

# Capturing Undocumented Expert Knowledge

Electric Delivery Topics for Public Service Electric and Gas

*Technical Report*





# **Capturing Undocumented Expert Knowledge**

Electric Delivery Topics for Public Service Electric and Gas Company

**1012127**

Final Report, August 2005

Cosponsor  
Public Service Electric and Gas Company  
80 Park Plaza  
Newark, NJ 07102

Project Manager  
J. Del Monaco

EPRI Project Manager  
D. Ziebell

## **DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES**

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

**Electric Power Research Institute (EPRI)**

## **NOTE**

For further information about EPRI, call the EPRI Customer Assistance Center at (800) 313-3774 or email [askepri@epri.com](mailto:askepri@epri.com)

Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc.

Copyright © 2005 Electric Power Research Institute, Inc. All rights reserved.

# CITATIONS

---

This report was prepared by

Electric Power Research Institute (EPRI)  
1300 W.T. Harris Blvd.  
Charlotte, NC 28262

Principal Investigator  
D. Ziebell

This report describes research sponsored by EPRI and Public Service Electric and Gas Company.

The report is a corporate document that should be cited in the literature in the following manner:

*Capturing Undocumented Expert Knowledge: Electric Delivery Topics for Public Service Electric and Gas.* EPRI, Palo Alto, CA, and Public Service Electric and Gas Company, Newark, NJ: 2005. 1012127.



# PRODUCT DESCRIPTION

---

Public Service Electric and Gas Company (PSE&G) faces the retirements of skilled, productive experts in the areas of asset management system protection engineering and pipe-type cable design and operations. The project team used the Electric Power Research Institute (EPRI) guidelines and methods, described in the EPRI report *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (1002896) to capture and retain the tacit knowledge held by these key experts. The difficulty of retaining expert knowledge is faced by many in the utility industry. Efforts to capture and transfer knowledge throughout the industry will be significant in the next five years.

## Results and Findings

PSE&G has acquired through this project a framework for sustaining mission-critical knowledge that exists in the minds of key individuals. In addition to the framework, PSE&G now has available a broad base of detailed experiential knowledge that serves as a reference for less experienced individuals and also as a roadmap to the kinds of knowledge that future experts will be expected to have. The detailed knowledge bases, which were captured from PSE&G experts, cover system protection engineering and asset management, pipe-type cable engineering, and underground transmission event response. These new knowledge bases are supplemented by, and complementary to, existing PSE&G documents. The knowledge bases also contain links to relevant EPRI reports so that users of the knowledge bases will be able to understand the scope of information available beyond PSE&G's in-house resources.

## Challenges and Objectives

This report is a summary of the process used, and it is for the benefit of PSE&G managers as they improve work processes and sustain mission-critical knowledge for the long-term success of their business. The actual knowledge bases are not included in this report, but have been provided separately for inclusion in PSE&G's existing business practices.

## Applications, Value, and Use

It now remains for PSE&G personnel to use and maintain the knowledge bases that have been provided. Recommendations for doing so are included in this report. Beyond this minimum step to realize the value of this project, PSE&G could further capitalize on this project in at least two ways: first, by expanding the scope of effort to other key knowledge domains, and second, by collaborating with EPRI and other utilities to share the expertise that is truly generic within appropriate communities of practice.

## **EPRI Perspective**

Engineers at PSE&G are enthusiastic about the process and the results they are achieving, and EPRI benefits from PSE&G's dynamic, collegial approach. For example, lessons learned from this project are helping the industry as we develop faster self-elicitation techniques to add to the EPRI toolbox. This project demonstrates that EPRI's understanding of practical approaches to capturing and transferring knowledge is immediately useful to utility engineers, and that EPRI's process is flexible enough to minimize the disruption in the workplace that is typically associated with taking on a new initiative.

## **Approach**

EPRI and PSE&G applied the EPRI report *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (1002896) to three domains of knowledge selected by PSE&G. Each knowledge domain was allotted three interview sessions with each subject matter expert provided by PSE&G. Each interview session lasted approximately two-and-one-half days. The EPRI knowledge elicitation team involved peers of the experts, future users of the knowledge modules being developed, and PSE&G management in guiding the interviews toward valuable knowledge and in providing the necessary technical review of the materials.

## **Keywords**

Undocumented knowledge  
Knowledge management  
Aging workforce  
Knowledge retention  
Knowledge elicitation  
Concept mapping

# CONTENTS

---

- 1 SCOPE AND METHOD ..... 1-1**
  - Scope ..... 1-1
    - Initial Project Description ..... 1-1
    - Expanded Scope ..... 1-3
    - Generic Schedule ..... 1-4
  - Method ..... 1-5
    - Overview of Methods ..... 1-5
    - Concept Maps ..... 1-6
    - Publication of Content ..... 1-7
  
- 2 RESULTS ..... 2-1**
  - Results for the Domain of Asset Management System Protection Engineering ..... 2-1
    - Schedule Compliance ..... 2-2
    - Content Description ..... 2-2
      - Knowledge Modules ..... 2-2
      - Remaining Gaps ..... 2-3
    - Key Methods Used ..... 2-3
      - Concept Map-Based Interviews ..... 2-3
      - Knowledge Audit ..... 2-4
      - Self-Elicitation ..... 2-4
      - Critical Decision Method ..... 2-4
  - Results for the Domains of Pipe-Type Cable and Hydraulic Event Response ..... 2-5
    - Schedule Compliance ..... 2-5
    - Content Description ..... 2-5
      - Knowledge Modules ..... 2-5
      - Remaining Gaps ..... 2-8
    - Key Methods Used ..... 2-8
      - Concept Map-Based Interviews ..... 2-8

---

Knowledge Audit.....	2-8
Critical Decision Method .....	2-9
Modified Task Diagram Method .....	2-9
<b>3 EPRI LESSONS LEARNED .....</b>	<b>3-1</b>
Self-Elicitation Methods: Seek Templates When It Makes Sense.....	3-1
Personnel Turnover on the Knowledge Elicitation Team .....	3-2
Overlapping Projects.....	3-2
Value of the Tacit Big Picture .....	3-3
Three Stories .....	3-3
<b>4 OBSERVATIONS AND RECOMMENDATIONS.....</b>	<b>4-1</b>
Communicate the Big Picture and Mission.....	4-1
Tour the Plants.....	4-2
Maintain the Resource Tables.....	4-2
Maintain the Captured Knowledge .....	4-2
<b>5 REFERENCES .....</b>	<b>5-1</b>

# LIST OF FIGURES

---

Figure 1-1 Three Phases of Knowledge Capture.....	1-5
Figure 1-2 A Concept Map About Concept Maps .....	1-6
Figure 2-1 Top-Level Concept Map for Asset Management System Protection Engineering Functions .....	2-2
Figure 2-2 Top-Level Concept Map for Pipe-Type Cable and Hydraulic Event Response Domains .....	2-6



# LIST OF TABLES

---

Table 1-1 Generic Knowledge Elicitation and Review Schedule .....	1-4
---	-----



# 1

## SCOPE AND METHOD

---

The purpose of this project was to assist PSE&G in capturing valuable undocumented knowledge within the electric delivery workforce. The project applied EPRI's guidelines and methods, described in the EPRI report *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (1002896) [1]. All products developed by following that process have been delivered to PSE&G for publication within PSE&G's existing processes, with the intent that the captured knowledge will be available to PSE&G's electric delivery personnel in the future.

