A PROGRAM TO STABILIZE NUCLEAR MATERIALS AS MANAGED BY THE PLUTONIUM FOCUS AREA

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ABSTRACT

This paper describes the program to stabilize nuclear materials, consistent with the Department of Energy Office of Environmental Management (EM) plan, *Accelerating Cleanup: Paths to Closure*. The program is managed by the Plutonium Stabilization and Disposition Focus Area, which defines and manages technology development programs to stabilize nuclear materials and assure their subsequent safe storage and final disposition. The Department of Energy Idaho Operations Office, with support from Lockheed Martin Idaho Technologies Company and Argonne National Laboratory manages the Plutonium Stabilization and Disposition Focus Area (PFA).

The scope of PFA activities includes non-weapons plutonium materials, special isotopes, and other fissile materials. The PFA provides solutions to site-specific and complex wide technology issues associated with plutonium remediation, stabilization, and preparation for disposition.

Currently, PFA technology development projects are derived from the *Plutonium Stabilization and Disposition Focus Area Research and Development Plan, DOE/ID-10561 Revision 3, September 1998.* This Research and Development plan defines the current gaps in technology that may pose significant worker and public safety risk and/or programmatic risk to timely disposition of nuclear materials.

The PFA has identified 21 Functional Need Areas that remain to be addressed to reduce the programmatic risk of meeting Department of Energy milestones. Many of the needs are being adequately addressed with End Use Site program-specific technology development funds or by the Los Alamos National Laboratory Plutonium Applied Technology Program. Other functional needs are not currently pursued due to lack of funding. If funding is allocated, these needs will be addressed through calls for proposals.

Our paper describes an important programmatic function of the Department of Energy nuclear materials stabilization program, including the tie-in of policy to research needs and funding for the nuclear materials disposition area. The PFA uses a rigorous systems engineering determination of technology needs and gaps, under the guidance of a Technical Advisory Panel, consisting of complex-wide experts. The Research and Development planning provides an example for other waste areas and should be of interest to Research and Development managers. The materials disposition maps developed by the PFA and described in this paper provide an evaluation of research needs, data gaps and subsequent guidance for the development of

technologies for nuclear materials disposition. This paper also addresses the PFA prioritization methodology and its ability to forecast actual time to implementation.

INTRODUCTION

The Plutonium Stabilization and Disposition Focus Area (PFA), defines and manages technology development programs to stabilize nuclear materials and assure their subsequent safe storage and final disposition. The Department of Energy Idaho Operations Office (DOE-ID), with support from Lockheed Martin Idaho Technologies Company (LMITCO) and Argonne National Laboratory (ANL), manages the PFA.

Background. Greater than 20 tons of unstable plutonium residues remains in the weapons manufacturing pipeline. These unstable materials pose imminent environmental, safety and health hazards at several DOE sites (e.g., Rocky Flats Environmental Technology Site, Hanford, and Savannah River Site). The Defense Nuclear Facilities Safety Board (DNFSB) issued DNFSB Recommendation 94-1 in response to these significant safety concerns and the need for timely remediation action. Three and eight year commitments were established by the Department of Energy (DOE) to provide technology development and deployment resolving fissile material stabilization issues, and stewardship integration of site-specific and complex-wide issues.

The PFA was established in 1995 to support technology development for resolution of 94-1 issues. Specifically the PFA role is to:

- Meet the Secretary of Energy's commitments to the DNFSB.
- Develop and implement technologies in:
    - Pu Storage & Disposition Standards Development
    - Pu Stabilization Process Development
    - Transportation
    - Packaging & Storage
    - Surveillance & Monitoring
    - Core Technologies
- Develop and demonstrate technical solutions to site-specific and complex-wide issues associated with plutonium stabilization, packaging, and preparation for final disposition.
- Expedite complex-wide progress; standardize resolutions, practices & equipment systems; promote stewardship integration & interfacing; and produce cost-effective programmatic results.

Current Status. Technology development projects are derived from the *PFA Research and Development Plan, DOE/ID-10561 Revision 3, September 1998*. This Research and Development (R&D) plan defines the current gaps in technology that may pose significant worker and public safety risk and/or programmatic risk to timely nuclear materials disposition.

