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INCORPORATING THE TECHNOLOGY ROADMAP UNCERTAINTIES INTO THE PROJECT RISK ASSESSMENT

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ABSTRACT

This paper describes two methods, Technology Roadmapping and Project Risk Assessment, which were used to identify and manage the technical risks relating to the treatment of Sodium Bearing Waste at the Idaho National Engineering and Environmental Laboratory. The waste treatment technology under consideration was Direct Vitrification. The primary objective of the Technology Roadmap is to identify technical data uncertainties for the technologies involved and to prioritize the testing or development studies to fill the data gaps. Similarly, project management's objectives for a multi-million dollar construction project include managing all the key risks in accordance to DOE O 413.3 – *Program and Project Management for the Acquisition of Capital Assets*. In the early stages, the Project Risk Assessment is based upon a qualitative analysis for each risk's probability and consequence. In order to clearly prioritize the work to resolve the technical issues identified in the Technology Roadmap, the issues must be cross-referenced to the project's Risk Assessment. This will enable the project to get the best value for the cost to mitigate the risks.

INTRODUCTION

This paper discusses the tools used to identify, manage and mitigate the risks associated with treating Idaho Nuclear Technology and Engineering Center (INTEC) sodium bearing waste (SBW) using Direct Vitrification technology. These tools include:

- Technology Roadmapping,
- Technical Baseline Database (TBDB), and a
- Risk Management Plan (RMP).

Background

From 1953 to 1992, Spent Nuclear Fuel (SNF) was reprocessed at the Idaho Chemical Processing Plant, which is now known as the Idaho Nuclear Technology and Engineering Center (INTEC). The SNF was shipped to INTEC from various reactors located throughout the world and temporarily stored while some of it was chemically reprocessed to recover uranium, lanthanum, neptunium, and krypton. SNF reprocessing produced mixed liquid waste, which was concentrated and stored in a tank farm.

The liquid waste types that were stored in INTEC's tank farm include high-level waste (HLW) and sodium bearing waste (SBW). The HLW was generated as a direct result of reprocessing SNF while the SBW was generated from incidental activities, such as facility and equipment decontamination work associated with INTEC's operation. The label "Sodium Bearing Waste" relates to the high sodium concentration resulting from activities that extensively used sodium-based chemicals such as sodium hydroxide and sodium carbonate.

In 1992, spent fuel reprocessing was concluded and the SNF reprocessing facilities at INTEC were shutdown. Although HLW ceased to be generated, SBW generation continued as a result of SNF storage, waste management, off-gas cleanup, and decontamination and decommissioning of unused facilities. Currently, SBW evaporation continues in order to reduce the liquid volume and the concentrated SBW is stored in the tank farm.

There are two regulatory mandates for treating INTEC's radioactive wastes. In April 1992 a Consent Order to a Notice of Noncompliance between the EPA and the State of Idaho required that DOE "cease use" of five of the eleven tanks located in the tank farm by March 31, 2009. The Consent Order was modified in 1998 to move the "cease use" date of these tanks up to June 30, 2003. On October 16, 1995 a Settlement Agreement between the DOE, the U.S. Navy and the State of Idaho was made. The Settlement Agreement primary requirements include:

- SBW treatment and cease use of the tank farm storage tanks by December 31, 2012; and
- HLW treatment so it is ready for disposal and made road-ready for shipment out of Idaho by December 31, 2035.

SCIENCE AND TECHNOLOGY ROADMAPS

There are several types of technology roadmaps used by industry and government sectors. (1) In general, technology roadmapping is a disciplined, needs-driven, consensus-building process to identify, select and develop technology alternatives to satisfy a need.

