ORNL/TM-2001/66

Biological and Environmental Sciences Directorate

Value of Knowledge to the Cleanup-Stewardship Program of the U.S. Department of Energy

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April 2001

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managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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The scientific and technical (S&T) activities of the U.S. Department of Energy Office of Environmental Management (DOE/EM) provide solutions to DOE/EM remediation problems. In many cases, the solution of choice eventually involves deploying a new process or piece of equipment. There has been intensive scrutiny of such deployments over the last few years, and DOE/EM is now in the position of being able to track and depict its progress and plans regarding these solutions.

In addition to the well-recognized hardware solutions, many DOE/EM S&T activities result in improved knowledge or understanding of a particular situation or phenomenon that does not lead to a deployment but which nevertheless has proven to be very valuable. However, in many cases, the value of knowledge (VOK) is unrecognized, and it is certain that some key decision makers do not fully appreciate the VOK. The need to inform others concerning the VOK resulted in the preparation of this paper, the purposes of which are to

- provide conceptual background on the definition of VOK and why it is valuable to DOE/EM,
- cite examples of how knowledge has benefitted and will benefit DOE/EM, and
- provide recommendations on the actions that the DOE/EM Office of Science and Technology (OST) should undertake to ensure that DOE/EM's VOK contributions are routinely recognized in the future.

1. BACKGROUND ON THE VALUE OF KNOWLEDGE

<u>Definitions</u>. For the purposes of this paper, *knowledge* is defined as the product of S&T activities that results in increased understanding or information related to EM's activities. Alternatively, *knowledge* is the results of S&T that do not become explicit through the deployment of a new gadget, piece of equipment, reagent, or process. Rather, according to the concept that "knowledge is power," a knowledge product of S&T activities gives EM a new or enhanced insight needed to carry out its environmental mission.

<u>Value of Knowledge</u>. Improved knowledge is valuable to EM in two important ways. *First*, such knowledge can result in the ability to establish or make quantum improvements in baseline strategies by providing a better basis for decision making: regulatory and compliance decisions, overall remediation strategies, or process selection. The Science Committee of the DOE Environmental Management Advisory Board recently pointed out the need for a cadre of knowledgeable people who can provide insight to cleanup efforts [EMAB 1998]. *Second*, improved knowledge can lead to better performance of existing hardware. Such improvements are usually incremental, but with the large cost and scale of many EM operations, incremental savings can amount to billions of dollars. In either case, improvements can result in reduced cost (directly or through reduction of technological risk), reduction in human health risk, or both.

The complement to VOK is the Cost of Ignorance (COI), which is the excess cost that results from inadequately informed decisions or suboptimal hardware that continues to be used. Poor decisions can be particularly costly because the result is frequently the need to clean up both the original problem as well as the initial solution that proved inadequate (e.g., to rework waste forms that lose their integrity) or excessive cleanup of a site.

Conceptual Basis for the Value of Knowledge. The linear model of research, development, demonstration, and deployment (RDD&D) that proceeds through the stages of basic research, applied research, technology development, demonstration, deployment, and technical support was established near the end of World War II by Vannevar Bush (see [R&D Magazine 1997] for a summary or [Stokes 1997] and [Bush 1945] for details). This model can be viewed as a pipeline with basic research results proceeding through more applied stages of development and leading to the deployment of improved equipment or processes. However, it is increasingly accepted that this model is only partially applicable to RDD&D in general and to DOE/EM in particular. A more realistic model of RDD&D is shown in Fig. 1, which makes three major points:

- The linear model is valid only when the product is new hardware or processes. In this case, the new hardware or process is typically tested at a bench and pilot scale (both may involve tests with simulants and actual wastes) before proceeding to demonstration with actual wastes. Years of industrial and DOE experience have proven this to be a prudent approach because the cost of deploying hardware or a process that does not work can be billions of dollars or can place workers at risk. There are a few exceptions to this, such as very small devices (e.g., sensors) that can be invented, tested, and deployed without having to go through the entire linear process.

