00	0.00	1.11

Total: 11.40

Legend : Risk Reduced / Unreduced

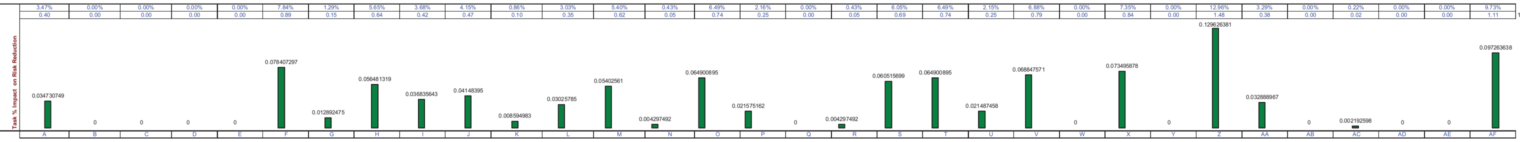


Figure A-13. PRAT matrix for the High Temperature Valves

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology / Component / Subsystem / System / Plant

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Legend: Risk Reduced / Risk Not

MIXING CHAMBER RISK REDUCTION TASKS

Tasks (TRL 6-7: A–R; TRL 7-8: S–U):
- A – Establish suppliers availability
- B – Evaluate existing industrial capability
- C – Determine required added industrial capability for each design
- D – Perform RAMI analysis for each design
- E – Perform supporting plant level analysis
- F – Perform safety & Investment protection analysis for each design
- G – Evaluate risk of PC contamination or PC release for each design
- H – Perform comparison of each design cost & impact on plant schedule
- I – Perform Trade Studies
- J – Select Suppliers
- K – Perform supporting single effects tests
- L – Finalize full-scale integrated conceptual design
- M – Identify test requirements, design test facility
- N – Fabricate Pilot Scale Mixing Chamber
- O – Test mixing chamber in test facility (Pilot Scale)
- P – Adjust design (if needed) using test results
- Q – Verify acoustic loads
- R – Develop final design for NGNP prototype Mixing Chamber
- S – Fabricate NGNP Mixing Chamber
- T – Test and qualify full scale NGNP prototype mixing chamber in integrated operational environment
- U – Verify acoustic loads

Each task cell has ΔC, ΔPc and ΔPe sub-cells; the delta printed under ΔPe (where any) and the resulting risk score are given.

ID	MIXING CHAMBER TECHNICAL RISKS	C	Pc	Pe	Baseline	Risk Score After Task Completion	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Risk % Reduction	Unreduced Risk %
259	Technology Development Collaboration - INL/EXT-05 - 00952(PLN-2489) Revision 3	3.00	1.00	0.90	2.70	1.49	2.70	2.70	2.70	ΔPe 0.07; 2.51	2.51	ΔPe 0.05; 2.38	2.38	ΔPe 0.03; 2.30	2.30	ΔPe 0.05; 2.16	ΔPe 0.05; 2.03	ΔPe 0.10; 1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	ΔPe 0.10; 1.49	1.49	63%	37%
260	Design and Material Stress Issues - INL/EXT- 07-12967 Revision 1	3.00	1.00	0.80	2.40	1.63	2.40	2.40	2.40	ΔPe 0.05; 2.28	2.28	ΔPe 0.10; 2.04	2.04	2.04	2.04	2.04	ΔPe 0.05; 1.92	1.92	1.92	1.92	ΔPe 0.05; 1.80	1.80	ΔPe 0.05; 1.68	1.68	1.68	ΔPe 0.02; 1.63	1.63	32%	68%
261	Inspection of Thick Sections and Weldments - INL/EXT - 08-15148	3.00	1.00	0.70	2.10	2.06	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	ΔPe 0.02; 2.06	2.06	2%	98%
145	Potential Acoustic or Flow Vibration in Mixing Chamber- TDRM_01_09	3.00	1.00	0.60	1.80	0.83	1.80	1.80	1.80	ΔPe 0.15; 1.53	1.53	1.53	1.53	1.53	1.53	1.53	ΔPe 0.05; 1.44	ΔPe 0.03; 1.39	1.39	1.39	ΔPe 0.10; 1.21	1.21	ΔPe 0.15; 0.94	ΔPe 0.03; 0.88	0.88	ΔPe 0.03; 0.83	0.83	54%	46%
144	Potential Inefficiency of Mixing Chamber - TDRM doc_01_09 or INL/EXT - 08 - 15148	3.00	1.00	0.50	1.50	0.95	1.50	ΔPe 0.07; 1.40	1.40	ΔPe 0.05; 1.32	ΔPe 0.05; 1.25	1.25	1.25	1.25	1.25	1.25	ΔPe 0.05; 1.17	1.17	ΔPe 0.05; 1.10	1.10	ΔPe 0.10; 0.95	0.95	0.95	0.95	0.95	0.95	0.95	37%	63%
262	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07- 12967	3.00	1.00	0.40	1.20	1.09	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	ΔPe 0.07; 1.12	1.12	1.12	ΔPe 0.02; 1.09	1.09	9%	91%

	Score	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Baseline-Average RVI Risk Score	1.95	0.00%	2.87%	0.00%	17.87%	2.05%	10.25%	0.00%	2.21%	0.00%	3.69%	11.48%	8.85%	2.05%	0.00%	12.30%	0.00%	12.95%	1.48%	0.00%	11.97%	0.00%
Average RVI Risk Score after Task Completion	1.15	0.00	0.11	0.00	0.65	0.08	0.38	0.00	0.08	0.00	0.14	0.42	0.32	0.08	0.00	0.45	0.00	0.47	0.05	0.00	0.44	0.00

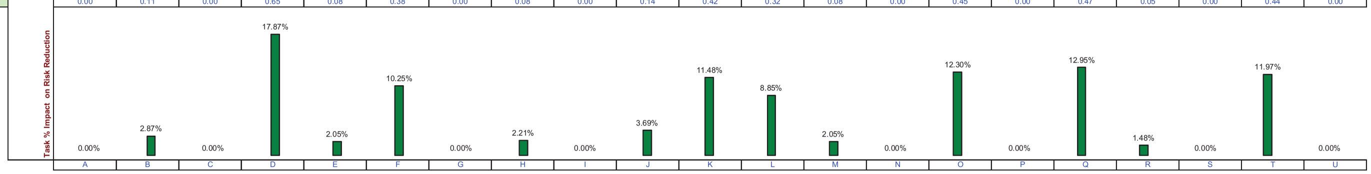

Figure A-14. PRAT matrix for the Mixing Chamber

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.5	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology – Component – Subsystem – System – Plant

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HPS - HTE RISK REDUCTION TASKS

Task	Description	TRL
A	Perform twenty 10x10 cm longterm degradation tests	TRL 4-5
B	Analyze cell degradation mechanisms	TRL 4-5
C	Test NASA cells	TRL 4-5
D	Test St. Gobain cells	TRL 4-5
E	Validate Recuperator performance	TRL 4-5
F	Validate sweepgas/oxygen Handling performance	TRL 4-5
G	Validate Hydrogen Recycle performance	TRL 4-5
H	Perform 5000hr cell test with less than 10% degradation per 1000hrs	TRL 5-6
I	Demonstrate heat and pressure management systems at 3 MPa	TRL 5-6
J	Demonstrate gas management systems at 3MPa	TRL 5-6
K	Demonstrate I&C systems at 3 Mpa	TRL 5-6
L	Perform 10,000 hr cell test with less than 5% degradation per 1000 hrs	TRL 6-7
M	Demonstrate heat and pressure management systems at 5Mpa	TRL 6-7
N	Demonstrate Tritium Detection and Removal	TRL 6-7
O	Develop and use System Model (analytical model)	TRL 7-8
P	Perform 20,000 hr cell test with less than 5% degradation per 1000hrs	TRL 8-9

Each task column is divided into ΔC, ΔPc and ΔPe sub-columns. The ΔC and ΔPc cells are empty for every risk, so the task columns below give only the ΔPe entries.