Beginning in FY 1999, the Office of Science and Technology (EM-50) assumed ownership of the PFA, which was formerly managed by the Office of Nuclear Material and Facility Stabilization (EM-60). With the transition into EM-50, PFA will incorporate technologies and other activities currently funded by other EM fund sources into the PFA. Current DNFSB Recommendation 94-1 needs identified in the R&D Plan will expand to include newly identified needs from Site Technology Coordinating Groups (STCGs). As the DOE plan for remediation and disposition of U-233, in response to DNFSB Recommendation 97-1, is finalized, technology gaps identified in this plan will be addressed in future PFA R&D Plans.

PFA Technology Development Process. The process PFA uses to develop, evaluate and prioritize technology needs is shown in Figure 1. It includes the tie-in of policy to research needs and funding for the nuclear materials disposition area. It uses a rigorous systems engineering determination of technology needs and gaps under the guidance of a Technical Advisory Panel (TAP), consisting of complex-wide experts, each from one of the major nuclear materials sites. The R&D planning provides an example for other waste areas and should be of interest to R&D managers. The materials disposition maps developed by the PFA provide an evaluation of research needs, data gaps and subsequent guidance for the development of technologies for nuclear materials disposition.

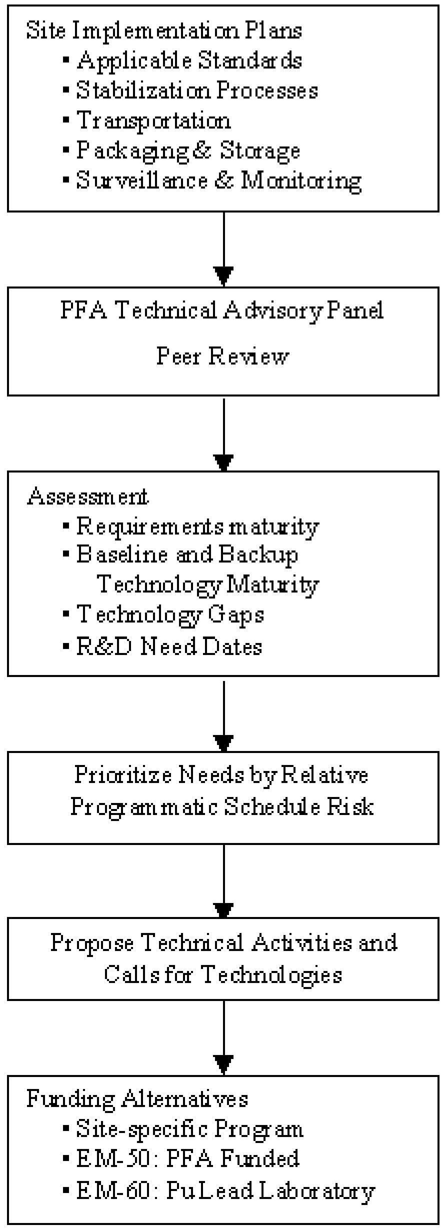

Figure 1. PFA Technology Development Process

REQUIREMENTS DEFNITION

Since nuclear materials stabilization is schedule driven and most of the requirements are broader functional requirements, the PFA developed its requirments based on a technology's R&D Need Date. The information provided in Table 1 relates an applicable milestone identified in the 94-1 Implementation Plan to the R&D Need Date, as reflected in a site-specific *Site Integrated Stabilization Master Plan (SISMP)*. The "R&D Need Date" is the date by which a particular technology must be available for deployment, including personnel, equipment, facility, and safety readiness to support the site comitment to meet the Due Date for completing the 94-1 milestone. The R&D Need Date shown is almost two years prior to Milestone Due Date to permit the end user adequate time to complete the mission of stabilizing salts by July 2001. The "DOE Site" is the end-use site responsible for completing the milestone. The "Milestone Text" is a summary of the milestone, as described in the Implementation Plan.