- The linear model holds that basic research is driven purely by the academic pursuit of knowledge, whereas in reality much basic research in government [e.g., the Environmental Management Science Program (EMSP), the Nuclear Energy Research Initiative (NERI)] and industry is stimulated by a vision of needs or applications. That is, the need for new science or technology does not proceed linearly back through the development sequence but instead leaps backward to inform RDD&D investigators in all stages of the development sequence.

- The linear model is largely invalid when the product is knowledge (as defined at the outset of this paper) because of these factors:
  - Useful knowledge can be generated by any stage in the linear model and have immediate application. Cases in point are summarized later in this paper.
  - The need for knowledge is frequently driven by a specific problem, even at the basic research stage.

The applicability of nonlinear RDD&D models such as that set forth by Stokes [1997] to S&T related to EM needs has been analyzed in a recent paper [Bjornstad 2000]. The conclusion of this analysis is that DOE's S&T program should involve both use-inspired applied research (i.e., technology development and demonstration) and basic research focused on using the knowledge it generates. A major challenge to including both types of research is that, despite the increasingly prevalent view that the linear model is valid only under the limited circumstances that do not include VOK, it is still deeply ingrained in government policy.

Delayed Gratification—Investing on the Basis of Experience and Faith. One important aspect of knowledge is the potential delay between the creation of knowledge and seeing the resulting benefits. Investments made years ago in areas such as cesium removal are currently paying handsome dividends, and more are possible in the future. Present investments to understand the chemistry of alkaline sludges and slurries promise to have payoffs in the future in the form of elimination of plugs in waste transfer lines. The important point is that investment in knowledge is often speculative at the time of the investment, and the validation of such decisions can occur years later. Therefore, such investments must be made on the basis of experience and faith.

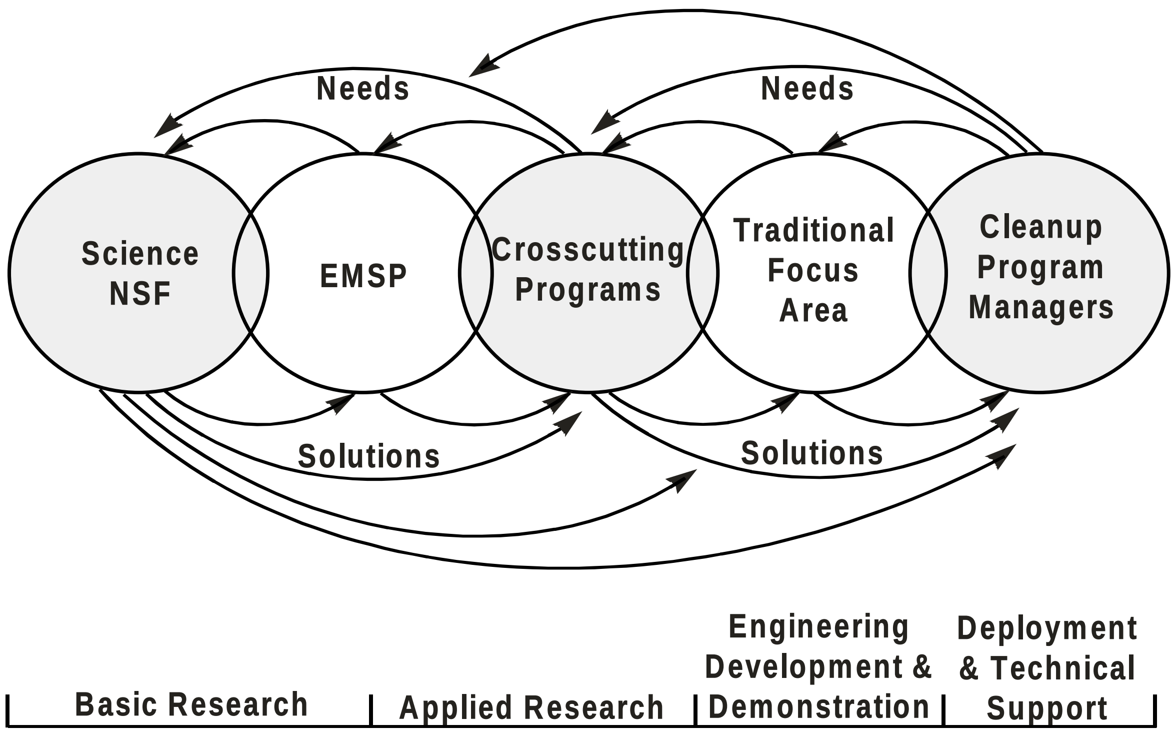

Fig. 1. Flow of S&T needs and results in the nonlinear technology development process.

