Technology Readiness Assessment of Department of Energy Waste Processing Facilities: When is a Technology Ready for Insertion?

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ABSTRACT

This paper will describe a technology readiness assessment process (TRA) that the U.S. Department of Energy (DOE) piloted at Hanford's Waste Treatment and Immobilization Plant (WTP) and has subsequently applied to other projects at Hanford and the Savannah River Site. The methodology used for these TRAs was based upon detailed guidance contained in the U.S. Department of Defense (DoD), Technology Readiness Assessment Deskbook [1] and adapted a technology readiness scale developed by the DOD and National Aeronautics and Space Administration (NASA) to the DOE. This paper will discuss the application of the TRA process to the WTP and the development of a Technology Maturation Plan (TMP) based on the TRA findings.

INTRODUCTION

The U.S Department of Energy (DOE), Office of River Protection (ORP) is constructing a Waste Treatment and Immobilization Plant (WTP) for the treatment and vitrification of the underground tank wastes stored at the Hanford Site in Washington State. The WTP Project is comprised of four major facilities: a Pretreatment (PT) Facility to separate the tank waste into high-level waste (HLW) and low-activity waste (LAW) process streams; a HLW Vitrification Facility to immobilize the HLW fraction; a LAW Vitrification Facility to immobilize the LAW fraction; and an Analytical Laboratory to support the operations of all four treatment facilities. Additionally, there are the Balance of Facilities operations that provide utilities and other support to the processing facilities. The WTP Project is DOE's largest capital construction project with an estimated cost of $12.263 billion, and a project completion date of November 2019.

Issues associated with the maturity of technology in the WTP have been evaluated by independent DOE Review Teams and in DOE's design oversight process. The most notable evaluation was the recently completed "Comprehensive External Review of the Hanford Waste Treatment Plant Flowsheet and Throughput"[2] completed in March 2006. This evaluation identified 28 separate technical issues, some of which had not been previously identified by the WTP Contractor (Bechtel National Inc. [BNI]) or DOE. A number of these issues originated from limited understanding of the technologies that comprise the WTP flowsheet.

As a result of these reviews, and DOE's desire to more effectively manage the technology risks associated with the WTP, DOE conducted a series of three Technology Readiness Assessments [3,4,5] to assess the technical maturity of the WTP design. These TRAs were patterned after guidance established by the DoD for conducting TRAs [1].

In parallel with the conduct of the WTP TRAs, the General Accounting Office (GAO) evaluated 12 major DOE projects to assess the role of technology maturity on cost growth and schedule extension [6]. The GAO found that of the 12 DOE major projects reviewed that 8 of the 12 projects experienced cost increases ranging from $79 million to $7.9 billion, and 9 of the 12 projects were behind schedule by 9 months to more than 11 years. Some of the cost growth and schedule extension was due to applying immature technologies in the design process. The GAO subsequently recommended that

> *"[DOE improve its] oversight of major construction projects by developing comprehensive standards for measuring and communicating the readiness of project technologies. In developing these standards, DOE should consider lessons learned from the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), as well as DOE's limited experience in measuring technology readiness."*

DOE has agreed with this recommendation and has committed to evaluation of the TRA process.

TECHNOLOGY READINESS ASSESSMENT PROCESS

The WTP TRA process consisted of three parts:

1. Identifying the Critical Technology Elements (CTEs), those technologies that are essential to successful operation of the facility, and are new or are being applied in new or novel ways or environments.
2. Assessing the TRLs of each CTE using the technical readiness scale used by DoD and the National Aeronautics and Space Administration (NASA) and adapted by the assessment team for use by DOE.
3. Developing a technology maturation plan (TMP) that contains plans, costs, and schedules for technology testing or engineering work necessary to bring immature technologies to appropriate maturity levels.

Identification of Critical Technology Elements

The working definition of the critical technology element (CTE) as defined in the Technology Readiness Assessment (TRA) Deskbook [1] was used as a basis for identification of CTEs for the WTP. The working definition is:

A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel. Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.