ΔPe by task

ID	HPS - HTE TECHNICAL RISKS	C	Pc	Pe	Baseline	Risk Score After Task Completion	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Risk % Reduction	Unreduced Risk %
273	Tritium Migration - et al.	9.00	1.00	0.90	8.10	4.05														0.50			50%	50%
275	I&C for HPS Environment -INL/EXT-05-00952(PLN-2489 Rev 3)	9.00	1.00	0.90	8.10	2.84											0.15			0.20	0.15	0.15	65%	35%
277	Integrity of Manifolds, Seals, Valves in H.T.E Environment - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	2.55									0.12	0.12			0.12			0.12	48%	52%
278	Personnel Safety Within HPS Boundaries- INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	2.60									0.15	0.12			0.20				47%	53%
280	Reactor I&C and HPS I&C Interaction - INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	2.84								0.10	0.15	0.12					0.05		42%	58%
150	Pressure Impact and Control in H.T.E-TDRM doc_01_09	3.00	1.00	0.30	0.90	0.51								0.05	0.20	0.15					0.03		43%	57%
190	H.T.E Process Efficiency - INL/EXT - 08 - 15151	3.00	1.00	0.30	0.90	0.12					0.10	0.10	0.10	0.05	0.10	0.10		0.05	0.10	0.10	0.02	0.05	87%	13%
149	Degradation of Cell in H.T.E Environment-TDRM doc_01_09	3.00	1.00	0.30	0.90	0.20	0.08	0.08	0.10	0.10				0.15				0.12				0.15	78%	22%
281	Effect of Chemical Releases Outside HPS - NUREG/CR-6944 NGNP Process Heat & Hydrogen Cogeneration (NGNP PIRT VOL.6)	3.00	1.00	0.30	0.90	0.50									0.10	0.10			0.15			0.10	45%	55%

Risk score after each task

ID	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
273	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	4.05	4.05	4.05
275	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	6.89	6.89	6.89	5.27	4.05	2.84
277	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.31	3.72	3.72	3.72	3.14	3.14	3.14	2.55
278	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.17	3.58	3.58	3.58	2.60	2.60	2.60	2.60
280	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.41	3.68	3.09	3.09	3.09	3.09	3.09	2.84	2.84
150	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.86	0.68	0.54	0.54	0.54	0.54	0.54	0.51	0.51
190	0.90	0.90	0.90	0.90	0.81	0.72	0.63	0.59	0.50	0.41	0.41	0.36	0.27	0.18	0.16	0.12
149	0.83	0.76	0.67	0.58	0.58	0.58	0.58	0.44	0.44	0.44	0.44	0.33	0.33	0.33	0.33	0.20
281	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.81	0.72	0.72	0.72	0.59	0.59	0.59	0.50

	Value	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Baseline-Average RVI Risk Score	2.23	0.39%	0.39%	0.49%	0.49%	0.49%	0.49%	0.49%	3.91%	13.21%	11.36%	6.64%	0.84%	9.80%	31.47%	8.22%	11.32%
Average RVI Risk Score after Task Completion	0.97	0.07	0.07	0.09	0.09	0.09	0.09	0.09	0.71	2.42	2.08	1.22	0.15	1.79	5.76	1.51	2.07

Legend : Risk Reduced / Unreduced Risk

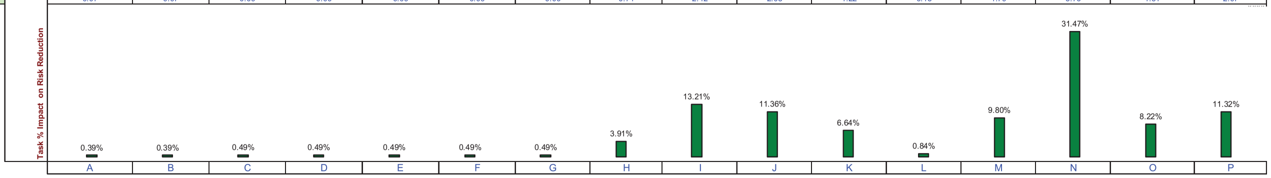

Figure A-15. PRAT matrix for the High Temperature Electrolysis Hydrogen Production System

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology — Component — Subsystem — System — Plant

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Legend: Risk Reduced

HPS - SI RISK REDUCTION TASKS

Col	Group	Task	TRL
A	Acid Decomposer	Test SI Bayonet Decomposer	TRL 3-4
B	Bunsen Reactor	Demonstrate bunsen section at prototypical scale	TRL 4-5
C	Reactive Distillation	Verify the assumed and extrapolated data	TRL 4-5
D	Reactive Distillation	Test Reactive Distillation (ILS)	TRL 4-5
E	Integrated System	Design and construct ILS experiment	TRL 4-5
F	Integrated System	Operate ILS Test	TRL 4-5
G	Integrated System	Modeling	TRL 4-5
H	Integrated System	Optimize Bayonet Decomposer design	TRL 5-6
I	Integrated System	Verify catalyst life	TRL 5-6
J	Integrated System	Demonstrate multi-tube bayonet decomposer	TRL 5-6
K	Integrated System	Demonstrate He-heated acid decomposer	TRL 5-6
L	Integrated System	Demonstrate He-heated acid decomposer	TRL 5-6
M	Integrated System	Design and fabricate pilot plant	TRL 5-6
N	Integrated System	Test pilot Plant 70 kW	TRL 5-6
O	Integrated System	Design and fabricate engineering scale plant with pilot of manufacturing process	TRL 6-7
P	Integrated System	Test engineering scale (1.5MW) inrelevant environment with transient testing	TRL 6-7
Q	Integrated System	Develop and verify Tritium mitigation	TRL 7-8
R	Integrated System	Design and fabricate NGNP decomposition SI plant	TRL 7-8
S	Integrated System	Test prototype : 15 MW	TRL 7-8

ID	HPS - SI TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	BASELINE Score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk %
274	I&C for HPS Environment -INL/EXT-05-00952(PLN-2489 Rev 3)	5.00	1.00	0.50	2.50	0.25	90%	10%
199	Materials Longevity in High Temperature Corrosive Environment - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	0.49	90%	10%
57	Bunsen Reactor not successful at prototypical scale - Mike Patterson	9.00	1.00	0.50	4.50	1.13	75%	25%
59	Process cross contamination - Charles Park, et al.	5.00	1.00	0.40	2.00	0.80	60%	40%
279	Reactor I&C and HPS Interaction - INEEL/EXT-04-01816	5.00	1.00	0.70	3.50	0.70	80%	20%
196	Hydrogen Quality - INEEL/EXT-04-01816,INL/EXT - 08 -15148	7.00	1.00	0.50	3.50	1.40	60%	40%
147	Unsuccessful Reactive Distillation in SI Environment-TDRM doc_01_09	9.00	1.00	0.50	4.50	0.68	85%	15%
193	Process Efficiency of Hydrogen Production System - INL/EXT - 08 - 15148	5.00	1.00	0.50	2.50	0.75	70%	30%
115	Effect of Chemical Releases Outside HPS (Accident Conditions) - NUREG/CR-6944 NGNP Process Heat & Hydrogen Cogeneration (NGNP PIRT VOL.6)	5.00	1.00	0.50	2.50	0.75	70%	30%
276	Integrity of Seals, Manifolds, Valves, Gaskets in SI Environment	7.00	1.00	0.50	3.50	0.35	90%	10%
121	Tritium Migration -et al.	5.00	1.00	0.50	2.50	0.38	85%	15%

ΔPe per task (ΔC and ΔPc cells are empty)

ID	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
274	0.05	0.05	0.05	0.10	0.05	0.05	0.05			0.05	0.05		0.05	0.05	0.05	0.10		0.05	0.10
199	0.10	0.10		0.10		0.05		0.05		0.05	0.10	0.10		0.10		0.10			0.05
57		0.35				0.10								0.10		0.10			0.10
59		0.50		0.10															
279	0.05					0.05	0.10	0.05		0.15	0.10	0.10		0.15		0.05			0.05
196		0.10	0.10	0.10										0.10		0.10			0.10
147			0.30	0.40										0.05		0.05			0.05
193	0.05	0.05	0.05	0.05			0.10	0.05	0.05	0.10	0.10			0.10		0.05			0.05
115	0.05			0.05		0.05	0.05	0.05		0.10	0.05	0.05		0.10		0.10			0.10
276	0.03	0.03			0.03	0.03	0.03	0.03		0.20	0.10	0.30	0.03		0.03	0.03		0.03	0.03
121							0.20							0.10			0.35		0.20

