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A CASE STUDY IN KNOWLEDGE ELICITATION FOR INSTITUTIONAL MEMORY PRESERVATION USING CONCEPT MAPS

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Abstract. This article contains a description of knowledge elicitation for institutional memory preservation in the nuclear power industry. Because of the large number of pending retirements in the industry, the preservation of expertise is deemed a critical concern, and efforts to do so are extensive. The work described in this article pertains to knowledge elicitation (KE) based on the creation of Concept Maps in the domain of air effluent sensing, analysis and compliance. This paper starts with a brief description of literature pertaining to knowledge elicitation using Concept Maps. This review is followed by a discussion of preparations for this effort made by the elicitors, attributes of the expert, the schedule of events pertaining to the effort, the conduct and results of the sessions, challenges faced along the way, and preliminary results of the endeavor.

1 Introduction

The Nuclear Power industry produces approximately 20% of the energy consumed in the United States, an important contribution to our aggregate energy supply. However, fearsome events that occurred at Three Mile Island more than 20 years ago have had a lingering negative impact on the industry's ability to attract new talent, particularly in more esoteric fields such as nuclear physics. For this reason, this industry faces even greater challenges than most regarding the loss of expertise due to the pending retirement of baby boomers.

The industry has gone to extraordinary lengths for decades to ensure safety and reliability at generation plants, and the industry is aggressively instituting programs to deal with this anticipated loss of expertise. A pro-active approach is necessary since it is estimated that 40% of current workers will be eligible for retirement over the next 5 years. Knowledge retention programs have been initiated in order to capture and understand the skills and training necessary to replace retiring senior engineers, scientists, and crafts persons, and to capture best practices and other undocumented knowledge before it is permanently lost.

This article contains a description of a knowledge retention pilot study, based upon the elicitation of Concept Maps (Novak & Gowin, 1984; Novak, 1998), which took place on-site at a nuclear power plant. The knowledge retention work involved extensive interviews with a nuclear physicist who is an air effluent specialist, using a "tag team" knowledge elicitation (KE) technique, with Concept Mapping as a guiding factor in the sessions. The work with the physicist involved two 2 ½ day site visits, and will include a final wrap-up trip to incorporate the tangibles from the work into training materials, policies and procedures, the records of human resources, etc. The remainder of this article contains a brief description of relevant literature pertaining to knowledge elicitation using Concept Maps, and a description of the case study addressing preparations, characteristics of the expert, the conduct of the sessions, and preliminary results.

2 Knowledge Elicitation using Concept Maps

The following brief literature summary points to some of the prior work that has had an influence on how the current study was conducted. Since Novak and Gowin (1984) originally defined Concept Maps as a means of externalizing what science students knew, several groups have embraced Concept Mapping for KE. Over time, the elicitation of Concept Maps has proven to be an effective means of externalizing an expert's key concepts of a knowledge domain. The elicited Concept Maps have been used to structure what have been termed knowledge models (Ford *et al.*, 1991, Ford & Bradshaw, 1995). McNeese *et al*. (1993, 1995) were early adopters of concept mapping techniques to create an external representation of knowledge that is being communicated, and as an organizing factor in KE efforts. One of several studies they cited involved the elicitation of maps from engineers by a team composed of a primary map creator and one or two additional facilitators. Hoffman, Shadbolt, Burton, and Klein (1995) described various types of KE methods including what they termed contrived techniques that bring to bear some sort of experimental or semi-experimental manipulation of the expert's familiar tasks. One type of contrived task involves creation of diagrammatic representations of knowledge in the form of linked networks of concepts or Concept Maps. Novak (1998) described knowledge elicitation as a means of idea generation in groups of people.

Concept Maps have been used in institutional memory preservation work (Coffey & Hoffman, 2002). In work at NASA Glenn Research Center, Concept Maps were used in order to capture, represent, and preserve institutional memory of senior scientists on issues pertaining to launch vehicle systems integration (Coffey, 1999). The Centaur upper stage and the RL-10 engine were chosen for detailed analysis in this study. Six engineers, all of whom were at or near retirement from NASA or NASA contractors, were involved in this project. The result of the effort was a knowledge model organized around Concept Maps that was used in training.

