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DOE G 413.3-4A
9-15-2011

Technology Readiness Assessment Guide

[*This Guide describes suggested non-mandatory approaches for meeting requirements. Guides* *are not* *requirements documents and* *are not* *to be construed as requirements in any audit or appraisal for compliance with the parent Policy, Order, Notice, or Manual.*]

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FOREWORD

This Department of Energy (DOE) Guide is for use by all DOE elements. This Guide assists individuals and teams involved in conducting Technology Readiness Assessments (TRAs) and developing Technology Maturation Plans (TMPs) for the DOE capital asset projects subject to DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, dated 11-29-10. This Guide presents a tailored version of a National Aeronautics and Space Administration (NASA) and Department of Defense (DoD) technology readiness assessment model to assist in identifying those elements and processes of technology development required to ensure that a project satisfies its intended purpose in a safe and cost-effective manner that will reduce life cycle costs and produce results that are defensible to expert reviewers. DOE Guides are part of the DOE Directives Program and are issued to provide supplemental information and additional guidance regarding the Department's expectations of its requirements as contained in rules, Orders, Notices, and regulatory standards. Guides may also provide acceptable methods for implementing these requirements but are not prescriptive by nature. Guides are not substitutes for requirements, nor do they replace technical standards that are used to describe established practices and procedures for implementing requirements.

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1.0 Introduction

1.1 Purpose

Technology development is the process of developing and demonstrating new or unproven technology, the application of existing technology to new or different uses, or the combination of existing and proven technology to achieve a specific goal. Technology development associated with a specific acquisition project must be identified early in the project life cycle and its maturity level should have evolved to a confidence level that allows the project to establish a credible technical scope, schedule and cost baseline.[1] Projects that perform concurrent technology development and design implementation run the risk of proceeding with an ill-defined project baseline. The purpose of this document is to present a tailored version of a proven NASA and DoD technology assessment model that will assist DOE Program Offices in identifying those elements and processes of technology development required to reach proven maturity levels to ensure project success. A successful project is a project that satisfies its intended purpose in a safe, timely, and cost-effective manner that would reduce life-cycle costs and produce results that are defensible to expert reviewers (Reference: *DoD Technology Readiness Assessment Deskbook*, July 2009).

This document was developed to assist individuals and teams that will be involved in conducting Technology Readiness Assessments (TRAs) and developing Technology Maturation Plans (TMPs) for the Department of Energy (DOE) capital acquisition assets subject to DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets.* TRAs and TMPs activities are a tool to assist in identifying technology risks and enable the correct quantification of scope, cost and schedule impacts in the project. This document is intended to be a "living document" and will be modified periodically as the understanding of TRA processes evolves within the DOE programs. **DOE programs could use this Guide (the TRA process model) to assist in the development of their own TRA Process Guides/Manuals tailored to their own particular technologies and processes.** A program TRA Guide/Manual should take precedence over the DOE G 413.3-4A when conducting a TRA for projects under that specific program, as applicable to their technologies and/or processes.

DOE G 413.3-4A should not be applicable or appropriate to a project if: (1) the technology was adequately demonstrated previously for identical situations in one or more separate projects (see Appendix H, section 2.0, Technology Heritage); or (2) the technology readiness level does not apply if the objective of the project is to research scientific principles.

1.2 Background

To meet the requirements of DOE O 413.3B, Independent Project Reviews (IPRs) are one of the measures that can be implemented to ensure the timely resolution of engineering, system integration, technology readiness assessments, design, quality assurance, operations,

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[1] DOE O 413.3B, Table 2.1, requirement for hazard Category 1, 2 and 3 nuclear facilities to conduct an Integrated Project Review (IPR) to ensure early integration of safety in the design of a facility. For example, if a safety system requires technology development, then it must be identified early in the project life cycle. (Refer to DOE G 413.3-9 and DOE-STD-1189-2008)

maintenance of nuclear safety issues (Reference: DOE G 413.3-9, *U.S. Department of Energy Project Review Guide for Capital Asset Projects*). The purpose of an IPR is to acknowledge, identify, and reduce technical risk and uncertainty. The IPR also increases visibility of the risks and identifies any follow on activities that need to take place to mitigate the risks. Technical risk reduction increases the probability of successful achievement of technical scope. IPRs can include TRAs, as applicable and appropriate, to provide an assessment of the maturity level of a new proposed technology prior to insertion into the project design and execution phases to reduce technical risk and uncertainty. A TRA provides a snapshot in time of the maturity of technologies and their readiness for insertion into the project design and execution schedule. A TMP is a planning document that details the steps necessary for developing technologies that are less mature than desired to the point where they are ready for project insertion. TRAs and TMPs are effective management tools for reducing technical risk and minimizing potential for technology driven cost increases and schedule delays.

A TRA evaluates technology maturity using the Technology Readiness Level (TRL) scale that was pioneered by the NASA in the 1980s. The TRL scale ranges from 1 (basic principles observed) through 9 (total system used successfully in project operations). See section 2.0 for an explanation of the adaptation of the TRLs model in the context of DOE projects.

In 1999, the General Accounting Office (GAO) (GAO/NSIAD-99-162) recommended that the DoD adopt NASA's TRLs as a means of assessing technology maturity prior to transition. In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major programs. Subsequently, the DoD developed detailed guidance for performing TRAs using TRLs in the 2003 *DoD Technology Readiness Assessment Deskbook* [updated in July 2009]. Recent legislation (2006) has specified that the DoD must certify to Congress that the technology has been demonstrated in a relevant environment (TRL 6) prior to transition of weapons system technologies to design or justify any waivers. TRL 6 is also used as the level required for technology insertion into design by NASA; it is normally the last stage where technology has been demonstrated in the engineering/pilot scale in the relevant environment.

In March of 2007, the GAO issued a report on the results of a review of DOE projects performance which concluded, among other findings, that DOE's premature application of technologies was a reason for cost growth and schedule extension. GAO recommended that DOE adopt the NASA/DoD methodology for evaluating new technology maturity in their major construction projects (Reference: *GAO-07-336*). Subsequently, the DOE Office of Environmental Management (EM) conducted several pilot TRAs in their projects using an adaptation of the NASA/DoD TRA model for evaluating technology maturity and reported that the benefits of using the TRAs process include providing a structured, criteria-based, and clearly documented assessment. The process also identifies specific actions to reduce risk, assists in comparing candidate technologies, promotes decision-making discipline, and improves technical communication.

In an April 2008 report on the root cause analysis of contract and project management deficiencies within DOE, it was concluded that DOE has not always ensured that critical new technologies in final project designs have been demonstrated to work as intended. This has led to scope, cost and schedule increases from the originally approved project baselines (Reference:

DOE Root Cause Analysis, Contract and Project Management, April 2008). A Corrective Action Plan to this report was approved in July 2008 which addressed this shortcoming by planning the development of a DOE-wide technology readiness level model to assist DOE programs in the performance of TRAs for new technologies in their major construction and cleanup projects. The Corrective Action Plan includes a metric that requires, by the end of FY 2011, all projects greater than $750M (i.e., Major System Projects) applying new technology to implement technology readiness assessment methodologies no later than Critical Decision-2 (CD-2), as applicable and appropriate. [Reference: Root Cause Analysis, Contract and Project Management, Corrective Action Plan, July 2008]. Section 1.3 in this Guide provides further guidance with a strong message that TRA assessments by the programs for critical new technologies should begin early in the critical decision process. Technology development and associated risks are a key component of the project alternatives down select process and a key item in baseline cost and schedule development which begins at CD-1.

1.3 Technology Development Process Model

Various technical baseline deliverables, including associated technology development, are produced as a project evolves from pre-acquisition design to operation. The technology development process is not limited to the pre-acquisition and conceptual development stages, but instead, transitions throughout the life of the project. In addition, a safety strategy input is required early in the project life cycle as part of the technology development process.[2] The process recognizes the evolution of the project and the iteration necessary to continue support of the design. This integrated technology development approach also addresses emerging issues related to the technology that are driven by the design process, to include the corresponding safety function.

Figure 1 identifies the integration of the technology development phases with the project stages. In practice, technology development precedes design, which is followed by design implementation (construction). This is depicted with bold blue arrows signifying completion of technology development activities supporting the follow-in process in the project development. Also the red arrows at the bottom part of the figure reflect the early continuous interaction of the plant support group (operations) with the technology development and design group for setting process and performance requirements to support plant startup, commissioning and operations.

The following sub-sections provide suggested guidance to line management within projects or programs to ensure that technology development activities are brought to an appropriate level of maturity and transitioned for each project stage with a continued effort to reduce technological risk, as applicable and appropriate to the specific project and DOE program.

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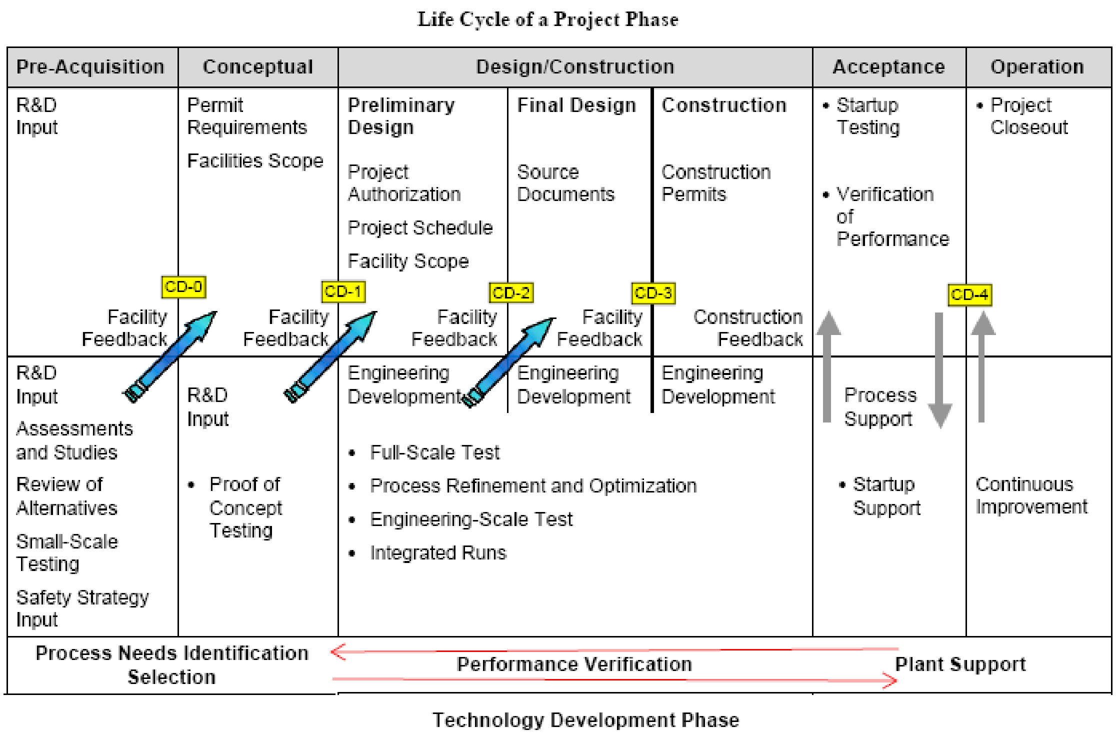
[2] DOE O 413.3B, Table 2.1, a safety design strategy is required for Hazard Category 1, 2 and 3 nuclear facilities for projects subject to DOE-STD-1189-2008.

Figure 1. Technology Development Integration with Project Management.



1.3.1 Technology Development Program Plans

Technology development plans are prepared when new technology development activities are identified during project planning. They provide a comprehensive planning document describing technology development activities required for the successful execution of the project, and the development relationship to the overall project scope and schedule relative to project phases. Areas addressed by the plan should include process needs identification, selection, system engineering, evaluation, performance verification, and demonstrations.

In support of technology development, it usually follows that a roadmap is developed to provide the technology development path forward for successful deployment of the selected technology. A work scope matrix is then developed that expands on the roadmap. The matrix provides the high-level details of each segment of research and development, assigning responsibility for the execution of each segment and documenting the path through each segment in the form of logic diagrams that are linked to the roadmap.