The process for identification of the CTEs for the WTP involved two steps:

1. An initial screening by the DOE of the complete list of systems in the WTP facilities for those that have a potential to be a CTE. In this assessment, systems that are directly involved in the processing of the tank waste or and secondary wastes were initially identified as potential CTEs.
2. A final screening of the potential CTEs by the DOE and supported by the WTP contractor to determine the final set of CTEs for evaluation. The potential CTEs were evaluated against the two sets of questions presented in Table 1. A system is determined to be a CTE if a positive response is provided to at least one of the questions in each of the two sets of questions.

DOE considered 186 separate systems within the WTP as potential CTE's and identified 21 for further evaluation.

Table 1. Questions used to Determine the CTEs for the Pretreatment Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

Determination of Technology Readiness Level of CTEs

The determination of the Technology Readiness Level (TRL) of each CTE was completed using a slightly modified version of the TRL Calculator originally developed by Nolte et al [7]. The TRL Calculator tabulates responses to a standard set of questions addressing hardware, software, program, and manufacturability. The TRL Calculator is implemented in Microsoft Excel™ and produces a graphical display of the TRL achieved. It was used to provide a structured and consistent assessment to determine the TRL of each CTE identified. The TRL Calculator was adapted by adding and modifying existing questions to make it more applicable to DOE waste treatment equipment and processes.

The TRL scale developed for the WTP TRAs is shown in Table 2. The scale is based on the DoD and NASA scales. Minor modifications have been made to reflect the chemical processing nature of the WTP. The scale requires that testing of a prototypical design in a relevant environment be completed prior to incorporation of the technology into the final design of the facility.

Table 2 Technology Readiness Levels used in WTP Assessments

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	TRL 9	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	TRL 8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full-scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	TRL 6	Engineering/pilot-scale, similar (prototypical) system validation in a relevant environment.	Representative engineering-scale model or prototype system, which is well beyond the lab-scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory-scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	TRL 4	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	TRL 3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	TRL 1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

The testing requirements used in the WTP TRAs are compared to the TRLs in Table 3. These definitions provide a convenient means to understand the relationship between the scale of testing, fidelity of testing system, and testing environment and the TRL. This scale requires that for a TRL 6, testing must be completed at an engineering- or pilot-scale, with a testing system fidelity that is similar to the actual application and with a range of simulated wastes and/or limited range of actual waste, if applicable.

Table 3. Relationship of Testing Requirements to the TRL

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full-Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot-Scale < Full-Scale (Typical)
   Lab-Scale < 1/10 Full-Scale (Typical)

2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)

3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

Fourteen of the 21 CTE's selected for evaluation were determined to have a technology readiness level less than six. The primary reasons these technologies were determine to be immature were:

- Inadequate and incomplete definition of technology performance requirements.
- Lack of completion of prototypic testing (e.g. testing in systems that can be scaled to the plant system)
- Lack of completion of relevant testing (e.g. testing with a range of simulants and wastes that represent actual operations)

Development of the Technology Maturation Plan

The requirements for the maturation of the CTEs that have a TRL less than 6 are identified in a TMP [8]. The development of the TMP used qualitative risk assessment and value engineering principles (Figure 1) to identity the specific technology maturation requirements and ensure that:

- Maturation plans for the CTEs were developed using a systematic approach.
- WTP project-specific and life-cycle implications of maturing the CTEs were understood.

- Technology maturation can be completed on a schedule that does not affect design and construction.
- The current plan, and potential alternative strategies, for closing the technology risks considered the requirements, system functions, cost, and life cycle operations.
- Opportunities for improving operational performance, reducing cost, or simplifying the system were identified and considered.

The approach used to establish the maturation plans for the CTEs involved a re-assessment of their functions and critical design requirements, an evaluation of the risk of technology failure, and a determination of the acceptability of the current development plan. This approach provided an understanding of the uncertainties and assumptions used in the CTE requirements, the design, and operational interfaces within the WTP. It also provided the background for a "first order" risk evaluation of the CTE.