In the draft guidance document entitled "Applying Science and Technology Roadmapping in Environmental Management (Draft B)", EM-50 defines the purpose for a science and technology roadmap. (2) "Within EM, science and technology roadmapping includes planning for scientific research and engineering development, with the end goal of cleanup and stewardship mission application." Roadmapping identifies "what, when and why" the activities must be done but does not identify "who, where or how" they will be accomplished. "Project-level roadmapping identifies and mitigates the technical risk in the project baseline. The goal is to identify and schedule R&D activities so that all proofs-of-concept are completed by the end of the pre-conceptual design phase, and sufficient engineering knowledge on process parameters and scaling is available to complete conceptual design. Thus, the roadmapping process synchronizes facility engineering with R&D."

Early in fiscal year (FY) 2000, the Department of Energy (DOE-ID) and Idaho National Engineering and Environmental Laboratory (INEEL) identified the need to develop a roadmap for technologies applicable to the treatment and disposal of the SBW.

The need for a science and technology roadmap was driven by two major factors. First, the National Environmental Policy Act's (NEPA) environmental impact statement (EIS) process for technology selection for SBW treatment has yet to be completed. Realizing a potential schedule conflict for a line-item construction project versus the Settlement Agreement's deadline, it was decided to develop a technology roadmap for the three most probable SBW treatment scenarios.

The other integral driver for the development of the roadmap is the technical complexity of each treatment scenario. Each treatment option has several uncertainties associated with its application to the treatment of SBW. Since time is of the essence and funds are in limited supply, the roadmapping process identified the technical uncertainties for these three possible treatment methods, so then when the EIS Record of Decision (ROD) is issued, the INEEL will be prepared to carry out the activities required to implement that decision.

The three SBW treatment technologies that were roadmapped include Cesium Ion Exchange (CsIX), then the baseline treatment option, Solvent Extraction (SX), and Direct Vitrification. (3) In FY-2001, DOE-ID, using a project management decision process, changed the baseline SBW treatment option to Direct Vitrification subject to the results of the EIS-ROD. This increased the focus on the Direct Vitrification portion of the roadmap, while the development of the uncertainties for the other options was put on hold.

Developing the Direct Vitrification Roadmap

Developing the Direct Vitrification technology roadmap involved four phases or steps. The first was the initiation step that ensured the roadmap work scope was adequately defined. Agreement was reached on the roadmap's scope, leadership, participants and deliverables. The second phase consisted of using a structured approach for identifying the technical issues for treating SBW by Direct Vitrification. This phase also included the generation of a documented consensus on the technical needs for Direct Vitrification. To this end, scientific and engineering representatives from both the INEEL and other DOE sites, including experts from Savannah River Site and Pacific Northwest National Laboratory, discussed uncertainties relating to process and equipment failure, safety, and engineering design.

The team consisted of members with a variety of expertise and experience. These individuals were skilled in the design and operation of the technologies relating to Direct Vitrification in a highly radioactive environment. The technologies of interest include SBW feed preparation, joule-heated melter design, and off-gas/secondary waste treatment systems. After identifying and compiling the issues, the technologists and engineers then assessed the existing knowledge base for each uncertainty.

The third phase included developing a plan to gather information necessary to resolve the identified uncertainties. Finally, the roadmap report was reviewed, released and implemented. The roadmap was used to develop R&D budgets and prioritize the work to support the pre-conceptual design of the Direct Vitrification process.

Direct Vitrification Technical Issues

The roadmap team developed a list of approximately 100 issues that were categorized into one of six separate technology areas. These areas included: waste feed and delivery; waste/glass/frit formulations; melter; off-gas system; secondary waste; and integration. Samples of the issues are presented in Table I.