### Scope

The project began in May 2004 with a broadly defined scope of effort and a clearly defined financial scope. Project tasks were developed in appropriate detail at an initial meeting of project personnel and PSE&G personnel. Results from that meeting included a timeline for this project, an estimate of the amount of knowledge that was to be captured, and an understanding of the extent to which PSE&G wished to build internal capacity to sustain a process for capturing and delivering valuable knowledge in the future. To transfer the technology and build PSE&G's internal capacity required PSE&G's active participation and commitment of internal resources to knowledge capture.

The three stages of the EPRI guidelines and methods were used as a framework for the detailed tasks for this project. The three stages are the following:

1. Identify valuable knowledge and who has it.
2. Plan appropriate methods to capture the knowledge.
3. Execute the plan, including publication of results.

Using this approach allowed the project team to be responsive to the urgency of the situation as perceived by PSE&G and to provide for long-term benefits to PSE&G.

### ***Initial Project Description***

The following project description was developed and agreed to in May 2004.

The EPRI Team will apply EPRI's guidelines and methods, including the following tasks: screen, plan, execute, and deliver high-value undocumented knowledge from one expert on PSE&G's Asset Management System Protection Engineering Team and one expert on PSE&G's Pipe-Type Cable Engineering Team as identified by PSE&G. For the on-site portions of this

task, PSE&G will provide a suitable quiet space for interviews and meetings. Steps to complete this task include the following:

1. Preparation: The EPRI team will review background materials provided by PSE&G to understand the scope of the Asset Management System Protection Engineering Team's responsibilities and the state of existing explicit knowledge.
2. Initial meetings: The EPRI team will meet individually with Colin Loxley and others designated by PSE&G to further focus the EPRI team on PSE&G's expectations for this project and to identify the ongoing support that PSE&G will provide to the project team. This meeting and the orientation meeting to follow will provide the EPRI team with a basis for selecting from the existing methods appropriate techniques to apply initially during knowledge elicitation.
3. Orientation meeting: The EPRI team will meet with the entire staff of the teams participating in this project and additional PSE&G managers and personnel to provide an overview of the EPRI guidelines and methods and to convey the roles that the PSE&G personnel will fill during this project. For example, we will determine who will be interviewed, who will validate the results, who will provide input on the form of the results for best fit with the team's needs, how existing resources will be brought into the product, and what the overall schedule will be.
4. Knowledge elicitation: The EPRI team will meet with each designated expert in a series of three interview sessions. Each session will last approximately two-and-one-half days, during which EPRI will conduct knowledge elicitation, obtain additional knowledge resources, and consult additional team members regarding existing gaps or needs. Examples of additional knowledge resources that might be needed include photographs or videos; existing manuals, notes, or corporate records; and external technical contacts. PSE&G personnel may be asked to provide such additional knowledge resources. Each session will include a brief departure meeting with relevant managers to convey the status and to establish and communicate priorities. Following each session, EPRI will provide interim results for PSE&G's review within three business days. PSE&G will provide comments back to EPRI within four business days and before the next session.
5. Interim reviews: The schedule for knowledge elicitation sessions will allow time for PSE&G personnel to review the materials from the previous session and provide comments to the EPRI team. The EPRI team will structure the next session based on PSE&G's input from the previous session.
6. Review and finalization of knowledge modules: EPRI will provide an independent review of the knowledge modules by an EPRI subject matter expert before final publication. EPRI will meet with one or more team members who will be using the knowledge modules to review the format of the final modules in order to maximize the future benefit. The knowledge modules resulting from the knowledge elicitation sessions with the key experts are the main deliverables from this effort.
7. Lessons learned and recommendations: When the knowledge modules are complete, EPRI will meet with the relevant PSE&G personnel to verbally convey any lessons learned from the knowledge elicitation process and any recommendations that may help PSE&G to

maximize the value of the knowledge modules in the future through changes in business processes or infrastructure.

### **Expanded Scope**

In October 2004, PSE&G and EPRI agreed to expand the project scope to include the Hydraulic Event Response group. The following project description, similar to the preceding description, was developed and agreed to for this additional activity. The main difference for this additional activity is that instead of interviewing only one key expert from each discipline, the team will interview three individuals. EPRI will interview each expert once, with each session lasting approximately two-and-one-half days.

The project team will apply EPRI's guidelines and methods, including the following tasks: screen, plan, execute, and deliver high-value undocumented knowledge from operational experts on PSE&G's Pipe-Type Cable Engineering Team who are knowledgeable about underground transmission hydraulic event response. For the onsite portions of this task, PSE&G will provide a suitable quiet space for interviews and meetings. Steps to complete this task include the following:

1. Preparation: The EPRI team will review background materials provided by PSE&G to understand the scope of the operational experts' responsibilities and the state of existing explicit knowledge.
2. Orientation meeting: The EPRI team will meet with the entire staff of the teams participating in this project to provide an overview of the EPRI guidelines and methods and to convey the roles that the various PSE&G personnel will fill during this project. For example, we will determine who will be interviewed, who will validate the results, who will provide input on the form of the results for the best fit with the team's needs, how existing resources will be brought into the product, and what the overall schedule will be. (This activity was substantially completed during a meeting with PSE&G on October 5, 2004, and will be revisited as necessary during the first elicitation session.)
3. Knowledge elicitation: The EPRI team will meet with each designated expert in a series of three interview sessions. Each session will last approximately two-and-one-half days, during which EPRI will conduct knowledge elicitation, obtain additional knowledge resources, and consult additional team members regarding existing gaps or needs. Examples of additional knowledge resources that may be needed include photographs or videos; existing manuals, notes, or corporate records; and external technical contacts. PSE&G personnel may be asked to provide such additional knowledge resources. Each session will include a brief departure meeting with relevant managers to convey the status and to establish and communicate priorities (when PSE&G managers' schedules support such meetings). Following each session, EPRI will provide interim results for PSE&G's review within approximately one week. PSE&G will provide comments back to EPRI prior to each subsequent session.
4. Interim reviews: The schedule for knowledge elicitation sessions will allow time for PSE&G personnel to review the materials from the previous session and provide comments to the EPRI team. The EPRI team will structure the next session based on PSE&G's input from the previous session.

5. Review and finalization of knowledge modules: EPRI will provide an independent review of the knowledge modules by an EPRI subject matter expert prior to final publication. EPRI will meet with one or more station team members who will be using the knowledge modules to review the format of the final modules in order to maximize the future benefit. The knowledge modules resulting from the three interviews with each expert are the main deliverables from this effort.
6. Lessons learned and recommendations: When the knowledge modules are complete, EPRI will meet with the relevant PSE&G personnel to verbally convey any lessons learned from the knowledge elicitation process and any recommendations that may help PSE&G to maximize the value of the knowledge modules in the future through changes in business processes or infrastructure.

### Generic Schedule

Table 1-1 describes the “best possible” schedule that was discussed. This schedule assumes no competing activities on the part of any of the participants. In actual practice during this project, a more reasonable duration turned out to be about four months for each knowledge domain. The sequence of milestones proved applicable.