Table 1. Requirements for Stabilization of Chloride Salts at RFETS

94-1 Milestone Number	Due Date	R&D Need Date	DOE Site	Milestone Text
IP-3.3-022	July 2001	Nov. 1999	RFETS	Complete stabilization of high plutonium concentration salts

THE TECHNICAL ADVISORY PANEL

A unique feature of the PFA is its TAP. The TAP consists of technical experts and senior technical representatives knowledgeable in special nuclear materials and experienced in plutonium operations, storage and transportation. Initially, a Research Committee was formed in 1995 to review existing technologies available and technologies under development in order to determine adequacy of these technologies relative to 3- and 8-year commitments for DNFSB Recommendation 94-1. Expertise in the area of special nuclear materials is principally available only at DOE-operated sites; therefore, the site and laboratory mangers at the major DOE sites involved in 94-1 issues nominated members to the committee. The responsibility for updating the 94-1 R&D Plan beyond the initial research committee was charged to the PFA TAP, which retained many members from the Research Committee. The TAP defined a mechanism for nomination, selection, and operation of the TAP to maintain its independence. The responsibilities of the TAP are part of the mission defined for the PFA, and include:

- Technical peer review of core and applied technologies under development at Los Alamos National Laboratory (LANL), the lead laboratory for 94-1 stabilization research
- Technical peer review of technologies under development at other laboratories currently including ANL, Hanford and SRS
- Assessment of technical and process maturity of ongoing research identifying gaps and stabilization technologies at risk
- Updating the R&D Plan annually and making recommendations regarding program direction to PFA
- Recommending technologies that are inadequate, untimely, or no longer meet scope be refocused or concluded.
- Reviewing and assessing newly-proposed research to address gaps
- Preparing recommendations on significant issues affecting the DOE complex
- Providing a key interface between the technology users and the research which is applied to site specific and complex-wide needs.

TAP PEER REVIEW AND TECHICAL MATURITY EVALUATION

The TAP reviews technologies using a structured systems engineering method to produce:

- R&D Need Date Evaluations
- Technology Gap Identification
- Requirements Maturity Evaluations
- Baseline and Backup Technology Maturity Evaluations

The TAP reviews the End User needs (e.g. Table 1), and evaluates the realism of the proposed R&D Need Dates by examining detailed schedules and process maturity. Technology gaps are identified when it becomes clear that no realistic technological capability to complete the proposed path forward to meet a site commitment. Evaluation of requirements and technology maturity uses a quantitative method that was adapted from aerospace systems engineering by the Research Committee.

Table 2. Adaptation of Aerospace Process Maturity Assessment Scale to Nuclear Engineering

LEVEL	AEROSPACE CRITERIA	NUCLEAR CRITERIA
10	No currently identified solutions meet requirements	No currently identified solutions meet requirements
9		Design concept / technology application formulated
8	Design concept / technology application formulated	Cold feasibility demonstrated
6	Analytical and experimental critical function and/or characteristic proof of concept shows solution may meet requirements	Hot feasibility demonstrated
5	Component / breadboard validation in lab environment	End-to-end design (flowsheet) complete
4	Component / breadboard validation in relevant environment	Cold prototype demonstrated at end-use site
3	System / subsystem model or prototype demonstration in relevant environment	
2	System prototype demonstration in operational environment	Hot prototype demonstrated at end-use site
1	System qualified through test and demonstration	
0	System with successful mission operations	Process integrated into operations

Technical maturity was assessed for seven individual parameters: requirements maturity (RM), process maturity (PM), hardware equipment maturity (EQ), facility readiness (FAC), operational safety readiness (SAFT), personnel resource status (PER), and schedule status (SCH). A

parameter score of 0 means that a technology is in use and a score of 10 means that it is pre-conceptual.
An example of adapting an aerospace systems engineering parameter to nuclear engineering is shown in Table 2. The progression from concept to operational readiness is a typical complete cycle; however, steps can be skipped if evidence allows developers to do so. Nuclear engineering is much more empirical in development of its chemical processes compared to the ability of aerospace designers to use simulation and analysis to a greater extent to mature a design. Thus completion of a design concept rated only a 9 in nuclear engineering, whereas it rated a maturer score of 8 in aerospace engineering. The Research Committee decided that a significant advance in maturity occurs when demonstrating a prototype with hot material instead of surrogates, and arranged their scale to leap two steps when this occurred. For nuclear engineering projects, the risks of skipping the system qualification step are less, because they are ground-based systems that are much more easily repaired than orbiting satellites. The clarifying emphasis on requiring prototyping to be complete at the end-use site was added by the TAP in 1996 as a result of application of the Technical Maturity model by other groups in the program for trade study performance criteria. Typically, a process developed at a research laboratory requires extensive effort to be implemented at an end-use site. For this reason, the trade study teams recommended and the TAP formally accepted this added emphasis in the model.

