PRESERVING TECHNICAL KNOWLEDGE – WHEN TECHNOLOGY'S LIFETIME EXCEEDS THE HUMAN LIFE SPAN

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1. Introduction

Industry is being challenged by the departure of experienced managers and workers. The loss of skills and the difficulty of finding qualified replacements can negatively affect operations, environment, safety, and economics. There is a need to capture, preserve and pass along both documented and undocumented knowledge before aging workers depart the workplace.

How to do it? Our ancestors faced the same problem, and they often solved it in a personal way through a Master-Journeyman-Apprentice system. Our modern education system is an extension of that system, augmented by extensive use of textbooks. This system now is stretched to its limits by two factors, (a) the need to update the teacher's knowledge, and (b) the need to update high quality textbooks. Modern Masters are so busy doing their work that they have no time to pass knowledge on in an effective manner. When they retire, their knowledge often is lost.

The CANTEACH project was initiated to fill this gap. The essence of this knowledge capture process is acquisition of archival documents that are relevant to current practice in the field – in our case, CANDU power plant engineering. This project is made possible by voluntary contributions from Masters in the field; it can proceed only by avoiding the pitfalls of excessive security and intellectual property rules. This paper describes the mechanisms used to make this archival knowledge openly available for operators, designers, educators, and students of this technology.

2. The CANTEACH Concept

The archive was conceived as a knowledge repository that should provide high quality technical documentation relating to all facets of the CANDU nuclear energy system. This information is public and is intended for use in various aspects of education, training, design and operation. The project, underway for nearly five years, has the objective of building this knowledge repository.

The original project agreement (signed on July 21, 2001 and revised on April 1, 2002) states the basic goal:

> "The CANTEACH Partners agree to develop a comprehensive set of education and training documents prepared according to the highest academic standards to describe the various aspects of CANDU power plant technology. These documents will be subjected to planning and review by the Academic Director and the Project Director, and then will be recommended to the Board of Directors for incorporation into the set of deliverables of the project."

Annex B to the Agreement refers to potential source materials such as course notes from AECL, Universities, and Utilities as well as to a collection of monographs developed in China. The original CANTEACH project agreement expired in March 2005. The project has been sustained by Canadian COG[1] members since that date. Much of the conceptual structure of the original project has been validated. Some weak areas have been revealed, as discussed herein.

3. Why Do We Need a Knowledge Archive?

This part is simple. The operating lifetime of a modern nuclear plant will extend possibly 60 to 100 years beyond the date at which the conceptual design is completed, or 50 to 90 years past the plant's first startup.

The working life of an engineer is judged to be about 30-40 years, an optimistic estimate because a professional engineer normally works in his or her discipline for much less time than this before moving on to non-engineering or supervisory jobs. The long time span of these projects raises the issue of the location and possession of design authority for plant systems. The original plant designer is the obvious authority during the early years. But after several decades, staff of the design organization probably has moved on to work on new designs, and is no longer devoted to maintenance and refurbishment of the company's old plants. In these circumstances, design authority must pass to the Chief Engineer of the operating company. The problem of knowledge transfer remains the same; only the location of the expertise changes.

As a consequence of this long time span we must sustain the communication of high quality plant information over three or four generations of professionals, allowing for some overlap between generations. Staff overlap is essential because it gives an opportunity for informal transfer of knowledge, akin to the old Master-Apprentice system. Courses, procedures and other "third person" methods usually cannot transfer all of the essential knowledge – this may be possible in a theoretically ideal documentation system, but is impossible to achieve in practice. Two-way communication between established stations and new stations also is required, to take advantage of lessons learned during operation as well as design. For example, a principal mandate of the CANDU Owners Group[1] is aimed exactly at this aspect of information exchange from operating experience and general knowledge preservation.

Retraining programs, properly conducted, offer an opportunity to keep plant information fresh over the long term. Trainers must first be trained, thereby suggesting close contact with educators in academic institutions. Preparation and modification/updating of training materials is a continuous process, and provide a natural procedure for incorporating the lessons learned as operating experience accumulates.

Sixty-six years have passed since the nuclear energy venture began in Canada. Fifty-four years have gone by since the founding of Atomic Energy of Canada (AECL). Tens of thousands of dedicated people have forged a new and successful primary energy supply. CANDU technology is well launched into the first decade of the 21st century. This specialty within the world's technology community is unique, first because it was established as a separate effort very early in the history of world fission energy, and second because it grew in an isolated environment with tight security requirements, in its early years. Commercial security rules later sustained a considerable degree of isolation. As a result, many of the correct answers to the important "Why?" questions are different for CANDU than for other reactor types. While standardization of lessons learned across different reactor types is often useful, it is important to guard against situations in which the correct answer for one reactor type is the wrong (or irrelevant) answer for another type.