**Table 1-1  
Generic Knowledge Elicitation and Review Schedule**

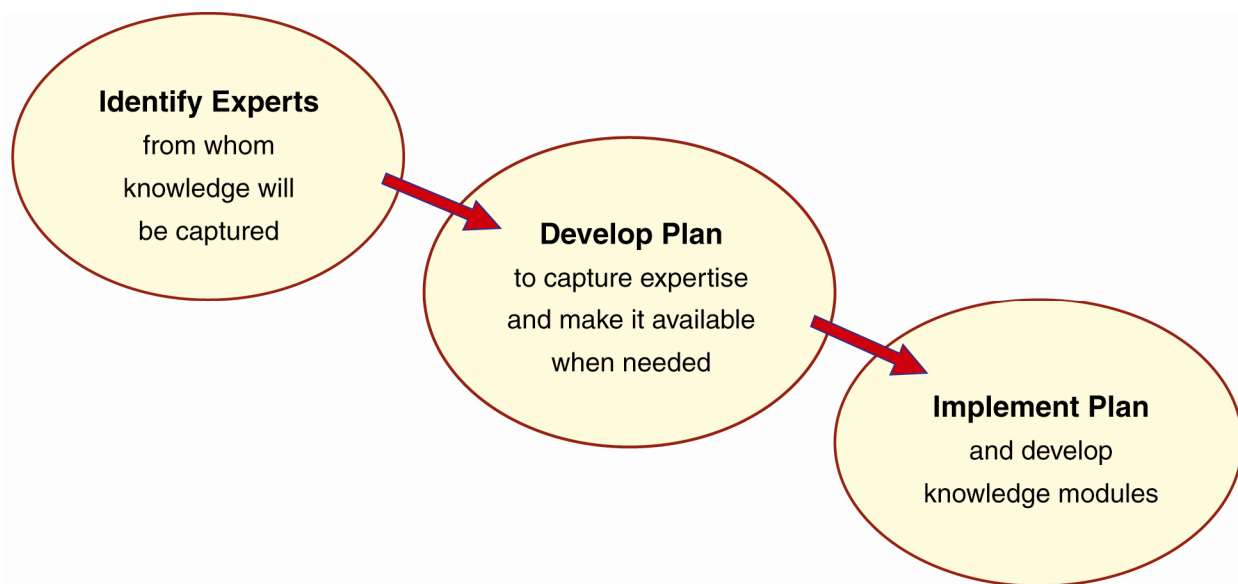
Milestone	Date	Participants
Orientation (0.5 day)	Prior to first session	EPRI, utility expert(s), members of utility department, utility manager(s)
Session 1 (2.5 days)	Week 1*	EPRI, utility expert(s)
Draft materials to utility	Week 2*	
Utility review to EPRI	End of Week 2*	
Session 2 (2.5 days)	Week 3*	EPRI, utility expert(s)
Draft materials to utility	Week 4*	
Utility review to EPRI	End of Week 4*	
Session 3 (2.5 days)	Week 5*	EPRI, utility expert(s)
Draft materials to utility	Week 6*	
Utility review to EPRI	End of Week 6*	
EPRI finalize deliverable and transmit to utility	Week 7*	
	* Contingent on schedule availability of participants	

## Method

The EPRI report *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (1002896) describes the initial methods that the knowledge elicitation team applied [1]. These methods were developed to address the theory of knowledge capture that was expressed in the EPRI report *Guidelines for Capturing Valuable Undocumented Knowledge from Energy Industry Personnel* (1004663) [2]. The reader is referred to these reports for details.

### Overview of Methods

Figure 1-1 describes the general approach used. In this project, PSE&G started with a clear understanding of who the experts were in the various knowledge domains. The EPRI team used the EPRI guidelines and methods to verify the appropriateness of the selections and determined that there were no surprises in PSE&G's selection of individuals. Beyond selecting the individuals, EPRI's methods explore what type of knowledge the experts are thought to hold and how others would use that knowledge. By applying in detail the screening and planning methods contained in EPRI's guidelines, the EPRI team was able to focus on efficient methods for capturing the knowledge.



**Figure 1-1**  
**Three Phases of Knowledge Capture**

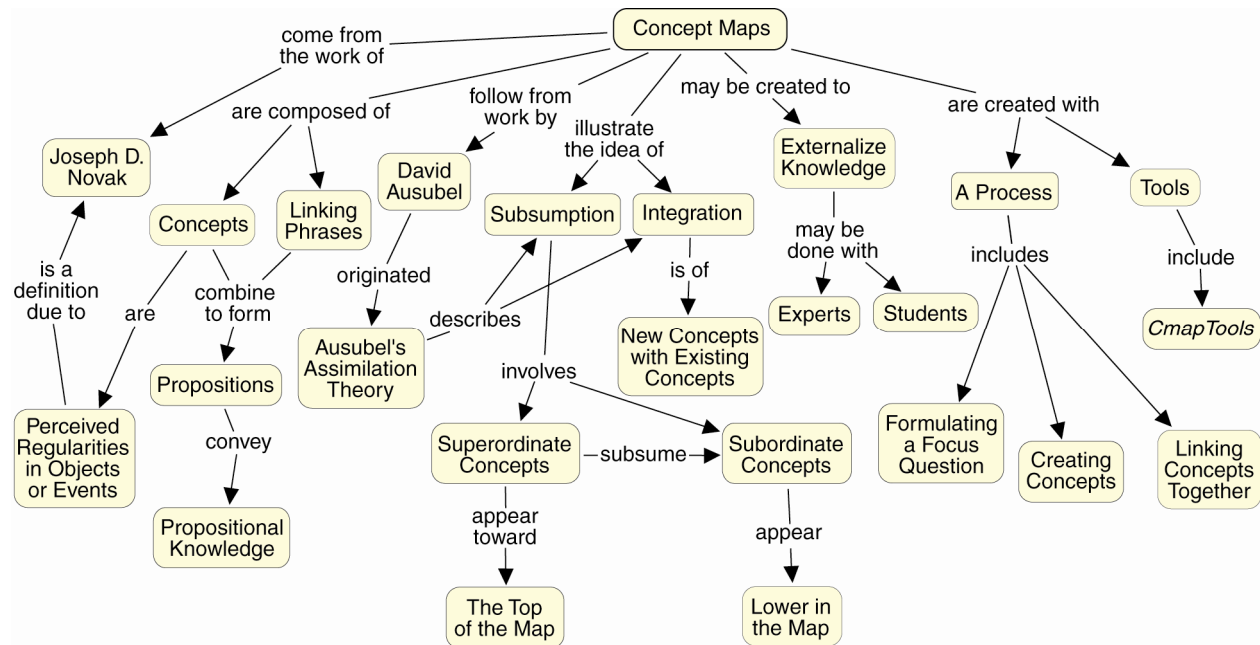
For example, in the process of interviewing system protection engineers who were prospective users of the knowledge, the team determined that the primary piece they lacked was detailed information about the historical basis for the various protection schemes used within the PSE&G system. The team also determined that the prospective users were not lacking in a broad understanding of the domain of technical knowledge; however, they had had little exposure to a broad understanding of asset management tasks regarding the protection system. These broad

aspects needed to be captured and conveyed to them, especially as these aspects related to the technical experience on which they had been focused. The EPRI team solved the historical basis need by devising a template approach (a modified knowledge audit per the EPRI report *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* [1002896]) and delivered the historical basis information in an interactive, maintainable matrix, suitable for rapid reference and easy updates [1]. The EPRI team solved the asset management need by developing a series of concept maps supplemented by narratives.

Section 2, “Results,” provides a complete description of how EPRI’s guidelines and methods led to particular forms of results.