2. BENEFITS OF IMPROVED KNOWLEDGE

This section contains specific examples of the VOK to the DOE/EM mission. The following should be noted about these examples:

- The list is far from comprehensive.
- The cost and schedule reductions are generally already reflected in site baselines.
- Cost and schedule benefits of improved knowledge are difficult to determine because such benefits often become evident in a series of steps over a protracted period of time. Initial baselines are usually based on simplistic or brute-force techniques, and the calculated savings can be unreasonably large because the initial baseline would never have been implemented. More-reasonable savings result from later baselines, but the existence of multiple answers often confuses stakeholders and raises suspicions.

2.1 Historical Examples of the Value of Knowledge

2.1.1 Mercury Bioavailability and Cleanup Action Levels

Mercury contamination of the East Fork of Poplar Creek (EFPC) in Tennessee was caused by defense activities at the DOE site in Oak Ridge. The maximum allowable residual concentration of mercury (the "action level") was initially proposed to be 5 ppm, based on standard State of Tennessee and U.S. Environmental Protection Agency (EPA) criteria for methyl mercury. Setting the "action level," the mercury concentration that would trigger cleanup at any given location, was an extremely important issue from both the risk perspective and a cost perspective. In particular, the initial estimates of the EFPC remediation cost were in the range of $150M to $200M. Additionally, the extent of environmental disruption, which involved mostly private property, depended critically on the action level.

It was well known that risks due to mercury depend on the complex environmental chemistry of the element and the bioavailability of different chemical forms (see sidebar on COI). Acting on this knowledge, DOE/EM (EM-40 and EM-50), with some contributions from EPA and the Electric Power Research Institute, supported cutting-edge research at Oak Ridge National Laboratory (ORNL) on soils from EFPC that totaled less than $1M. This research showed that the mercury bioavailability was much lower than in other environments with similar levels of total mercury contamination because the element was not in the form of the more toxic methyl mercury at EFPC and it was shown that this would remain the case. This knowledge, which was obtained in

Cost of Ignorance: Mercury in Minimata Bay

In the 1960s, mercury discharged into Minimata Bay in Japan resulted in 23 human deaths from consumption of contaminated fish. It was subsequently discovered that the chemical form being discharged, methyl mercury, was far more bioavailable than inorganic forms of mercury and consequently the concentrations in fish from the bay were higher than expected. Had the bioavailability been known, protective controls could have been imposed before this terrible event occurred.

stages over a few years, was pivotal in decisions by the EPA, the State of Tennessee, and DOE (in which the public was heavily involved) to increase the mercury remediation action level first to 50 ppm, then to 200 ppm, and finally to 400 ppm. As a result, the cost of cleanup was reduced by at least $150M, and possibly as much as $1B if the action levels were set at 5 ppm. The area of floodplain that was destroyed during cleanup was reduced by 75 to 80%.

2.1.2 Molten Salt Reactor Experiment Remediation

The Molten Salt Reactor Experiment (MSRE) operated at ORNL from 1965 to 1969 to test the molten salt concept for commercial nuclear power reactors. The reactor was fueled by uranium tetrafluoride and cooled by molten lithium and beryllium salts. Rather than being confined to fuel rods, as in current commercial power reactors, the fuel was a molten salt that flowed through the reactor chamber, where the nuclear chain reaction produced heat. During 1970–1971, preparations were completed for long-term storage of the fuel subsequent to permanent shutdown of the MSRE. The fuel was drained into two fuel drain tanks designed to store the fuel between operating runs. The fuel salt was allowed to solidify in these tanks, and a batch of initially clean salt used to flush the MSRE was allowed to solidify in a third tank.