The pioneers of CANDU development have finished their work. Most of the people of the second generation also have moved on. And yet, up to this time we cannot point to a consistent and complete record of this remarkable achievement. We, as a nuclear enterprise, have not captured the knowledge legacy in a form readily accessible to current and future generation of professionals involved with CANDU reactors -- students, designers, operations staff, regulators, consultants or clients. This is a serious oversight.

Young people entering our field of study must make do with one or two textbooks and a huge collection of diverse technical papers augmented by limited-scope training materials. General textbooks include much of the basic information, but there is not a single definitive text or handbook specifically aimed at the details of CANDU technology as it is applied today. Those employed in the various parts of the nuclear industry rely mostly on a smaller set of CANDU-related documents available within their own organization; documents that sometimes are rather limited. University professors often have even more limited access to in-depth and up to date information. In fact, they often depend on literature published in other countries when preparing lectures, enhanced by guest lecturers from various parts of the industry. Because CANDU was developed mostly inside Canada and because the system is unique in many aspects of its design, few of these non-Canadian text materials contain useful data describing processes important to the CANDU system.

For many years it has been recognized that a "CANDU Textbook" is needed. However, other work priorities and intense work activity within the industry have prevented the completion of such a reference volume. There is, in fact, a large volume of existing documents describing CANDU systems and operation. Much of this documentation is repetitious and contains less depth than is desirable. Very few of the documents detail <u>why</u> CANDU is designed the way it is. How can designs evolve appropriately and how can

retrofits and design changes be implemented correctly if the 'whys' are not elucidated? How are the graying experts passing on their knowledge and wisdom? It is this need that the CANTEACH project strives to fill.

4. Intellectual Property

The first and only purpose of the CANTEACH project is to preserve the knowledge base on which the technology of the Canadian Deuterium-Uranium energy system is founded. The chosen means of preserving this knowledge is to establish an open-source archive, as complete and comprehensive as possible. The chosen origins of this archive material are the writings, lessons, and publications of the professionals involved in the research, development, design, and operation of the CANDU energy system.

One of the first questions that many people have is "How about my intellectual property rights?" The best answer to this question can be found[2] under the title "Why it Makes Sense to Give Stuff Away". The essence of the argument lies in the distinction between (a) fundamental training and education and (b) the applied world in which application of knowledge is part of a commercial enterprise. On the fundamental level there is no need to give away secrets in the process of training and education. On the applied level information belongs to two or more parties exchanging technology for money, and so become true secrets.

On the level of training and education, the project aims to provide a technical library that is open, and freely available to all. As such it helps to maintain the sense of community that once enabled the success of the remarkable achievement that is known under the mnemonic of CANDU and gives those people who may choose to work in this field the best way for them, as individuals, to contribute to its further development. As previously described[2], the CANTEACH project addresses all three dimensions of human empowerment (competence, relatedness, and autonomy). People are empowered through education, and professionals emerge. The basic human characteristic, that a person is motivated to do something if that person is good at it, if the activity is meaningful in some way, and if he or she has personally decided to do it[3] results in the motivation so essential to success of the larger enterprise. Using other language, the success of the nuclear enterprise depends on maintenance of a safety culture in which an individual habitually does the right thing even when nobody is looking. This goal can be achieved only through individual behaviors and motivation.

Here is the reason for establishing an open source archive. Also, here is the reason that agencies and companies should freely contribute to that archive. What about the security of sensitive information?

5. Information Security

Obviously, it is wise to restrict the distribution of some specific information regarding any facility. This is a vital part of defence in depth, whereby several barriers are established between a valuable facility and any potential threat, either natural or human. Distribution of information that threatens any of these barriers should be discouraged. Unfortunately, defence is often taken to mean overt, physical defence in the form of guards and weapons as well as fences and ramparts of all sorts.

The most important element of defence is often neglected. This is the group of people always present and in control of the facility itself. Their attitudes and motivations lie at the very core of defence. Do these people care? Are they vigilant? Do they feel a sense of community with their co-workers and with the objectives of the enterprise? Will they risk harm to themselves to maintain the overall security of the facility?

It is a realistic presumption that security depends to some extent on the ignorance of the threatening agent as to the specifics of the facility. Locations of, and specific procedures for, operation of plant systems should not be common knowledge. As noted already it is completely unnecessary to give away such secrets while providing the education and training of professional individuals who have the option of entering the field of nuclear engineering. Specific plant-related knowledge is best communicated at the appropriate time by professionals already familiar with, or responsible for, operation of the facility.

Information donated to the CANTEACH archive comes, as it must, from people inside the organizations and those working in the field. These individuals carry the primary authority and responsibility for retention of

sensitive information. Project staff will ensure that information received has passed normal review and approval by these donating organizations. Further, it may at some time be appropriate (as judged by the sponsors of this project) to establish a second, confidential, archive containing information valuable to the users but which is deemed sufficiently sensitive that it should not be distributed widely.