The risk evaluation was designed to determine the qualitative probability and consequences of not maturing the CTE to a TRL 6 prior to completion of WTP Project construction. The outcome of the analysis, either a low or high risk, was used to determine the preference for maintaining the current development plan or the identification and examination of an alternative plan based on potential impacts.

If determined necessary, based on a high risk, a more detailed value engineering study was identified in the Technology Maturation Plan (TMP). The value engineering study is a planned, detailed evaluation of the functions and requirements of the technology to identify a preferred approach to improve the performance of the technology solution. The purpose of the value engineering study is to determine more completely if the current technology plan is acceptable and identify and select an alternative for development.

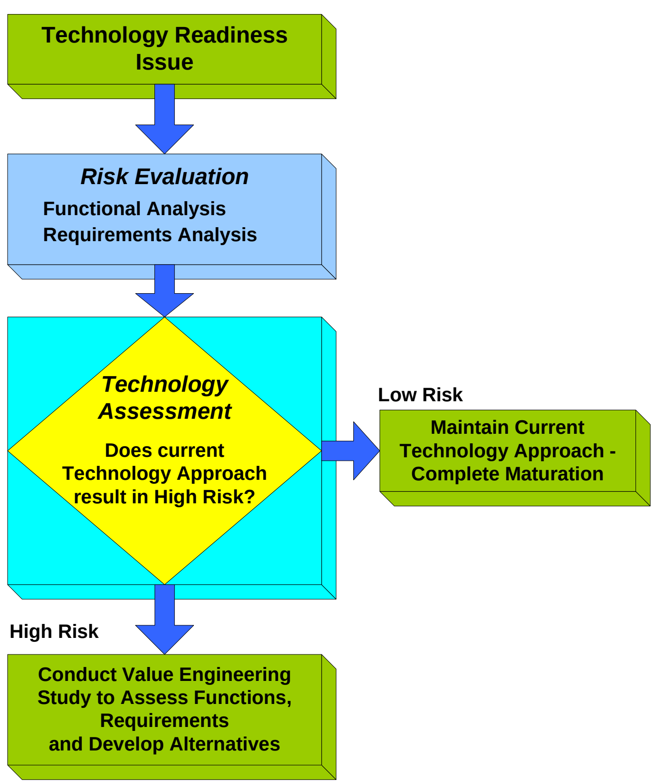

Figure 1 Risk Assessment and Value Engineering Process used to Prepare WTP Technology Maturation Plan

TECHNOLOGY INSERTION INTO THE WTP DESIGN

The WTP facility design is comprised of a facility structure with supporting services and utilities, and installed technologies (e.g., equipment systems) located within the facility structure. The purpose of the WTP facility structure is to provide shielding for personnel from the radioactive material being processed, and containment and confinement of radioactive materials. Based on design concepts for radiochemical facilities, including the WTP, the design of the facility is developed in parallel with the initial selection of technologies. This design process results in the specification of the physical interfaces between the facility and the technologies. This design concept provides an opportunity to mature and insert technologies during construction, and provides the flexibility to accommodate modified and alternative technologies at a future date. This approach, as used in the WTP will allow the shorting of the overall project completion schedule.

The figure below shows the DOE O 413.3 [9] project management process, as applied to the WTP, and the technology maturation process. This figure shows the relationship of the Critical Decision (CD) process with major project activities (e.g., design, construction, commissioning, and operations) and the desired maturity level of critical technologies. This figure illustrates that technology demonstration (e.g., testing to achieve a TRL 5 or 6) can be in progress during the final design and facility construction phase. However, technologies that have not achieved a TRL 6 represent a potential risk to the facility design. This risk was evaluated in the development of the TMP. Where required, the need to develop alternative technologies has been specified.

Technology performance risks also exist during the cold and hot commissioning phases of the WTP project. These risks will be identified and mitigated during technology installation and acceptance, and cold and hot commissioning, of the actual plant equipment systems.