1.3.1.1 Process Needs Identification, Selection, and Evaluation

Process needs identification, selection, and evaluations occur during the pre-acquisition and conceptual design stages. Within these stages, as applicable and appropriate, the technology development program identifies the needs and requirements of a system or component and associated risks. This may include laboratory or pilot work to better understand system or process performance. The product of these activities provides input to performance requirement documents and criteria. Involving the plant support group early at this stage will help to ensure the manufacturability of designs, plants can presents lessons learned from previous designs, and suggest design improvements, as well as help identify the critical new technologies.

The next step in this effort involves selecting equipment that meets or most closely meets the performance requirements or criteria. In the selection process, existing equipment or processes are utilized to the maximum extent possible. However, in many cases, particularly those processes performed in hazardous or remote environments, the equipment may not be commercially available. In these situations, efforts are made to adapt commercial technologies to the specific environment and requirements. During this activity, the available equipment is compared and those identified as most closely meeting the defined requirements are selected for further evaluation.

Equipment and or process evaluation involves experimental or pilot facility testing of the process or equipment identified in the selection process. Although selection identified those processes and equipment that most closely meet design requirements, it is not uncommon for evaluation of those selected processes and equipment to identify areas where the process or equipment fails to meet requirements. In those cases, it may be necessary to return to the selection of alternatives to modify or select another preferred option. The following subsections describe various activities used to support the identification, selection, and evaluation of the selected technology.

Assessments and Studies

Inherent with technology development is the risk associated with first-of-kind applications. A technical risk assessment should be performed to identify risks that may affect the achievement of technical objectives that ultimately affect cost, schedule and performance. Results of technical risk assessments and risk-handling strategies are factored into technical assessments/reviews and studies [References: DOE G 413.3-7A; DOE G 413.3-9; and DOE O 413.3B].

Technical assessments and studies are conducted during the pre-acquisition project stage to evaluate and select the design approach that best meets the customer's goals, objectives, and preliminary technical and functional requirements. Topics addressed during this activity should include, as applicable, supporting program risks, technology maturation risks, process technology, facility concepts, major system concepts, component technology, safety, and risk-handling strategies identified through completion of technical risk assessments.

Review of Alternatives

Results of technology development assessments and studies are documented and reviewed to determine the validity of the approach that best meets project goals, objectives, and the physical, functional, performance, and operational requirements of the project at the best value; to include testing and validation of all required functions, including any safety functions.

A team consisting of members from the customer, engineering, operations, maintenance organizations, technology development program management, and selected subject matter experts reviews the documented assessments and study results. The team review focuses on the results of the assessments and studies relative to the alternatives considered, evaluation of systems used to select the recommended design approach, and the potential life-cycle cost savings. The objective of the review is to review the documented assessment and study evidence to identify the basis for endorsing the selected design approach, including development and testing of the technology to ensure its maturation in subsequent project phases.

Small-Scale and Proof-of-Concept Testing

Small-scale and proof-of-concept testing is performed at the conceptual project stage to verify initial assumptions relative to system and process performance. Test results are compared with the initial input parameters. Based on the reviews of test results, refinements in the technology (i.e., its design) are applied when necessary to ensure that the technology concept meets project requirements prior to the start of project design activities. As necessary, the technology development program plans are modified consistent with these test results.

1.3.2 Performance Verification

Performance verification occurs during the design and construction project stages. Once a process or equipment has been selected and proven to perform in an acceptable manner, verification against the design requirements is performed to ensure that the process or equipment will perform properly in the operating environment. Verification addresses performance of the selected process or equipment on both the component level and from an integrated system perspective. Verification attributes may include checking that the operating parameters are within the operating envelope of supporting systems (e.g., power, feed rate, etc.) as well as meeting the physical expectations of the equipment or examining properties of material produced against the stated requirements.

Following verification activities, full-scale testing to assess the durability and reliability of the process and/or equipment is conducted. Integrated runs involving combining components, systems, or processes are performed to provide a demonstration of process conditions over extended periods of time and provide opportunities of process optimization. This testing stage is intended to prove that the long-term operating goals, especially where remote operations are required, can be reliably achieved while producing the end product at acceptable quality standards in a safe and controlled manner.

1.3.3 Plant Support

Following construction completion, support for the new technology is provided through start up and turnover to operations. This continued integration of technology development provides an opportunity for the operations technical staff to attain a better understanding of the technology application. However, it is recommended that the plant support group involvement should start early in the pre-acquisition and conceptual phases to ensure the manufacturability of designs, to incorporate lessons learned from previous designs and operational experiences, and to help in the identification of what the new critical technologies are in the project (see Figure 1).

1.3.4 Technology Readiness Assessment (TRA) Reviews

IPR teams may be established to conduct TRA reviews and provide recommendations to the program/project sponsor and the Acquisition Executive in terms of the project technology readiness and maturity. These review teams serve in an advisory capacity at key project design points such as CD-0, CD-1, CD-2, and CD-3. (see section 2.0). At a minimum, team membership may consist of senior-level technical personnel and subject matter experts on the project. The team should also be able to leverage outside experts as appropriate to contribute to the review process. The team should perform its review relying on documented reports and other formal evidence, and minimize reliance on verbal assurances from project personnel. A technology review report is issued after each review, presenting the results of the review and specific recommendations for maturing technologies relative to the design process, as needed.

When this IPR review activity includes a sub-team of experts that are selected from personnel who are independent of the project, the sub-team reviews can be considered to satisfy the expectation to conduct a TRA, as discussed in the sections of this Guide that follow.

Ad hoc teams of subject matter experts may also perform additional technology development reviews at any point in the development process. These reviews target specific areas of development. The results from these reviews and recommendations are formally communicated to the project team and user.

1.3.4.1 Records

Records retention is usually dictated by customer/program requirements and the requirements from DOE O 413.3B in support of the project reviews process, and to support the formulation of lessons learned reports. Because of the significant documentation generated by technology development activities, judgment should be exercised prior to discarding any documented plans, reports, or studies utilized to validate technology development selection and test results.

2.0 Technology Readiness Assessment Process Model

"A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies [called Critical Technology Elements (CTEs)] used in systems." [2003 *DoD Technology Readiness Assessment Deskbook* (updated July 2009)].

The TRA is an assessment of how far technology development has proceeded based upon documented evidence. It is not a pass/fail exercise and is not intended to provide a value judgment of the technology developers or the technology development program. It is a review process to ensure that critical technologies reflected in a project design have been demonstrated to work as intended (technology readiness) before committing to construction expenses. TRAs should be conducted by technically qualified personnel who are independent of the project. A TRA can:

- Identify the gaps in testing, demonstration and knowledge of a technology's current readiness level and the information and steps needed to reach the readiness level required for successful inclusion in the project;

- Identify at-risk technologies that need increased management attention or additional resources for technology development; and

- Increase the transparency of management decisions by identifying key technologies that have been demonstrated to work or by highlighting immature or unproven technologies that might result in increased project risk.

The TRA process model consists of three sequential steps:

(1) **Identifying the Critical Technology Elements (CTEs)**. CTEs are the at-risk technologies that are essential to the successful operation of the facility, and are new or are being applied in new or novel ways or environment (see section 3.0 for more details of CTEs).

(2) **Assessing the Technology Readiness Level (TRL)**. The TRL scale used by the DoD and NASA, and adopted by EM in their pilot demonstration program is used for conducting Technology Readiness Assessments. Other DOE programs, in developing their own program guides/manuals, should consider lessons learned from EM, DoD and NASA, and their own domain or experience in measuring technology readiness, as applicable and appropriate to their specific projects and programs. TRL indicates the maturity level of a given technology, as defined in Table 1 primarily for hardware items. Figure 2 provides a schematic of the meaning of the TRL's in the context of DOE/EM waste processing projects. The TRL scale ranges from 1 (basic principle observed) through 9 (total system used successfully in project operations). TRL is not an indication of the quality of technology implementation in the design. Testing should be done in the proper environment and the technology tested should be of an appropriate scale and fidelity. A DOE/ EM example of the TRL requirements and definitions regarding testing "scale," "system fidelity," and "environment" are provided in Tables 2 and 3. (See section 4.0 for more details on TRLs)

(3) **Developing a Technology Maturation Plan (TMP).** If the TRL level for a CTE does not meet the expectation level at each Critical Decision level (especially for CD-2 and later), then a maturity level gap exists that requires further evaluation testing or engineering work in order to bring the immature technology to the appropriate maturity level. The development or revision of a Technology Maturation Plan (TMP) identifies the activities required to bring immature CTEs up to the desired TRL (see section 5.0 for more details on the TMP).

Table 1. Technology Readiness Levels

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected mission conditions.	The technology is in its final form and operated under the full range of operating mission conditions. Examples include using the actual system with the full range of wastes in hot operations.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	The 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 actual waste in hot commissioning. Supporting information includes operational procedures that are virtually complete. An Operational Readiness Review (ORR) has been successfully completed prior to the start of hot testing.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing full-scale prototype in the field with a range of simulants in cold commissioning[1]. Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering scale prototypical system with a range of simulants.[1] Supporting information includes results from the engineering scale testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for the testing should closely represent the actual operating environment.
Technology Development	**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, laboratory scale system in a simulated environment with a range of simulants[1] and actual waste[2]. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical.

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	The 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 and small scale tests on actual waste[2]. Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) 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 tested with simulants.[1] Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3 the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected on simulants. Components of the technology are validated, but there is no attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
Basic Technology Research	**TRL 2**	Technology concept and/or application formulated	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. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
	TRL 1	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or other references that identify the principles that underlie the technology.

[1] Simulants should match relevant chemical and physical properties.

[2] Testing with as wide a range of actual waste as practicable and consistent with waste availability, safety, ALARA, cost and project risk is highly desirable.

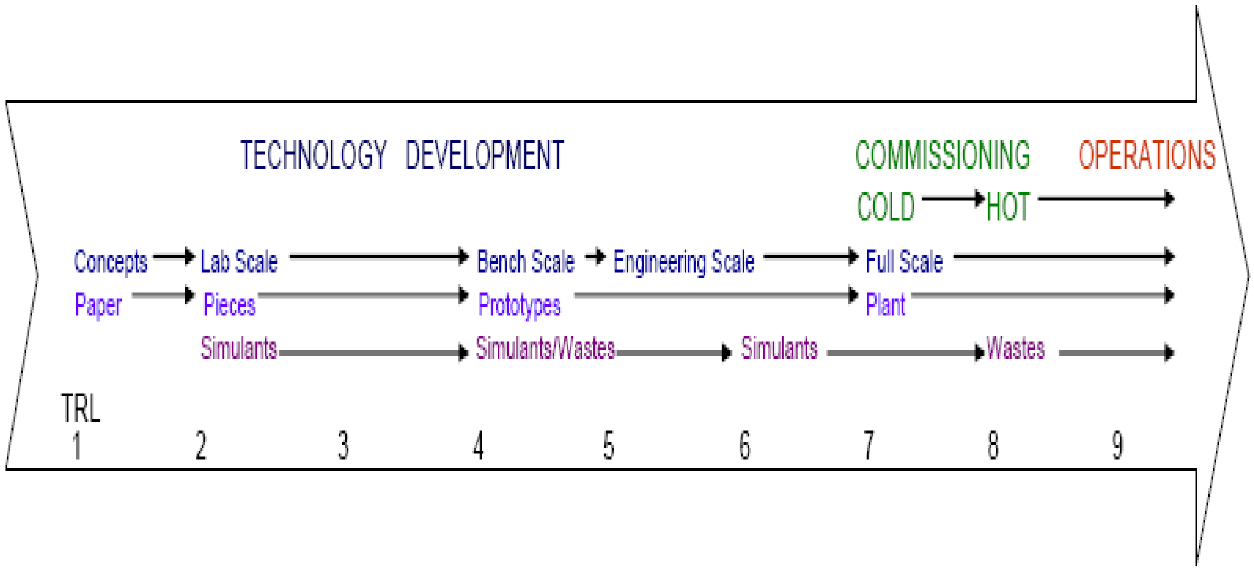


Figure 2. Schematic of DOE/EM Technology Readiness Levels

Table 2. DOE/EM TRL Scale, fidelity and Environment Definitions

Scale	
Full Plant Scale	Matches final application
Engineering Scale[1]	Typical (1/10 < system < Full Scale)
Laboratory/Bench[1]	< 1/10 Full Scale

[1] The Engineering Scale and Laboratory/Bench scale may vary based on engineering judgment.