6. Target Audience

Understanding the limitations imposed both by commercial value, intellectual property claims and by information security we must define, at least in general terms, the audience to whom these works are directed. The CANTEACH project aims to provide the information necessary to attract, then to educate and train, professionals in the broad aspects of CANDU technology.

Reference 4 summarizes some of the basic causes of the known shortages of skilled manpower in the Canadian nuclear industry as existed at that time. Written today, that summary would be more optimistic with regard to future prospects, given the present resurgence in the number of plant life extensions and potential "new builds". It is expected that the demand for new nuclear capacity will grow very rapidly of the next few decades. However, the basic problems of staffing will not change greatly, and in fact will be exacerbated by the demands for staff to accomplish these new tasks as well as by the steadily increasing requirements of operating facilities as the nuclear industry grows over the next few decades.

Reference 4 outlines the needs of the nuclear industry's "supply chain" for new staff. A typical example of staff demand ratios is about 1000 2-year community colleges graduates, about 100 Baccalaureate engineers, about 10 MSc graduates, and about 2 doctoral graduates. Given this distribution, it is obvious that the first level of CANTEACH information should be usable by students 1 or 2 years beyond high school. Given the associated need to give their instructors a firm grounding in nuclear energy technology, at least a second level of documentation is essential. Students who will eventually graduate with higher degrees also will begin at level 1. Their instructors and professors must, of course, be highly qualified. There will be a somewhat higher demand for PhD graduates in the near future simply to fill professorial openings.

Staff entering the CANDU program will undergo in-house education and training beyond graduation, to improve their specific knowledge of operating systems. Operating companies may choose to do this job through their own schools or via contracts. Security and intellectual property restrictions force this separation between the academic world and the practical world of industry. Our conclusion is that the main thrust of CANTEACH archive material should be directed to the general public and to "Entry Level" students and their instructors. A proper definition of this beginner's level is important – because of the advanced knowledge of physics, chemistry, mathematics, material science, and diverse other fields that are essential to understanding of nuclear plant engineering, the "entry level" for this discipline may be at the baccalaureate or post-graduate stage of an individual's education.

7. CANTEACH Archive Elements

Collecting information from contributors is the first and most important step. We welcome contributions from companies, agencies and individuals; the only requirement is relevance to some aspect of the CANDU energy system, ranging from exploration, research, development, design, manufacturing, construction, operation, decommissioning, and management of radioactive materials. All aspects are considered for inclusion in the archive, from education to economics to public relations. The most directly useful materials are formal course notes that have been proven through presentation and re-examination.

When received the materials are scanned into pdf format files, converted to searchable format, indexed and bookmarked. They are catalogued by name of the contributing organization or individual. A keyword-based search system has been introduced recently. At the present time, work is proceeding on collection and classification of photographs, diagrams, and descriptive presentation materials for use by educators and instructors. The next step will be to review each contribution and incorporation of the "best" set of materials into evaluated information files. Up to this stage of the project we have done no editing of the material except for organization, sorting, and correction of substantial errors.

The products of the CANTEACH archival process are located on a website maintained by the CANDU Owners Group, at <http://canteach.candu.org>. Approximately 1400 documents containing a variety of archival information are grouped into .pdf files, bookmarked, and indexed. This website is completely public at the present time, however there is provision for establishing a confidential site available only to authorized individuals. This second website will allow the project to broaden the scope and to increase the depth of detail in description of components and systems utilized in CANDU reactor systems.

8. Accomplishments and Present Status

Figure 1 shows the "entry " page of the CANTEACH archive. The best way to discover what is available on the web site, and also what is missing, is to "walk around" the website guided by this starting page. The "Search" category is still under construction, with only a fraction of the total entries having been populated