### Concept Maps

Concept maps were used extensively during the project as the basis for most of the interviews that were conducted. Developed by Joseph Novak and his research team at Cornell University, concept maps are graphical representations of knowledge, consisting of concepts and the relationships among them [3]. Novak defined a *concept* as “a perceived regularity in events or objects, or a record of events or objects, designated by a label” [4]. Concepts are usually nouns, and relationships between concepts are typically verb-like, indicated by connecting lines that link the concepts together. The label for most concepts is a single word or a short phrase. Concept-link-concept triples form propositions, which are meaningful statements about some object or event. Figure 1-2, adapted from the work of Joseph D. Novak [4], presents a concept map pertaining to concept maps.



**Figure 1-2**  
**A Concept Map About Concept Maps**

An important starting point for the creation of a concept map is a specific question to be addressed by the map, called a *focus question* [4]. The concept map pertains to some situation or event that one is trying to understand through the organization of relevant knowledge; the focus question specifies that situation or event. Concept maps are useful, succinct, easily elicited representations of knowledge. For this reason, concept maps have proven useful for the recording of expert knowledge relating to knowledge retention in a knowledge domain. The creation of concept maps using Cmap Tools software developed by the Institute for Human and Machine Cognition (IHMC) and licensed to EPRI was fast and convenient for most of the project's purposes. The software is available to utilities at no charge from IHMC.

### **Publication of Content**

As the project proceeded, it became apparent that the client's infrastructure for publishing electronic documents remained to be fully developed. Indeed, in discussions with the managers responsible for the knowledge domains, it became clear that exploring how best to develop an infrastructure was part of the motivation for this project.

PSE&G's local area network (LAN) and Intranet will be the destinations of the knowledge modules produced in this project. Applying the EPRI guidelines and methods, as guided by PSE&G's technology leader, Colin Loxley, led to involving PSE&G's web coordinators in discussions about the final publication method. These discussions proved useful and resulted in the EPRI team committing to publishing the contents in a combination of forms, including standard Microsoft Office documents that will be suitably hyperlinked, HTML representations of concept maps that will be fully interactive and searchable using standard techniques, and concept maps in their original form. PSE&G can maintain the concept maps using Cmap Tools software from IHMC, if desired.



# 2

## RESULTS

---

The initial project scope involved two domains of knowledge. When the scope was expanded to include a third domain, it soon became apparent that the Pipe-Type Cable and Hydraulic Event Response domains were so closely related as to make separating them inappropriate. Separating these domains would have led to mass redundancy of information and would have compounded the difficulty of maintaining the information. Consequently, the results from the three domains are presented in the following two sections.

Because the detailed information captured during this project is considered proprietary to PSE&G, it is not included in this report. Instead, it was transmitted separately to PSE&G. To provide examples of how the process worked, this report refers at times to specific detailed elements for the purpose of description only; there is no need for general readers to access the detailed information in order to understand the process-related examples.

### **Results for the Domain of Asset Management System Protection Engineering**

The domain of Asset Management System Protection Engineering initially posed the interesting questions: “What is the scope of the expert’s duties?” “How should the expert’s newer duties associated with asset management tasks be related to the more technical aspects of system protection engineering as such?” The scope of asset management tasks was rather new and had not been explicitly stated prior to this effort. Brief interviews with the department director at the start of Sessions 1 and 2 and his continued involvement in planning and executing the project provided the necessary clarity to the project team.

The department director had previously developed a draft document, Dimensions of the Knowledge Asset, that consists of a table listing the types of knowledge that PSE&G believes are of value. The project team used the table as a reference to identify areas where there was a high tacit (undocumented) component to the knowledge asset and as a checklist to determine whether the project captured the tacit knowledge that could be captured.

Additionally, interviews with the prospective users of the information being captured had a strong shaping influence on the outcome. Specifically, the users were highly experienced engineers with backgrounds other than system protection engineering. As a result, they needed less overall understanding of basic information and more detailed historical knowledge. They also explicitly desired less concept map-style presentation and more text and matrix-style presentation of the detailed historical knowledge. These desires were accommodated during the course of the project.

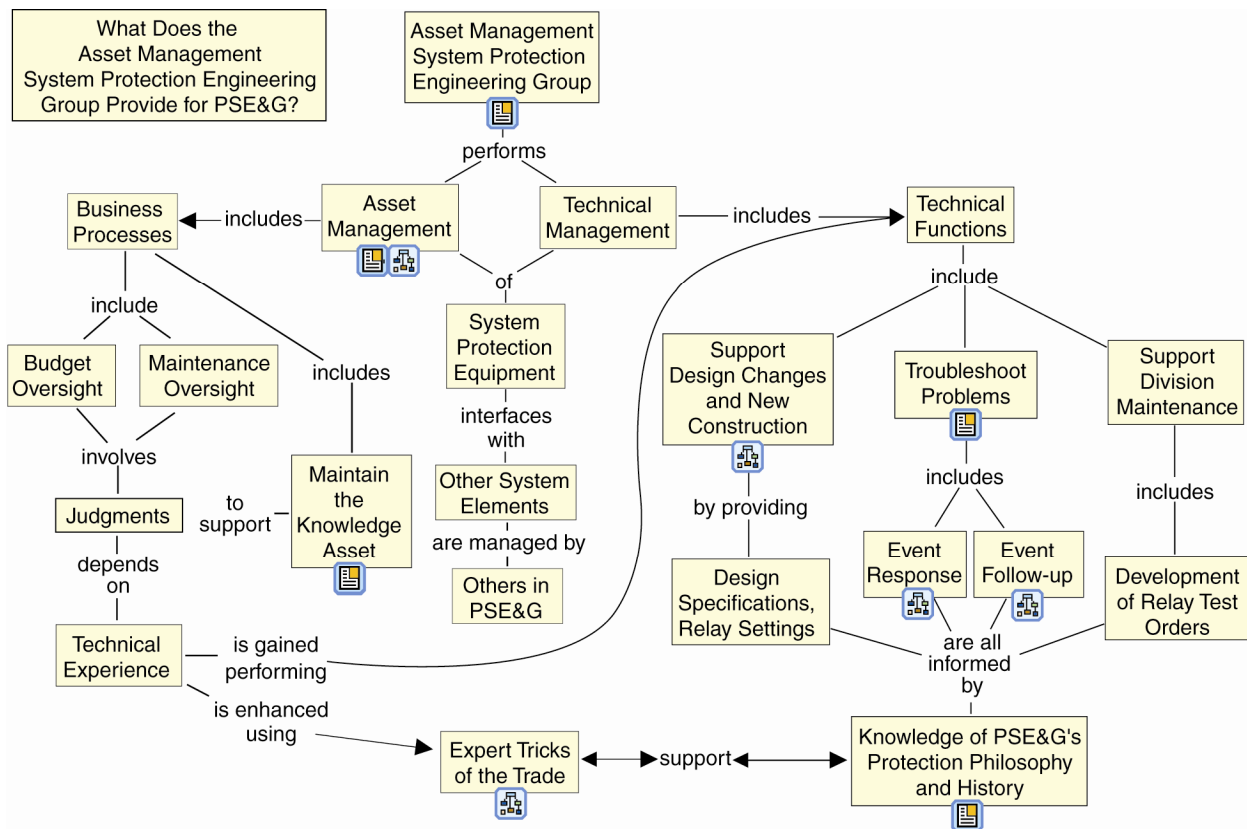
## Schedule Compliance

Interviews with Don Wardlow, PSE&G’s expert on asset management system protection engineering, began in June 2004. The final interview was conducted in July 2004. The reviews of the material continued through August 2004, and the final materials were delivered in September 2004, for an effective project duration of approximately four months.