System Fidelity	
Identical System Configuration	-matches final application in all respects
Similar Systems Configuration	-matches final application in almost all respects
Pieces	-system matches a piece or pieces of the final application
Paper	-system exists on paper (i.e., no hardware system)

Environment (Waste)	
Operational (Full Range)	Full range of actual waste
Operational (Limited Range)	Limited range of actual waste
Relevant	Simulants plus a limited range of actual wastes
Simulated	Range of simulants

Table 3. DOE/EM TRL Testing Requirements

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

[1] Simulants should match relevant physical and chemical properties
[2] Testing with as wide a range of actual waste as practicable; and consistent with waste availability, safety , ALARA, cost, and project risk is highly desirable

*** Note: See Tables 5 & 6 for definitions of the TRL testing descriptive terms used in the table.**

2.1 Relationship of TRAs and TMPs to the DOE Critical Decision Process

Technology development should be the responsibility of the program/project, as it is applicable and appropriate. A TRA provides management an independent assessment of the program/project's progress in its technology development activities in support of a project.

The TRA process can be employed in a variety of situations requiring the determination of the state of technology development. In the realm of project management, TRAs and the resulting TMPs can be used as a project management tool to reduce the technical and cost risks associated with the introduction of new technologies. The TRA process can serve as one of the tools employed in helping to make effective Critical Decisions, as required by DOE O 413.3B. DOE O 413.3B (Appendix C, page C-27) requires for Major System Projects where new critical technologies are being deployed that a TRA shall be conducted and the associated TMP developed prior to CD-2. On those projects where a significant critical technology element modification occurs subsequent to CD-2, another TRA should be conducted prior to CD-3. For other projects the implementation of TRAs may be a discretionary decision of the Acquisition Executive or the DOE Program, but the associated risks may need to be identified and captured per Appendix F of DOE-STD-1189-2008, as applicable and appropriate. See also DOE G 413.3-7A, *Risk Management Guide*, dated January 2011, for additional information on risk management.

The five CDs are major milestones approved by the Secretarial Acquisition Executive or Acquisition Executive that establish the Mission Need, the recommended alternative, the Acquisition Strategy, the Performance Baseline, and other essential elements required to ensure that the project meets applicable mission, design, security, and safety requirements. Each CD marks an increase in commitment of resources by the Department and requires successful completion of the preceding phase or CD. Collectively, the CDs affirm the following:

- There is a need that cannot be met through other than material means [CD-0];
- The selected alternative and approach is the optimum solution [CD-1];
- The proposed scope, schedule and cost baseline is achievable and minimum key performance parameters (KPPs) that must be achieved at CD-4 [CD-2];
- The project is ready for implementation [CD-3]; and
- The project is ready for turnover or transition to operations [CD-4].

The recommended guidance is to conduct TRAs during conceptual design and preliminary design processes; and at least 90 days prior to CD milestones. The assessment process should follow the guidance in this document by applying the system engineering approach to assess proper integration of systems with new technologies into the project (system within systems rather than piecemeal review), to include testing and validation of all the critical technologies, including the safety functions in the relevant operational environment. Deviations from the recommended approach may result in unquantifiable and unknown project risks. Figure 3 shows how TRAs and other key reviews support each of the CDs. (There are numerous additional requirements for each CD. See Tables 2.1-4 of DOE O 413.3B and DOE-STD-1189-2008 for a complete listing.)

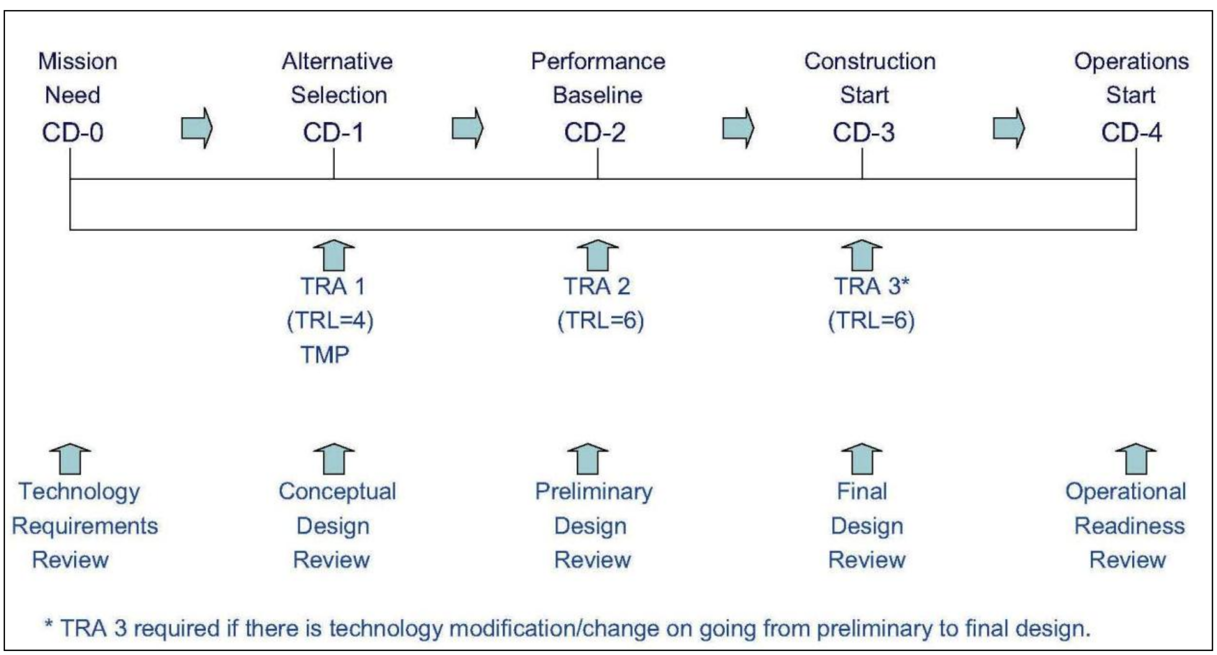


Figure 3. Suggested Technology Assessments and Review Requirements for Critical Decisions

<u>Note</u>: The technology reviews, the design reviews, and the Operational Readiness Reviews (ORR) are conducted in advance of the CD milestone to support the milestone decision. The TRL values above (in parenthesis) at each CD point are recommended minimum values. DOE programs should justify and document through risk management processes deviations from the recommended minimum TRLs at each CD based on their particular technology's complexity and associated risks, as deemed applicable and appropriate.

<u>Graded Approach for TRAs:</u> The recommended approach is that TRAs should be conducted in advance for each CD such that they feed the associated technology and safety risks into the overall project risk assessment for evaluating cost and schedule impacts. The recommended integrating mechanism for such an approach could be through the IPR which evaluates the project overall technical and safety risks, among other things. DOE programs should justify and document through risk management processes deviations from the recommended minimum TRLs at each CD in Figure 3 weighing their particular technology's complexity and associated risks, as deemed applicable and appropriate. Any discrepancy/gaps on the TRL findings from a TRA with the expectations at each CD should trigger a TMP to bring the TRL to par with the expectations for TRL at CD-2 (establishing project baseline) and CD-3 (start of construction). If not so, the Acquisition Executive should be made aware of the resulting risks in a quantifiable form, to include safety implications. Deviating from the recommended approach could result in project risks that are not identified and captured per Appendix F of DOE-STD-1189-2008.

<u>CD-0, Approve Mission Need</u>: Identification of a mission-related need and translation of this gap into functional requirements for filling the need. *The mission need is independent of a particular solution and should not be defined by equipment, facility, technological solution, or physical end item*. The focus for technology development assessments, at this stage, should be on a clear statement of the requirements of the input and the desired output of the process, to include the safety strategy input, as applicable and appropriate. A Technology Requirements Review would assess the adequacy of requirements definition and characterization information and determine any additional work necessary, to include an assessment of technology unknowns that need to be further evaluated. If additional work is necessary to adequately define technical scope of the project, a plan should be developed detailing its scope and schedule.

<u>CD-1, Alternative Selection and Cost Rang</u><u>e</u>: Identification of the preferred technological alternative, preparation of a conceptual design, and development of initial cost estimates. A TRA should be performed during conceptual design, to support the CD-1 approval process and a TMP prepared, as applicable and appropriate. Any TMPs should be linked to the project risk assessment process as a whole. Prior to CD-1 approval, it is recommended that all Critical Technology Elements (CTEs) of the design should have reached at least TRL 4 and a TMP should have been prepared, or revised, for all CTEs that are not assessed to have reached the appropriate recommended level for CD-2, as applicable and appropriate.

Prior to CD-1 approval, the Program Secretarial Officer must conduct an IPR as required in DOE O 413.3B: "For Hazard Category 1, 2, and 3 nuclear facilities, conduct an IPR to ensure early integration of safety into the design process." The review must ensure safety documentation is complete, accurate, and reliable for entry in the next phase of the project (Reference: DOE-STD-1189-2008). The IPR should include within its scope a TRA, as applicable and appropriate. If a safety system requires technology development, then it must be identified early or the objective of credible technical scope, schedule, and cost baseline cannot be successfully achieved (note: the activity is not optional, but the means to achieve the activity is optional).

CD-2, Performance Baseline: Completion of preliminary design, and development of a performance baseline that contains a detailed scope, schedule, and cost estimate, and KPPs that must be achieved at CD-4. The process of technology development, in accordance with the program/project's technology development plans and any TMPs issued as a result of a prior TRA, should ensure that all CTEs have reached at least TRL 6, which indicates that the technology is ready for insertion into detailed design, as applicable and appropriate. A TRA should be performed at least 90 days prior to reaching CD-2 to independently assure that the CTEs have in fact reached TRL 6 or the supportable recommended program/project's target level for CD-2, as applicable and appropriate. Projects are encouraged to achieve TRL 7 prior to CD-3 as a recognized best practice, but in no instance it is recommended that CD-2 be approved with a TRL less than 6. In either case, the residual risks should be accounted in the Risk Management Plan, recorded in the risk register and assigned the proper contingency in the project baseline (see DOE G 413.3-7A).

Prior to CD-2 approval (refer to DOE O 413.3B), the PSO must conduct a TRA and develop a TMP for major system projects where new critical technologies are being developed, as appropriate.

CD-3, Start of Construction: Completion of essentially all design and engineering and beginning of construction, implementation, procurement, or fabrication. A TRA is recommended if there is a significant CTE modification subsequent to CD-2 as detailed design work progressed. If substantial modification to a CTE occurs, the recommended TRA should be performed and a TMP should be prepared or updated to ensure that the modified CTE will attain TRL 6, prior to its insertion into the detailed design and baseline, as applicable and appropriate. Prior to the start of operations, start-up testing and operational readiness reviews should ensure that the CTEs have advanced to the target maturity level at CD-4 (TRL 6 toward TRL 9), as applicable and appropriate.

Prior to CD-3 approval (refer to DOE O 413.3B), the PSO must conduct a TRA for major system projects where a significant critical technology element modification occurs subsequent to CD-2.

CD-4, Start of Operations or Project Completion: Readiness to operate and/or maintain the system, facility, or capability. Successful completion of all facility testing and entry into operations corresponds to attainment of TRL 9. Nuclear and other hazardous operations may have additional post CD-4 start-up requirements and qualifications that must be completed before full operations begin under mission conditions.

2.2 Relationship of TRAs to Independent Project Reviews

IPRs are one of the measures that can be taken to ensure the timely resolution of engineering, system integration, technology readiness assessments, design, quality assurance, operations, and maintenance and nuclear/non-nuclear safety issues. It should also be emphasized that supporting program issues and their resolution should also be reviewed under the IPR since they could overshadow the technology development or other elements of the project, and as such, present an element of uncertainty to the project. The purpose of an IPR is to assist reducing technical risk and uncertainty which increases the probability of successful implementation of technical scope including new technologies.

IPRs can include TRAs to provide an assessment of the maturity level of a new proposed technology prior to insertion into the project design and execution phases to reduce technical risk and uncertainty.

The TRA should not be considered a *risk* assessment, but it should be viewed as a tool for assessing program risk and the adequacy of technology maturation planning by the program/project. The TRA scores the current readiness level of selected system elements (i.e., CTEs), using defined TRLs (see section 4.0). The TRA highlights critical technologies and other potential technology risk areas that may need the program manager/Federal Project Director attention. If the system does not meet pre-defined TRL scores, then a CTE TMP should be required. As discussed in section 5.0, this TMP explains in detail how the target TRL (the CTEs maturity) will be advanced prior to the next milestone Critical Decision and it allows the program/project to properly reflect the CTEs risk within the project's baseline.