Table I. Selected Technical Uncertainties for Direct Vitrification of SBW

Issue Category	**Issue Title**	**Full Description**
Feed Prep and Delivery		
Feed Mixing & Delivery	Slurry Characteristics (homogenous mixing, pump performance)	Undissolved solids, frit (glass formers): must be pumpable and homogeneous
Formulations		
Glass Formulation and Certification	Glass qualification/certification	Perform testing and qualification activities to support waste product characterization and qualification requirements
Melter		
Feed Mixing & Delivery	Selection of frit or glass forming compounds (GFC) additives to waste slurry	Evaluate the impact of frit vs. GFC on the blended feed rheology and melt rate, selection between GFC, time effects on rheology from digestion
Melter Type Evaluation	Melter Type	1) Can we make Glass? 2) Melter operability; a. Throughput, b. Lifetime/durability, c. Flexibility – wet/dry, batch-vs. -continuous, d. Performance, e. D&D, f. Ancillary equipment
Off-Gas System		
Maximum Air Pollution Control Technology (MACT)	MACT compliance	Depending on the upstream process, MACT compliance may or may not be required. Stakeholders may insist that MACT emission limits be met.
Mercury Adsorption Bed Design/Operation for Target D/F	Mercury removal technologies	Carbon adsorption seems to be the least-risk alternative for removing mercury. However, if granulated activated carbon (GAC) doesn't look capable of removing all species of mercury present, other technologies must be vigorously pursued.

Secondary Waste		
Scrub Solution Treatment Design & Verification	IX media selectivity based on off-gas and scrubber characterization	Select ion exchange media for removal of cesium from scrubber blowdown.
Integration		
Feed Mixing & Delivery	Simulants	Develop representative SBW simulant for testing

The uncertainties were then categorized as high, medium, or low in order to prioritize the work envisioned necessary to resolve each uncertainty. The primary criterion used to classify each concern was based upon the available information for each topic. If an uncertainty had no known data to support an engineering solution, it was assigned a "high" uncertainty. This rating should not be confused with the level of difficulty for resolving the problem. It only means that there were no known data to validate a possible solution. If there were data supporting a solution to the problem but with limited evidence of implementation, it was listed as a "medium" uncertainty. Identified issues that had evidence of an engineering solution(s) and examples of DOE complex-wide successful implementations were classified as "low". Often, but not always, this rating also corresponded to the consequence of the uncertainty proving to have negative impact. Table II lists some of the issues that were categorized in the aforementioned manner.

To better understand these classifications, consider a fictitious example of having an uncertainty relative to off-gas emissions. If there is some compound that has to be managed below a threshold level, and it is unclear whether or not the process will emit the compound above or below that level, there is some uncertainty. The cost of that uncertainty is proportional to either the ramification of allowing that emission to exceed the threshold (potential shut-down of the operation), or the cost associated with installing a device that would reduce the emission level. If there were no data on a device that could reduce the emission level, then this would be a "high" level uncertainty. If there were a device that could reduce the emission level, but had only been used once on a different type of off-gas, this would be a "medium" uncertainty. If the device had been used many times successfully on different types of off-gas, it would be a "low" uncertainty.

Table II. Samples of Categorized Uncertainties for Direct Vitrification of SBW

Unit Operation	**Mode of Failure**	**Consequence**	**H, M, L**	**Explanation**
DeNoxidizer(off-gas treatment)	Causes rise in Hg oxidation state, Hg goes through GAC beds, exceeds emission	Emissions limit exceeded; Operating permit denied.	H	Don't know oxidation state

Unit Operation	**Mode of Failure**	**Consequence**	**H, M, L**	**Explanation**
	limit. Interface incompatibility.			
Granular Activated Carbon	Hg not in proper oxidation state, carbon beds do not remove it.	Emissions limit exceeded; Operating permit denied.	H	Don't know Hg speciation for sure, no data
Vitrification	Unknown feed composition, off-gas composition unknown then, so off-gas treatment needs unknown.	Can't design proper off gas treatment	H	Limited data available
SBW Feed Characterization	Liquid chemical composition not known. Simulated testing does not characterize interferences.	Required DFs, other ops. constraints, and WAC not met.	M	Have some data on problem causing materials, can engineer in that envelope
Vitrification	"Uncontrolled pours" result in excessive and continuous spilling.		M	SRS is dealing with it
Vitrification	Electrode failure	Melter failure (burn up)	M	Don't have enough data to be low, but too much to be high
SBW Feed Characterization	Liquid radionuclide composition not known. Simulated testing does not bracket the requirements for waste processing.	WAC not met.	L	A combination of test data and knowledge of tank input lowers this uncertainty.