## Content Description

### Knowledge Modules

The knowledge modules that evolved are a combination of text (an overview of asset management functions, with hyperlinks for ease of use) and a parallel set of concept maps that cover roughly the same territory. Key elements include a document that lists existing information sources, an “analysis of events” document that describes in detail the expert’s thought process, and a protection schemes matrix. The matrix is a Microsoft Excel spreadsheet that provides access, through hyperlinks, to numerous text articles, each of which contains historical information and basis information for a specific protection scheme. The overall scope is demonstrated by the concept map shown in Figure 2-1.



**Figure 2-1**  
**Top-Level Concept Map for Asset Management System Protection Engineering Functions**

EPRI recommends publishing the protection schemes matrix in such a way that the users can maintain it in the course of using it, for example, by publishing the material on a common disk drive on the corporate LAN. The remaining materials are more static in nature and can be considered “read-once” material for most of the prospective users. These materials can easily be published on the corporate Intranet.

## Remaining Gaps

At the end of this stage of the project, several protection schemes basis documents remained to be completed by the client. All materials provided to PSE&G had been reviewed by EPRI technical experts and PSE&G, and comments had been incorporated within the scope of the effort.

One PSE&G reviewer, Jim Hubertus, provided numerous comments on the protection schemes basis documents that are part of the protection schemes matrix. These comments may warrant future consideration by PSE&G because they are consistent with a highly developed knowledge management system. In general, the comments requested one of three types of information:

- Additional technical detail, in which case the comments were provided to the expert for incorporation
- Detail that already resides in existing information sources, and so did not constitute undocumented knowledge
- Links to materials that could be found on the Internet or company Intranet, and so are primarily convenience items having to do with collecting knowledge from diverse sources

The EPRI team evaluated these comments in detail and shared the disposition and details of the comments with PSE&G during the project.

## **Key Methods Used**

The specific methods presented in this section are described in detail in the EPRI report *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (1002896) [1].

## Concept Map-Based Interviews

Knowledge capture interviews began with concept map-based interviews and continued extensively in this mode. An audio recorder was used during the sessions to ease follow-up during editing of the materials. The quality of the recordings is inadequate to provide supplemental materials for multimedia presentation. It appears that the client’s infrastructure would not benefit from including audio recordings as reference material. Therefore, no effort was made to edit or deliver audio recordings; instead, the recordings were destroyed at the

completion of the project. The audio recording proved valuable and efficient when the interviewer could note in his handwritten notes specific times when interesting topics were being discussed.

## Knowledge Audit

A modified knowledge audit approach was used to quickly capture protection scheme basis and historical information. The knowledge elicitation team worked with Don Wardlow to develop for each protection scheme a Microsoft Word template that contained the following elements:

- History: Protection philosophy, changes to philosophy or policy, evolution of PSE&G's use of specific relay brands or models, and the "why" for each philosophy
- Advantages and disadvantages: Pros and cons of this protection scheme, or specific details for when options exist or engineering judgment is expected
- Specific applications of note: Details of significant applications, usually by station or line, and sometimes by relay type, including the "why"
- Operating experience: Description of important events, including what happened, actions taken as a result, and the "why" for actions taken and possible actions that were considered but not taken
- Alternatives: Options that have been considered and not used in the past but are still relevant, including the "why"
- Rules of thumb: Guidance that is generally consistent with the overall philosophy or general prudence
- Additional references: Information related to the protection scheme that might provide additional guidance—not necessarily a comprehensive list, but items that one might otherwise overlook

## Self-Elicitation

Once the template was developed, Don Wardlow remarked, "I could just fill these out," and the process entered a phase where self-elicitation rapidly and efficiently captured a large amount of information. This process of using a knowledge elicitor to develop a template was successfully demonstrated here and became part of the basis for EPRI's 2004 report *Real-Time Expert Knowledge Acquisition and Transfer — Needs and Technology Assessment: Toward Self-Elicitation and Automated Knowledge Capture Methods*, 1009581 [5].

## Critical Decision Method

The critical decision method was often used to understand how an expert analyzes events. Normally, the knowledge elicitor would ask for an example of something named by the expert, and the expert would immediately recall the circuit number, the location, and many specifics. When possible, the elicitation team constructed a brief timeline and then probed further using the

critical decision method. Often, the resulting documentation was only a few concepts on a concept map. Because of the preference for text-based modules, these concept maps were eventually described textually in an “analysis of events” document.

## **Results for the Domains of Pipe-Type Cable and Hydraulic Event Response**

The domains of pipe-type cable and hydraulic event response are so closely related as to make separating them inappropriate. Separating these domains would have led to mass redundancy of information and would have compounded the difficulty of maintaining the information for the future.

That said, combining the domains presented unique challenges for the knowledge elicitation team. First, the goals of the responsible managers for these two domains remained very different and drove the style of the interviews and the level of detail in different but appropriate directions. Second, the challenge of incorporating input from three individuals regarding hydraulic event response and one individual regarding pipe-type cable created a dynamic in which the knowledge elicitation team could not begin to finalize any part of either domain until essentially all the interviews were completed. This was the only way to ensure consistency of perspective and terminology.

### ***Schedule Compliance***

Interviews with Sankar Basu, PSE&G’s expert on pipe-type cable, started in late October 2004 after the team completed the System Protection Engineering work. Mr. Basu was unavailable from November 2004 to February 2005. Work resumed with one interview conducted in February 2005 and the final interview conducted in March 2005. Review of the material continued until May 2005 for an effective project duration of approximately four months.

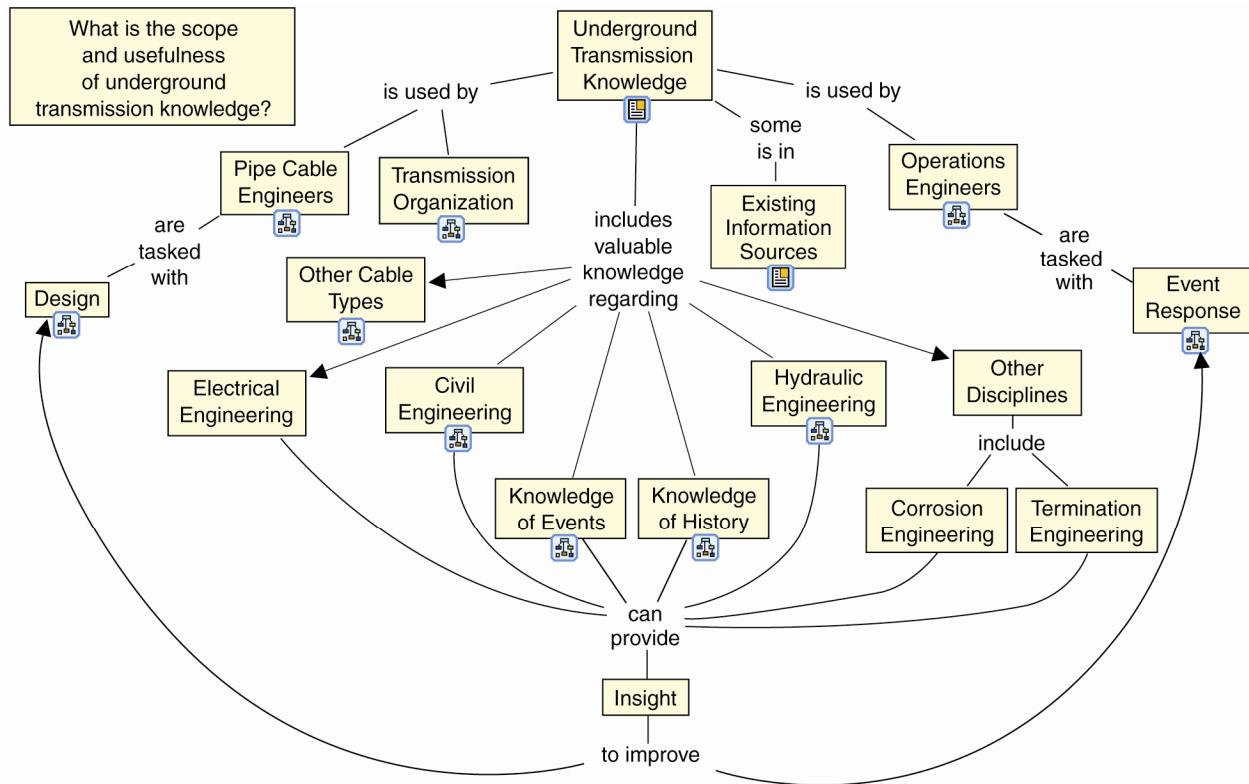
The Hydraulic Event Response scope was added in October 2004, and interviews began with Bill Werkmiester before the holiday break in December 2004. A second interview with Ray Markunas was scheduled for January 2005, but had to be rescheduled to February, and the third interview with John Bridges was conducted in early March 2005. The effect of the rescheduling and the overlap with the interviews for pipe-type cable reduced the time available for interim reviews. As a result, review of the material continued up to publication of the captured materials in May 2005, for an effective project duration of approximately five months.