Risk score after each task

ID	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
274	2.38	2.25	2.13	1.88	1.75	1.63	1.50	1.50	1.50	1.38	1.25	1.25	1.13	1.00	0.88	0.63	0.63	0.50	0.25
199	4.41	3.92	3.92	3.43	3.43	3.19	3.19	2.94	2.94	2.70	2.21	1.72	1.72	1.23	1.23	0.74	0.74	0.74	0.49
57	4.50	2.93	2.93	2.93	2.93	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.03	2.03	1.58	1.58	1.58	1.13
59	2.00	1.00	1.00	0.80	0.80	0.80	0.80	0.00	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
279	3.33	3.33	3.33	3.33	3.33	3.15	2.80	2.63	2.63	2.28	1.93	1.58	1.58	1.05	1.05	0.88	0.88	0.88	0.70
196	3.50	3.15	2.80	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.10	2.10	1.75	1.75	1.75	1.40
147	4.50	4.50	3.15	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.13	1.13	0.90	0.90	0.90	0.68
193	2.38	2.25	2.13	2.00	2.00	2.00	1.75	1.63	1.50	1.50	1.25	1.25	1.25	1.00	1.00	0.88	0.88	0.88	0.75
115	2.38	2.38	2.38	2.25	2.25	2.13	2.00	1.88	1.88	1.75	1.63	1.50	1.50	1.25	1.25	1.00	1.00	1.00	0.75
276	3.40	3.29	3.29	3.29	3.19	3.08	2.98	2.87	2.87	2.28	1.93	0.88	0.77	0.77	0.67	0.56	0.56	0.46	0.35
121	2.50	2.50	2.50	2.50	2.50	2.50	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.75	1.75	1.75	0.88	0.88	0.38

	Score	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Baseline-Average RVI Risk Score	3.31	3.76%	12.39%	6.41%	10.97%	0.76%	4.02%	4.78%	5.17%	0.41%	7.69%	5.55%	6.62%	0.76%	9.58%	0.76%	7.95%	2.87%	0.76%	8.79%
Average RVI Risk Score after Task Completion	0.70	1.15	3.77	1.95	3.34	0.23	1.23	1.46	1.58	0.13	2.34	1.69	2.02	0.23	2.92	0.23	2.42	0.88	0.23	2.68

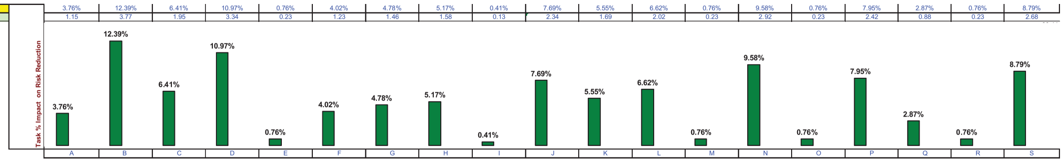

Figure A-16. PRAT matrix for the Sulfur-Iodine Hydrogen Production System

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.3	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels: 1 Basic Principle; 2 Application Formulated; 3 Proof of Concept; 4 Bench Scale; 5 Experimental Scale; 6 Pilot Scale; 7 Engineering Scale; 8 Prototype; 9 Plant Operational; 10 Commercial scale (Technology, Component, Subsystem, System, Plant)

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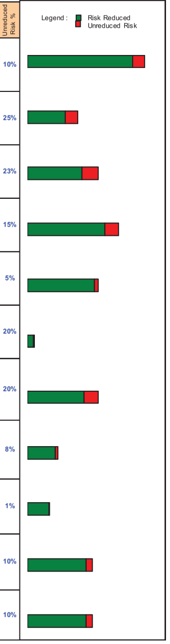
HPS - HyS RISK REDUCTION TASKS

Task	Group	Description	TRL
A	Electrolyzer	Multi-cell Stack Testing	TRL 2-3
B	Electrolyzer	Single cell testing at 100 celcius,10 atm	TRL 3-4
C	Electrolyzer	Baseline Electrolyzer Component Development	TRL 3-4
D	Electrolyzer	Design and construct 200L/h ILS electrolyzer(170 cm2)	TRL 4-5
E	Electrolyzer	Further development and optimize SDE performance	TRL 4-5
F	Electrolyzer	Scale -up to 400cm2 cell active area	TRL 5-6
G	Electrolyzer	Scale -up to 1000cm2 cell active area	TRL 6-7
H	Electrolyzer	Scale -up to 10,000cm2 cell active area	TRL 7-8
I	Acid Decomposer	Test SI Bayonet Decomposer	TRL 3-4
J	Acid Decomposer	Optimize Bayonet Decomposer design	TRL 3-4
K	Acid Decomposer	Verify catalyst life is consistent with duration of Acid Decomposer	TRL 4-5
L	Integrated System	Design and construct HyS ILS Experiment	TRL 3-4
M	Integrated System	Operate HyS ILS Experiment	TRL 4-5
N	Integrated System	Develop and use system model (analytical model)	TRL 5-6
O	Integrated System	Demonstrate multi-tube bayonet decomposer	TRL 5-6
P	Integrated System	Demonstrate He-heated acid decomposer (1 tube full scale)	TRL 5-6
Q	Integrated System	Verify reference seal design	TRL 5-6
R	Integrated System	Design and construct HyS 300 kW Pilot plant	TRL 5-6
S	Integrated System	Operate HyS 300 kW Pilot Plant	TRL 5-6
T	Integrated System	Demonstrate I&C systems	TRL 5-6
U	Integrated System	Design and construct HyS Eng Scale Demo	TRL 6-7
V	Integrated System	Operate integrated HySEng Scale Demo(5 tubes)	TRL 6-7
W	Integrated System	Test prototype HyS Demo (19 tubes)	TRL 7-8
X	Integrated System	Design and Construct NGNP HPS	TRL 7-8

Each task cell below gives the risk score after the task; Δ values (ΔC, ΔPc, ΔPe) printed for the task are shown in parentheses.