Unit Operation	**Mode of Failure**	**Consequence**	**H, M, L**	**Explanation**
Chemical Makeup	Technology for uniform mixing of vit. feed solids not developed.	Glass does not meet performance specs of Yucca.	L	SRS has engineered this

TECHNICAL BASELINE DATABASE

During FY-2001, a Technical Baseline Database (TBDB) was developed as a management tool for tracking the status of the design basis for the Direct Vitrification process. The central data entity in the TBDB is the design basis element (DBE). The DBEs are the process requirements and assumptions needed to generate an overall mass balance for the process. Each DBE is a statement of what is required (i.e. process functional requirement), or what is currently known or assumed regarding a specific element or aspect of the process flowsheet. The TBDB also contains for each DBE its current technical basis and a breakdown of development tasks that should be completed to validate it. In aggregate the TBDB therefore constitutes a description of the technical baseline for the process as well as a blueprint for its validation.

The TBDB was developed in response to a need for a managed technical baseline. Many of the assumptions used to develop process mass balances (a major part of the technical baseline) for the Direct Vitrification process were invalidated. This caused disagreement among the project team concerning the baseline's legitimacy. Therefore, the project team decided that the mass balance assumptions should be coupled to the uncertainties, which had been identified in the technology roadmap and made accessible to all program members. This was accomplished using an Access ® database stored on a server that everyone assigned to the project could view from his or her desktop computer station. In the interest of configuration management only one individual can update the DBEs as the validation information becomes available and is reviewed/approved by the TBDB change control board.

RISK MANAGEMENT PLAN

Upon formalizing the Direct Vitrification treatment option for SBW, the Project Manager initialized the risk management strategy process. In accordance to DOE Order 413.3, a Risk Management Plan (RMP) that defines the scope, responsibilities, and methodology for identifying, evaluating impacts of, and managing assessable risks was made. (4) This DOE order, issued in October 2000, recognizes that one of the major reasons for a project's failure is the lack of appropriate risk management.

The purpose of the RMP is to ensure that the Direct Vitrification project incorporates appropriate, efficient, and cost-effective measures to mitigate unacceptable project-related risks. As such, it provides the necessary project planning to ensure that all the risks associated with the project are identified, analyzed, and determined to be eliminated, mitigated, or manageable.