### ***Content Description***

#### **Knowledge Modules**

Knowledge modules for this domain are chiefly concept maps with some supplemental material linked in. The goals of the responsible managers for the two domains remained different. On the Pipe-Type Cable side, after discussion with the various parties, it became clear that they needed a roadmap for the sorts of experiences and knowledge that a prospective pipe cable engineer

would need to pursue in order to become an authoritative expert. On the Hydraulic Event Response side, after discussion with the various parties, it became clear that they needed information about how to respond to a wide range of operational and maintenance/repair situations with sufficient background regarding why these methods are important to PSE&G. Because of a wide overlap in the knowledge needed in both of these domains, it is important to explain the top-level concept map, shown in Figure 2-2, that resulted.



**Figure 2-2**  
**Top-Level Concept Map for Pipe-Type Cable and Hydraulic Event Response Domains**

Important points about this map include the following:

- The overlap of knowledge required in these two domains is the result of the many engineering disciplines required to carry out the underground transmission mission. The middle of this concept map indicates that it takes input from all the disciplines to gain insight regarding either better design or better event response.
- The concept map also illustrates that PSE&G has historically considered design ownership as the role of a pipe cable engineer and ownership of event response and other operational issues as the role of an operations engineer. This separation of roles is not fundamental, but rather is a result of PSE&G decisions made over time.
- Finally, the fact that this map names underground transmission knowledge as the unifying feature leads to a conclusion that PSE&G's expert knowledge regarding pipe-type cable is really a subset of all possible underground transmission knowledge. This was identified by EPRI's in-house technical reviewer. As a result, this map and several others incorporate the

slightly wider perspective regarding alternatives to PSE&G's existing methods. This map shows, for example, that there is knowledge about other cable types that should be available for future users, but it was properly excluded from the interviews for this project because PSE&G does not have current experience with these other cable types.

There is a natural hierarchy of the captured and supplemental material in relation to the starting point of the concept map. On the design side, the concept maps branch out to cover three primary topics, some of which contain several layers of detail. The three areas are the design and construction process, failure modes the designer works to avoid, and problem solving from a design engineering perspective. Sprinkled throughout the maps are maps that describe particular historical events that lead to or illustrate why the interviewed experts think the way they do. On the design side, there is very little "how to" and quite a lot of broad overview with pointers to detail that should be found elsewhere. In this respect, it should function as a roadmap to the knowledge and experience needed to sustain PSE&G's design efforts into the future.

On the hydraulic event response side, there is also a natural hierarchy among the maps. The concept maps branch out to cover three primary topics, all of which are aimed at supporting a high level of detail about responses to particular events (alarm responses). The three areas are general types of events and operating philosophy to avoid them, strategies for operational control of key parameters (fluid pressure, fluid inventory, fluid purity), and condition assessment and preventive maintenance. A uniform level of detail is provided for alarm response, which is intended to provide a common level of understanding among on-call engineers and possibly field personnel about what is important regarding each alarm and the relationships among alarms.

Key supplemental materials should be referred to often as the materials are put to use. The key supplemental materials include the following:

- A table of underground information sources. The team developed this table early in the project. Little EPRI effort was expended on this table other than to collect input from the various interviewees. However, if PSE&G were to digitize the table and store it on the LAN or Intranet, it would provide an organized index of materials.
- A spreadsheet that lists 125 highly relevant EPRI reports that can be sorted based on content. The report summaries of approximately 25 of the reports are linked directly into one or more concept maps. The project team made no attempt to verify whether PSE&G already owns all of these reports by virtue of its membership in EPRI. However, they are included to provide perspective to future users about the range of information and detailed guidance that is available beyond PSE&G's in-house resources.
- An index of the concept maps in the form of a Microsoft Word document. A direct request from one of the potential users, this index will speed access to information for some users of the concept maps and will provide an overview of what is included in the project.

## Remaining Gaps

The EPRI knowledge elicitation team frequently asked, “What aren’t we covering that may be of value?” Knowledge elicitation efforts could go on indefinitely, and so it should be expected that some details or areas might not be covered in a project of fixed scope. EPRI’s guidelines and methods lead the knowledge elicitation team to deal with the “big rocks” first. The resulting “big rocks” are described in the “Knowledge Modules” paragraphs of this section. By comparison, the remaining areas in which we could have gone into more detail are rather limited in scope and were communicated to PSE&G privately.

## **Key Methods Used**

The specific methods described in this section are explained in detail in the EPRI report *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Methods* (1002896) [1].

## Concept Map-Based Interviews

Knowledge capture interviews began with concept map-based interviews and continued extensively in this mode. An audio recorder was used during the sessions to ease follow-up during editing of the materials. The quality of the recordings is inadequate to provide supplemental materials for multimedia presentation. It appears that the client’s infrastructure would not benefit from including audio recordings as reference material. Therefore, no effort was made to edit or deliver audio recordings; instead, the recordings were destroyed at the completion of the project. The audio recording proved valuable and efficient when the interviewer could note in his handwritten notes specific times when interesting topics were being discussed.

## Knowledge Audit

A modified knowledge audit approach was used to quickly capture alarm response content. During the early discussion of hydraulic event response, it became apparent that responding to alarms is problematic for inexperienced engineers and that much tacit knowledge is needed to simplify a response to alarms. The tacit knowledge used by experienced engineers consists of an understanding of the overall system—not just the local component or even the local pumping plant—from which the experienced engineers draw their understanding of possible causes for the symptoms that are presented to them (the big picture). The experienced engineers also have historical operating experience to draw on, as well as a “hands-on” perspective (the ability to visualize the actual pumping plant) that comes from having been in many, if not all, of the pumping plants. The knowledge elicitation team worked with Ray Markunas to develop a template for alarms, in the form of a concept map, that organizes the priorities among alarms, identifies the kinds of information needed from the big picture, lists key actions that should be taken, and provides a location to store relevant operating experience in the future. The alarm

response concept maps will be useful to transfer to less experienced personnel a large percentage of the tacit advantage held by experts. The only part that cannot be transferred in this way is the ability to visualize the specific plant.