Surveillance activities during the period 1987–1994 found unexpectedly high concentrations of fluorine gas and uranium hexafluoride vapor in the piping system connected to the storage tanks. Subsequent investigations led to the discovery of a 2–3 kg deposit of uranium in a charcoal bed that filtered the off-gas from the tanks containing the fuel salt. Analysis showed that a nuclear criticality event was possible if water were to leak into the charcoal bed and that the interaction of fluorine compounds and charcoal was potentially explosive at elevated temperatures. As a result of this, an intensive effort to stabilize the storagetank system and then remove the salt was initiated by DOE and executed by ORNL staff members. (To date, approximately 60% of the total uranium inventory has been removed as gaseous UF_6. The remainder of the uranium resides in the lithium-beryllium fluoride fuel salt in the form of UF_4. Design and procurement activities are under way to assemble the processing equipment necessary to extract the remaining uranium; melt the fluoride salt with its associated fission products; and transfer the melted salt into storage canisters, which will then be moved to a secure facility.

The unique nature of the MSRE fuel salt resulted in the unexpected behavior that initiated the remediation activity and a continuing series of unanticipated challenges during the remediation process. Throughout this process, ORNL scientific staff members with extensive research credentials related to the chemistry of fluorine compounds have been conducting laboratory studies supported by DOE/EM. These research studies and the expertise of the ORNL staff were crucial in determining the extent of the hazards present and which remediation approaches were acceptable. Examples of such studies include identifying and characterizing the hazards associated with mixtures of fluorine compounds and charcoal and determining that the much more efficient process of melting the salt to allow removal by pumping would not result in an unacceptable chemical reaction.

2.1.3 Reduction of HLW Glass Volume in DWPF

High-level waste (HLW) is being vitrified in the Defense Waste Processing Facility (DWPF) at the Savannah River Site (SRS). The life-cycle cost of HLW vitrification is tied to many factors, including the “waste loading” achievable in each glass canister. A small increase in waste loading can result in large life-cycle cost savings. For example, reducing the volume of the HLW by 1% is estimated to save approximately $250M. Waste loading is controlled by a statistically defined, quality assurance–based operating envelope that was established many years ago with available data. By collecting additional technical data for one component of the waste-loading operating envelope, it has been possible to increase the statistical confidence. This has, in turn, enlarged the operating envelope by 1–2%, which yields savings of $250M–$500M. Although a new technology is not being developed, knowledge is being delivered and will be deployed through authorization of a revised operating envelope for DWPF, resulting in significant cost savings to DOE.

2.1.4 Resolution of the Hanford Tank Safety Issue

For the past few years, the crust level in Hanford Tank SY-101 has been growing, raising containment safety concerns. DOE Tank Focus Area researchers used a series of dilution and pumping models to identify and evaluate SY-101 surface-level mitigation options for Hanford Site tank farm operations personnel. DOE/EM S&T projects provided technical data to support a key programmatic decision and reduce the technical risks associated with that decision. The preferred option involved a four-step implementation of waste transfer to Tank SY-102 and dilution coupled with intermediate decision points to assess the success of the previous step. In parallel with this approach, in-tank testing was performed to determine the effects of spraying water on the crust in an attempt to dissolve it. The results of the testing were designed to be used in performing the dilution efforts. The options were presented to DOE and contractor senior managers, and preliminary approval was given to proceed with the preferred option. This option was implemented in 1999 and completed in 2000, thus resolving this important and costly safety issue.

2.1.5 Acceptable Glass Composition for Hanford Tank Waste

One of the projects supported by the DOE/EM EMSP investigated the effect of a sodium ion-exchange reaction on the release of radionuclides from low-activity waste glass in subsurface disposal at Hanford. Low-temperature ion-exchange had not previously been thought to be an important factor in the durability of waste glass. However, the research showed that the sodium ion-exchange reaction can increase the release rate of important radionuclides such as technetium by a factor of 100. Technetium-99 is the primary contributor to the calculated dose from the proposed low-level waste (LLW) site, and a factor-of-100 increase would not have been acceptable. The consequence of belatedly discovering the effect of the sodium ion-exchange reaction could have been a costly redesign and refurbishment of the LLW vitrification facility or unacceptable levels of technetium release leading to the need to remediate the LLW disposal site. Instead, this research provided the impetus for the development of a new glass formulation that does not undergo the sodium ion-exchange reaction, thus resulting in the calculated doses again being acceptable. Further, the results of this research convinced a critical review panel to reverse its previous decision and approve the LLW disposal performance assessment.