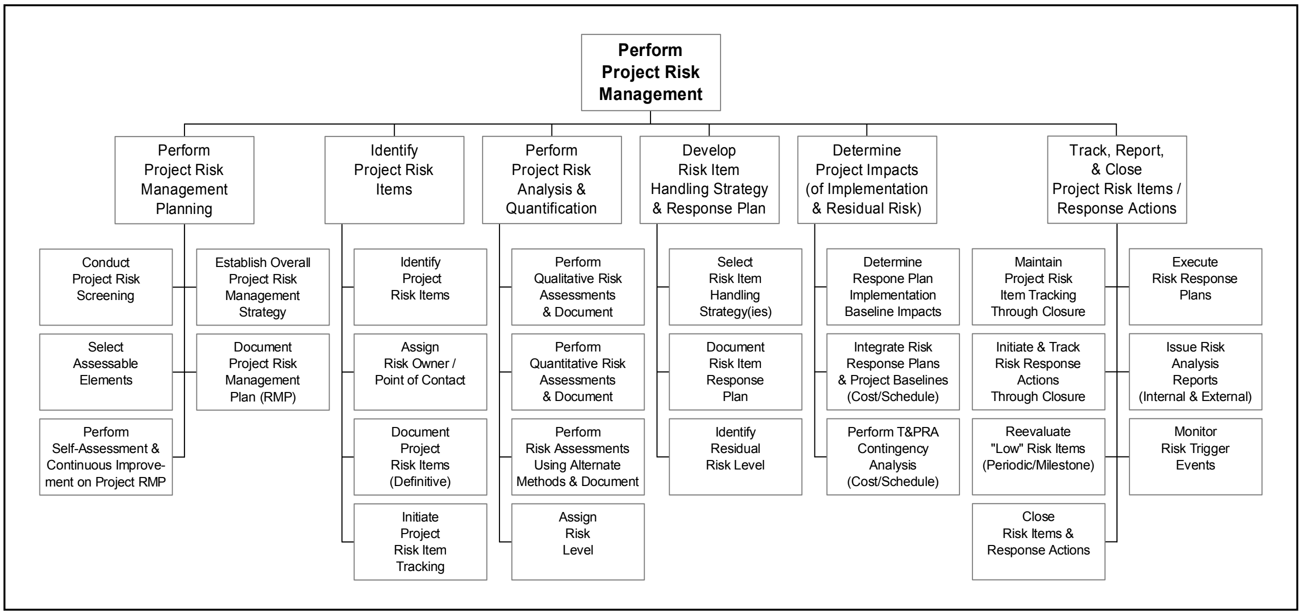
The RMP focused on all identifiable risks that could jeopardize the successful SBW treatment using Direct Vitrification technology. These include programmatic (non-technical), technical, cost, and schedule risks.

Figure 1 below shows the top-level risk management functional hierarchy. The timeline shown in Figure 2 depicts the conceptual timing of risk management activities over the course of the project. In the figure these activities are shown relative to the CD milestones described in DOE O 413.3.

The RMP generally excludes external programmatic risks since they are outside of the project’s ability to control or manage. However, these risks may, at the project manager’s discretion, be tracked in the Risk Item Log to ensure that appropriate interface controls are established with the affected external organizations.

There is considerable overlap in scope between the technology roadmap and the project’s technical risk assessment results that were developed in accordance to the RMP. However, the project’s risk assessment is more inclusive of all the technical facets for the project. For example, the RMP includes the identified risks for the infrastructure envisioned for executing the Direct Vitrification project, whereas the technology roadmap focuses on the treatment process per se.