In a similar fashion to process maturity, the other six individual maturity parameter scales were defined, and a weighted average was taken to produce an overall score from 0 to 10. Again, an overall Technical Maturity of 10 means that the process is in a pre-conceptual stage. A score of 0 represents an operational system that meets all requirements. The weightings used were 1, 3, or 9 following the standard low, medium, or high correlation to success model used in Quality Function Deployment.

Several stabilization technologies have been assessed annually as to their relative maturity and availability for use in stabilizing nuclear materials. After three years of assessments, several of the technologies have been assessed repeatedly and the evolving numerical technical maturity scores provide a powerful predictor of the time remaining until the operational application, as shown in Figure 2.

Using this quantitative technical maturity assessment, the predicted technology operational availability date is compared to the R&D Need Date to produce an overall programmatic risk score. The method selected was to follow the general principle of programmatic risk calculation used in aerospace, where the Overall Programmatic Risk is:

Programmatic Risk = Probability of Failure x
Consequence of Failure.

In aerospace, the technical maturity is converted to the probability of failure using various techniques that range from nonlinear equations to simple linear interpolation. The TAP decided to use a simple linear transformation in which Technical Maturity is related to the Probability of Failure as follows:

Probability of Failure = Technical Maturity /10.

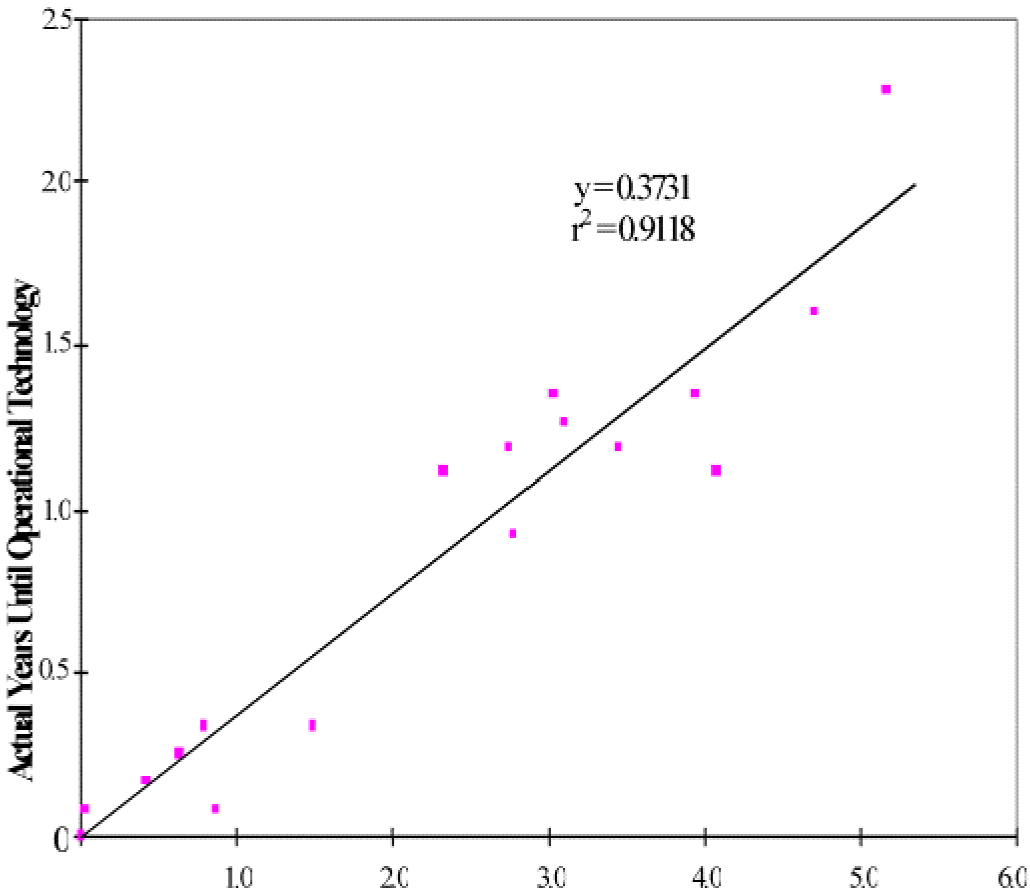

Figure 2. Technical Maturity Scoring by A Panel of Experts is Strongly Correlated to Actual Technology Operational Availability Dates

Since nuclear materials stabilization commitments are basically schedule commitments against broader functional requirements, the TAP developed a quantitative Consequence of Failure calculation based on a technology's R&D Need Date. The Consequence of Failure is:

Consequence of Failure = MIN{1, MAX{0, 1- (Years from Present to Need Date / 3.731)}}.

The denominator relates to the slope of the line in Figure 2, which predicts that a technology in conceptual phase will take a maximum of 3.731 years to become operational, given the appropriate amount of sponsor support. The programmatic risk scores are between 0 and 1, and provide for a categorization of risk as either High (programmatic risk > 0.32), Medium (0.32 > programmatic risk > 0.25), Low (0.25 > programmatic risk > 0), or Operational (programmatic risk by definition = 0 for operational / deployed technologies), shown in Figure 3.