ID	HPS - HyS TECHNICAL RISKS	Baseline C	Baseline Pc	Baseline Pe	Baseline score	Risk Score After Task Completion	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Risk % Reduction	Unreduced Risk %
14	Hydrogen Production Accident Conditions (Chemical Releases H2S04, S02 etc) - INL/EXT-07-12967, NUREG/CR-6944 NGNP Process Heat & Hydrogen Cogeneration (NGNP PIRT VOL.6)	9.00	1.00	0.90	8.10	0.81	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	7.70 (ΔPe 0.05)	7.29 (ΔPe 0.05)	7.29	7.29	7.29	6.48 (ΔPe 0.10)	6.48 (ΔPe 0.10)	6.08 (ΔPe 0.05)	5.67 (ΔPe 0.05)	5.67	4.86 (ΔPe 0.10)	4.05 (ΔPe 0.10)	4.05	1.22 (ΔPe 0.35)	0.81 (ΔPe 0.05)	0.81	90%	10%
55	I&C for HPS Environment -INL/EXT-05-00952(PLN-2489 Rev 3)	7.00	1.00	0.50	3.50	0.88	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.33 (ΔPe 0.05)	3.33	3.33	3.33	2.98 (ΔPe 0.10)	2.28 (ΔPe 0.20)	2.80 (ΔPe 0.05)	2.45 (ΔPe 0.10)	2.45	2.45	2.28 (ΔPe 0.05)	1.93 (ΔPe 0.10)	1.58 (ΔPe 0.10)	1.23 (ΔPe 0.10)	0.88 (ΔPe 0.10)	0.88	75%	25%
198	Integrity of Manifolds, Seals, Valves in Hybrid Sulfur Environment - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	1.12	4.90	4.90	4.90	4.66 (ΔC 0.05)	4.66	4.66	4.66	4.66	4.42 (ΔPe 0.05)	4.19 (ΔPe 0.05)	4.19	3.96 (ΔPe 0.05)	3.72 (ΔPe 0.05)	3.72	3.03 (ΔPe 0.15)	2.70 (ΔPe 0.07)	2.56 (ΔPe 0.03)	2.33 (ΔPe 0.05)	2.00 (ΔPe 0.07)	2.00	1.77 (ΔPe 0.05)	1.44 (ΔPe 0.07)	1.12 (ΔPe 0.07)	0.98 (ΔPe 0.03)	77%	23%
196	Sulfur Accumulation in MEA Electrode Assembly - INL/EXT - 08 - 15148	7.00	1.00	0.90	6.30	0.94	5.99 (ΔPe 0.05)	4.73 (ΔPe 0.20)	4.41 (ΔPe 0.05)	4.41	3.78 (ΔPe 0.10)	3.47 (ΔPe 0.05)	3.15 (ΔPe 0.05)	2.84 (ΔPe 0.05)	2.84	2.84	2.84	2.84	1.89 (ΔPe 0.15)	1.89	1.89	1.89	1.89	1.89	1.58 (ΔPe 0.05)	1.58	1.58	1.26 (ΔPe 0.05)	0.94 (ΔPe 0.05)	0.94	85%	15%
199	Materials Longevity in High Temperature or Corrosive Environment - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	0.25	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.41 (ΔPe 0.10)	4.17 (ΔPe 0.05)	4.17	4.17	3.68 (ΔPe 0.10)	3.68	3.19 (ΔPe 0.10)	2.70 (ΔPe 0.10)	2.21 (ΔPe 0.10)	1.96 (ΔPe 0.05)	1.47 (ΔPe 0.10)	1.47	1.23 (ΔPe 0.05)	0.74 (ΔPe 0.10)	0.25 (ΔPe 0.10)	0.00 (ΔPe 0.05)	95%	5%
61	Hydrogen Purity - INEEL/EXT-04-01816,INL/EXT - 08 -15148	5.00	1.00	0.10	0.50	0.10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40 (ΔPe 0.20)	0.40	0.40	0.40	0.40	0.40	0.30 (ΔPe 0.20)	0.30	0.30	0.20 (ΔPe 0.20)	0.10 (ΔPe 0.20)	0.10	80%	20%
59	Electrolyzer Longevity - Charles Park, et al.	7.00	1.00	0.70	4.90	0.98	4.66 (ΔPe 0.05)	3.92 (ΔPe 0.15)	3.92	3.92	3.92	3.68 (ΔPe 0.05)	3.43 (ΔPe 0.05)	3.19 (ΔPe 0.05)	3.19	3.19	3.19	3.19	2.45 (ΔPe 0.15)	2.45	2.45	2.45	2.45	2.45	1.96 (ΔPe 0.10)	1.96	1.96	1.47 (ΔPe 0.10)	0.98 (ΔPe 0.10)	0.98	80%	20%
60	Reactor I&C and HPS I&C Interaction - INEEL/EXT-04-01816	7.00	1.00	0.30	2.10	0.17	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.00 (ΔPe 0.05)	1.89 (ΔPe 0.05)	1.89	1.89	1.89	1.89	1.74 (ΔPe 0.07)	1.53 (ΔPe 0.10)	1.32 (ΔPe 0.10)	1.32	1.11 (ΔPe 0.10)	0.90 (ΔPe 0.10)	0.90	0.69 (ΔPe 0.10)	0.17 (ΔPe 0.25)	0.17	92%	8%
201	Process Efficiency of Hydrogen Production System - INL/EXT - 08 - 15148	5.00	1.00	0.30	1.50	0.02	1.44 (ΔPe 0.04)	1.31 (ΔPe 0.09)	1.31	1.31	1.25 (ΔPe 0.04)	1.19 (ΔPe 0.04)	1.13 (ΔPe 0.04)	1.07 (ΔPe 0.04)	1.01 (ΔPe 0.04)	0.95 (ΔPe 0.04)	0.89 (ΔPe 0.04)	0.83 (ΔPe 0.04)	0.69 (ΔPe 0.09)	0.69	0.56 (ΔPe 0.09)	0.42 (ΔPe 0.09)	0.42	0.42	0.29 (ΔPe 0.09)	0.29	0.29	0.15 (ΔPe 0.09)	0.02 (ΔPe 0.09)	0.02	99%	1%
272	Tritium Migration- et al.	9.00	1.00	0.50	4.50	0.45	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	3.15 (ΔPe 0.30)	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	0.45 (ΔPe 0.60)	0.45	90%	10%
282	Longevity of Catalyst Decomposer	5.00	1.00	0.90	4.50	0.45	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	2.03 (ΔPe 0.55)	2.03	2.03	2.03	2.03	2.03	2.03	2.03	1.35 (ΔPe 0.15)	1.35	1.35	0.68 (ΔPe 0.15)	0.45 (ΔPe 0.05)	0.45	90%	10%
	Baseline-Average RVI Risk Score				4.15		1.57%	5.39%	0.80%	0.62%	1.74%	1.57%	1.57%	1.57%	3.71%	2.65%	6.41%	0.74%	10.97%	3.82%	2.39%	4.84%	3.15%	1.21%	9.42%	3.46%	2.09%	14.99%	15.33%	0.97%	100%	
	Average RVI Risk Score after Task Completion				0.56		0.62	2.13	0.32	0.24	0.69	0.62	0.62	0.62	1.47	1.05	2.54	0.29	4.34	1.51	0.95	1.92	1.24	0.48	3.73	1.37	0.83	5.93	6.06	0.38	39.54	



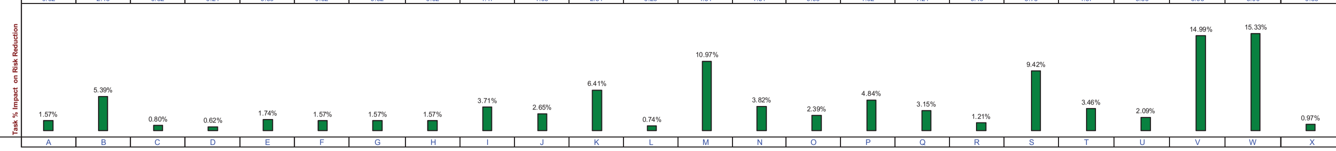


Figure A-17. PRAT matrix for the Hybrid-Sulfur Hydrogen Production System

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale

Technology – Component – Subsystem – System – Plant

STEAM GENERATOR RISK REDUCTION TASKS

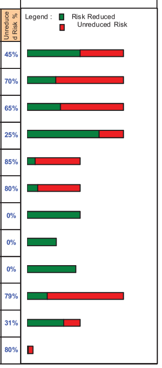
Task	Group	TRL	Task description
A		TRL 4-5	Perform Trade Studies
B		TRL 4-5	Structural Tests of Materials
C	Computer Modeling	TRL 4-5	Thermal Sizing
D	Computer Modeling	TRL 4-5	Evaluate Steady state pressure drop
E	Computer Modeling	TRL 4-5	Structural Evaluation of tubes and supports
F		TRL 5-6	Demonstrate manufacturability
G		TRL 5-6	Bimetallic Weld Qualification
H	Test Steam Generator	TRL 5-6	Test Coil bundles under various transient conditions
I	Test Steam Generator	TRL 5-6	Establish lead-in/lead-out, transition lead expansion & assembly room
J	Test Steam Generator	TRL 5-6	Select / design tube support & wear protection
K	Test Steam Generator	TRL 5-6	Test ability to assemble steam generator
L	Test Steam Generator	TRL 5-6	Verify mechanical/thermal characteristics
M		TRL 5-6	Test flows and flow controls
N		TRL 5-6	Size inlet and verify pressure drop characteristics
O		TRL 5-6	Further develop manufacturing techniques
P		TRL 5-6	Select Suppliers
Q		TRL 6-7	Fabricate Engineering Scale Steam Generator
R	Engineering Scale Steam Generator Integrated testing	TRL 6-7	Confirm thermal hydraulic performance and verify code
S	Engineering Scale Steam Generator Integrated testing	TRL 6-7	Confirm flow stability
T	Engineering Scale Steam Generator Integrated testing	TRL 6-7	Estimate flow induced vibration
U	Engineering Scale Steam Generator Integrated testing	TRL 6-7	Evaluate effect of water quality on scale buildup
V	Engineering Scale Steam Generator Integrated testing	TRL 6-7	Perform seal and weld performance tests
W	Engineering Scale Steam Generator Integrated testing	TRL 6-7	Evaluate in-service inspection methods
X		TRL 6-7	Fabricate NGNP Steam Generator
Y	Test and qualify full scale NGNP prototype SG in operational environment	TRL 7-8	Confirm maintenance and inspection methods