Figure 1. Project Risk Management Functions



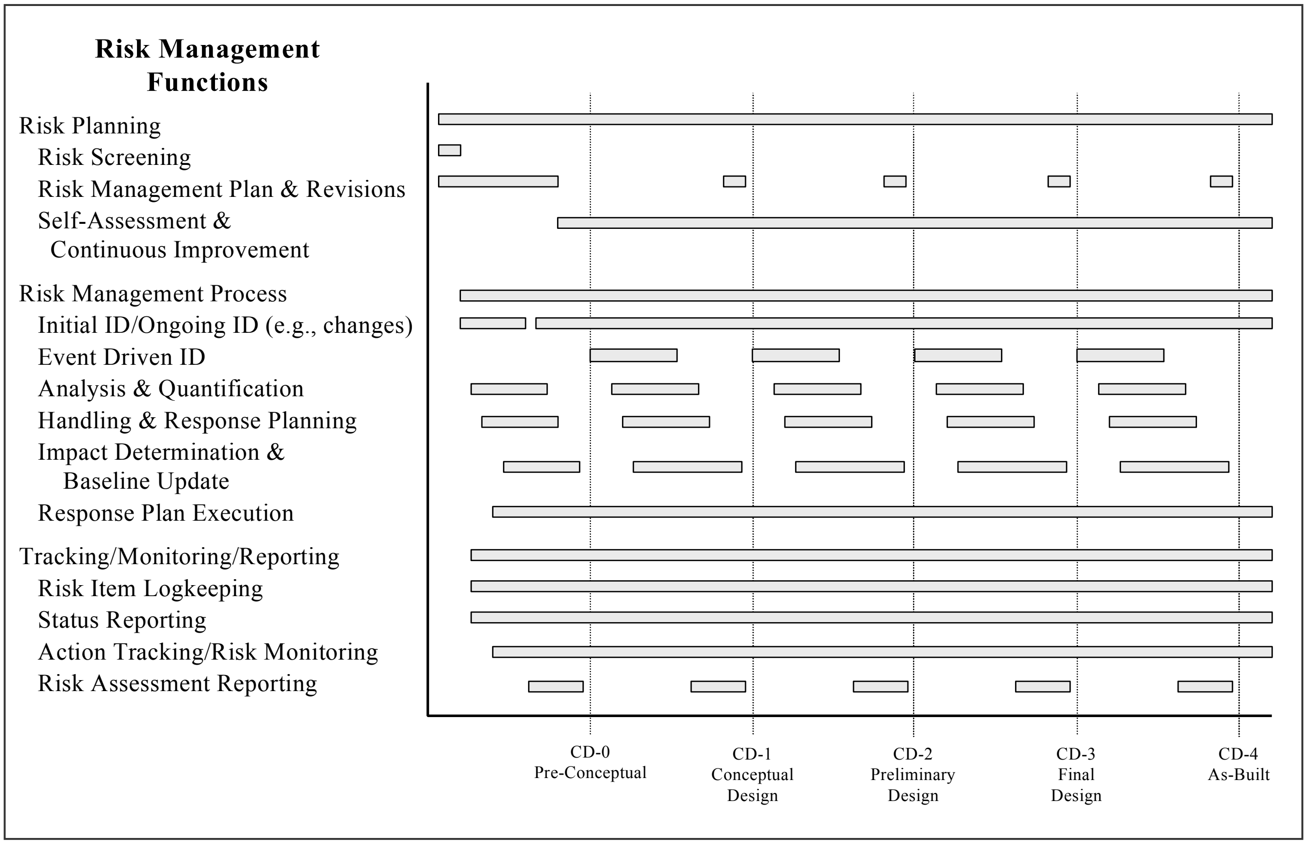


Figure 2. Risk Management Process Timeline (Conceptual Based on Milestones)

The RMP is considered to be the governing document for managing the project risks and ultimately the Direct Vitrification technology roadmap uncertainties will be integrated into the project's risk management process for reasons discussed later in this report.

Strategy Summary

The project strategy for managing risk has five underlying elements. These are; focus, maturity, process, resource utilization, and graded approach. The paragraphs below describe these elements and serve as a guide for the plan's evolution throughout the project life cycle.

Focus

The RMP recognizes that the type and nature of project risk will change as the project moves from phase to phase in its life cycle. Risks tend to be programmatic and system-oriented in early project phases and become more detailed and specific (i.e., technical) as the project progresses. Thus, by creating risk management processes that can handle a broad range of risk items and by considering the plan a controlled but living document, the project will be able to accommodate these changes in risk focus. Revisions to the plan are expected, but may not be required, at each CD milestone.

Process Strategy

The risk management process strategy is to use a structured, stepwise methodology, which includes the following major elements:

- Risk management planning (including self-assessment and continuous improvement)
- Risk identification
- Risk analysis and quantification (probability and consequence)
- Risk handling and response (e.g., avoidance, reduction, mitigation, or acceptance)
- Risk impact determination for the selected handling and response implementation and any residual risk impacts
- Risk tracking and reporting (including periodic reevaluation of "low" risks and risk event trigger monitoring).