2.1.6 Toxicology of Trichloroethylene

Another EMSP project conducted research concerning the toxicology of trichloroethylene (TCE), a chemical widely used in DOE’s nuclear weapons complex and now contaminating groundwater at many DOE sites. The research results showed that liver tumors in mice are caused by TCE acting as a tumorpromoting agent instead of as a genotoxic agent. This result means that TCE is less toxic than previously thought and that the drinking water standard for TCE might be increased by as much as an order of magnitude. Remediation of contaminated groundwater resulting from DOE activities is driven by the provisions of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), which is based on the drinking water standards. Increasing the drinking water limit for TCE could result in numerous DOE remediation sites meeting the new standard and, thus, reducing DOE's cleanup mortgage.

2.2 Current Projects Producing Knowledge Likely to Yield Future Benefits

2.2.1 Solids Formation and Pipeline Plugging

During the last few years, DOE/EM has supported experimental and modeling activities to provide knowledge required to define the operating window for waste transfers at Hanford, and this work is expected to continue for the next few years. It is necessary to transfer waste at Hanford from leaking single-shell tanks to double-shell tanks, consolidate waste in preparation for processing, and transfer the waste to planned facilities to be built and operated by a contractor. During previous waste transfer operations at Hanford, five cross-site transfer lines have been plugged by highly radioactive waste and are now unusable. The knowledge obtained from the ongoing S&T, the total of which is expected to amount to about $7M, will enable an envelope of waste compositions to be defined that will reliably prevent plugging of these transfer lines in the future. The cost of a plugged pipeline is the $43M cost of its replacement, plus an estimated cost of $2M for each day the planned waste processing facilities are idle while awaiting feed material.

2.2.2 Separation of Cesium from Tank Wastes

In 1983 a process using tetraphenylborate as a reagent to implement in-tank precipitation (ITP) of the radioactive element cesium (predominantly cesium-137) was demonstrated. Based on this demonstration, the process was deemed feasible. Over subsequent years the technology was developed to the point it was believed ready for deployment. When ITP was deployed, an unexpectedly large amount of flammable and toxic benzene was generated as a result of decomposing tetraphenylborate. Investigations over the next 2 years resulted in the conclusion that the excess benzene generation could not be alleviated and, therefore, the initially conceived ITP process could not provide a robust process which would meet the processing requirements of the DWPF. In early 1998, it was recommended that operation of ITP cease and that other alternatives be considered to remove cesium from the highly alkaline water solutions typical of SRS and Hanford.

In parallel with the development of ITP at SRS, DOE/EM supported a sequential set of projects to identify, test, evaluate, and demonstrate a preferred technology for removing radiocesium from highly alkaline water solutions. The result of this sequence was the identification of crystalline silicotitanate (CST) ion-exchange material as the preferred material for radiocesium removal. CST was developed by Sandia National Laboratory with support from Hanford and a cooperative research and development agreement (CRADA) with UOP to commercialize the process. The efficacy of the CST material was subsequently demonstrated in radioactive operations at ORNL. In parallel, the DOE Office of Science (DOE/SC) and DOE/EM also supported research on solvent extraction techniques to recover cesium from wastes.

When the need for alternatives to the SRS ITP process became evident in 1998, the expertise and results of the DOE/EM and DOE/SC efforts (dating from the early 1990s) to identify a preferred method for removing radiocesium became pivotal. Specifically, in the second and third quarters of 1998, SRS conducted an evaluation of approximately 130 process alternatives to remove radiocesium from alkaline water solutions. The list of 130 alternatives was reduced to four that would be pursued further: a modified (small-tank) version of ITP; radiocesium removal with CST; solvent extraction; and grouting of the waste without radiocesium removal, the last of which presented significant regulatory issues and has subsequently been dropped from consideration.