ID	STEAM GENERATOR TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	BASELINE score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk %
146	Corrosion and Wear Issues in SG - TDRM doc_01_09	7.00	1.00	0.70	4.90	2.18	55%	45%
203	High Pressure Seal Performance in SG - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	3.43	30%	70%
23	Fouling or Plugging in SG - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	3.19	35%	65%
265	RAMI of Steam Generator- et al	7.00	1.00	0.70	4.90	1.23	75%	25%
62	Alloy 617 Code Case (52Ni-22Cr-13Co-9Mo) - INL PLN-2674	3.00	1.00	0.90	2.70	2.30	15%	85%
270	Effect of Reactor Temperature Transients on SG - et al	3.00	1.00	0.90	2.70	2.16	20%	80%
269	Tube Rupture in Steam Generator - et al	3.00	1.00	0.90	2.70	0.00	100%	0%
15	Product Steam Contamination - INL/EXT- 05 - 00952 (PLN-2489) Revision 3	3.00	1.00	0.50	1.50	0.00	100%	0%
266	Failure Mechanisms for Design Criteria - Creep - Fatigue - INL PLN-2674	5.00	1.00	0.50	2.50	0.00	100%	0%
271	Instrmentation and Control - ITRG INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	3.87	21%	79%
267	Pursue Alloys 617 and 230 in Thin Product Form (small grain sizes)- INL PLN-2674	3.00	1.00	0.90	2.70	0.84	69%	31%
268	Tritium Migration - Phil Mills, et al.	1.00	1.00	0.30	0.30	0.24	20%	80%
	Baseline-Average RVI Risk Score				3.30			
	Average RVI Risk Score after Task Completion				1.62			

Each task column has ΔC / ΔPc / ΔPe sub-cells. Any printed delta is shown in brackets after the risk score.

ID	A	B	C	D	E	F	G	H	I	J	K	L	M
146	4.66 (ΔPe 0.05)	4.41 (ΔPe 0.05)	4.41	4.17 (ΔPe 0.05)	4.17	4.17	3.68 (ΔPe 0.10)	3.68	3.68	2.98 (ΔC 0.10, ΔPc 0.10)	2.98	2.98	2.78 (ΔPe 0.05)
203	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
23	4.66 (ΔPe 0.05)	4.66	4.66	4.17 (ΔPe 0.10)	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	3.92 (ΔPe 0.05)
265	4.75 (ΔPe 0.03)	4.61 (ΔPe 0.03)	4.46 (ΔPe 0.03)	4.31 (ΔPe 0.03)	4.17 (ΔPe 0.03)	4.02 (ΔPe 0.03)	3.87 (ΔPe 0.03)	3.72 (ΔPe 0.03)	3.58 (ΔPe 0.03)	3.43 (ΔPe 0.03)	3.28 (ΔPe 0.03)	3.14 (ΔPe 0.03)	2.99 (ΔPe 0.03)
62	2.70	2.57 (ΔPe 0.05)	2.57	2.57	2.57	2.57	2.43 (ΔPe 0.05)	2.43	2.43	2.43	2.43	2.30 (ΔPe 0.05)	2.30
270	2.65 (ΔPe 0.02)	2.59 (ΔPe 0.02)	2.46 (ΔPe 0.05)	2.46	2.46	2.46	2.40 (ΔPe 0.02)	2.35 (ΔPe 0.02)	2.35	2.35	2.35	2.35	2.30 (ΔPe 0.02)
269	2.57 (ΔPe 0.05)	0.00 (ΔPe 0.05)	0.00	0.00	0.00	0.00	0.00 (ΔPe 0.15)	0.00 (ΔPe 0.05)	0.00	0.00 (ΔPe 0.15)	0.00	0.00 (ΔPe 0.05)	0.00
15	1.43 (ΔPe 0.05)	0.00	0.00	0.00	0.00	0.00	0.00 (ΔPe 0.10)	0.00	0.00	0.00	0.00	0.00	0.00
266	2.50	0.00	0.00 (ΔPe 0.03)	0.00 (ΔPe 0.03)	0.00 (ΔPe 0.03)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
271	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.17 (ΔPe 0.15)
267	2.70	2.65 (ΔPe 0.02)	2.65	2.65	2.65	2.38 (ΔPe 0.10)	2.19 (ΔPe 0.07)	2.19	2.19	2.19	1.78 (ΔPe 0.15)	1.78	1.78
268	0.30	0.30	0.30	0.30	0.30	0.30	0.27 (ΔPe 0.10)	0.27	0.27	0.27	0.27	0.27	0.27
Task %	4.47%	35.32%	1.40%	4.37%	0.73%	2.07%	5.18%	1.00%	0.73%	4.19%	2.74%	1.40%	6.84%
Task value	0.90	7.13	0.28	0.88	0.15	0.42	1.05	0.20	0.15	0.85	0.55	0.28	1.38

ID	N	O	P	Q	R	S	T	U	V	W	X	Y
146	2.78	2.78	2.78	2.78	2.58 (ΔPe 0.05)	2.58	2.18 (ΔPe 0.10)	2.18	2.18	2.18	2.18	2.18
203	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	3.43 (ΔPe 0.30)	3.43	3.43	3.43
23	3.92	3.92	3.92	3.92	3.68 (ΔPe 0.05)	3.68	3.68	3.19 (ΔPe 0.10)	3.19	3.19	3.19	3.19
265	2.84 (ΔPe 0.03)	2.70 (ΔPe 0.03)	2.55 (ΔPe 0.03)	2.40 (ΔPe 0.03)	2.25 (ΔPe 0.03)	2.11 (ΔPe 0.03)	1.96 (ΔPe 0.03)	1.81 (ΔPe 0.03)	1.67 (ΔPe 0.03)	1.52 (ΔPe 0.03)	1.37 (ΔPe 0.03)	1.23 (ΔPe 0.03)
62	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30
270	2.30	2.30	2.30	2.30	2.16 (ΔPe 0.05)	2.16	2.16	2.16	2.16	2.16	2.16	2.16
269	0.00 (ΔPe 0.05)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
266	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
271	4.17	4.17	4.17	4.17	4.17	3.92 (ΔPe 0.05)	3.87 (ΔPe 0.01)	3.87	3.87	3.87	3.87	3.87
267	1.78	1.51 (ΔPe 0.10)	1.51	1.51	1.11 (ΔPe 0.15)	1.11	1.11	1.11	0.97 (ΔPe 0.05)	0.97	0.97	0.84 (ΔPe 0.05)
268	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26 (ΔPe 0.03)	0.25 (ΔPe 0.05)	0.25	0.24 (ΔPe 0.02)
Task %	0.73%	2.07%	0.73%	0.73%	5.60%	1.94%	2.94%	3.16%	8.73%	0.80%	0.73%	1.43%
Task value	0.15	0.42	0.15	0.15	1.13	0.39	0.59	0.64	1.76	0.16	0.15	0.29



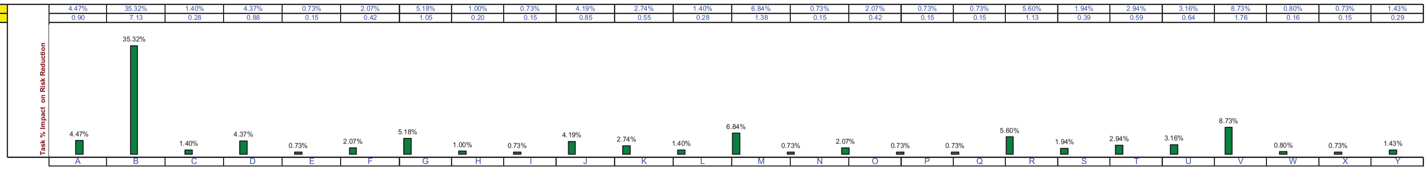


Figure A-18. PRAT matrix for the Steam Generator

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operational	Commercial scale
Technology		Component		Subsystem	System		Plant		