3.0 Model for Identifying Critical Technology Elements (CTEs)

The following definition of a CTE was adopted from the 2003 DoD, Technology Readiness Assessment Deskbook, updated July 2009:

A technology element is "critical" if the system being acquired depends on this technology element to meet operational requirements (with acceptable development cost and schedule and with acceptable production and operation costs) and if the technology element or its application is either new or novel, or in an area that poses major technological risk during design or demonstration. 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.

Disciplined identification of CTEs is important to a program. The management process/procedure for CTE identification is as important as the technical task because it adds to the credibility of the resulting CTE list. If a CTE is overlooked and not brought by the program/project to the requisite maturity level for later project insertion at the start of System Design and Development, the system performance, program schedule, and cost could be jeopardized. On the other hand, if an overly conservative approach is taken and a plethora of technologies are categorized as critical, energy and resources are likely to be diverted from the few technologies that deserve an intense maturation effort.

The *Defense Acquisition Guidebook*, updated July 2011, specifically recommends the use of the Work Breakdown Structure (WBS) for a project to initially assist in identifying the CTEs (see Figure 4 for a sample DOE project WBS). The WBS has several beneficial attributes for this purpose:

- It is readily available when system engineering practices are used.

- It evolves with the system concept and design.
- It is composed of all products that constitute a system and, thus, is an apt means to identify all the technologies used by the system.
- It relates to the functional architecture and, therefore, to the environment in which the system is intended to be employed.
- It reflects the system design/architecture and the environment and performance envelope for each product in the system.

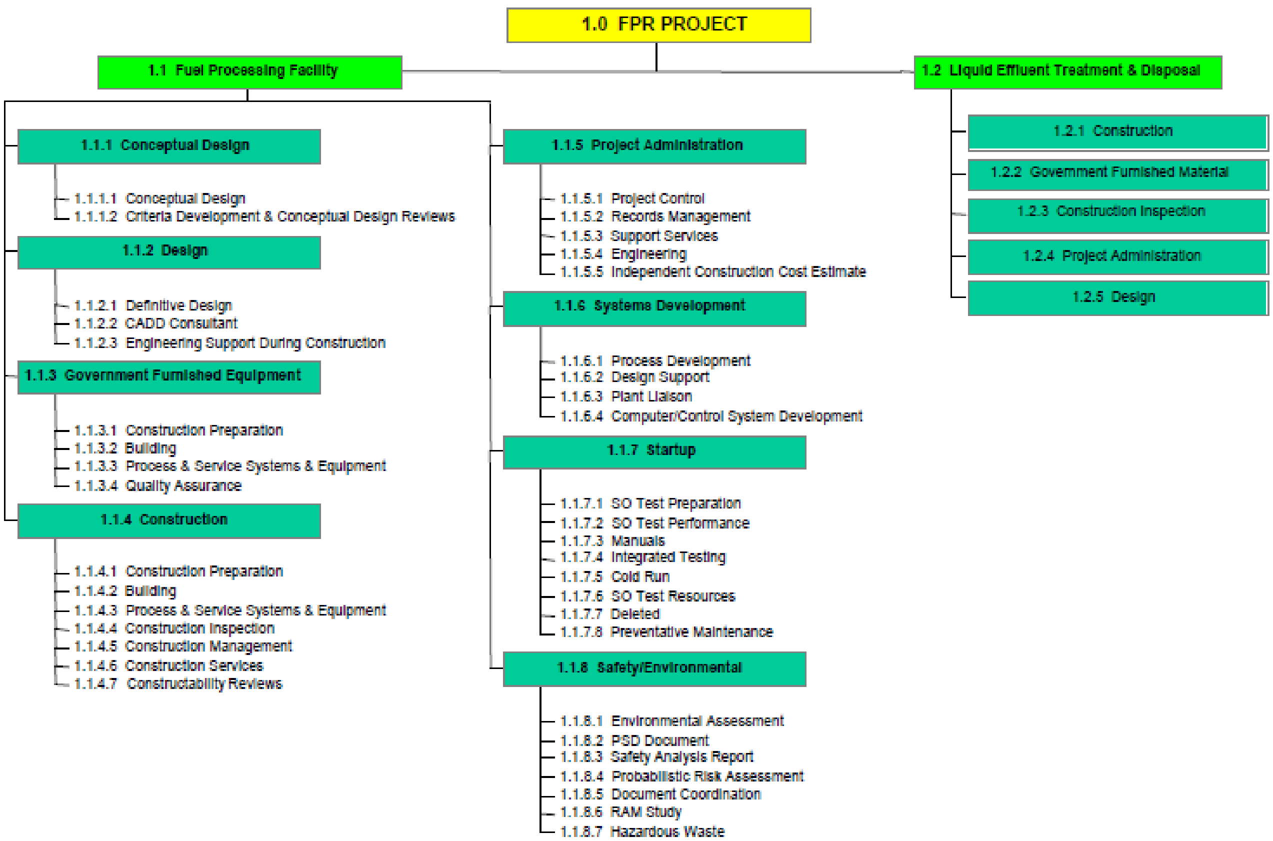


Figure 4. Sample DOE Project Work Breakdown Structure

Some programs within DOE (such as EM) have found that a WBS is not readily usable for CTE identification, and system flow diagrams (for example in waste processing technologies) were a more helpful tool for identifying CTEs (see Figure 4a). DOE programs elements should develop their own guidance on how to best approach the identification of CTEs for their technologies.

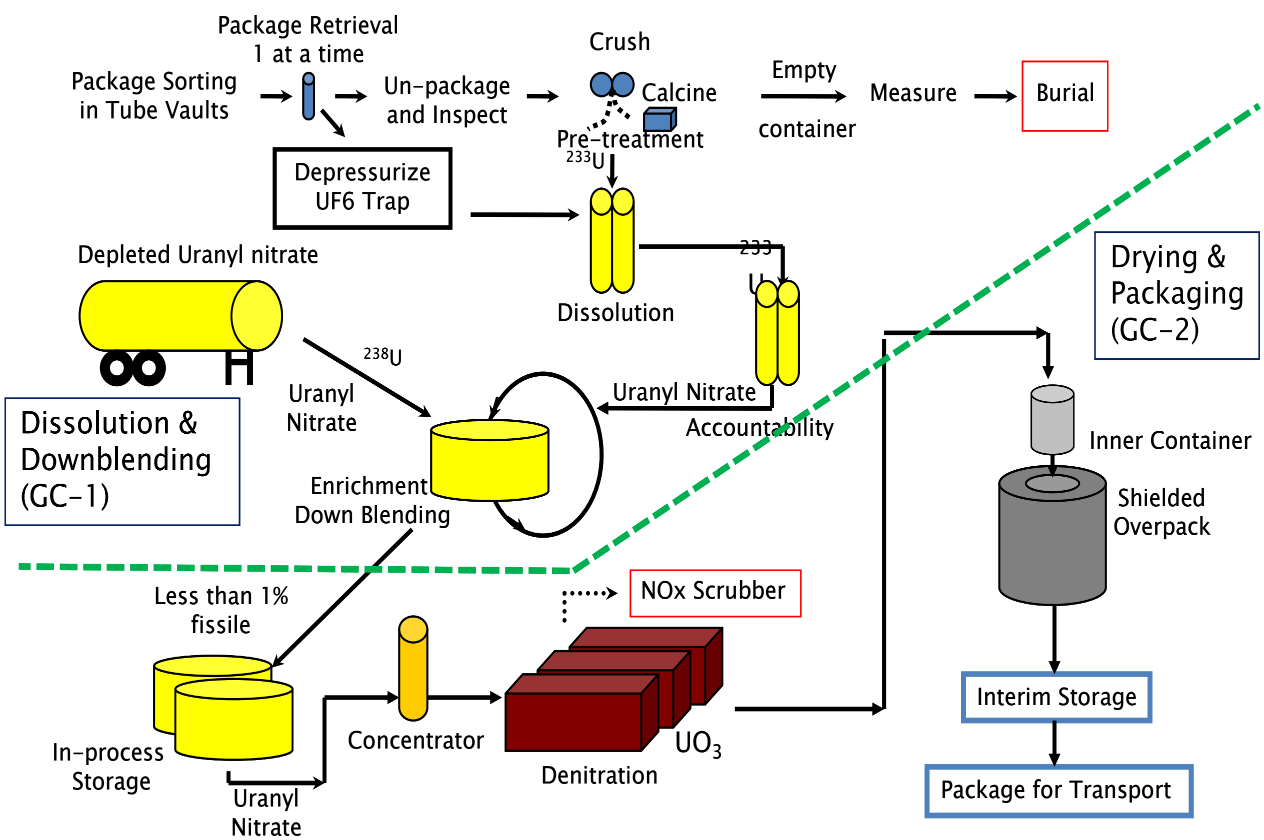


Figure 4a. DOE/EM Example of a Flow Diagram to Assist in Identifying CTEs

From a management process/procedure perspective, CTE identification should be a two-step process. In the first step, the CTE definition is applied across the system's WBS or flow diagram to identify critical technology candidates. This process should be thorough, disciplined, and conservative. Any questionable technology should be identified as a candidate CTE. For these questionable technologies, the information required to resolve their status should be documented.

The program manager, the program office technical staff and the system contractors – the people best informed about the system – should lead the first step. In any case, they should be able to defend the logic of the method/process used for identifying the CTEs.

The second step consists of resolving, where possible, the status of technologies in question by filling the information gaps noted in the first step. An independent panel of technical experts convened by the sponsoring program office should conduct the second step.

All individuals involved in these steps should be familiar with:

- CTE identification in the context of a TRA and its importance to the technical and programmatic success of the program.
- The concept of the WBS (or systems architecture) or flow diagram as a complete description of the products/things that comprise a system.

- The distinction between hardware, software, and manufacturing technologies and the metrics that evaluate their maturity (as described in Table 1 and section 4.0).
- The affordability and production criteria for CTEs.
- The role that "environment" has in identifying CTEs.

CTE Determination Criteria

The technical task in the second step involves the use of a series of questions to test whether the CTE definition applies. The series of questions are divided in two sets of criteria:

(1) Criticality to program criteria, and

(2) New or novel criteria.

Appendix E presents a sample template for the series of questions suggested for determining whether a technology element is a CTE. It is advisable that this template be completed for each candidate CTE so that a formal record of the CTE determination can be maintained by the project.

For a technology to be critical, the answer to one of the following questions should be "yes":

Criticality to Program Criteria

- Does the technology directly impact a functional requirement of the process or facility?
- Do the 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?
- Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?
- Do limitations in the understanding of the technology impact the safety of the design?
- Are there uncertainties in the definition of the end state requirements for this technology?

In addition, the answer to one of the following questions should also be "yes":

New or Novel Criteria

- Is the technology new or novel?
- Is the technology modified?
- Have the potential hazards of the technology been assessed?
- Has the technology been repackaged so that a new relevant environment is realized?

- Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

The environment in which the system will operate plays a significant role in answering these last four questions. Generally, the requirement statement for the system will provide some description of the environment in which the system is expected/required to operate. This can be called the *external* or i*mposed environment.* It may be natural or man-made, friendly or hostile (e.g., weather, terrain and hostile jamming, terrorism, and so forth). Another environment – the one generally more important for identifying and evaluating CTEs – can be called *internal* or *realized environment.* It is derived from the performance required of each design item (product, subsystem, component, WBS element). The design analysis should include the required or expected performance envelope and conditions for each WBS or flow diagram technology element.

A complete definition of the operational environment for the system and its components is necessary to determine that the planned environment is identical to prior applications where this technology has been successfully used. Deviations between the planned environment and the environment of prior applications results in the need to qualify (mature) the planned use of the technology by the program/project.

People with the requisite technical knowledge and the independence needed to make a good judgment should guide the actual set of questions asked for each CTE candidate. The program manager and the suppliers should present clear, convincing, and succinctly summarized data that show what is known/not known about the environment and should explain the similarities and dissimilarities between the expected/demonstrated environments.

4.0 Model for Technology Readiness Level Assessments

Determination of a TRL should be conducted by the program/project as part of normal project planning and development early in the project, and assessed by a TRA team of independent project experts prior to key critical decisions. Both the project and the TRA team can use the following process:

TRL is a measure used by some United States government agencies (sometimes as a direct result of Congressional direction) and many of world's major companies (and agencies) to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem. Generally speaking, when a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven or matured, it can be incorporated into a system/subsystem. TRL at its most basic definition describes the maturity of a given technology relative to its development cycle.