The S&T efforts of DOE/EM, especially the DOE/EM OST Efficient Separations and Crosscutting Program and the OST Tank Focus Area* provided the expertise both to (1) reduce the time required to evaluate alternative technologies for removing radiocesium from highly alkaline aqueous solutions to a period of months rather than years and (2) provide the CST and solvent extraction alternatives that have the potential to be preferred in this application and others. Without the S&T activities on cesium removal, SRS would be limited to the small-tank ITP or direct grouting of the waste. Other options exist, but they are not sufficiently mature to meet the schedule requirements at SRS, which entail costly penalties for delay.

The benefits of knowledge resulting from DOE/EM S&T and DOE/SC programs to the SRS issue of removing radiocesium from its aqueous alkaline wastes are as follows:

- <u>Shortening the time required to select and deploy a new process.</u> Making highly efficient alternatives for removal of radiocesium from aqueous alkaline wastes available for immediate consideration at SRS and elsewhere. The cost of continuing to maintain DWPF while awaiting the completion of sufficient S&T to provide the basis for selecting alternatives would have been very costly.

- <u>Making specialized expertise immediately available</u>. Providing readily available expertise necessary to evaluate many cesium removal options. This expertise was crucial in facilitating the identification and evaluation of alternatives to ITP at the SRS.

Pending the final decisions at SRS concerning the process to be used for removal of radiocesium from aqueous alkaline wastes, the cost benefits of the DOE/EM S&T investments are imponderable. However, it is estimated that the base of knowledge resulting from DOE/EM S&T investments has reduced the cost of remediating SRS tanks by hundreds of millions of dollars by shortening the time these expensive facilities must be kept operational.

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*DOE/EM S&T on cesium removal via solvent extraction had its beginnings in research funded by DOE/SC.

2.2.3 Hanford Canyon Disposition Initiative

Hanford has five (or six, if the Plutonium Finishing Plant is included) large chemical processing facilities called “canyons.” The canyons contain the largest inventories of radioactive and hazardous wastes at Hanford outside the underground HLW tanks. DOE is presently in the process of deciding how to disposition these facilities by using the Canyon Disposition Initiative (CDI) on the U Plant to gain information to support a Record of Decision. Alternatives under consideration include the following:

1. Complete dismantling and demolition, with the resulting wastes being disposed of in the Environmental Restoration Disposal Facility (ERDF) on the Hanford site.
2. Partial demolition that would take the facility to ground level, covering the portion remaining below ground level with a barrier, and disposing of a lesser amount of waste in ERDF.
3. Leaving the facility in place, filling the interior with LLW, and covering the filled facility with a barrier.
4. Leaving the facility in place, filling the interior with LLW, placing LLW around the facility, covering the facility, and surrounding the waste with a barrier.

The fourth alternative is believed to be the best. It is no more risky than the other alternatives, would save $1B as compared with the other alternatives (if it were applied to all five chemical processing facilities), and would leave 35 acres of ERDF burial ground free for other wastes. However, the basis for this belief is largely intuitive and a strong case to convince the decision makers and regulators has yet to be made. Obtaining regulatory approval and a favorable decision requires sufficient characterization of the facility structure, its contents, and the surrounding soil/vadose zone to provide the technical basis for a defensible performance assessment that will satisfy regulator, stakeholder, and decision-maker concerns. The key to a defensible performance assessment is obtaining the necessary data on and, most importantly, a predictive understanding of the performance of the barriers and surrounding vadose zone. Thus, additional knowledge is expected to be very valuable in that it can lead to a decision resulting in a savings of about $1B.

3. NEEDED ACTIONS

This section considers the actions that should be taken to ensure that the VOK is properly recognized by stakeholders and that DOE/EM can comprehensively identify knowledge-based needs and articulate the VOK.