### Critical Decision Method

The critical decision method was often used to understand how an expert analyzes events. Normally, the knowledge elicitor would ask for an example of something named by the expert, and the expert would immediately recall the circuit number, the location, and many specifics. When possible, the elicitation team constructed a brief timeline and then probed further using the critical decision method. Often, the resulting documentation was only a few concepts (the name of the event, what happened relative to the overall issue on the map, and a key lesson or two) on a concept map. For example, the concept map for design and engineering defects refers to a specific historical leak event to emphasize the importance of communication among departments. In two cases, the resulting documents are very extensive concept maps that describe the timeline, the thought process, and the key decision points described by the expert. One concept map describes a medium-pressure oil-filled cable leak, and the other explains diagnosis of a frequent pump alarm on a specific circuit.

### Modified Task Diagram Method

A modified task diagram method was used near the end of the project to portray the mental model for problem solving used by one expert, Sankar Basu. The method is called *modified* because the interviewer intended the resulting documentation to be in the form of a concept map with several submaps providing additional detail. The benefit of using this method is that the expert divided his thought process into chunks quite naturally, and the expert could describe each main chunk by telling stories or listing the main inputs. The resulting maps are those whose titles start with “problem solving.” These maps could be criticized as being very simplistic, relative to the body of knowledge that is available regarding troubleshooting and cause analysis. However, the intent of the maps is not to teach problem solving, but rather to represent the organized approach that has been used by one expert and to indicate the specific talents that would be needed to use this thought process effectively.



# 3

## EPRI LESSONS LEARNED

---

During the course of this project, EPRI acquired several useful insights that will improve the industry's ability to conduct undocumented knowledge capture efficiently.

### **Self-Elicitation Methods: Seek Templates When It Makes Sense**

Knowledge capture has traditionally been considered time consuming and labor intensive. However, at several points during this project, the PSE&G experts and the knowledge elicitation team discovered opportunities to efficiently capture large amounts of information using self-elicitation techniques. These opportunities were noticed when in the course of general, concept-map-based interviews it was noted that, “We’ve talked about this sort of thing before.” When this repetitive process is noted, the knowledge elicitor should evaluate whether there is a general class of objects or topics that one might expect to discuss in the future. If there is such potential, the knowledge elicitor should engage the expert in clarifying what is interesting about this class of objects or topics, with the thought of developing a template that, if it were filled in, would cover the necessary information about the objects or topics.

One example of a situation in which this became obvious was when we discovered that each relay protection scheme had the same pattern of historical considerations, pros and cons, and operating experience. Initially, the expert believed that the information necessary to understand any particular relay protection scheme was so complex that it would be difficult to cover the territory. However, when the knowledge elicitation team proposed building a matrix to see just how complex the information was, the team quickly determined that it was possible to simplify much of the information into a matrix and that the details of each scheme followed a template form. After this was discovered, the expert noted that it would be simple for him to just fill in the templates and that it wasn't really necessary to use the knowledge elicitor after the template had been developed.

The second example comes from the hydraulic event response work. Initially, the knowledge elicitors and the expert grappled with the complexity of all the variations and permutations of alarm response. However, when discussions began to focus on questions such as “What is that alarm for?” “How could you fool this alarm?” “What do you do to find the cause of that other alarm?” we noticed that these standard forms of questions could be applied to any alarm, and so the template for alarms was developed. After working with the knowledge elicitors to flesh out several alarms in this way, Ray Markunas took the idea to his training session, and the workers in the training session developed an alarm response on their own using the template. Thus, the expert's tacit knowledge—that you need to know only a few categories of things in order to figure out any alarm—is now available to all the workers in the group.

This discovery—that a knowledge elicitor can speed the process by building a template and letting the expert complete many templates directly—is one of the key insights in EPRI’s follow-up report on knowledge elicitation, *Real-Time Expert Knowledge Acquisition and Transfer — Needs and Technology Assessment: Toward Self-Elicitation and Automated Knowledge Capture Methods* (1009581) [5].

## **Personnel Turnover on the Knowledge Elicitation Team**

During the course of this project, EPRI participants included one knowledge elicitor, three subject matter experts, and two in-house technical reviewers. Only the knowledge elicitor participated in all nine of the interview sessions. We learned two important lessons from the experience of using different subject matter experts in the course of the interview series.

The first lesson is that subject matter experts participating on the knowledge elicitation team must understand the knowledge elicitation process from the beginning, and they must participate from the start in any interview series with a single interviewee. The EPRI team’s subject matter experts were somewhat knowledgeable about the process, based on time spent by each learning the process outside the interview sessions. This proved valuable and is recommended to continue. However, changing subject matter experts in the course of an interview series with one utility expert creates avoidable problems. It is difficult for a person to join a series of interviews in progress without causing significant retracing of topics already covered. Also, it is difficult to have to reestablish rapport with the utility expert on each visit. This is time consuming and easy to forget. (Because most members of the team are already familiar with each other, it is difficult to remember to properly introduce the new person.) It is recommended that the need for continuity of team members be emphasized in future projects.

One entire session and parts of another were conducted with EPRI’s team consisting of a single knowledge elicitor without a subject matter expert in attendance. From EPRI’s perspective, this seemed to work because it occurred late in the series of interviews, so the knowledge elicitor had become familiar with many of the technical aspects of the domain, and also because the elicitor was confident in EPRI’s in-house reviewers. In future projects of this kind, it may be possible to reliably conduct one-person interviews if a similar match-up of interviewer familiarity and review capability can be established.

## **Overlapping Projects**

Scheduling one project at a time is difficult but manageable. In this project, we encountered overlapping projects. As a result, rescheduling only one session overwhelmed the team’s ability to review and incorporate comments between sessions, and both projects were delayed (but within the scope of the customer’s ability to respond). If overlapping projects are to be scheduled, it will be important to establish expectations with the client that small schedule changes will likely cause significant delays.

## **Value of the Tacit Big Picture**

### ***Three Stories***

Early in the series of interviews with Sankar Basu, we were discussing the difficulty of passing on knowledge about pipe-type cable design to others. Sankar said at one point, “It is hard to pass on [this detailed knowledge] without the 101 course.” Of course, the Pipe-Type Cable Engineering 101 course does not exist in any school, and a pipe-type cable project is in reality a multidiscipline affair. The expert job incumbents acquired their understanding of the intricate interrelations among the various components, systems, support groups, and disciplines over the course of their careers, and both they and we take it for granted that they understand the “big picture.”

Early in the series of interviews with Don Wardlow, we were discussing the possibility of developing a thought process for understanding off-normal relay events with the other system protection engineers. One of the system protection engineers, comparing Don’s results with his own expected results given a similar starting point, said something along the lines of, “It looks like Don just goes to the correct answer and then assembles the facts to prove it. I don’t need his thought process so much as I need to know what he knows. Without that, we just muddle through.” However, after numerous discussions with Don about how he solved this problem or that problem, it became clear that his organized approach and his mental model were what helped him speed to the answer. His follow-up to assemble the facts was really just the process of communicating the results in such a way that others would see that the answer was authoritative and also of documenting the details so it could be accessed later for asset management purposes. Like Sankar, Don acquired his understanding of the intricate interrelations among the various components, systems, support groups, and disciplines over the course of his career. We now take it for granted that he understands the big picture. What is difficult to see is that the difference between “muddling through” and Don’s results is not vast quantities of simple factual knowledge; rather, it is specifically the big picture.