Technology maturity is a measure of the degree to which proposed CTEs meet program objectives and can be related to program risk. A TRA examines program concepts, technology requirements, and demonstrated technology capabilities including the safety function, in order to determine technological maturity. Table 4 provides a summary view of the technology maturation process model adopted from NASA and DoD, and somewhat modified by DOE-EM, which could be tailored for use by other DOE programs. This DOE-wide model has the following attributes: it includes (a) "basic" research in new technologies and concepts (targeting identified goals, but not necessarily specific systems), (b) focused technology development addressing specific technologies for one or more potential identified applications, (c) technology development and demonstration for each specific application before the beginning of full system development of that application, (d) early identification of all potential hazards from the technology and the testing of the safety functions in the relevant environment, (e) system development (through first unit fabrication), and (f) system "launch" and operations.

Hazard Analysis/Safety: Design and performance requirements for CTEs should address hazards early to ensure safety is "designed in" early instead of "added on" later with increased cost and decreased effectiveness. Analysis of hazards results in the identification of potential accident scenarios and the determination of how to prevent or mitigate accidents. Safety Structures, Systems and Components (SSCs) are identified and incorporated into the design to prevent or mitigate the consequences of hazards to the facility worker, the collocated worker and the public. These SSCs are classified as safety class, safety significant or defense in depth as required by their safety function. Testing and validation of safety functions in the relevant environment for the CTEs is part of the TRA, as applicable and appropriate. (Reference: DOE O 420.1B and DOE O 413.3B]

Table 4. DOE Technology Readiness Level Scale

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	**TRL8**	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.
Technology Development	**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.
	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 TRL scale used in Table 4 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. All technology readiness levels should include compliance with DOE-STD-1189-2008 and DOE O 413.3B to include worker and public safety considerations early in the design process.

The testing performed on the CTEs to demonstrate its operational capability and performance is compared to the TRLs in Table 5 (DOE/EM application). The TRL definitions provide a convenient means to understand further 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 should be completed at an engineering or pilot scale, with a testing system fidelity that is similar to the actual application. Table 6 provides additional definitions of the TRL descriptive terms often used by DoD in the testing recommendations for TRLs for some of their technologies.

Table 5. DOE/EM Relationship of Testing Recommendations 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

Table 6. Additional Definitions of TRL Descriptive Terms
(Source: *Defense Acquisition Guidebook*)

Term	Definition
Breadboard	Integrated components that provide a representation of a system/ subsystem and that can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.
High Fidelity	Addresses form, fit, and function. A high-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.
Low Fidelity	A representative of the component or system that has limited ability to provide anything but first-order information about the end product. Low-fidelity assessments are used to provide trend analysis.
Model	A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.
Operational Environment	Environment that addresses all the operational requirements and specifications required of the final system to include platform/ packaging.
Prototype	A physical or virtual model used to evaluate the technical or manufacturing feasibility or military utility of a particular technology or process, concept, end item, or system.
Relevant Environment	Testing environment that simulates the key aspects of the operational environment.
Simulated Operational Environment	Either (1) a real environment that can simulate all the operational requirements and specifications required of the final system or (2) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.

The primary purpose of using the above Technology Readiness Level definitions (Levels 1 through 9) is to help management in making decisions concerning the development and maturation of technology to ensure it can perform its intended mission. Advantages include:

- Provides a common standard for systematically measuring and communicating the readiness of new technologies or new applications of existing technologies at a given point in time in the project life cycle.

- Provides a measure of risk as a management tool. The gap between the maturity of the technology and the project requirements represents the risks or unknowns about the technology.

- Assist in making decisions concerning technology funding.

- Assist in making decisions concerning transition of technology.

- Assist in selecting the best technology alternative.

4.1 Supporting Documentation for the Technology Readiness Levels Assessments

Table 7 lists typical generic documentation (not all inclusive and varies by technology application and program) that should be extracted or referenced to support a TRL assignment.

Table 7. Hardware TRL Definitions, Descriptions and Supporting Information
(Source: *Defense Acquisition Guidebook*)

TRL	Definition	Description	Supporting Information
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.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to validate physically the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?

Table 7. Hardware TRL Definitions, Descriptions and Supporting Information (continued)

TRL	Definition	Description	Supporting Information
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space). Examples include testing the prototype in a test bed aircraft.	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

4.2 CTEs Assessments for Maturity (Technology Readiness Level)

The evaluation process should include the following steps for all CTEs (Reference: DoD Technology Readiness Assessment Deskbook, July 2009):

- Describe the technology (subsystem, component, or technology). Describe the function it performs and, if needed, how it relates to other parts of the system. Provide a synopsis of development history and status. This can include facts about related uses of the same or similar technology, numbers or hours of testing of breadboards, numbers of prototypes built and tested, relevance of the test conditions, and results achieved.

- Describe the environment in which the technology has been demonstrated. Provide a brief analysis of the similarities between the demonstrated environment and the intended operational environment.

- Apply the criteria for TRLs and assign a readiness level to the technology. State the readiness level (e.g., TRL 5) and the rationale for choosing this readiness level.

- Provide references to papers, presentations, data, and facts that support the assessment. Includes data tables and graphs that illustrate that a key fact is appropriate.

- If the CTEs are presented in categories (e.g., super-conducting magnets, detectors or sensors), the information specified in the previous bullets (e.g., describing the technology, describing the function it performs, and so forth) should be provided for each CTE within a category.

- State the review team's position concerning the maturity (technology readiness level) of the CTEs and whether this maturity is adequate for the system to enter the next stage of development. If the position supports entering the next stage even though some CTEs are less mature than would ordinarily be expected, explain what circumstances or planned work justifies this position. Include references to a separately submitted Technology Maturation Plan (see section 5.0) for each immature CTE.

4.3 Technology Readiness Level Calculator

The TRL Calculator is a tool developed by the US Air Force Research Laboratory for applying TRLs for technology development programs (Reference: Nolte, William L., et al., "*Technology Readiness Level Calculator,"* October 20, 2003, Air Force Research Laboratory (AFRL), presented at the NDIA System Engineering Conference). In its present form, the calculator is a Microsoft Excel spreadsheet application that allows the user to answer a series of questions about a technology project. Once the questions have been answered, the calculator displays the TRL achieved. Because the same set of questions is answered each time the calculator is used, the calculator provides a standardized, repeatable process for evaluating the maturity of any hardware or software technology under development. In this way, the TRL Calculator is one tool that can serve to answer the question of how one can measure TRLs for CTEs using a standardized method.

The present version of the calculator is limited to values of TRLs corresponding to TRL 6 or lower. This is because, in the Air Force Research Laboratory, the stated objective of a technology development program is to mature the technology to TRL 6. While it is certainly possible to mature a given technology beyond that level, there are no purely programmatic activities that take place within the laboratory beyond TRL 6. Because the calculator was initially created for use in the laboratory, a TRL 6 was deemed sufficient. Extending the TRL concept to a level corresponding to TRL 9 is the subject of future work by the original developers of the tool. (A copy of the latest version of the US Air Force's TRL Calculator can be obtained directly for William Nolte at the AFRL.)

A modified version of the DoD TRL Calculator has been used extensively during the conduct of DOE-EM TRAs and is included in Appendix F as an example of a tailored version. DOE programs should adapt/modify the suggested calculator to their particular technologies and processes. The TRL Calculator herein is used in a two step process. First, a set of top-level questions (Table F1 of Appendix F) is used to determine the anticipated TRL. The anticipated TRL is determined from the question with the first "yes" answer. Second, evaluation of the detailed questions (Tables F2 through F7 of Appendix F) is started one level below the anticipated TRL. To attain a specific TRL, the CTE should receive a "yes" response to all questions at the TRL level from which the questions are found. If it is determined from the detailed questions that the technology has not attained the maturity of the starting level, then the next levels down are evaluated in turn until all of the questions for a specific TRL are answered "yes". The TRL is defined by the level from which all questions are answered affirmatively. However, it is recognized that a negative response to one single question for the TRL under evaluation might not be indicative of the relative importance of the particular item to the success of the technology. In this instance a graded approach could be appropriate during the evaluation and justified when assigning the highest TRL number achieved for the technology. TRL calculators are expected to evolve over time based upon lessons learned from previous versions of calculators used by the programs.

TRLs are documented within the TRA Report. As a minimum, the TRL should be expressed numerically and described in text. Additionally, the basis for the TRL determination should be clearly and concisely documented. DOE/EM has found that completing the forms found in Appendix F for all CTEs serves to document the basis for the TRL decision.

4.4 TRA Report

The purpose of the TRA Report is to document the description of the process used to conduct the TRA and provide a comprehensive explanation of the assessed TRL for each CTE. While the Appendix F forms document the answers to the questions, the basis for these answers is what the report should focus on. The report should provide citation to and summary descriptions of the salient aspects of the reference documents which serve the basis for the answers documented in the forms.

The TRA review team leader is responsible for coordinating the report preparation with detailed input from the review team members (see DOE G 413.3-9 for the protocol to conduct project reviews of which TRA reviews is one under the category of Technical IPRs; Appendix D is the suggested template for a TRA Review Plan). See Appendix G for the suggested format of the report. As a minimum, completion of the TRA should provide:

- A comprehensive review, using an established program/project Work Breakdown Structure or flow diagram as an outline, of the entire platform or system. This review, using a conceptual or established baseline design configuration, identifies CTEs.

- An objective scoring of the level of technology maturity for each CTE by subject matter experts.

- Results should assist the Integrated Project Team in preparing maturation plans for achieving an acceptable maturity roadmap for CTEs prior to critical milestones decision dates.

- A final report documenting the findings of the assessment review team.

- Continuous improvement is an important part of an evolving TRA process and as such lessons learned that benefit future TRAs and/or technology development projects should be identified during the conduct of the TRA. These lessons learned should be documented within the TRA Report or they may be documented in a separate document. In the case of a separate lessons learned document, the TRA report should be referenced within the document and the document should be filed with the TRA Report.

A TRA team should plan to reference relevant portions of the project's report in developing its own report.

5.0 Technology Maturation Plan

5.1 Process Overview

The purpose of the TMP is to describe planned technology development and engineering activities to mature CTEs that did not receive at least TRL 6 or higher. This threshold should be a DOE Program level option tailored to their specific technologies, as required and appropriate. TRL 6 is the recommended standard for advancing from the conceptual design phase to the design finalization phase due to the vast amount of industry, DoD and NASA experience that shows that unless a technology has been advanced to this level of maturity at the time of CD- 2 (project baseline) approval, the potential for baseline performance deviations is so great and the later corrective actions so disruptive and costly to the project that proper project management control cannot be expected to be successful at bringing the project to completion within the originally approved technical, cost and schedule baselines. DOE-EM has adopted a level 6 during their most recent TRAs in their effort to reduce the probability of cost and schedule overruns due to immature CTEs.

The program/project should be beginning the development of its TMP subsequent to the approval of the project's mission need at CD-0. As a result of conducting a TRA, the project may be required to revise its TMP in order to address and remedy TRL deficiencies noted in a TRA report. TRA induced changes to TMPs can be likened to a corrective action plan in that the changes to the TMP are prepared by the project and describes the additional or corrective actions for those CTEs that did not mature as the project had intended [because they did not received the desired TRL by the time the associated critical decision was reached (i.e., for example CD-1, TRL=4; CD-2, TRL=6)].

5.2 TMP Preparation

The suggested major steps in preparing a TMP are summarized below (each DOE Program Office should develop its own protocol for concurrences and approvals of this documentation):

- The Project Manager/Contractor prepares the draft TMP. The suggested format and contents of the document are provided below and in Appendix H.

- At CD-0 and thereafter as appropriate, the Project Manager for the project provides the draft report to the Federal Project Director and the DOE Program Office for review and approval. To expedite the schedule, these reviews are often accomplished in parallel.

- If the project is modifying a TMP in response to a TRA, after approval by the program/project, the TMP is provided to the TRA review team for review. The review verifies (1) responsiveness to gaps identified in the draft TRA, (2) reasonableness of the proposed approach, and (3) reasonableness of the proposed schedule and costs associated with technology maturation requirements.

Note: The Project Manager should have updated a TMP prior to the TRA review team visit, anticipating the necessary changes based on the project's own internal program reviews of its technology maturation status.