The principal programmatic risk identified during FY 1998 by the TAP is that the combination of acceptance of the "Pipe and Go" baseline at RFETS in the face of pending lawsuits and limited funding of backup technologies may be putting stabilization timelines at significant risk. This is demonstrated in the right panel of Figure 3, which shows three backup technologies to the Pipe and Go baseline that pose high programmatic risk relative to achieving the stabilization date of May 2002 if they were to be adopted as the baseline approach. The technologies are the Shred, Wash, and Dry process for RFETS combustibles, and the Agglomeration and Chemically Bonded Phosphate Ceramification processes for RFETS ash. Funding of these backup technologies as alternatives to the Pipe and Go baseline should be continued until initial shipments of these residues are achieved.

There are two high-risk baseline technologies shown in the left panel: (1) the thermal stabilization process at Lawrence Livermore National Laboratory (LLNL) for ash, and (2) the vitrification process at SRS for the stabilization of Americium/Curium solutions. These projects may not meet long-term DOE objectives, and it essential that adequate resources are available for the technologies under development to meet the need dates. In addition, innovative backup technologies should be funded and expanded whenever there is potentially significant savings in cost and schedule.

PRIORITIZATION

Using the programmatic risk ranking of the ongoing program provided by the detailed data behind Figure 3, an Integrated Functional Priority List is developed by the PFA that responds to risk reduction needs identified by the TAP evaluation. The Integrated Functional Priority List shown in Table 3 is the equivalent of a prioritized STCG need list. For example, the second item in Table 3 is "Pu Ash Stabilization Process to meet WIPP requirements." This functional need is justified from the data used to derive Figure 3, because two high programmatic risk items are "Agglomeration for WIPP" and "Phosphate Ceramification for WIPP" are processes for stabilization of Pu ash residues at RFETS. Since the 94-1 milestone IP-ES-025 the two technologies are supporting is the same, we use a single line to describe the functional need in Table 4. If a functional need covers more than one IP Milestone / End Use Site, we have additional entries to indicate the multiple applicability listed in order of need date. The driving need date used for planning purposes is the earliest date from the multiple site applications. The remainder of Table 3 is constructed from the data behind Figure 3 in a similar way, where technologies that provide the same function are grouped together to describe a functional need and the programmatic risk category is derived from the programmatic risk assessment of ongoing technologies. The result is a list of 21 prioritized functional needs presented in Table 3.

Table 4 is a prioritized listing of PFA funded tasks in response to the prioritized needs from Table 3. Many of the needs identified in Table 3 are being adequately addressed with End Use Site program-specific technology development funds or by the LANL Plutonium Applied Technology Program. Other functional needs are not currently pursued due to lack of funding. As funding is allocated, these needs will be addressed through calls for proposals.