The literature on concept mapping for KE contains studies involving one-on-one sessions with a single elicitor and single expert, several interviewers working with a single expert, several elicitors with several experts, etc. Studies have described uses that were prospective, retrospective, at a global strategic level and at a highly detailed level. The current case study, described in the next section, describes the use of Concept Mapping at a lower, technical level with one expert and two elicitors.

3 The Case Study

Since this was a pilot study, a relatively small undertaking was planned involving three experts. Due to space constraints, this article contains a description of KE work performed with one of them, an expert on air effluent analysis. The experts for this study were chosen by plant management based on a survey of employees who hold critical positions and are either currently, or will shortly become, eligible for retirement. This survey resulted in a two-page document that identified the critical areas of expertise for each expert. In order to prepare for the pilot study, IHMC personnel were given the assessments from which a set of questions were generated and answered by plant personnel before the first trip. Although preparations could have been deeper and more comprehensive, this advance work proved to be critically important given the limited amount of time with the expert. IHMC personnel went into the endeavor already familiar with ideas such as counting room, Offsite Dose Calculation Manual (ODCM), gamma and beta counting, etc.

The amount of time allocated for contact with the experts was based upon the number of hours of contact time that the budget for the work could support. The level of effort involved two 2½-day sessions with the expert. Additional time, equal to approximately half the time allocated for face-to-face work with the expert, was allocated for one person from IHMC to prepare trip reports pertaining to the current trip, to improve the elicited Concept Maps, and to prepare for the next trip. This amount of time was also dictated by the limited budget, and reflected a significant underestimate of the actual amount of time that was required. Plant personnel participating in the study were tasked with creating accompanying resources such as pictures, digital videos, etc., that would go into the knowledge model. Results of this part of the initiative have so far been limited. An additional goal of the effort was for personnel at the plant to acquire capability to do knowledge elicitation by sitting in on the sessions to observe the techniques of the IHMC personnel.

The approach to knowledge elicitation utilized in this study was the one that has become standard at IHMC over the last several years. Two elicitors were employed: one called a moderator, who interacts with the expert, and a second called a recorder who builds Concept Maps pertaining to the proceedings as they unfold (Coffey *et al*., 2003). *CmapTools* (Cañas *et al*,. 2004), a knowledge modeling toolkit, were used to make electronic versions of Concept Maps as knowledge was elicited. Frequently, "placeholder" maps, small map segments that pertained to promising topics, were created to be revisited later. These and the other maps were consolidated into a knowledge model as part of the work. Details of this work, including attributes of the expert, a description of the sessions, and some preliminary results of the effort follow.

3.1 Attributes of the expert

The expert was highly verbal and knowledgeable in his area. He had experience at another plant before coming to the current facility; he had worked as a consultant, as a college professor, on the ODCM Environmental group, etc. He embodied an interesting combination of knowledge of nuclear physics and acumen pertaining to software for gamma spectroscopy. He had played a major role in the in-house development of mission-critical gamma spectroscopy software for which he could have related many valuable shortcuts and special uses. However, the team did not succeed in eliciting knowledge from him in this area. He was also quite predisposed to digress, and presented an ongoing challenge to keep on-track. Since the expert was computer-savvy, at the end of the first round, he was given the *CmapTools* software and the Concept Maps that had been elicited during the first round of mapping sessions. However, he never produced any additional maps under his own initiative.

3.2 Subdomains of Expertise.

As would be expected of such a long-term professional, the air effluent specialist had significant expertise in several areas. He had deep theoretical and practical groundings in detecting various types of radiation, and in the different types and applications of monitors. He was extremely well versed in regulations relevant to air emissions, and use of the ODCM, the governing document for air effluent detection, analysis and compliance. It was his responsibility to maintain the ODCM; accordingly, he had a significant responsibility to stay current with NRC regulations. He was also expert at source interpretation (determining where radiation came from) – from some part of the plant, as a natural occurrence in the environment, or even brought in by a worker who had undergone radionuclide imaging and had trace amounts of radioactivity is his/her system. He was expert at analyzing the impacts of releases on compliance and many other issues.