- As applicable, the Project Manager resolves the review comments, revises the TMP, and forwards the revised TMP to the Federal Project Director.

- The Federal Project Director approves the final TMP.

- The Federal Project Director incorporates the impact of changes in the project's TMP into the project risk management plan.

As described in Appendix H, the TMP revision should summarize any previous TIPRs, other technical assessments, and any previous TRAs that may have contributed to the need for the revision of the document. This summary should include the TRLs for each CTE as documented in the latest TRA. Previous technology development activities that brought the technology to its current state of readiness should be described. Also, ongoing technology development should be included because progress and completion of this ongoing work will influence the interfaces and schedule for the TMP. The TMP should describe the approach used in defining the additional required technology development activities that will be conducted. Approaches may include evaluating incomplete criteria in the TRL calculator, risk assessments, and value engineering.

In preparing the TMP for relatively mature technologies, TRA results should be evaluated using a risk evaluation and value engineering approach. Figure 5 provides a diagram of the technology maturation planning process. An identified technology readiness issue (or technology need) is evaluated using the system engineering functions and requirement analysis. Then, a first order of risk evaluation is conducted to determine whether the current path can be followed with negligible risk or if alternatives (current path with modifications or a new system) should be pursued. A more detailed, second order risk evaluation is conducted to determine if the modifications or new system alternatives have sufficient payoff to be incorporated into the TMP.

In describing the required technology development activities, specific maturation plans should be prepared for each CTE assessed at less than TRL 6 (threshold option for the DOE Program Office to decide). The plan for each CTE should include:

- Key Technology Addressed
- Objective
- Current State of the Art
- Technology Development Approach
- Scope
- Schedule
- Budget

The high-level schedule and budget (including the total maturation costs) that incorporate the major technology development activities for each CTE should be provided. Any major decision points such as proceeding with versus abandoning the current technology or selection of a backup technology should be included in the schedule. More detailed schedules will be prepared for executing and managing the work.

5.3 TMP Execution

After the TMP is approved, the Contractor will prepare or modify detailed test plans to conduct the technology development activities described in the TMP. These test plans will define the test objectives, relevant environment, the scale of the planned tests, and performance targets (or success criteria) for the tests. Then, more detailed cost and schedule estimates will be prepared by the Contractor to support preparation of a Baseline Change Proposal (BCP), if required. The BCPs will be approved in accordance with the approved Project Execution Plan or as directed by the DOE Program Office when outside the project scope.

The Contractor may conduct the technology development in house or work with DOE to select a technology developer by open procurements to industry, identification of national laboratories with appropriate expertise, etc. Schedule status will be maintained by the contractor based on periodic updates from the technology development performer. Any significant changes in scope and schedule will require formal change control by the contractor and the DOE organization providing the funding through the assigned DOE Contracting Officer.

Technical reports will be written as major technology development tasks are completed. A Final Technical Report will be prepared when all of the technology development tasks in the TMP have been completed as required by the TRL 6 criteria, or higher, as it may apply.

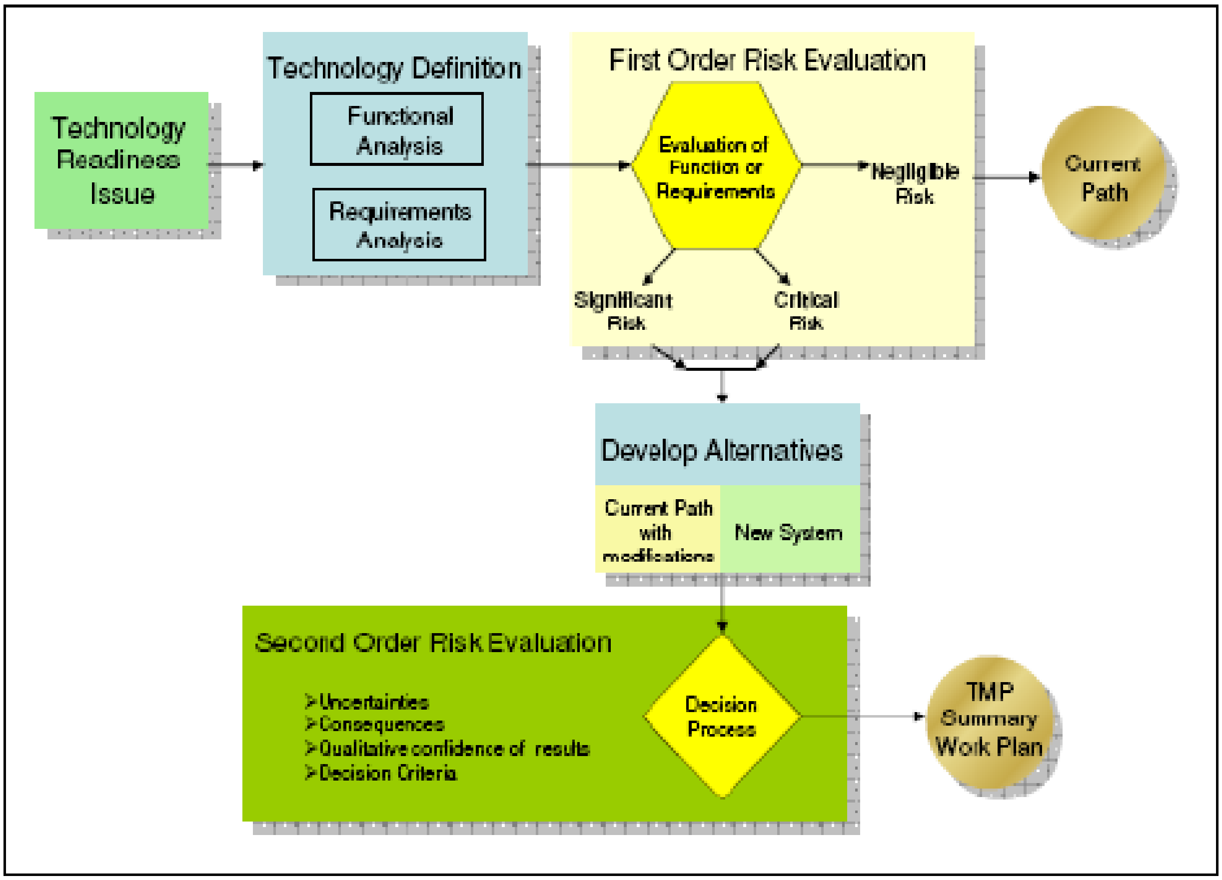


Figure 5. Technology Maturation Planning Process

APPENDIX A: GLOSSARY

1. Acquisition Executive. The individual designated by the Secretary of Energy to integrate and unify the management system for a program portfolio of projects and implement prescribed policies and practices.

2. Breadboard. Integrated components that provide a representation of a system/subsystem and that can be used to determine concept feasibility and to develop technical data. Typically it is configured for laboratory use to demonstrate the technical principles of immediate interest. It may resemble the final system/subsystem in function only.

3. Critical Technology Element (CTE). 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.

4. External Independent Review. A project review performed by personnel from OECM and augmented by individuals outside DOE, primarily to support validation of either the Performance Baseline (CD-2) or Construction/Execution Readiness (CD-3). OECM selects an appropriate group of subject matter experts in a contracted capacity to assist with these reviews.

5. High Fidelity. A representative of the component or system that addresses form, fit and function. A high-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specification within a laboratory setting.

6. Independent Cost Estimate. A cost estimate, prepared by an organization independent of the project sponsor, using the same detailed technical and procurement information to make the project estimate. It is used to validate the project estimate to determine whether it is accurate and reasonable.

7. Independent Cost Review. An independent evaluation of a project's cost estimate that examines its quality and accuracy, with emphasis on specific cost and technical risks. It involves the analysis of the existing estimate's approach and assumptions.

8. Independent Project Review. A project management tool that serves to verify the project's mission, organization, development, processes, technical requirements, baselines, progress and/or readiness to proceed to the next successive phase in DOE's Acquisition Management System.

9. Key Performance Parameter (KPP). A vital characteristic, function, requirement or design basis, that if changed, would have a major impact on the facility or system performance, scope, schedule, cost and/or risk, or the ability of an interfacing project to meet its mission requirements. A parameter may be a performance, design, or interface requirement. Appropriate parameters are those that express performance in terms of

accuracy, capacity, throughput, quantity, processing rate, purity, reliability, sustainability, or others that define how well a system, facility or other project will perform. In aggregate, KPPs comprise the scope of the project.

10. Low Fidelity. A representative of the component or system that has limited ability to provide anything but first-order information about the end product. Low fidelity assessments are used to provide trend analysis.

11. Operational Environment. Environment that addresses all the operational requirements and specifications required of the final system to include platform/packaging.

12. Project Definition Rating Index. This is a project management tool which is used for assessing how well the project scope is defined. The tool uses a numeric assessment which rates a wide range of project elements to determine how well the project is defined.

13. Relevant Environment. Testing environment that simulates the key aspects of the operational environment; such as physical and chemical properties.

14. Simulated Operational Environment. Either (1) a real environment that can simulate all the operational requirements and specifications required of the final system or (2) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.

15. Technical Independent Project Review. An independent project review conducted prior to obtaining CD-2 for Hazard Category 1, 2, and 3 nuclear facilities. At a minimum, the focus of this review is to determine that the safety documentation is sufficiently conservative and bounding to be relied upon for the next phase of the project.

16. Technology Maturation Plan. A TMP details the steps necessary for developing technologies that are less mature than desired to the point where they are ready for project insertion.

17. Technology Readiness Assessment. An assessment of how far technology development has proceeded. It provides a snapshot in time of the maturity of technologies and their readiness for insertion into the project design and execution schedule.

18. Technology Readiness Level. A metric used for describing technology maturity. It is a measure used by many U.S. government agencies to assess maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem.

19. Technology Readiness Level Calculator. A tool developed by the U.S. Air Force Research Laboratory for applying TRLs to technology development programs. In its present stage of development, the calculator is a Microsoft Excel spreadsheet application that allows the user to answer a series of questions about a technology project. Once the questions have been answered, the calculator displays the TRL achieved.

APPENDIX B: ACRONYMS

AE	Acquisition Executive
CD	Critical Decision
CDR	Conceptual Design Report
CFR	Code of Federal Regulations
CO	Contracting Officer
CY	Calendar Year
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
CTE	Critical Technology Element
EIR	External Independent Review
EIS	Environmental Impact Statement
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
ESAAB	Energy Systems Acquisition Advisory Board
EVMS	Earned Value Management System
FAR	Federal Acquisition Regulations
FONSI	Finding of No Significant Impact
FPD	Federal Project Director
FY	Fiscal Year
GAO	Government Accountability Office
GPRA	Government Performance and Results Act
HA	Hazard Assessment
ICE	Independent Cost Estimate
ICR	Independent Cost Review
IMS	Integrated Master Schedule
IOC	Initial Operating Capability
IPR	Independent Project Review
IPS	Integrated Project Schedule
IPT	Integrated Project Team
ICE	Independent Cost Estimate
IPR	Independent Project Review
ISM	Integration Safety Management
ISMS	Integrated Safety Management System

ISO	International Standards Organization
IT	Information Technology
KPP	Key Performance Parameter
MNS	Mission Need Statement
MS	Major System Project
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NNSA	National Nuclear Security Administration
NQA-1	Nuclear Quality Assurance Standard – 1 (ANSI/ASME standard)
NRC	National Research Council
OBS	Organizational Breakdown Structure
OECM	Office of Engineering and Construction Management
OMB	Office of Management and Budget
OPC	Other Project Costs
ORR	Operational Readiness Review
OSHA	Occupational Safety and Health Administration
PARS	Project Assessment and Reporting System
PB	Performance Baseline
PBC	Performance-Based Contract
PBS	Performance Baseline Summary
PDS	Project Data Sheet
PED	Project Engineering and Design
PEP	Project Execution Plan
PM	Program Manager
PMB	Performance Measurement Baseline
PPBES	Planning, Programming, Budgeting and Execution System
PSO	Program Secretarial Office
PMSO	Project Management Support Office
QA	Quality Assurance
QAP	Quality Assurance Plan
QAPP	Quality Assurance Program Plan
QC	Quality Control
RAMI	Reliability, Accessibility, Maintainability, Inspectability
RCRA	Resource Conservation and Recovery Act

RD	Requirements Document
RFP	Request for Proposal
RLS	Resource Loaded Schedule
SAE	Secretarial Acquisition Executive
TEC	Total Estimated Cost (Capital)
TIPR	Technical Independent Project Review
TPC	Total Project Cost
TRA	Technology Readiness Assessment
TMP	Technology Maturation Plan
TRL	Technology Readiness Level
VM	Value Management
WBS	Work Breakdown Structure
WA	Work Authorization

APPENDIX C: REFERENCES

10 CFR 830, Subpart A, Quality Assurance Requirements.

10 CFR 830, Subpart B, Safety Basis Requirements.

10 CFR 830.206, Preliminary Documented Safety Analysis.

29 CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals.

48 CFR 970.5223-1, Integration of Environment. Safety, and Health into Work Planning and Execution.

DOE O 205.1B, *Department of Energy Cyber Security Program*, dated 5-16-11.

DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, dated 11-29-10.

DOE O 414.1D, *Quality Assurance*, dated 4-25-11.

DOE O 420.1B, *Facility Safety*, dated 12-22-05.

DOE O 425.1D, *Verification of Readiness to Start-Up or Restart Nuclear Facilities*, dated 4-16-10.

DOE O 436.1, *Departmental Sustainability*, dated 5-02-11.

DOE O 451.1B Chg 2, *National Environmental Policy Act Compliance Program*, dated 6-25-10.

DOE P 226.1B, *Department of Energy Oversight Policy*, dated 4-25-11.

DOE P 470.1A, *Safeguards and Security Program*, dated 12-29-10.

DOE P 450.4A, Integrated *Safety Management Po*licy, dated 4-25-11.

DOE-STD-1189-2008, *Integration of Safety into the Design Process*, dated April 2008

DOE-STD-3006-2010, *Planning and Conduct of Operational Readiness Reviews (ORR)*, dated year 2010.

DOE M 470.4B, *Safeguards and Security Programs*, dated 7-21-11.

DOE G 413.3-9, *DOE Project Review Guide for Capital Asset Projects*, dated 9-23-08.

DOE G 413.3-7A, *Risk Management Guide*, dated 01-08-11

ANSI-EIA-649, National Consensus Standard for Configuration Management.

Department of Defense, *Technology Readiness Assessment (TRA) Deskbook*, prepared by the Deputy Undersecretary of Defense for Science and Technology, July 2009.

DOE, SPD-07-195, Aiken, South Carolina, Savannah River Site Tank 48H Waste Treatment Project, Technology Readiness Assessment, dated July 2009.

DOE, Office of Engineering and Construction Management (OECM), *External Independent Review (EIR), Standard Operating Procedure (SOP)*, dated July 2008.

DOE, Office of Engineering and Construction Management (OECM), *Root Cause Analysis Contract and Project Management*, April 2008.

DOE, Office of Engineering and Construction Management (OECM), *Root Cause Analysis Contract and Project Management, Corrective Action Plan*, July 2008.

DOE, Office of Environmental Management, *Project Definition Rating Index (EM-PDRI) Manual*, Revision 1, dated February 2001.

DOE, Office of Management, Budget and Evaluation, *Reviews, Evaluations, and Lessons Learned*, Rev E, dated June 2003.

DOE, Office of River Protection, Richland, Washington, Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities, dated March 2007.

DOE, Office of Science, *Independent Review Handbook*, dated May 2007.

House Report 109-86, Energy and Water Development Appropriations Bill, 2006.

GAO-07-336, Report to the Subcommittee on Energy and Water Development, and Related Agencies, Committee on Appropriations, House of Representatives, *DOE Major Construction Projects Need a Consistent Approach for Assessing Technology Readiness to Help Avoid Cost Increases and Delays*, dated March 2007.

GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Can Improve Weapon Systems Outcomes*, July 1999, US General Accounting Office.

National Research Council, *Improving Project Management in the Department of Energy*, 1999.

National Research Council, *Progress in Improving Project Management in the Department of Energy*, 2001.

National Research Council, *Progress in Improving Project Management in the Department of Energy*, 2003.

National Research Council, *Assessment of the Results of External Independent Reviews for U.S. Department of Energy Projects*, 2007.

NNSA Policy Letter: BOP-50.003, *Establishment of NNSA Independent Project Review Policy*, dated June 2007.

NNSA, Office of Project Management and System Support, *Project Definition Rating Index (PDRI) Manual*, Revision 0, dated June 2008.

Nolte, William L., et al., *Technology Readiness Level Calculator, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference*, October 20, 2003

APPENDIX D: TEMPLATE FOR A TECHNOLOGY READINESS ASSESSMENT (TRA) REVIEW PLAN

1.0 INTRODUCTION

Briefly state who requested the TRA, what organization is responsible for conducting the TRA, and what technology is to be assessed. State where the technology is being developed (i.e., facility, site).

2.0 PURPOSE

Briefly state the objective of the TRA. Specifically, state how the customer will use the results from the TRA. Additionally, state any other drivers for conduct of the TRA (e.g., Critical Decision milestone support, technology downselect support).

3.0 TECHNOLOGY BACKGROUND

Provide a general description of the technology and the project supported by the technology. The description should include details regarding the function that the technology accomplishes for the project and a brief summary of status of the technology development. Additionally, summarize the results of any previous TRAs conducted on the technology.

4.0 TRA TEAM

Include a table that lists the position, title, name and area of expertise of each TRA Team Member

Position	*Title*	*Company*	*Name*	*Area of Expertise*
Team Leader	*Person 1 Title*	*Person 1 company*	*Person 1 name*	*Person 1 expertise*
Team Member	*Person 2 Title*	*Person 2 company*	*Person 2 name*	*Person 2 expertise*
Team Member	*Person 3 Title*	*Person 3 company*	*Person 3 name*	*Person 3 expertise*
Team Member	*Person 4 Title*	*Person 4 company*	*Person 4 name*	*Person 4 expertise*

5.0 TRA ESTIMATED SCHEDULE *(conservative Projected Durations which may vary by project complexity)*

Task Number	Projected Duration	Task Description
1	6 weeks	Establish TRA Team
2	4 weeks	Distribute critical documents to Team
3	4 weeks	Conduct onsite assessment activities
4	4 weeks	Draft TRA Report
5	4 weeks	Issue Final Report

6.0 TRA ESTIMATED COST

Provide an estimate of the total man-hours and associated cost for conduct of the TRA. Additionally, state the organization responsible for funding the TRA.

7.0 DEFINITIONS

8.0 REFERENCES

Appendices

APPENDIX E: TEMPLATE FOR THE IDENTIFICATION OF CRITICAL TECHNOLOGY ELEMENTS (CTEs)

A CTE is identified if there is at least one positive response for each set of criteria

Set 1 - Criteria	Yes	No
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. Do limitations in the understanding of the technology impact the safety of the design?		
5. Are there uncertainties in the definition of the end state requirements for this technology?		

Set 2 - Criteria	Yes	No
1. Is the technology new or novel?		
2. Is the technology modified?		
3. Have the potential hazards of the technology been assessed?		
4. Has the technology been repackaged so a new relevant environment is realized?		
5. Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		

Appendix F: Template Examples for the TRL Assessment Calculator as Modified for DOE-EM

Note: The process/mechanics to follow with the use of the calculator are found in the reference: Nolte, William L., et al., "Technology Readiness Level Calculator," October 20, 2003, Air Force Research Laboratory (AFRL), presented at the NDIA System Engineering Conference. Tables F-2 – F-7 were primarily based on an EM waste processing facility. DOE programs should modify the tables to fit program needs and/or updated.

Table F-1. Top Level Questions for Determining Anticipated TRL

Top-Level Question		Yes/No	If Yes, Then Basis and Supporting Documentation
TRL 9	Has the actual equipment/process successfully operated in the full operational environment (hot operations)?		
TRL 8	Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?		
TRL 7	Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?		
TRL 6	Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment; to include testing of the safety function?		
TRL 5	Has bench-scale equipment/process testing been demonstrated in a relevant environment?		
TRL 4	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?		
TRL 3	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?		
TRL 2	Has an equipment and process concept been formulated?		
TRL 1	Have the basic process technology process principles been observed and reported?		

Note: All TRLs should include compliance with DOE-STD-1189-2008. Testing and validation of safety functions in the relevant environment for the critical technology element is part of the TRA to include worker and public safety considerations.