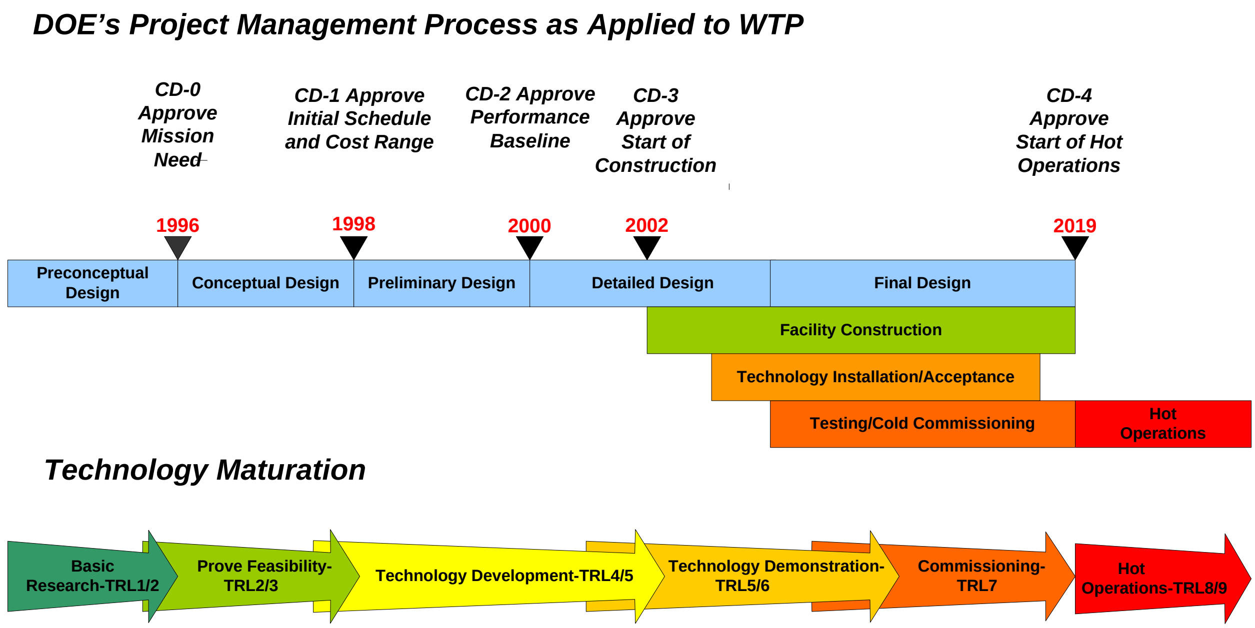

Figure 2 DOE Critical Decision Process and Technology Readiness Level as applied in the WTP

ACTIONS TO ENSURE CONSISTENCY WITH DOD TRA PROCESS

During the conduct of the WTP TRAs and development of the TMP the DOE devoted additional effort to ensure consistency with the concepts and methods identified by the DoD. The following actions were taken to ensure consistency with these processes.

- The DoD TRA Deskbook was used guide in all phases of the TRA process.
- DOE TRL definitions for waste treatment processing were defined based on the NASA and DoD TRL definitions.
- Air Force Research Laboratory (AFRL) staff participated in the initial DOE TRA to ensure consistency. This also included support in the modification and use of AFRL TRL Calculator [7] to ensure consistency with NASA and DoD scoring
- The WTP TRA's and TMP were independently reviewed by experts in the TRA process from the AFRL and NASA-retired.

CONCLUSIONS

The use of the TRA approach to assess and plan technology maturation for the WTP has resulted in:

- Reduced overall project costs by resolving technology maturity issues and avoiding engineering re-work and potential delays during WTP commissioning.
- Higher confidence that the WTP design will achieve program mission operating requirements by the assessment of technology readiness and the completion of required technology maturation activities.
- Higher confidence that the WTP will meet its operating goals at a reduced life-cycle operating cost.

Technology maturation costs are small compared to impacts from design re-work and potential delays in the WTP operating schedule (estimated at over $1 billion per year). The TRA process is also designed to ensure that future performance issues associated with the technology systems are identified and resolved before operations.

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