SUMMARY AND CONCLUSIONS

The initial focus of the PFA was on EM-60 facility stabilization commitments to address the DNFSB 94-1 recommendation. The PFA developed a process that:

- Uses a panel of technical experts that provide objective evaluation and complex-wide integration, and
- Links prioritization to mission-driven functional and schedule needs of the end users.

Its focus now is on technology development within EM-50 to ensure timely deployment to meet DOE and end-user milestones.

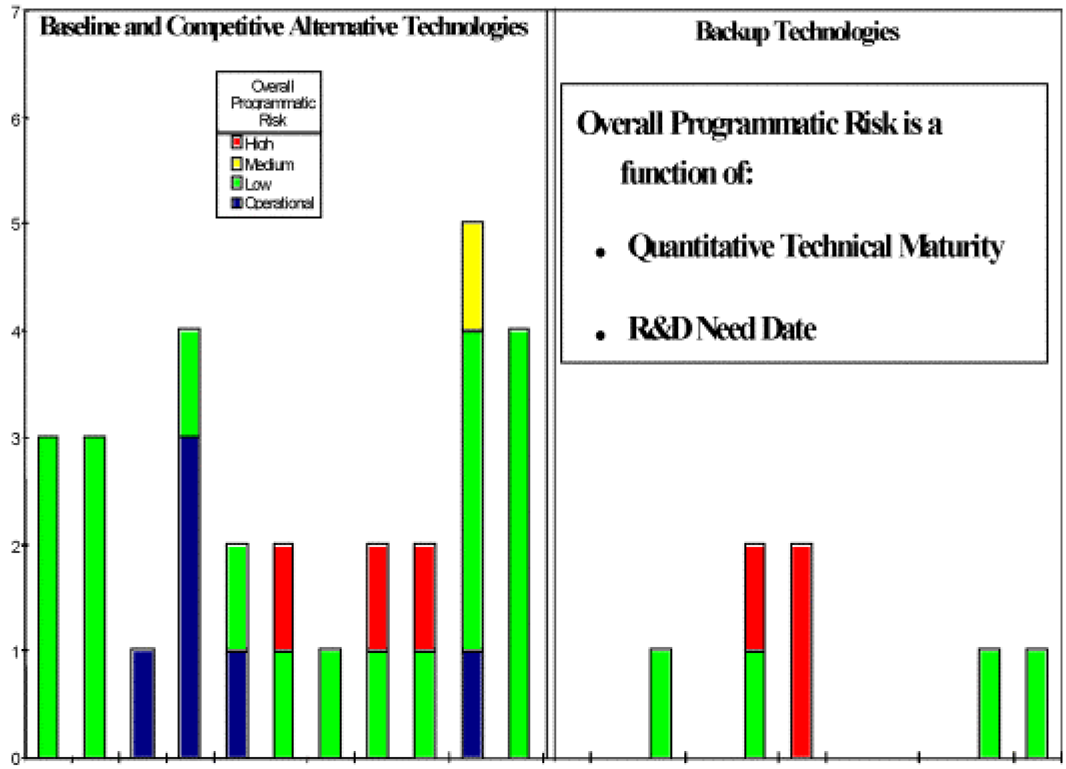

Figure 3. Summary of August 1998 TAP Evaluation of Technologies

Table 3. Nuclear Materials Stabilization Integrated Functional Priority List

Number of Technology Programs

PFA Functional Needs Priority	Functional Need Description	Potential End-Use Sites	Driving End User Need Date	FY 1999 Proposed Technical Activity
1	Miscellaneous Pu Residue Requirements Definition	RFETS, LLNL HAN, SRS	Aug-99	PFA Comprehensive Assessment of Current Legacy and Anticipated Future Residue Inventories
2	Pu Ash Stabilization Process to meet WIPP requirements	RFETS	Jun-99	Phosphate Bonded Ceramics
3	Safety Surveillance Requirements Development for a new vault	SRS	Dec-99	DOE Standards Development for Safety Surveillance of material stored under long-term storage requirements.
4	Pu Combustible Stabilization Process to meet WIPP requirements	RFETS	Jul-98	PFA call for technology proposals to be issued
5	Am/Cm Stabilization Process for SRS	SRS	Mar-00	Russian Porous Crystalline Matrix
6	Development of characterization requirements and methods to meet WIPP Part B RCRA Requirements	All	Aug-99	Individual End-Use Sites
7	Accelerated installation and checkout methods for PuSPS	RFETS, LLNL, HAN, SRS	Dec 1999	PuSPS Project
8	Accelerated installation and checkout methods for MSRE	ORNL	Jan 1999	MSRE Project
9	Completion of Pack-0011 storage requirements	RFETS, LLNL, HAN, SRS	Dec-99	LANL Lead Laboratory Applied Technology PFA call for technology proposals to be issued