POWER CONVERSION SYSTEM RISK REDUCTION TASKS

ID	POWER CONVERSION SYSTEM - He TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	Baseline score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk %
25	Technology Development Collaboration - INL/EXT- 05 - 00952(PLN-2489) Revision 3	9.00	1.00	0.90	8.10	3.40	58%	42%
71	Turbine Compressor Blade/ Bypass leakage (FULL-SCALE TESTING)- INEEL/EXT- 04- 01816	7.00	1.00	0.70	4.90	3.63	26%	74%
156	Turbo Machinery - Titanium and Steel Embrittlement in Helium Environment - TDRM doc_01_09	7.00	1.00	0.70	4.90	2.94	40%	60%
180	High Pressure Seals and Bearing Performance - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	0.98	80%	20%
204	Corrosion and Wear in PCS and Electrical insulation - Equipment for Direct Combined Cycle - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	2.55	48%	52%
123	Development Challenges With NGNP Special Features - PLN-2489 (INL/MIS-08-14339) Revision 2	7.00	1.00	0.70	4.90	4.90	0%	100%
67	Isolated Pressure Valves For High and Low Temperatures Operations- INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	4.90	0%	100%
258	Instrumentation and Control Systems for PCS - et al.	7.00	1.00	0.70	4.90	3.19	35%	65%
259	Tritium Migration - et al.	3.00	1.00	0.90	2.70	2.30	15%	85%
260	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07- 12967	3.00	1.00	0.90	2.70	1.08	60%	40%
	Baseline-Average RVI Risk Score				4.78			
	Average RVI Risk Score after Task Completion				2.99			

Each task has ΔC, ΔPc and ΔPe sub-columns. Each cell below gives the risk score after the task, with any Δ value printed in that cell in parentheses.

Tasks A–E: Experimental Scale Generator Testing (TRL 4-5); F–J: Pilot Scale Generator Testing in He (TRL 5-6); K: Experimental Scale Turbine Testing (TRL 4-5)

ID	A Winding tests at operating pressures and temperatures	B Mechanical strength tests of electrical lead-outs	C Leak testing of electrical lead-outs	D Resistivity tests of electrical lead-outs	E Electrical strength tests of insulation	F Winding tests at operating pressures and temperatures	G Mechanical strength tests of electrical lead-outs	H Leak testing of electrical lead-outs	I Resistivity tests of electrical lead-outs	J Electrical strength tests of insulation	K Clearance tests between rotor & catcher bearings
25	7.94 (ΔPe 0.02)	7.94	7.94	7.94	7.94	7.78 (ΔPe 0.02)	7.78	7.78	7.78	7.78	7.78
71	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
156	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
180	4.90	4.90	4.80 (ΔPe 0.02)	4.80	4.80	4.80	4.80	4.70 (ΔPe 0.02)	4.70	4.70	4.61 (ΔPe 0.02)
204	4.90	4.90	4.90	4.90	4.80 (ΔPe 0.02)	4.80	4.80	4.80	4.80	4.70 (ΔPe 0.02)	4.36 (ΔPe 0.07)
123	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
67	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
258	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
259	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70
260	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70
%	0.90%	0.00%	0.55%	0.00%	0.55%	0.90%	0.00%	0.55%	0.00%	0.55%	2.46%
Impact	0.16	0.00	0.10	0.00	0.10	0.16	0.00	0.10	0.00	0.10	0.44

Tasks L–Q: Experimental Scale Turbine Testing (TRL 4-5); R–W: Pilot Scale Turbine Testing in He (TRL 5-6)

ID	L Performance tests of aerodynamics	M Performance tests of rotating seals	N Performance tests of EM bearings	O Verification tests of rotor dynamics and control	P Friction tests of catcher bearings	Q Helium Embrittlement tests of steel and titanium components	R Clearance tests between rotor & catcher bearings	S Performance tests of aerodynamics	T Performance tests of rotating seals	U Performance tests of EM bearings	V Verification tests of rotor dynamics and control	W Friction tests of catcher bearings
25	7.61 (ΔPe 0.02)	7.45 (ΔPe 0.02)	7.29 (ΔPe 0.02)	7.29	7.29	7.13 (ΔPe 0.02)	7.13	6.97 (ΔPe 0.02)	6.80 (ΔPe 0.02)	6.64 (ΔPe 0.02)	6.48 (ΔPe 0.02)	6.48
71	4.80 (ΔPe 0.02)	4.80	4.80	4.80	4.80	4.80	4.80	4.70 (ΔPe 0.02)	4.70	4.70	4.70	4.70
156	4.90	4.90	4.90	4.90	4.90	4.90	3.92 (ΔPe 0.20)	3.92	3.92	3.92	3.92	3.92
180	4.61	4.26 (ΔPe 0.07)	3.92 (ΔPe 0.07)	3.92	3.68 (ΔPe 0.05)	3.68	3.58 (ΔPe 0.02)	3.58	3.23 (ΔPe 0.07)	2.89 (ΔPe 0.07)	2.89	2.65 (ΔPe 0.05)
204	4.36	4.36	4.36	4.36	3.87 (ΔPe 0.10)	3.87	3.53 (ΔPe 0.07)	3.53	3.53	3.53	3.53	3.04 (ΔPe 0.10)
123	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
67	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
258	4.90	4.90	4.90	4.66 (ΔPe 0.05)	4.66	4.66	4.66	4.66	4.66	4.66	4.41 (ΔPe 0.05)	4.41
259	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70
260	2.70	2.70	2.70	2.30 (ΔPe 0.15)	2.30	2.30	2.30	2.30	2.30	2.30	1.89 (ΔPe 0.15)	1.89
%	1.45%	2.81%	2.81%	3.62%	4.10%	0.90%	7.92%	1.45%	2.81%	2.81%	4.53%	4.10%
Impact	0.26	0.50	0.51	0.65	0.74	0.16	1.42	0.26	0.51	0.51	0.81	0.74

Tasks X–Y: Experimental Scale Compressor Testing (TRL 4-5); Z–AA: Pilot Scale Compressor Testing in He (TRL 5-6); AB; AC–AD: Engineering Scale PCS Integrated Testing (TRL 6-7); AE; AF; AG–AI: Test and qualify full scale NGNP prototype PCS in Operational Environment (non-rad ops) (TRL 7-8)

ID	X He embrittlement tests of steel and titanium components	Y Verification tests of no self-welding	Z Suboptimal speed tests under operating conditions	AA Acoustic tests with non-excessive acoustic loads	AB Fabricate engineering scale Power Conversion System	AC Test Control software and instrumentation	AD Verification that PCS meets functional and performance requirements	AE Fabricate NGNP Power Conversion System	AF Verification that PCS meets functional and performance requirements at full scale	AG Confirm maintenance and inspection methods	AH Test control software,power,electronics and instrumentation	AI Design basis event testing
25	6.32 (ΔPe 0.02)	6.16 (ΔPe 0.02)	5.99 (ΔPe 0.02)	5.83 (ΔPe 0.02)	5.02 (ΔPe 0.10)	4.62 (ΔPe 0.05)	4.62	3.81 (ΔPe 0.10)	3.40 (ΔPe 0.05)	3.40	3.40	3.40
71	4.70	4.70	4.70	4.70	4.70	4.70	3.97 (ΔPe 0.15)	3.97	3.97	3.97	3.97	3.63 (ΔPe 0.07)
156	2.94 (ΔPe 0.20)	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94
180	2.65	2.55 (ΔPe 0.02)	2.45 (ΔPe 0.02)	2.45	2.45	2.45	1.96 (ΔPe 0.10)	1.96	1.47 (ΔPe 0.10)	1.47	1.47	0.98 (ΔPe 0.10)
204	3.04	3.04	3.04	2.55 (ΔPe 0.10)	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
123	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
67	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
258	4.41	4.41	4.41	4.41	4.41	3.68 (ΔPe 0.15)	3.68	3.68	3.68	3.68	3.19 (ΔPe 0.10)	3.19
259	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.57 (ΔPe 0.05)	2.30 (ΔPe 0.10)	2.30	2.30
260	1.89	1.49 (ΔPe 0.15)	1.49	1.49	1.49	1.49	1.22 (ΔPe 0.10)	1.22	1.08 (ΔPe 0.05)	1.08	1.08	1.08
%	6.36%	3.71%	1.45%	3.63%	4.51%	6.35%	8.33%	4.51%	6.49%	1.50%	2.73%	4.64%
Impact	1.14	0.67	0.26	0.65	0.81	1.14	1.50	0.81	1.17	0.27	0.49	0.83