3.3 The Sessions

Trip 1. The goal of the first trip was to develop a series of maps that captured the scope of the expert's knowledge. The first Concept Map that was elicited was titled "Cornerstones" (the cornerstones of his job), which were nuclear physics, radiation detection, programming, and people skills. Concept Maps on Regulatory Agencies, Releases – volume and concentration, onsite and offsite, the Software the expert uses including elements that were developed in-house and those that were outsourced, were also elicited. Two somewhat informal maps were created, entitled "Getting things done" which pertained to running analyses, getting equipment fixed, influencing management, etc., and "Learning as you go," which addressed the need for life-long learning and set-aside time on the job to remain current with changes in the field. Other maps pertained to the need to keep up with INPO initiatives, NRC regulations, industry practices, policies dictating requirements, the state of the practice in sensing technology and software, etc.

An important part of the expert's work pertained to monitoring equipment and effluent paths. Maps were created on the various monitor types - liquid and gas, process and effluent. One map pertained to gas monitors - CAMs and area monitors, and problems with unmonitored release paths. The topic of radiation detection, including the types of radiation of concern and the means to detect it, were mapped. Several maps were elicited on reporting doses, source interpretation, and compliance. Data reduction was another concern, and maps were created on counting, summing, and correction factors. Information was elicited from the ODCM such as release points, release information, environmental monitoring controls, etc. The expert was interested in the evolving policy distinctions between verbatim compliance and risk-based assessment of impacts, and the differences between an approach based upon quantity released and one that considered dose to the public. As this listing indicates, the expert had a substantial depth of knowledge in a wide range of areas.

Trip 2. The goal of the second trip was to delve more deeply into issues identified during the first trip. On day 1 of the second trip, Concept Maps pertaining to Algorithms, Germanium Detectors, Managing Procedures, and Review of Surveillance Instructions were created. A review of changes to maps that had been identified on the last afternoon of the first trip was undertaken. During this trip, two maps of particular interest were created. They are interesting because they demonstrate the range of capabilities that Concept Map-based knowledge elicitation provides. The first are called “Activity maps,” maps for which the concepts are things that a person *does*. These are quite different than ordinary maps in which the concepts are typically nouns. Activity maps pertaining to Entry-level and Journeyman level activities associated with the expert’s job were created.

A demonstration Process map pertaining to the process to establish free release count time was also created. It is presented in the model in the context of the basic organizing Concept Maps and the Journeyman Activity Map, demonstrating the integration of conceptual knowledge and skills (background needed to do the job) through the activity itself (indicated in the Activity map) to the process of carrying out the activity, with links to supporting documentation that the expert uses. Due to the limited time available, only one demonstration of this capability was created. It would have been possible to elicit many more of these linkages from background knowledge through activity to documentation that supports the process, given sufficient time with the expert. At the end of the second trip a preliminary knowledge model was created and presented it to the expert.

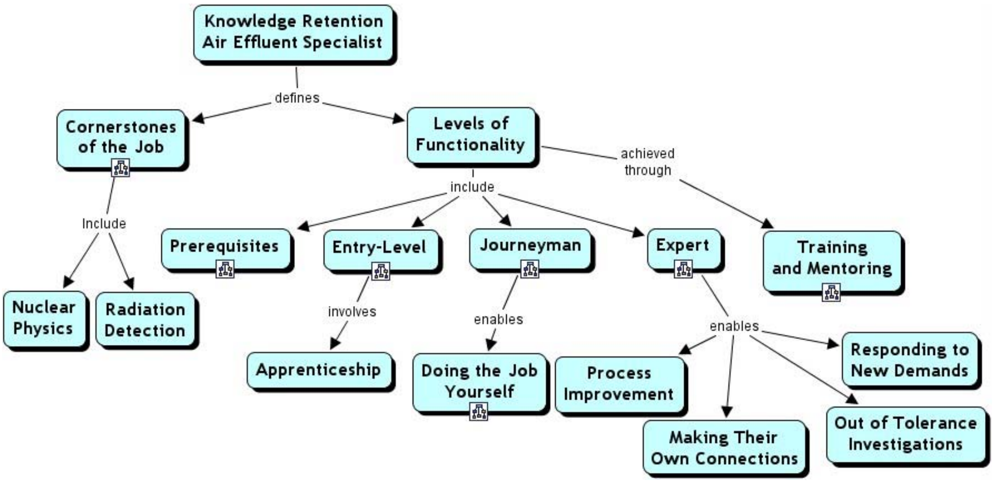

Figure 1. The top-level Concept Map for the Air Effluent Specialist.