PFA Functional Needs Priority	Functional Need Description	Potential End-Use Sites	Driving End User Need Date	FY 1999 Proposed Technical Activity
10	Accelerated readiness review, installation, and checkout methods for LLNL residue processing	LLNL	Mar 2000	LLNL Stabilization Project
11	Integrated Surveillance & Monitoring Testbed to support APSF vault design, development, and validation	SRS	Dec-99	IMSS Testbed
12	Surveillance & Monitoring Component Technology Development to support APSF	SRS	Dec-99	LANL Lead Laboratory Applied Technology PFA call for technology proposals to be issued
13	Accelerated readiness review, installation, and checkout methods for Pu metal & oxide thermal stabilization processes	RFETS, LLNL, HAN, SRS	Apr 2000	Individual End-Use Sites
14	Accelerated Readiness Review, installation, and checkout methods for canyon processing	SRS	Jul 2000	SRS H-Canyon Project
15	Recycled Metal for Pu-239 storage containers and/or pipe component	RFETS, LLNL, HAN, SRS	Dec-99	PFA call for technology proposals to be issued
16	Alternatives to Residue Cementation at Hanford	HAN	Mar 2000	PFA call for technology proposals to be issued
17	Alternatives to Vertical Calciner for Pu Solution Stabilization at Hanford	HAN	Nov-00	PFA call for technology proposals to be issued
18	Salt Treatment Alternatives for RFETS	RFETS	Jul-00	PFA call for technology proposals to be issued
19	Alternatives to Pyrolysis for Residue Stabilization at Hanford	HAN	May-03	PFA call for technology proposals to be issued

PFA Functional Needs Priority	Functional Need Description	Potential End-Use Sites	Driving End User Need Date	FY 1999 Proposed Technical Activity
20	Completion of MD Acceptance Criteria	All	Oct-04	MD Program Analysis
21	U-233 Stabilization Technology Development	INEEL, ORNL	TBD	PFA call for technology proposals to be issued

Table 4. PFA-funded Technology Projects.

Technology	Summary
Phosphate Bonded Ceramics	Chemically-Bonded Phosphate Ceramics have been shown to be a stable, leach-resistant waste for immobilizing Plutonium ash and ash heel at the RFETS, which would pass the RCRA Part B requirements for TCLP testing. RFETS has shown a $10M savings and a 9-month schedule improvement using ceramification rather than vitrification, which is the current backup technology.
Integrated Monitoring and Surveillance System (IMSS)	The IMSS provides established resources for process definitive testing of sensor technologies necessary for the monitoring and surveillance of special nuclear material in short, intermediate, and long-term storage. The testbed includes an evaluation facility, necessary infrastructure, a wide range of Pu-bearing materials, 3013 packages, nondestructive assay systems, prototype storage configurations, and an inventory of sensor systems. This combination allows full-scale demonstration and process definitive testing. . The analytic capability developed under the IMSS project and the systems engineering expertise at INEEL will be used to develop safety surveillance requirements for a new vault before final design choices are made.
Porous Crystalline Matrix for Problematic Solutions (Russian Collaboration)	This technology, for example, provides an alternative to a vitrification process for liquid waste at SRS and is based on using a porous crystalline matrix that absorbs liquids at room temperature. The final waste form is a stable ceramic material, suitable for safe, long-term storage and transportation. The 15,000 liters of SRS liquid waste contain Am/Cm isotopes that have a commercial value and recovery of the isotopes is possible by dissolving the ceramic in an acid-based solution.

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