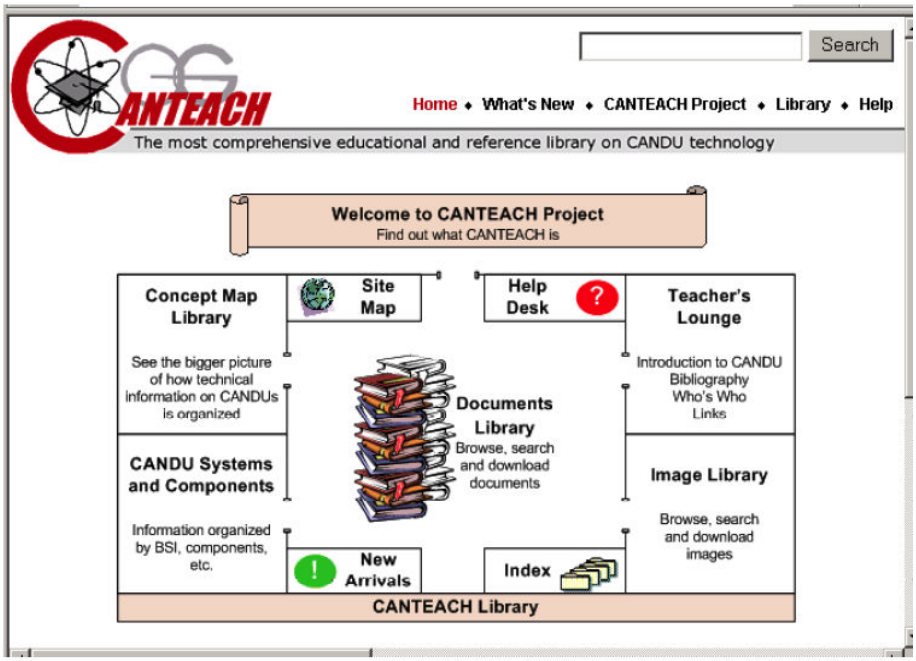

Figure 1 – The starting point of a search for CANTEACH information

with keywords. It is usable, but limited in scope. The Documents Library is organized by contributing organization and individual. The layout follows the pattern of the original lecture course or technical paper/conference. This archive changes when new documents are added, as indicated in New Arrivals. The Image Library is the newest major component of the archive. It now contains only a few images, but hundreds of new images are in process of being added. Material in this section will be extracted from existing documents, revised as necessary to make them more accessible with highest achievable resolution.

CANTEACH is a work in progress. Immediate tasks, now underway, include extension of document search capability using a keyword search system for the library. We also plan to refine and post several thousand pictures and other figures and make them available to CANTEACH users. Over the next three years, in addition to collection and posting of new archival files, staff intend to undertake editing and refinement of all existing files to improve their overall quality of the content and presentation.

8. Current Developments and Improvements

There are weaknesses in the current archives in breadth, depth, and content. Regarding breadth, essentially no project files exist covering areas of the CANDU enterprise such as fuel resources, mining, decommissioning, and waste disposal as well as several aspects of electrical, civil, and mechanical design. The numerous subjects concerning operations are not covered at all -- for example load following, load

cycling, maintenance, refurbishment, and economics. Regarding weaknesses in depth, the whole archive is weak in descriptions of **why** equipment and processes are as they are in CANDU plants. Also, in some respects only the general aspects of plant systems and operation are presented, without any deeper examination. Some aspects of systems are treated repetitiously, while other aspects are not even mentioned.

Several potential contributors have personal files and records that would be very valuable to the next generation of CANDU personnel – but whose contributions have not yet been collected, due to a lack of project manpower. These skilled individuals are now mostly retired or are nearing retirement -- time is short. Today's plan includes a proposal to initiate a series of task-specific contracts with experts who are willing and able to improve the CANTEACH archive. These contracts will be administrated by COG.

Finally, the underlying rationale for continuing this work is that the CANDU enterprise must continue to serve the people of Canada and the world for generations to come. For a variety of reasons, neither the academic, the commercial, the industrial, nor the academic participants in this enterprise have produced a comprehensive set of education and training documents prepared according to the highest standards to describe the various aspects of CANDU technology. Current deficiencies in staffing have stimulated education efforts such as those recently undertaken by UNENE and via utility support of community college training programs. These programs need comprehensive documentation in order to be effective.

9. New Contributions

1) Populate existing documents with keywords, to take advantage of the new search engine.
2) Refine, identify, index, and post to the website, several hundred pictures and graphics with.
3) Increase the breadth and depth of document acquisition from companies and Universities.
4) Issue task-specific contracts to experts – to correct, sort, and resolve differences between different presentations and courses on the same general topic (e.g. reactor physics, safety).
5) Expand the archival record on the subject of radioactive waste management.

Tasks 4 and 5 represent our first moves toward upgrading the quality of the existing archive. It is the area which will require additional resources and, consequentially, additional funding. It is proposed that staff plan and conclude a sequence of small contracts (200-800 hours each) with very specific goals, schedules, and deliverables. The scope of these tasks will be limited, of course, by available funding.

The full duration required for completion of the CANTEACH project is somewhat difficult to determine. The original estimate was about ten years, and it appears that this is still valid. Of course, the actual end of the project will depend on the need as indicated by the usage level and the number of requests for new information. Neither of these measures shows any sign of declining up to this time.

10. Summary

The project will continue until the users decide that the archive is sufficient to fulfill their objectives. It is hoped that professionals who work in this field of engineering will continue to contribute to this body of knowledge for many years to come.

11. References

[1] CANDU Owners Group Website, URL: <http://www.candu.org/>
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