Resource Utilization Strategy

The risk management strategy for resource utilization focuses on the use of multidisciplinary risk management team members to perform risk analyses and response planning activities and dedicated project support personnel for administration of the risk management process. The team members will ideally consist of a small number of permanent, or core, members with additional members (e.g., subject matter experts) brought in on an as needed basis

Graded Approach Strategy

A graded approach has been and will continue to be applied to risk management activities relative to specific risk items based on their assigned risk level. In other words, the level of detail and degree of management applied to a risk item will increase as the assessed risk level increases.

Risk Item Analysis and Quantification

Due to the preliminary nature of the project, all the risks identified thus far have been analyzed using a qualitative assessment. This method of risk analysis involves using qualitative scales to determine the probability of occurrence of a risk and its consequences. The qualitative assessment method is typically preferred earlier in the project life cycle and for risk items that are broad, vague, non-technical, or not otherwise suitable for quantitative or analytical assessment methods. The following steps were used to analyze the risks.

1. Each risk item was carefully described to avoid duplication and minimize issue overlap.

2. A multidisciplinary team analyzed each risk.

3. The qualitative probability of occurrence (P_O) rating for each risk item was assigned using the criteria in Table III. The rating was based upon the risk condition prior to

implementation of any risk handling strategy. A team consensus was required to assign the rating.

4. The qualitative consequence of occurrence (C_O) rating for each risk item was assigned using the criteria in Table IV. The rating was based upon the risk condition prior to implementation of any risk handling strategy. A team consensus was required to assign the rating.

5. The justification or rationale for the each risk rating and whether it applies for the duration of all project phases or for the activity being assessed was also documented. Significant dissenting opinions by the team members(s) were also recorded.

6. Based upon the probability and consequence a risk level was assigned to each risk item. The risk level is read directly from the Risk Level Matrix (Table V).

Table III. Risk Probabilities

Qualitative Probability Occurrence (P_o)	**Criteria**
Very Unlikely	Will not likely occur anytime in the life cycle of the facilities; **or** the estimated recurrence interval exceeds 1,000 years; **or** the P_O is less than or equal to 10%.
Unlikely	Will not likely occur in the life cycle of the project or its facilities; **or** the estimated recurrence interval is between 100 to 1,000 years; **or** the P_O is greater than 10% but less than or equal to 40%.
Likely	Will likely occur sometime during the life cycle of the project or its facilities; **or** the estimated recurrence interval is between 10 to 100 years; **or** the P_O is greater than 40% but less than or equal to 80%.
Very Likely	Will likely occur sometime during the life cycle of the project; **or** the estimated recurrence interval is less than 10 years; **or** the P_O is greater than 80%.

Table IV. Risk Consequences

Consequence of Occurrence (C_O) Qualitative	**Criteria**[a]
Negligible (N)	Minimal or no consequences; unimportant. Cost estimates minimally exceeded (i.e., TPC increases up to $5M). Negligible impact on program. Slight potential for schedule change; compensated by available schedule float. No milestone changes required. Typically, less than 1 month.
Marginal (M)	Small reduction in technical performance and/or quality. Moderate threat to facility mission, environment, or people; may require minor facility redesign or repair, minor environmental remediation, or first aid/minor medical intervention. Minor slip in schedule with some potential adjustment to milestones required. Typically, between 1 and 6 months.
Significant (S)	Significant degradation in technical performance and/or quality. Significant threat to facility mission, environment, or people; requires some facility redesign or repair, significant environmental remediation, or causes injury requiring medical treatment. Cost estimates significantly exceed budget (i.e., TPC increases between $25M to $125M) Significant slip in schedule with resulting milestone changes that may affect facility mission. Typically, between 6 and 12 months.
Critical (C)	Technical and/or quality goals of project cannot be achieved. Serious threat to facility mission, environment, or people; possibly completing only portions of the mission or requiring major facility redesign or rebuilding, extensive environmental remediation, or intensive medical care for life-threatening injury. Cost estimates seriously exceed budget (i.e., TPC increases between $125M to $250M) Excessive schedule slip unacceptably affecting overall mission of facility and endangering the Settlement Agreement Enforceable Milestones. Typically, between 12 and 18 months.