Table F-2. TRL 1 Questions for Critical Technical Element

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. “Back of envelope” environment.	
T		2. Physical laws and assumptions used in new technologies defined.	
T		3. Paper studies confirm basic principles.	
P		4. Initial scientific observations reported in journals/conference proceedings/technical reports.	
T		5. Basic scientific principles observed and understood.	
P		6. Know who cares about the technology, e.g., sponsor, funding source, safety and hazardous materials handling (DOE-STD-1189-2008 compliance), etc.	
T		7. Research hypothesis formulated.	
T		8. Basic characterization data exists.	
P		9. Know who would perform research and where it would be done.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-3. TRL 2 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P		1. Customer identified.	
T		2. Potential system or components have been identified.	
T		3. Paper studies show that application is feasible; to include compliance with DOE-STD-1189-2008.	
P		4. Know what program the technology would support.	
T		5. An apparent theoretical or empirical design solution identified.	
T		6. Basic elements of technology have been identified.	
T		7. Desktop environment (paper studies).	
T		8. Components of technology have been partially characterized.	
T		9. Performance predictions made for each element.	
P		10. Customer expresses interest in the application.	
T		11. Initial analysis shows what major functions need to be done.	
T		12. Modeling & Simulation only used to verify physical principles.	
P		13. System architecture defined in terms of major functions to be performed.	
T		14. Rigorous analytical studies confirm basic principles.	
P		15. Analytical studies reported in scientific journals/conference proceedings/technical reports.	
T		16. Individual parts of the technology work (No real attempt at integration).	
T		17. Know what output devices are available.	
P		18. Preliminary strategy to obtain TRL Level 6 developed (e.g., scope, schedule, cost); to include compliance with DOE-STD-1189-2008.	
P		19. Know capabilities and limitations of researchers and research facilities.	
T		20. The scope and scale of the waste problem has been determined.	
T		21. Know what experiments are required (research approach).	
P		22. Qualitative idea of risk areas (cost, schedule, performance).	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-4. TRL 3 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. Academic (basic science) environment.	
P		2. Some key process and safety requirements are identified; to include compliance with DOE-STD-1189-2008.	
T		3. Predictions of elements of technology capability validated by analytical studies.	
P		4. The basic science has been validated at the laboratory scale.	
T		5. Science known to extent that mathematical and/or computer models and simulations are possible.	
P		6. Preliminary system performance characteristics and measures have been identified and estimated.	
T		7. Predictions of elements of technology capability validated by Modeling and Simulation (M&S).	
M		8. No system components, just basic laboratory research equipment to verify physical principles.	
T		9. Laboratory experiments verify feasibility of application.	
T		10. Predictions of elements of technology capability validated by laboratory experiments.	
P		11. Customer representative identified to work with development team.	
P		12. Customer participates in requirements generation.	
P		13. Requirements tracking system defined to manage requirements creep.	
T		14. Key process parameters/variables and associated hazards have begun to be identified; to include compliance with DOE-STD-1189-2008.	
M		15. Design techniques have been identified/developed.	
T		16. Paper studies indicate that system components ought to work together.	
P		17. Customer identifies technology need date.	
T		18. Performance metrics for the system are established (What must it do).	
P		19. Scaling studies have been started.	
M		20. Current manufacturability concepts assessed.	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
M		21. Sources of key components for laboratory testing identified.	
T		22. Scientific feasibility fully demonstrated.	
T		23. Analysis of present state of the art shows that technology fills a need.	
P		24. Risk areas identified in general terms.	
P		25. Risk mitigation strategies identified.	
P		26. Rudimentary best value analysis performed for operations.	
T		27. Key physical and chemical properties have been characterized for a number of waste samples.	
T		28. A simulant has been developed that approximates key waste properties.	
T		29. Laboratory scale tests on a simulant have been completed.	
T		30. Specific waste(s) and waste site(s) has (have) been defined.	
T		31. The individual system components have been tested at the laboratory scale.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-5. TRL 4 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. Key process variables/parameters been fully identified and preliminary hazard evaluations have been completed and documented to include compliance with DOE-STD-1189-2008.	
M		2. Laboratory components tested are surrogates for system components.	
T		3. Individual components tested in laboratory~~/~~ or by supplier.	
T		4. Subsystems composed of multiple components tested at lab scale using simulants.	
T		5. Modeling & Simulation used to simulate some components and interfaces between components.	
P		6. Overall system requirements for end user's application are <u>known.</u>	
T		7. Overall system requirements for end user's application are documented.	
P		8. System performance metrics measuring requirements have been established.	
P		9. Laboratory testing requirements derived from system requirements are established.	
M		10. Available components assembled into laboratory scale system.	
T		11. Laboratory experiments with available components show that they work together.	
T		12. Analysis completed to establish component compatibility (Do components work together).	
P		13. Science and Technology Demonstration exit criteria established (S&T targets understood, documented, and agreed to by sponsor).	
T		14. Technology demonstrates basic functionality in simulated environment; to include test and validation of safety functions.	
M		15. Scalable technology prototypes have been produced (Can components be made bigger than lab scale).	
P		16. The conceptual design has been documented (system description, process flow diagrams, general	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
		arrangement drawings, and material balance).	
M		17. Equipment scale-up relationships are understood/accounted for in technology development program.	
T		18. Controlled laboratory environment used in testing.	
P		19. Initial cost drivers identified.	
M		20. Integration studies have been started.	
P		21. Formal risk management program initiated.	
M		22. Key manufacturing processes for equipment systems identified.	
P		23. Scaling documents and designs of technology have been completed.	
M		24. Key manufacturing processes assessed in laboratory.	
P/T		25. Functional process description developed. (Systems/subsystems identified).	
T		26. Low fidelity technology “system” integration and engineering completed in a lab environment.	
M		27. Mitigation strategies identified to address manufacturability/ producibility shortfalls.	
T		28. Key physical and chemical properties have been characterized for a range of wastes.	
T		29. A limited number of simulants have been developed that approximate the range of waste properties.	
T		30. Laboratory-scale tests on a limited range of simulants and real waste have been completed.	
T		31. Process/parameter limits and safety control strategies are being explored.	
T		32. Test plan documents for prototypical lab- scale tests completed.	
P		33. Technology availability dates established.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-6. TRL 5 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. The relationships between major system and sub-system parameters are understood on a laboratory scale.	
T		2. Plant size components available for testing.	
T		3. System interface requirements known (How would system be integrated into the plant?).	
P		4. Preliminary design engineering begins.	
T		5. Requirements for technology verification established; to include testing and validation of safety functions.	
T		6. Interfaces between components/ subsystems in testing are realistic (bench top with realistic interfaces).	
M		7. Prototypes of equipment system components have been created (know how to make equipment).	
M		8. Tooling and machines demonstrated in lab for new manufacturing processes to make component.	
T		9. High fidelity lab integration of system completed, ready for test in relevant environments; to include testing and validation of safety functions.	
M		10. Manufacturing techniques have been defined to the point where largest problems defined.	
T		11. Lab-scale, similar system tested with range of simulants.	
T		12. Fidelity of system mock-up improves from laboratory to bench-scale testing.	
M		13. Availability and reliability (RAMI) target levels identified.	
M		14. Some special purpose components combined with available laboratory components for testing.	
P		15. Three dimensional drawings and P&IDs for the prototypical engineering-scale test facility have been prepared.	
T		16. Laboratory environment for testing modified to approximate operational environment; to include testing and	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
		validation of safety functions.	
T		17. Component integration issues and requirements identified.	
P		18. Detailed design drawings have been completed to support specification of engineering-scale testing system.	
T		19. Requirements definition with performance thresholds and objectives established for final plant design.	
P		20. Preliminary technology feasibility engineering report completed; to include compliance with DOE-STD-1189-2008.	
T		21. Integration of modules/functions demonstrated in a laboratory/bench-scale environment.	
T		22. Formal control of all components to be used in final prototypical test system.	
P		23. Configuration management plan in place.	
T		24. The range of all relevant physical and chemical properties has been determined (to the extent possible).	
T		25. Simulants have been developed that cover the full range of waste properties.	
T		26. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes.	
T		27. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed.	
T		28. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed.	
T		29. Test results for simulants and real waste are consistent.	
T		30. Laboratory to engineering scale scale-up issues are understood and resolved; to include testing and validation of safety functions.	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		31. Limits for all process variables/parameters and safety controls are being refined.	
P		32. Test plan for prototypical lab-scale tests executed – results validate design; to include testing and validation of safety functions.	
P		33. Test plan documents for prototypical engineering-scale tests completed.	
P		34. Finalization of hazardous material forms and inventories, completion of process hazard analysis, and identification of system/components level safety controls at the appropriate preliminary design phase.	
P		35. Risk management plan documented; to include compliance with DOE-STD-1189-2008.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-7. TRL 6 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	
M		2. Availability and reliability (RAMI) levels established.	
P		3. Preliminary design drawings for final plant system are complete; to include compliance with DOE-STD-1189-2008.	
T		4. Operating environment for final system known.	
P		5. Collection of actual maintainability, reliability, and supportability data has been started.	
P		6. Performance Baseline (including total project cost, schedule, and scope) has been completed.	
T		7. Operating limits for components determined (from design, safety and environmental compliance).	
P		8. Operational requirements document available; to include compliance with DOE-STD-1189-2008.	
P		9. Off-normal operating responses determined for engineering scale system.	
T		10. System technical interfaces defined.	
T		11. Component integration demonstrated at an engineering scale.	
P		12. Scaling issues that remain are identified and understood. Supporting analysis is complete.	
P		13. Analysis of project timing ensures technology will be available when required.	
P		14. Have established an interface control process.	
P		15. Acquisition program milestones established for start of final design (CD-2).	
M		16. Critical manufacturing processes prototyped.	
M		17. Most pre-production hardware is available to support fabrication of the system.	
T		18. Engineering feasibility fully demonstrated (e.g., would it work).	
M		19. Materials, process, design, and integration methods have been employed (e.g., can design be produced?).	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P		20. Technology "system" design specification complete and ready for detailed design.	
M		21. Components are functionally compatible with operational system.	
T		22. Engineering-scale system is high-fidelity functional prototype of operational system.	
P		23. Formal configuration management program defined to control change process.	
M		24. Integration demonstrations have been completed (e.g. construction of testing system); to include testing and validation of safety functions.	
P		25. Final Technical Report on Technology completed; to include compliance with DOE-STD-1189-2008.	
P		26. Finalization of hazardous material forms and inventories; completion of process hazard analysis, identification of system/components level safety controls at the appropriate preliminary/final design phase.	
M		27. Process and tooling are mature to support fabrication of components/system	
T		28. Engineering-scale tests on the full range of simulants using a prototypical system have been completed.	
T		29. Engineering to full-scale scale-up issues are understood and resolved.	
T		30. Laboratory and engineering-scale experiments are consistent.	
T		31. Limits for all process variables/parameters and safety controls are defined.	
T		32. Plan for engineering-scale testing executed - results validate design.	
M		33. Production demonstrations are complete (at least one time).	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

APPENDIX G: TEMPLATE FOR A TRA REPORT

REPORT CONTENT:

EXECUTIVE SUMMARY

Briefly state who requested the TRA, what organization was responsible for conducting the TRA, what technology was assessed? Provide a summary table of the CTEs and corresponding TRLs determined during the review.

INTRODUCTION

Technology Reviewed

Provide a detailed description of the technology that was assessed.

TRA Process

Provide an overview of the approach used to conduct the TRA. Reference applicable planning documents.

RESULTS

Provide the following for each CTE assessed:

- ***Function***
  Describe the CTE and its function.
- ***Relationship to Other Systems***
  Describe how the CTE interfaces with other systems.
- ***Development History and Status***
  Summarize pertinent development activities that have occurred to date on the CTE.
- ***Relevant Environment***
  Describe relevant parameters inherent to the CTE or the function it performs.
- ***Comparison of the Relevant Environment and the Demonstrated Environment***
  Describe differences and similarities between the environment in which the CTE has been tested and the intended environment when fully operational.
- ***Technology Readiness Level Determination***
  State the TRL determined for the CTE and provide the basis justification for the TRL.
- ***Estimated Cost/Schedule***
  State the estimated cost and time requirements, with associate uncertainties, and programmatic risks associated with maturing each technology to the required readiness level.

ATTACHMENTS

Include the following planning documents:

- *TRA Plan*
- *Supporting documentation for identification of CTEs*
- *Completed tables:*

    - *Top Level Questions for Determining Anticipated TRL (Appendix F, Table F-1)*
    - *TRL Questions for CTE (Appendix F, Tables F-2 through F-7)*
- *List of support documentation for TRL determination*
- *TRL Summary table*
- *Lessons Learned*
- *Team biographies*

Appendix H: Template Guide for a Technology Maturation Plan

(Note: The TMP is a high level summary document. It is not a collection of detailed test plans.)

TABLE OF CONTENTS
LIST OF TABLES
LIST OF FIGURES
ABBREVIATIONS AND ACRONYMS

1.0 INTRODUCTION

- Purpose of the Project

  Provide a brief summary of the project's mission, status, technology(s) being deployed, etc.

- Purpose of the TMP

  Describe the objectives and content of this TMP and relate it to the status of the project and any upcoming CDs.

2.0 TECHNOLOGY ASSESSMENTS OF THE PROJECT

- Summary of Previous TIPRs

  Summarize any previous TIPRs or other technical assessments that may have contributed to the need for a TRA and this TMP.

- Summary of Previous TRA(s)

  Describe the results of previous TRAs with particular emphasis on the latest TRA that is driving this TMP. Include the definition of TRLs as used in the TRA. Discuss the CTEs that were determined for the project.

- Technology Heritage

  Summarize the previous technology development activities that brought the technology to its current state of readiness. Include discussions of any full-scale plant deployments of the technology in similar applications.

- Current Project Activities and Technology Maturation

  Describe ongoing technology development activities (if any) that were initiated prior to this TMP. Completion of these activities should define the starting point for this TMP.

- Management of Technology Maturity

  Indicate the DOE and contractor organizations that will be responsible for managing the activities described in this TMP. Include a brief discussion of key roles and responsibilities.

3.0 TECHNOLOGY MATURATION PLAN

- Development of Technology Maturation Requirements

  Describe the approach used in defining the required technology development activities that will be conducted as described in this TMP. These could include *evaluating incomplete criteria in the TRL Calculator, risk assessments, and value engineering.*

- Life-Cycle Benefit

  Briefly discuss life-cycle benefits to the project that will result from successful completion of the TMP technology development activities.

- Specific TMPs for each CTE will be described following the format below for each CTE that was defined in the latest TRA.

  - CTE A
    - Key Technology Addressed (Describe the function that the CTE carries out in the project.)
    - Objective (Succinctly state the objective of the CTE)
    - Current State of Art (Describe in one paragraph the current status of the CTE including the specific TRL assigned in the latest TRA.)
    - Technology Development Approach (In paragraph form, describe how the needed technology development work to reach TRL 6 will be performed. This could include the performing organization, location, simulant versus actual waste, etc.)
    - Scope (Provide a list of the key steps to be taken in performing the work. Include a table that gives milestones, performance targets, TRL achieved at milestones, and a rough order of magnitude cost of development.)
  - CTE B
    - Key Technology Addressed
    - Objective
    - Current State of Art
    - Technology Development Approach
    - Scope
  - CTE C (etc., as needed)

4.0 TECHNOLOGY MATURITY SCHEDULE

Provide and briefly discuss a high-level schedule of the major technology development activities for each CTE. Any major decision points such as proceeding with versus abandoning the current technology, selection of a back-up technology, etc. should be included. Detailed schedules should be given in test plans or used for status meetings during implementation.

5.0 SUMMARY TECHNOLOGY MATURITY BUDGET

Present the rough order of magnitude costs to reach TRL 6 for each major technology development activity for all CTEs in the project. Include the total technology maturation costs.

6.0 REFERENCES

Appendix A.	Crosswalk of CTEs identified in previous independent reviews and assessments (if applicable)
Appendix B.	TRL Calculator as Modified by the DOE Program Office (if applicable)
Table 1.	TRLs Used in this Assessment (taken from DoD)
Table 2, etc.	Table(s) for each CTE, listing of test activities, planned completion date, performance targets, resulting TRL level as each increment of testing is completed, and rough order of magnitude costs.
Table X.	Technology Maturity Budget for Project
Figure 1.	Process Flow Diagram (for technology being assessed)
Figure 2.	Technology Maturity Schedule
Figure 3.	Project Execution Strategy Diagram