4 Organization of the Knowledge Model.

The goal of this work was to create a knowledge model of critical knowledge the expert has. Creating a knowledge model requires organizing the various Concept Maps that have been elicited into a coherent, navigable system that makes explicit the relationships among the various aspects of the expert's knowledge. The Top-Level Map of the knowledge model provides the framework for this organization and provides access to details within the model. Figure 1 contains the top-level map for the work with this expert. It is a simple piece that reflects the fundamental capabilities that a replacement must bring to the job, and the career progression a new entrant in the job might follow. The "Cornerstones" map, which is accessed in the model from the node just below and to the left of the root node in the Top-Level Map, contains the expert's assessment of the requisite capabilities needed to perform the job, and is presented in Figure 2. This map is typical of the level of detail in the Concept Maps that were elicited, and it contains links to other more detailed maps on radiation detection, source interpretation, software, statistics, etc.

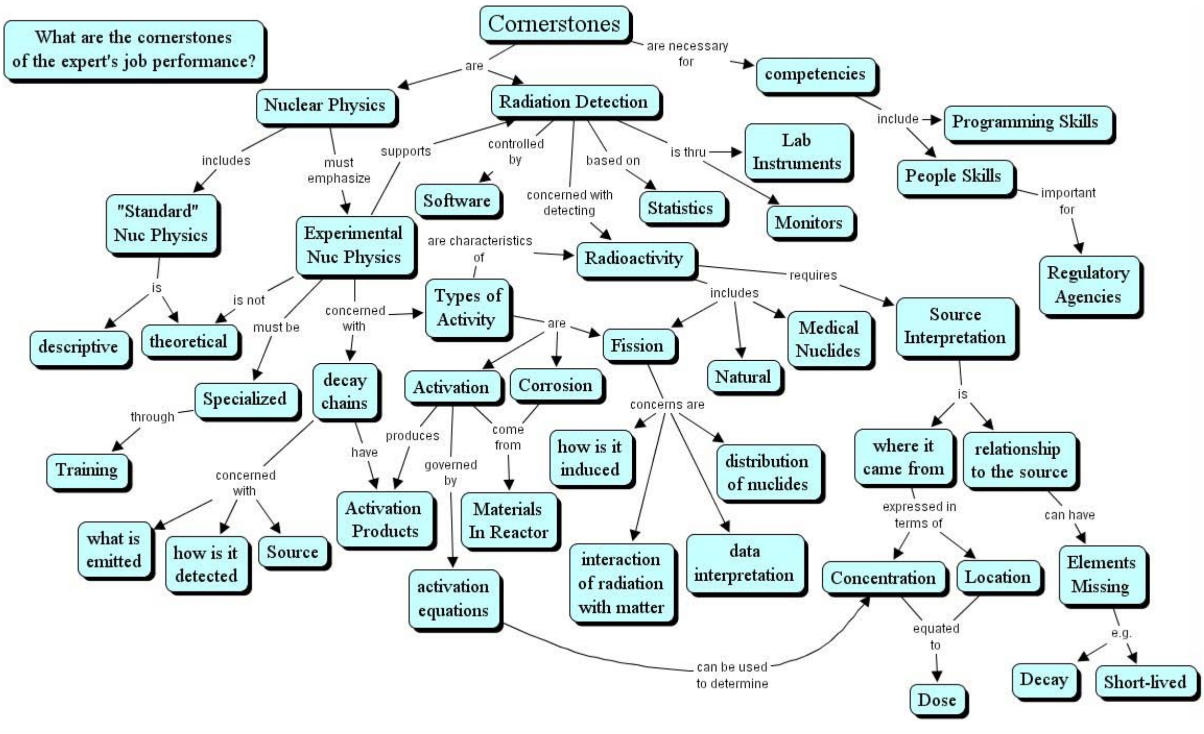

Figure 2. The Cornerstones Map.

The account of a possible career progression that is organized in the top-level map is expressed in terms of prerequisites for the job, entry-level, journeyman and expert-level job performance. The entry-level, journeyman and expert-level nodes contain links to Concept Maps that describe:

- Knowledge and skills necessary for the job
- Activities associated with the knowledge and skills – the Activity Maps.