Consequence of Occurrence (C_O) Qualitative	**Criteria[a]**
Crisis (Cr)	Project cannot be completed. Catastrophic threat to facility mission, long-term environmental abandonment, and death. Cost estimates for TPC increase by more than $250M. Schedule slip invalidates overall facility mission through non-attainment of Settlement Agreement Enforceable Milestones. Typically, greater than 18 months.

a. Any one or more of the criteria in five level consequences may apply to a single risk. The consequence level for the risk being evaluated must be based upon the highest level for which a criterion applies.

Table V. Risk Level Matrix

Probability of Occurrence (P_O)	Very Likely	Moderate	Moderate	High	High	High
	Likely	Low	Moderate	High	High	High
	Unlikely	Low	Low	Moderate	Moderate	High
	Very Unlikely	Low	Low	Low	Low	Moderate
		Negligible	**Marginal**	**Significant**	**Critical**	**Crisis**
		Consequence of Occurrence (C_O)				

Technical Risk Assessment Results

Table VI is a breakdown of the technical risk assessment for the Direct Vitrification project. The risk identification and assessment process was as far as the risk management team was able to go during FY-2001. The next stage in the risk management process will be to formally identify and assess the project's programmatic risks, develop risk handling strategies and ensure that the technology roadmap uncertainties are covered by the project's the risk management activities.

Table VI. Technical Risk Assessment Rating Summary

Facility	**Total Risk Issues**	**High**	**Moderate**	**Low**	**Outside Project Control**	**Unrated**
SBW Storage Tank Farm	18	6	5	7		
SBW Direct Vitrification Treatment	56	11	17	23		5
SBW Waste Product Storage	17	4	3	6	4	
Total	91	21	25	36	4	5

SUMMARY

Because the Direct Vitrification technology roadmap was developed before the Direct Vitrification project was formalized, there is a disconnect between the roadmap and the project’s risk assessment. Specifically, in late summer of 2000, a team of INEEL scientists and engineers, with additional support of the Tank Focus Area individuals developed the technology roadmap for the vitrification of SBW. Evolving from this process was the Technology Baseline Data Base (TBDB). The database was made to tabulate the assumptions, uncertainties, requirements, and development needs for the vitrification process. The basis for ranking or prioritizing the work to resolve the technical issues was available technology information and potential uncertainty consequence.

In 2001, INEEL’s Engineering group developed the technical risk list for the project. These risks were ranked based upon probability of occurrence and potential consequences to the program. This activity created a different list and risk perspective than the roadmap.

Early in FY-2002, cross-referencing tables were developed as a first step in transitioning the risks from the technology roadmap to the project’s risk management process. These tables were necessary to establish if there are any design basis elements (DBEs) that are outside the identified technical risks (i.e. that can not be associated with any risk). It was determined that all 150 DBEs can be categorized into one or more of the 56 technical risks identified during the project’ risk assessment. Since the TBDBs have been given a priority number of 1,4,7 or 10, (1 is high priority, 7 is a low priority, and 10 is unprioritized) these tables are useful to plan future work based on important data needs. Data needs could be rated as follows: a high priority DBE mapped to a risk category rated “high” would merit more attention than a DBE mapped to a low risk.

Prior to project initiation, the focus for technology roadmaps is risk elimination around proof of technical viability. At a point in time when the project can be initiated (i.e., believed to be viable by management), the remaining risks in the roadmap need to be integrated with the project risk assessment and mitigation plans. For the INEEL Direct Vitrification project, engineering was responsible for performing the risk assessment whereas principally technologists generated the technology roadmap. This diversity produced different opinions regarding work priorities to resolve the risks and uncertainties. Therefore, the technology roadmap needs to be integrated into the project's risk assessment in order to prioritize risk mitigation efforts. This will enable the project to get the best value for the cost to mitigate the risks.

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