During early discussions of hydraulic event response, it became apparent that responding to alarms is problematic for inexperienced engineers and that much tacit knowledge is needed to simplify a response to alarms. The tacit knowledge used by experienced engineers consists of an understanding of the overall system—not just the local component or even the local pumping plant—from which the experienced engineers draw their understanding of possible causes for the symptoms that are presented to them (the big picture). The experienced engineers also have historical operating experience and a hands-on perspective (the ability to visualize the actual pumping plant) that comes from having been in many, if not all, of the pumping plants. The knowledge elicitation team worked with Ray Markunas to develop a template for alarms—in concept map form—that organizes the priorities among alarms, identifies the kinds of information needed from the big picture, lists key actions that should be taken, and provides a location to store relevant operating experience in the future. In this way, the alarm response concept maps will be useful to transfer to less experienced personnel a large percentage of the tacit advantage held by experts. The only part of the tacit knowledge that cannot be transferred in this way is the ability to visualize the specific plant.

The conclusion from these stories is that the big picture is a common, major tacit knowledge component with these characteristics:

- It has great value to the productivity of less experienced people.
- It is relatively easy to capture and document.
- It is easy to transfer to less experienced people if you describe it clearly.

# 4

## OBSERVATIONS AND RECOMMENDATIONS

---

The headings in this section indicate areas in which there are recommendations to PSE&G and that are of generic interest to similar utility companies. Observations are provided to indicate why a recommendation would be appropriate. The recommendations should not be construed as requirements or expectations; instead, they are offered to aid utility managers' considerations regarding their retention of mission-critical institutional knowledge.

### **Communicate the Big Picture and Mission**

The observations associated with the big picture are described in Section 3, "EPRI Lessons Learned." The observations associated with mission are presented in the following paragraphs as a series of stories. In all three segments of this project, it was important to ask the expert, "What are you trying to accomplish, overall?"

Don Wardlow answered about asset management by saying, "What keeps me awake at night is the possibility of Giants Stadium going dark during a Monday Night Football game and it being our fault." This was notable because for most of our discussions, the explicit mission, reporting relationships, and organization charts were less than clear, but Don always appeared to know what he had to do to keep the lights on.

Sankar answered about design engineering with a succinct answer that turned into a concept map describing the pipe cable engineer's mission. Most of the detailed content developed with Sankar fits into the hierarchy of that map.

In the hydraulic event response segment, no single picture of the experts' mission emerged, in part because three different individuals were interviewed, but also in part because the target audience for the captured knowledge has such a wide scope of duties or potential duties. This is evident from the concept map describing the scope of underground transmission responsibilities, which is in essence a partial organization chart showing where the operations engineer fits into the organizational responsibilities.

The conclusion from these observations about mission is that the experts know what they are trying to accomplish and how it relates to the corporate goals, but it is often less than clear to the less-experienced incumbents.

**Recommendation 1:** Communicate the big picture. Utilities can begin to ease the problem of long-term sustainability of the tacit component of their experience by focusing on communicating the big picture and mission. Consider discussing with each work group: "What is

the big picture?” “What is our mission?” “Who needs to know more about the big picture in order to have confidence in his or her assigned duties?” “Who needs what else in order for all of us together to meet our mission?” Consider focusing the big picture discussions on: “What is our span of control or sphere of influence?” Consider focusing the mission-related discussions on: “What is the value to the company of what we do?” Capture the results of these discussions as the consensus big picture and mission. Consider providing future new members of each work group with a thorough orientation, starting with the big picture and the mission.

## **Tour the Plants**

Observations: Repeatedly, experts that we interviewed in every organization described the importance of seeing for oneself, either during construction or during routine operations and maintenance. The experts attribute some of their facility with problem solving and diagnosis to the enhanced awareness that comes from having seen the physical thing at least once.

Recommendation 2: Tour the plants. Utilities can speed the transfer of the ability to visualize plant situations through the use of planned, scheduled tours during employee orientation. Consider expert-guided tours of key facilities for everyone with fewer than, say, five years of experience in their current position. During these tours, tell operating experience stories about the systems being observed.

## **Maintain the Resource Tables**

Observation: The information sources table for the System Protection Engineering project and the underground information sources table for the Pipe-Type Cable and Hydraulic Event Response projects are lists of explicit knowledge. Such lists form a starting point for utility line managers to evaluate whether they have the right information sources at hand and whether information is easy enough to obtain in the regular course of business.

Recommendation 3: Maintain the resource tables. Utilities concerned with sustaining their tacit knowledge should also consider establishing and maintaining lists of explicit knowledge sources in a suitable form to aid line managers in maintaining the value of this explicit information.

## **Maintain the Captured Knowledge**

Observations: All of the material captured during this project has been provided in electronic form so that it can be easily accessed. However, the project scope itself does not provide for future maintenance of the materials. Some of the materials are provided in Microsoft Office formats so they are readily updatable. The concept maps have been provided in HTML form, but they cannot be updated in that form. However, the concept maps can be edited using Cmap Tools software, which is available from IHMC at no charge, and then can be republished in HTML form.

Some of the content is expected to be relatively static, and some of the content should be expected to be updated as operational events occur or design decisions are implemented. An example of material that will need updating is the protection schemes matrix from the System Protection Engineering project. Another example of such material might be the alarm response concept maps, if they are made part of the on-call notebook that is being considered.

Recommendation 4: Utilities should consider budgeting for and implementing a process to review (either periodically or on an ongoing basis) the captured knowledge and to ensure configuration control over the contents. For content that will be referred to frequently and updated in the course of activities, a low-cost option would be to assign responsibility to the users for updating the materials. An example of such material is the protection schemes matrix from the System Protection Engineering project. Consider publishing all the captured content either on the LAN with suitable access controls or on the Intranet with suitable content ownership and update responsibility. Consider obtaining Cmap Tools software to enable updating the concept maps.



# 5

## REFERENCES

---

1. *Capturing and Using High-Value Undocumented Knowledge in the Nuclear Industry: Guidelines and Method*. EPRI, Palo Alto, CA: 2002. 1002896.
2. *Guidelines for Capturing Valuable Undocumented Knowledge from Energy Industry Personnel*. EPRI, Palo Alto, CA: 2002. 1004663.
3. Joseph D. Novak and Bob D. Gowin, *Learning How to Learn*. Cambridge University Press, New York, 1984.
4. Joseph D. Novak, “The Theory Underlying Concept Maps and How To Construct Them.” Retrieved from the World Wide Web, August 2005. <http://cmap.coginst.uwf.edu/info/>
5. *Real-Time Expert Knowledge Acquisition and Transfer — Needs and Technology Assessment: Toward Self-Elicitation and Automated Knowledge Capture Methods*. EPRI, Palo Alto, CA: 2004. 1009581.






## Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

© 2005 Electric Power Research Institute (EPRI), Inc. All rights reserved.  
Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc.

 Printed on recycled paper in the United States of America

## The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together...Shaping the Future of Electricity

*Program:*

Underground Transmission Systems  
Substations

1012127

---

### ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 USA  
800.313.3774 • 650.855.2121 • [askepri@epri.com](mailto:askepri@epri.com) • [www.epri.com](http://www.epri.com)