The "Training and Mentoring" item links to information relating to less formal sources of job improvement that the expert deemed important for a new-hire to know. A total of 34 more detailed Concept Maps were elicited and are linked into the Top-level map. A fully realized knowledge model for Institutional Memory Preservation could be expected to have a balance of traditional Concept Maps, Activity Maps, and Process Maps. The remainder of this section contains additional descriptions of two elements of the model that would bear further development in additional sessions with the expert: the Activity Maps and Process Maps.

4.1 Activity Maps

The technical lead of the pilot asked the elicitors to capture the knowledge and skills necessary to perform the expert's job. After doing so, it became evident that a gap existed in the sense that the knowledge and skills the expert relied on were enumerated, but the actual tasks the expert performed, based upon the knowledge and skills, were not. This gap provided the impetus for the creation of Activity Maps. In an Activity Map, the concepts are the basic activities associated with a job and the relationships among the concepts in the map elaborate the relationships among the activities. In the case of an entry-level worker in the current job, the various activities included managing procedures, doing data analysis from detectors, performing radiation monitor operations such as assessing availability and assisting with troubleshooting, generating reports, and using the computer system.

It was possible to enumerate numerous details under this general grouping of activities, and to create links to other parts of the knowledge model that dealt with various aspects of the activities. The Activity Maps were elicited by starting with the "knowledge and skills" maps and prompting the expert for activities associated with them. Figure 3 contains an Activity Map for the entry-level position. The Journeyman level Activity Map contained many more activities, more than 50 nodes, reflecting the increase in responsibility that comes with progression along this career path.

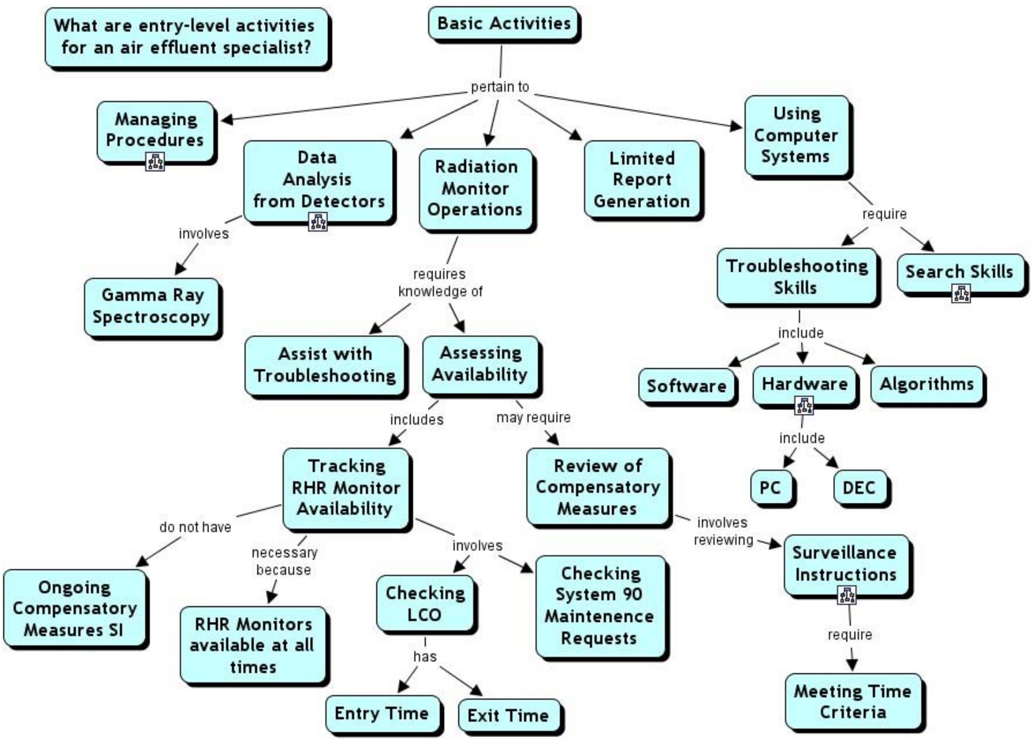

Figure 3. The Activity Map for an Entry-level Employee.