3.1 Educating Stakeholders on the Value of Knowledge and Cost of Ignorance

It is necessary to educate key stakeholders concerning the nonlinear model and the benefits of VOK so that they will recognize and support VOK-related S&T as follows:

- Cleanup Project Managers (CPMs): In part, CPMs may not require education because one manifestation of VOK is technical support, which is typically a high priority. However, CPMs must be convinced of the value of more-speculative investments in knowledge that is not directly tied to baselines.

- Focus Areas: On balance, the Focus Areas are expected to require little education concerning the benefits of VOK because EMSP and Crosscutting Programs staff will be receptive, as will elements in the Focus Areas that believe work on nonbaseline (e.g., contingency) issues is needed. However, staff in the core baseline-driven technology development and demonstration may be less receptive because supporting VOK could adversely impact their budgets. Educational efforts are needed to explain how knowledge is valuable in providing technical support to demonstrations and deployments.

- Congress and Executive Branch Policy Makers: Some elements of Congress (see [R&D Magazine 1997]) are already proponents of the nonlinear model and can be expected to understand the VOK. However, most members of Congress require further explanation to understand the critical importance of VOK and how its benefits can occur far after the investment is made. Such explanations are all the more challenging because of general pressures to reduce near-term budgets.

In all cases, efforts are needed to explain the nonlinear model of RDD&D, preferably by continuing to include the linear model as a component, and the benefits of knowledge. The abstractness of the nonlinear model of RDD&D and the delayed gratification inherent in most VOK situations make it difficult to rely on generic explanations. Thus, education should focus on anecdotal evidence of past successes and future opportunities where the benefits of knowledge are clear. The anecdotes must succinctly describe the problem, the knowledge that constituted the solution, the benefits, and a point of contact for more information. For Congress and policy makers, the anecdotes must be largely nontechnical and support a pithy “elevator speech” lasting no more than a couple of minutes. Bullet-style one-pagers and poster sessions with graphics should be important tools. For Focus Areas and CPMs, more-detailed anecdotal success stories in the form of presentations and written one-pagers should be beneficial.

3.2 Identifying Needs for Improved Knowledge and Tracking the Value of Knowledge

In DOE/EM, knowledge needs are not comprehensively identified, and such needs are not usually characterized as "seeking knowledge." The need for technical support to problem owners, which appears to be a universally high priority, has been captured only sporadically. The beneficial results of improved knowledge are not currently identified as such or tracked. Identification of knowledge-based technical support is difficult. Much of this activity is buried in large projects, in part because knowledge needs are relatively small in scope and in part because admission of such activities in a compliance-driven program has not been acceptable.

More information is required concerning the need for and the benefits of the valuable knowledge generated by DOE/EM. In particular, during the formulation of the program of work each year, each S&T project should identify where knowledge is expected to be used and each cleanup project should identify where it plans to use such knowledge. While simple in concept, this is not expected to be straightforward. From the S&T project perspective, it is not possible to know the uses of knowledge, especially when the knowledge is published in the open literature and could be of value to unknown users who have no obligation to interact with those producing the information. Further, significant amounts of knowledge are believed to be produced by "technical support" activities funded by problem owners. This work can be very difficult to identify because it is often an integral part of the cleanup project. This difficulty is exacerbated by a historical reluctance to admit to such activities because of a fear they would be deemed to not be compliance driven and therefore terminated. Nevertheless, identification of knowledge needs and benefits is imperative and should be pursued.

3.3 Enhancing Aspects of Science and Technology Programs Central to Generating Valuable Knowledge

As discussed earlier, knowledge can be valuable in problem-specific, near-term applications (e.g., troubleshooting, process improvements) or in more speculative applications that may yield potential benefits in the longer term (e.g., contingency technologies). Because of the clarity of the need, the former are generally supported by cleanup programs to the extent they are needed. However, during the last few years, speculative projects to generate knowledge have been underfunded because of the relatively small amount of funding available for applied research and the unacceptability of allowing Focus Areas to invest in S&T not directly tied to user needs. This situation is beginning to change with recent emphasis on increasing applied research budgets and allowing Focus Areas to "fence" a small portion of their budgets for discretionary S&T. However, continued efforts are needed in this area to ensure that budgets are brought up to desirable levels and then sustained to maintain the availability of the knowledge base in key areas.

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