Legend: Risk Reduced; Unreduced Risk

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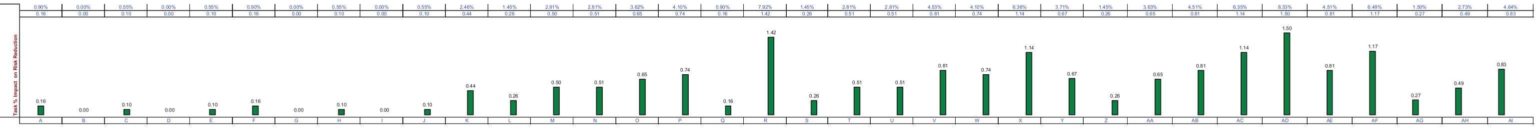

Figure A-19. PRAT matrix for the PCS Equipment for Direct Combined Cycle

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operations	Commercial scale

Technology – Component – Subsystem – System – Plant

FUEL HANDLING RISK REDUCTION TASKS

ID	FUEL HANDLING SYSYEM TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	BASELINE Risk Score	Risk Score After Task Completion	Risk % Reduction	Unreduced Risk %
257	Technology Development Collaboration - INL/EXT- 05 - 00952(PLN-2489) Revision 3	7.00	1.00	0.70	4.90	3.53	28%	72%
157	FHS - Contamination of Primary Coolant - TDRM doc	7.00	1.00	0.70	4.90	2.70	45%	55%
158	FHS - Performance of Seals, Bearings and Lubricants at High Temperatures - TDRM doc_01_09	7.00	1.00	0.70	4.90	2.06	58%	42%
291	Plant Control Systems - ITRG INEEL/EXT-04-01816	7.00	1.00	0.70	4.90	3.53	28%	72%
	Baseline-Average RVI Risk Score				4.90			
	Average RVI Risk Score after Task Completion				2.95			

Each risk row has sub-columns ΔC, ΔPc and ΔPe under every task, followed by the risk score after that task. Only the ΔPe values shown below are printed; all ΔC and ΔPc cells are empty.

Task	Description	Group	TRL	257 ΔPe	257 Score	157 ΔPe	157 Score	158 ΔPe	158 Score	291 ΔPe	291 Score	Task % Impact on Risk Reduction	Risk Score Reduction
A	Determine available suppliers	Experimental Scale Testing	TRL 4-5		4.90		4.90		4.90		4.90	0%	0.00
B	Electronic instrumentation tests	Experimental Scale Testing	TRL 4-5		4.90		4.90		4.90	0.05	4.66	3%	0.25
C	Viewing systems tests	Experimental Scale Testing	TRL 4-5		4.90		4.90		4.90		4.66	0%	0.00
D	Compatibility tests	Experimental Scale Testing	TRL 4-5		4.90		4.90		4.90		4.66	0%	0.00
E	Environmental Testing	Experimental Scale Testing	TRL 4-5		4.90	0.02	4.80	0.01	4.85		4.66	2%	0.15
F	Material qualification Testing	Experimental Scale Testing	TRL 4-5		4.90		4.80	0.01	4.80		4.66	1%	0.05
G	Functional Testing	Experimental Scale Testing	TRL 4-5		4.90	0.02	4.70	0.01	4.75		4.66	2%	0.15
H	Radiation Shielding Testing	Experimental Scale Testing	TRL 4-5		4.90		4.70	0.01	4.70		4.66	1%	0.05
I	Maintenance Testing	Experimental Scale Testing	TRL 4-5		4.90	0.07	4.36		4.70		4.66	4%	0.34
J	Packaging tests	Experimental Scale Testing	TRL 4-5		4.90		4.36		4.70		4.66	0%	0.00
K	Seal Testing	Experimental Scale Testing	TRL 4-5		4.90		4.36	0.10	4.21		4.66	6%	0.49
L	Inspection Testing	Experimental Scale Testing	TRL 4-5		4.90		4.36	0.01	4.17		4.66	1%	0.05
M	Verify acceptable performance over the range of expected operation		TRL 5-6		4.90		4.36	0.01	4.12		4.66	1%	0.05
N	Determine potential for degradation in He		TRL 5-6		4.90		4.36	0.07	3.77		4.66	4%	0.34
O	Determine performance as a function of temperature and time at temperature		TRL 5-6		4.90		4.36	0.01	3.72		4.66	1%	0.05
P	Determine mean time to failure		TRL 5-6		4.90		4.36	0.01	3.68		4.66	1%	0.05
Q	Determine component costs		TRL 5-6		4.90		4.36		3.68		4.66	0%	0.00
R	Determine component replacement time		TRL 5-6		4.90		4.36	0.01	3.63		4.66	1%	0.05
S	Determine lubricant release rates at temperature		TRL 5-6		4.90	0.01	4.31	0.10	3.14		4.66	7%	0.54
T	Analyze potential contamination issues		TRL 5-6		4.90	0.20	3.33		3.14		4.66	13%	0.98
U	Identify candidate materials,components,designs for testing		TRL 5-6	0.05	4.66		3.33	0.01	3.09		4.66	4%	0.29
V	Test vertical drive, horizontal transfer cable and complete grapple assembly	Pilot Scale Testing	TRL 5-6		4.66		3.33	0.01	3.04		4.66	1%	0.05
W	Speed, acceleration & accuracy tests under static and dynamic conditions	Pilot Scale Testing	TRL 5-6		4.66		3.33	0.01	2.99		4.66	1%	0.05
X	Endurance Testing	Pilot Scale Testing	TRL 5-6		4.66		3.33	0.02	2.89		4.66	1%	0.10
Y	Structural tests	Pilot Scale Testing	TRL 5-6		4.66		3.33	0.01	2.84		4.66	1%	0.05
Z	Flow induced vibration tests	Pilot Scale Testing	TRL 5-6		4.66		3.33	0.01	2.79		4.66	1%	0.05
AA	Test control electronics and computer coding	Pilot Scale Testing	TRL 5-6		4.66		3.33	0.01	2.74	0.15	3.92	10%	0.78
AB	Compare test results against functional & operational requirements		TRL 5-6		4.66	0.10	2.84	0.07	2.40		3.92	11%	0.83
AC	Software validation	Engineering Scale Testing in integrated relevant environment	TRL 6-7	0.05	4.41		2.84		2.40	0.05	3.68	6%	0.49
AD	Manufacture and install NGNP Fuel Handling System		TRL 7-8	0.15	3.68		2.84		2.40		3.68	9%	0.74
AE	Test and qualify full scale NGNP prototype Fuel Handling System in operational environment (non-rad ops)		TRL 7-8	0.03	3.53	0.03	2.70	0.07	2.06	0.03	3.53	10%	0.78

Legend: Risk Reduced / Unreduced

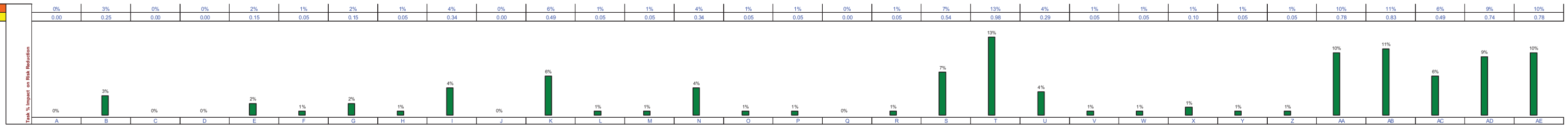

Figure A-20. PRAT matrix for the Fuel Handling System

Probability and Consequence Product Table

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principle	Application Formulated	Proof of Concept	Bench Scale	Experimental Scale	Pilot Scale	Engineering Scale	Prototype	Plant Operationa	Commercial scale

Technology / Component / Subsystem / System / Plant

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BOP I&C RISK REDUCTION TASKS

Each task column has sub-columns ΔC, ΔPc, ΔPe; the only change values printed are ΔPe values, shown below in parentheses after the risk score following that task.