4.2 *The ODCM and process maps*

The nuclear industry seeks reliability and safety by enumerating step-by-step processes for any activity that is amenable to proceduralization. Much of the expert's work was proceduralized. The current work demonstrated a means of creating Process Maps and tying parts of the process directly to pages from the ODCM using *CmapTools*. The demonstration involved the procedure for determining the counting time necessary to analyze a substance for free release from the plant. The Process Map contained a substantial amount of conceptual knowledge such as the categories of things that can be freely released, the ideas of normal and abnormal geometries, the separate steps of determining background radiation count and a Lower Limit of Detection (LLD) for background rate counting time before counting the actual sample itself. The Process Map contained links to tables and other relevant information in the ODCM that were pertinent to the process. Only parts of several tables needed to be used, and the three links in the Process Map were to items that several pages apart in the ODCM, thereby tying together disparate information. The final Process Map presented a succinct representation of the process.

5 Preliminary Results of the Study

Although this is still a work-in-progress, several interesting results have already been obtained. This effort affords a preliminary calibration of the amount of work that can be performed during intensive, on-site, multi-day sessions using Concept Maps. It illustrates a range of uses of Concept Maps for knowledge retention in a highly technical, but simultaneously practical, applied job setting. The work points to an aspect of knowledge retention for which Concept Map-based knowledge elicitation appears highly facilitative – assessment of knowledge and skills required to perform the job, and then assessment of the activities that are based upon the knowledge and skills. Finally, this work, while productive, was not perfectly executed. The work has yielded some lessons learned regarding improvements that could be made to the approach. These topics are discussed in the following sections.

5.1 *Calibration of intensive, on-site knowledge elicitation*

Over the course of two 2½-day trips, a total of 48 Concept Maps were elicited. They were consolidated into 35 maps. A half-day was lost in order to take a visit into the plant to the expert's lab and the counting room. An additional ½ day on-site was used to improve the Concept Maps and to build the knowledge model for presentation at the end of the second trip. Several hours were lost to interruptions that the expert had to deal with, and 2 hours were lost on a day when the expert arrived late. This sort of work is very cognitively intensive, and it is difficult to maintain focus for many hours per day, several days in a row. The half-day of each trip was relatively unproductive. However, through all the interruptions and lost time, this work demonstrates that 10 maps can be produced with a single expert per day over multi-day periods of time.

5.2 *The range of elicited maps*

A wide range of Concept Map types were elicited. While many of them had the expected, traditional, conceptual qualities, many did not. Process Maps have utility in a highly proceduralized knowledge domain, particularly to the degree that it is possible to identify and map difficult or poorly documented procedures. The Activity Maps were deemed to be useful, and could have been carried out into significantly more detail. Furthermore, it was interesting to note that a highly technical person such as this expert, would delve into less concrete areas such as the need to influence management, and the sources of information he utilized to keep current in his job.

The range of maps raises the issue of depth versus breadth in expert knowledge preservation. The current work confirms the generally held wisdom that the more profound an expert's knowledge, the more difficult it is for the expert to explicate. It also became clear that the expert experienced some difficulty assessing what knowledge might be more widely held and what he held individually. If one is trying to preserve what an expert knows, eliciting a somewhat wider and less deep knowledge model might be the best outcome that can be expected. It certainly provides a starting place for more in-depth explorations.

5.3 *What might have been improved?*

Several improvements could be made to the approach that was employed. When all the Concept Maps were organized into a rough model at the end of the second trip and presented to the expert, he had a surprisingly favorable response. It is clear that better buy-in to the process could have been obtained if the expert had a clearer idea, earlier in the process, of where the work was going. Attempts were made to make the anticipated results of the work clear to the expert at the outset, but presenting prior work did not have as much impact as the expert actually seeing the emerging model of his own knowledge. Experts should be made privy to the way the knowledge will be organized as soon as it is feasible to make a meaningful presentation. A second element that could have been improved would have been to have shorter trips, and shorter duration sessions with the expert. Due to time and travel constraints, this was not, and may not typically, be possible.

6 Summary

This paper contains a case study in the use of concept mapping for institutional memory preservation. It describes work in the nuclear power industry with an air effluent specialist, a highly applied knowledge domain. This work led to a variety of representations in Concept Maps – traditional Concept Maps of the sort described by Novak (1984), Process Maps with links to documents that support performance of the process, and Activity Maps that capture and elucidate the activities in which an expert engages. The work described here is preliminary. The intention is that knowledge elicited in this study will be rolled into training programs for workers who will replace retiring personnel who have performed these activities. The ultimate impacts of the elicited knowledge are still to be determined.

7 Acknowledgements

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