Tasks A–I: Preliminary Design Testing (A–H), Down Selection (I); TRL 3 - 4 (A–H), TRL 4 - 5 (I)

ID	BOP I&C TECHNICAL RISKS	Baseline C	Baseline Pc	Baseline Pe	Baseline score	Risk Score After Task Completion	A Radiological and high temperature testing	B Develop Leakage rate models	C Instrumentation testing	D Verification Testing of He Mass Flow Measurement	E Moisture Detection Equipment Design Testing	F Verification Testing for Reactor Control and Transient Calculations	G Bench-scale Reactor Control Transient Calculations	H Test Redundancy, Fail-over, Signal Transmission Quality, etc	I Select commercially available sensors based on manufacturer's data and NGNP design specifications
263	Technology Development Collaboration - INL/EXT- 05 - 00952(PLN-2489) Revision 3	9.00	1.00	0.90	8.10	3.48	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	(0.05) 7.70
164	Unidentified Equipment protection parameters - TDRM doc_01_09	9.00	1.00	0.90	8.10	5.67	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
264	I&C - Control strategy for of-normal and normal ops - TDRM doc_01_09	9.00	1.00	0.90	8.10	2.27	8.10	8.10	8.10	8.10	8.10	(0.10) 7.29	(0.10) 6.48	(0.02) 6.32	6.32
166	I & C - Absence of Safety Analysis Studies For NRC Requirements - TDRM doc_01_09	9.00	1.00	0.90	8.10	5.02	(0.02) 7.94	(0.02) 7.94	7.78	7.78	(0.02) 7.61	7.61	7.61	(0.02) 7.45	7.45
165	I&C - Lubricant Degradation For Incore Detection System -TDRM doc_01_09	7.00	1.00	0.70	4.90	2.70	(0.20) 3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92
54	Instrumentation of Reactor - INL/EXT-05-00952 (PLN-2489) Revision 3	7.00	1.00	0.70	4.90	1.13	(0.15) 4.17	4.17	(0.02) 4.07	(0.02) 3.97	(0.05) 3.72	3.72	3.72	3.72	3.72
13	Absence of Analysis for Diverse, Dependable, Defensible, Digital Instrumentation (Includes digital acceptance by NRC) -TDRM R&D Input	3.00	1.00	0.90	2.70	0.73	(0.02) 2.65	2.65	(0.02) 2.59	2.59	(0.02) 2.54	2.54	2.54	2.54	2.54
	Baseline-Average RVI Risk Score				5.15		8%	0%	1%	0%	2%	3%	3%	1%	2%
	Average RVI Risk Score after Task Completion				2.39		1.93	0.00	0.31	0.10	0.46	0.81	0.81	0.32	0.41

Tasks J–Q: Experimental Scale Instrumentation; TRL 4 - 5

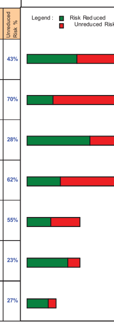
ID	J Develop Operational Requirements for each installed system	K Test Moisture detection sensors	L Test Plate out Probe Instrumentation	M Verify application of components tested	N Signal-to-Noise Tolerance Testing	O Digital Equipment Testing for Robustness and Failure Modes	P Verification of the 2-out-of-4 redundancy scheme	Q Preliminary Operator Interface Testing
263	(0.02) 7.53	(0.02) 7.37	(0.02) 7.21	7.21	(0.02) 7.05	(0.02) 6.89	(0.02) 6.72	(0.02) 6.56
164	(0.1) 7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29
264	6.32	6.32	6.32	(0.02) 6.16	(0.02) 5.99	(0.10) 5.18	(0.05) 4.78	(0.05) 4.37
166	7.45	(0.02) 7.29	(0.02) 7.13	(0.02) 6.97	(0.02) 6.80	6.80	6.80	6.80
165	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92
54	3.72	(0.05) 3.48	(0.05) 3.23	3.23	3.23	(0.02) 3.14	3.14	3.14
13	2.54	(0.02) 2.48	2.48	2.48	(0.02) 2.43	(0.20) 1.89	(0.02) 1.84	(0.02) 1.78
Baseline-Average RVI Risk Score	4%	3%	2%	1%	2%	7%	3%	3%
Average RVI Risk Score after Task Completion	0.97	0.62	0.57	0.32	0.54	1.61	0.62	0.62

Tasks R–Y: Pilot Scale Instrumentation Testing; TRL 5 - 6

ID	R Information transfer rate testing	S Data high way transmission testing	T Operating lifetime testing	U Online maintenance testing	V Verification testing of channel separation	W Steam generator moisture ingress detection and plate out probe testing	X Circular HE flow measurement Testing	Y Verification Testing of BOP Instrumentation
263	(0.01) 6.48	6.48	(0.02) 6.32	(0.02) 6.16	(0.02) 5.99	(0.02) 5.83	(0.02) 5.67	(0.05) 5.27
164	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29
264	(0.02) 4.21	(0.02) 4.05	4.05	4.05	(0.02) 3.89	3.89	3.89	3.89
166	(0.02) 6.64	6.64	6.64	6.64	(0.02) 6.48	(0.02) 6.32	6.32	6.32
165	3.92	3.92	(0.20) 2.94	2.94	2.94	2.94	2.94	2.94
54	3.14	3.14	(0.15) 2.40	(0.02) 2.30	2.30	(0.05) 2.06	(0.02) 1.96	(0.02) 1.86
13	(0.02) 1.73	(0.02) 1.67	(0.02) 1.62	1.62	(0.02) 1.57	(0.02) 1.51	1.51	(0.10) 1.24
Baseline-Average RVI Risk Score	2%	1%	8%	1%	2%	3%	1%	3%
Average RVI Risk Score after Task Completion	0.46	0.22	1.93	0.26	0.54	0.62	0.26	0.77

Tasks Z–AG: Testing Engineering Scale Instrumentation in integrated relevant operational environment (Z–AB), Resolve Other Issues (AC–AE); TRL 6 - 7 (Z–AE), TRL 7 - 8 (AF–AG)

ID	Z Software Validation Testing	AA Seismic Qualification Testing	AB Off-normal Conditions Testing	AC Leak detection instrumentation	AD Equipment condition monitoring	AE PCS I&C	AF Manufacture and install NGNP instrumentation	AG Test and qualify full scale NGNP prototype instrumentation in operational enviroment (non-rad ops)	Risk % Reduction	Unreduced Risk %
263	(0.05) 4.86	4.86	(0.05) 4.46	4.46	4.46	(0.05) 4.05	(0.05) 3.65	(0.02) 3.48	57%	43%
164	7.29	7.29	7.29	7.29	(0.2) 5.67	5.67	5.67	5.67	30%	70%
264	(0.10) 3.08	3.08	(0.05) 2.67	2.67	2.67	2.67	2.67	(0.05) 2.27	72%	28%
166	6.32	(0.05) 5.91	(0.05) 5.51	(0.02) 5.35	5.35	(0.02) 5.18	5.18	(0.02) 5.02	38%	62%
165	2.94	2.94	2.94	2.94	2.94	2.94	2.94	(0.05) 2.70	45%	55%
54	1.86	1.86	(0.10) 1.37	1.37	1.37	1.37	1.37	(0.05) 1.13	77%	23%
13	1.24	(0.05) 1.11	1.11	(0.02) 1.05	1.05	(0.02) 1.00	1.00	(0.10) 0.73	73%	27%
Baseline-Average RVI Risk Score	5%	2%	7%	1%	7%	3%	2%	6%		
Average RVI Risk Score after Task Completion	1.22	0.54	1.71	0.22	1.62	0.62	0.40	1.49		



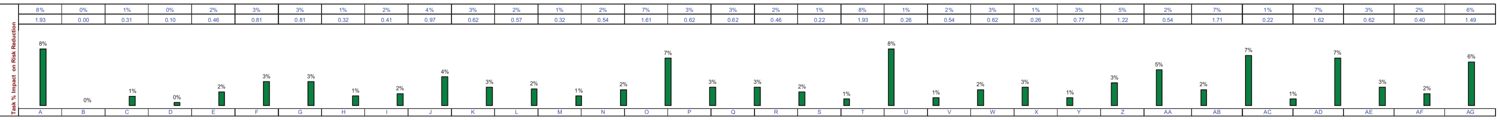


Figure A-21. PRAT matrix for BOP Instrumentation and Control